Green Energy and Technology

Elena Papadopoulou

Photovoltaic Industrial Systems

An Environmental Approach

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Once upon a time I had a lucky day and I met Forki, Argos, Sarik,

Fivo, Zoutska, Mouha, Strelka,…

and then I start to sympathize Earth…

I felt that is the biggest crime to destroy a planet.

And nobody has such a right.

Preface

The protection of environment and the optimization of energy efficiency acquire continuously bigger importance. In today's power scenario, we are facing a major power crunch. Day by day, the gap between demand and supply of electric energy is widening.

The aim of this handbook is to turn the attention to these subjects and to investigate the existing situation with regard to the environmental questions and more special the energy efficiency in the European Industry and especially the industrial units at the Greek area.

The reduction of consumption energy it is essential to be considered not only as a manner for the protection of environment via the reduction par example of gases emissions from greenhouse but also as a question that concerns the management of enterprise.

Consequently, in the frames of innovator approach, the reduction of consumption of energy can be achieved combining the projection of the hidden use of energy and the benefit of know-how for her reduction with the growth of required structures management.

Moreover, this book will develop the use of photovoltaic systems in the industry, focused in basic sizes (economically, technically, administratively) as well as a model of energy management as a proposal for that with regard to the energy questions can constitute part of management of enterprise.

The structure of this text allows flexibility in course content and design. It may be used equally well either a semester from students or also from engineers who want to introduce themselves to energy management and photovoltaic operation. Coverage of preliminary energy management system and photovoltaic operations topics is basic enough for the fundamental photovoltaic course; yet, it is broad and analytical enough to also be used in an advanced semester course that gives an in-depth treatment of specific topics. Furthermore, this text may be used at either the undergraduate or graduate level.

To aid the presentation of its subject matter, this text includes the followings features:

Figures, diagrams and charts to further explain and illustrate the concepts and techniques presented.

Questions at the end of the chapters to provide summaries and reviews of key points. For the most part, these require qualitative answers and may be used to alert the respondent to central areas which need closer examination.

Design and calculation of an operation of installation of roof mounted photovoltaic system.

Glossary with all the terms at photovoltaic technology.

I wish to acknowledge Photovoltaic SA which donates figures and materials and gratitude is particularly due to Spiros Papadopoulos and Georgios Sigalas. A special mention goes to Dr Mariah Castro for her editorial support.

Contents

Chapter 1
Introduction

The climatic change and the increase of gases emissions of greenhouse [(CO_2), (CH_4), (N_2O), (HFCs), (PFCs), (SF_6)] become various efforts from cities and states of even USA (the example of California), which did not sign the protocol of Kyoto, so that are found intelligent solutions for the saving of energy, the production of "clean" energy with right and brilliant systems of management.

The European Union participates for many years, in the efforts to save the change of climate, which constitutes henceforth more major priority of her strategic planning and, in consequence, her climatic policy. All the efforts try to:

- improve the efficiency of consumption of energy,
- reduce the produced pollutants,
- grown a friendlier to the environment and more balanced systems of transports,
- aid the responsibility of enterprises at way so that is not offended their competitiveness,
- subordinate of land-planning planning and agriculture in the cheques of protection of environment and create a good frame for the research and the innovation.
- change of used fuels
- concern for the environment

Saving of energy via the more efficient use:

- Energy output at the final use and the energy services
- Co-production of energy
- Energy output of buildings
- Energy efficiency of products
- More brilliant utilization of energy

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1.1 Photovoltaic System, a Short Preview

Photovoltaic cells convert sunlight directly into electricity. These cells are made of semiconductors, such as crystalline silicon or thin-film materials. The DC electricity produced by the photovoltaic system is either stored in batteries or sent to an inverter, where it's converted into AC electricity to power a home or business.

A PV system consists of semiconductor cells that absorb sunlight and generate electric current. Many cells are combined into a sealed "module." Modules are wired together into a PV "array." The direct current (DC) electricity produced is fed through an "inverter" which converts DC to AC, the alternating current needed by most homes and business, and compatible with the larger electric grid. Battery storage systems used to comprise a large part of the PV's investment, but are no longer necessary for most users since any electrical power not needed immediately can flow into the grid, where it is essentially "stored" for later use. A 2-kW photovoltaic generating system will eliminate about 40 tons of carbon dioxide emissions over its lifetime—the equivalent of planting half a hectare of trees.

A building photovoltaic power system includes solar panels, a grid-interactive current inverter, rooftop mountings and a full wiring system. Solar Photovoltaic Technology:

- Innovative manufacturing process technologies for raw materials, solar cell and solar module production;
- Photovoltaic (PV) manufacturing equipment and automation expertise;
- High efficiency solar-LED (light emitting diode) lighting systems;
- Novel photovoltaic module products;
- Hybrid concentrator PV-active solar thermal systems;
- Expertise in the design of solar electric systems for off-grid, remote or northern locations;
- Design of solar electric systems for large-scale grid-tied applications;
- Consulting services for site assessment and load analysis;
- Portable solar chargers for consumer electronics;
- Industry leading solar charge controllers, inverters, rectifiers and other balance of system components;
- Installation of off-grid power systems for rural telecommunication systems.

Photovoltaic systems can be installed on a variety of on- and off-grid applications, and can be integrated into buildings and other fixed structures. They have several inherent advantages over traditional power generation technologies.

- Energy from the sun is, for practical purposes, free, renewable and inexhaustible;
- Solar electricity generation offsets greenhouse gas and pollutant emissions from fossil fuel generation, and toxic waste from nuclear generation;
- PV is peak power—it produces most of its energy when demand peaks (daytime), that is when power is typically most expensive to produce. Its increased use can also eliminate the need for new high-cost centralized power plants;

- PV can create increased autonomy through independence from the electricity grid or backup during power outages.

The use of photovoltaic systems on a large scale in order to reduce fossil fuel consumption and greenhouse gas emissions requires that the energy associated with the construction, operation and decommissioning of PV systems be small compared with energy production during the system lifetime. That is, the energy payback time should be short. The energy intensity and cost of PV systems are closely related. At present the energy payback time for PV systems is in the range 8–11 years, compared with typical system lifetimes of around 30 years. About 60% of the embodied energy is due to the silicon wafers. As the PV industry reduces production costs and moves to the use of thin film solar cells the energy payback time will decline to about 2 years.

1.2 The Energy Crisis and the Electricity Demand

All around the world, the gap between demand and supply of electric energy is widening. Par example, the domestic final consumption of electric energy in Greece, was increased by 23.833 GWh in 1985 in 48.595 GWh in 2003, marking medium annual rhythm of enlargement 4% the period 1985–2003. The total final consumption in 2003 was distributed between domestic sector (33.8%), the sector of trade and services (30.8%), industry (29.1%), the rural sector (5.7%) and the sector of transports (0.5%) in the peak period. Bridging this gap from the supply side is a very difficult and expensive proposition. Also, limited energy resources, scarcity of capital and high interest costs for the addition of new generation capacity is leading to the increased cost of electrical energy. The only viable way to handle this crisis, apart from capacity addition, is the efficient use of available energy, which is possible only by continuously monitoring and controlling the use of electrical energy.

One of the most important problems in electric system is the guarantee of sufficient force of production so that is satisfied each time of the demand. Some years ago, the continuously increasing demand of electric energy in combination with the delays in the maintenance of transport and in the creation of new units of generation of electricity, they have led to dramatic reduction of margin of safety system. The problem is worsened by the imbalance of domestic electric system between North–South—the majority of installed force is found in Northern Greece while the basic centers of consumption in the Southerner—the limited capacity of international interconnections with the electric networks of neighboring countries and the relatively isolated geographic place of country in combination the electric networks of central Europe.

In domestic electrical system is dominated by the Public Power Corporation (PPC) which holds almost all installed of power stations and the 2004 produced 96% of the total domestic production of electricity. At the same time, the Public

Power Corporation owns the domestic transport system and the network distribution of electricity.

The total net installed power of power plant stations in Greece was in 2003 to 12.057 MW. From this 71% held the thermal power stations, producing the 91.9% from the 54.608 GWh clean electricity generation in the same year, 26% the hydro-electric involving 9.8% in total net production and the rest 3% generators with renewable energy sources, with the participation of 1.9% in total net production.

The lignite-fired Power Plants maintained the period 1985–2003 the important role in power generation, in contrast with the oil stations, whose participation in the overall net production fell. At the same time, however, has been strengthened considerably the contribution of gas stations in total net production, as well as the production from renewable energy sources, which, however, is still at a low level. The hydro-electric power in spite of the large size that has used primarily to cover peak loads.

The necessary add net available into force—in order to ensure the safety margin electrical system—assessed 325 MW up to 2010, size that corresponds to 327 around MW additional into force a year, the period 2005–2010 and to increase by 18% in relation to the net available force of system in 2004. However, the improvement (increase) of the rate load system from current levels (through e.g., application of measures electricity demand management) may reduce the necessary add into force until 2010 to 1,801 MW.

Delays to add validity, for the system, it is very likely to have serious problem competence electricity in the near future. At the same time, however, priority should be given to the purposes of managing demand of electricity with appropriate targeting, which may prove to be more efficiently, given that the deficit peak loads on minimum hours a year. With the systematic promotion of such measures would avoid making nonprofit investment in units will work only a few hours a year. In addition, the entry of new enterprises, will contribute to increased efficiency in the medium term and the security of energy supply.

Important initiatives necessary for the development of renewable energy sources (RES). International environmental obligations of the country and the achievement of the objectives of Directive 2001/77/EC on renewable sources of energy and enlargement of their participation in domestic energy balance makes it necessary to promote investment in the electricity generation by renewable sources. The problems in the sector of RES, summarized in time-consuming procedures licensing setup in limited capacity RES of the existing networks and the lack of land register and wider planning are known and in accordance with the announcements of Government efforts are being made in order to resolve soon. They will strengthen the production from renewable energy sources and partial the polluting production in lignite and oil stations and more rapid achievement of the environmental commitments of our country.

The situation in the European Union, consumption and production of electricity of the Member States initiated upwards, like the installed production capacity. The highest per capital consumption in the Nordic countries and the lowest in the

Mediterranean. The industrial sector is the largest electricity consumption in the European Union and follows the household sector and the area of trade and services. The electricity production in the European Union is based primarily on thermal and nuclear power stations. Participate in the production of the hydroelectric and renewable energy sources.

At present the level of EU made substantial changes in the institutional framework of the electricity market. The most important points of institutional changes relate to: (a) the acceleration of the process introduction of competition in the individual markets and the creation of a single internal market in electricity, (b) the laying down rules for cross-border exchanges in electricity and (c) develop the production of electricity from renewable energy sources. Full competition has achieved only in four Member States (United Kingdom, Sweden, Finland and Denmark), while welcome developed is competition in other two (Austria and the Netherlands). In some Member has made some progress, however, especially in Greece, Portugal and newcomers only some initial steps, with the result that the competition may not work.

1.3 Questions

1. What are the PV advantages over traditional power generation technologies?
2. What characteristics can be used to describe Solar Photovoltaic Technology?
3. Give a brief description to save energy via the more efficient use.
4. Identify the parts of a PV system consists.

Chapter 2
Energy Management

The effective management of energy costs has gained an increasing importance for European Industry because of the difficulties that they faced by the recession which followed the international energy and financial crisis.

The compression of the energy costs for businesses becomes imperative. In this way, resources are saved and this is beneficial for businesses and their customers.

However, there are additional reasons that require companies to be more aware of energy saving. The global reserves of energy raw materials are getting dry. At the same time, international efforts to reduce the wasted energy which is responsible for adverse climatic changes become more intense.

Consumers are fully aware of the need for effective protection of the environment. They will increasingly prefer companies that provide services and products more environmentally friendly and contribute to the saving of valuable energy sources.

The adjustment of businesses to this new situation, which requires the rational use of energy, is a necessity.

2.1 Basic Principles of Energy Management

Energy Management is the judicious and effective use of energy to maximize profits (minimize costs) and enhance competitive positions. The objective of Energy Management is to achieve and maintain optimum energy procurement and utilization, throughout the companies and:

- To save energy
- To minimize energy costs
- To waste without affecting production & quality
- To minimise environmental effects.

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2.2 Principles, Terms and Operation of Energy Management in Industry

The principles of Energy Management involve the following steps:

I. Adopting a policy for rational use of energy and implementation of such a policy
II. Procure all the energy needed at the lowest possible price (example: buy from original sources, review the purchase terms)
III. Manage energy use at the highest energy efficiency (example: improving energy use efficiency at every stage of energy transport, distribution and use)
IV. Reusing and recycling energy by cascading (example: waste heat recovery)
V. Use the most appropriate technology (select low investment technology to meet the present requirement and environment condition)
VI. Reduce the avoidable losses (make use of wastes generated within the plant as sources of energy and reducing the component of purchased fuels and bills)
VII. A strong proof of the environmental awareness of businesses

2.3 Energy Saving Management Strategy

Energy management should be seen as a continuous process. Strategies should be reviewed annually and revised as necessary. Adopting a policy for rational use of energy requires a long term commitment of the administration, of the stuff and the operational personnel of the company in order to implement an integrated program which, after a careful study, should be fully adjusted depending to the needs.

The implementation of such a policy of energy saving is an important issue for large industries that have significant electricity costs. Investments on equipment have already taken place and this means that important decisions must be made because the replacement of this equipment requires considerable costs.

In small businesses and individual companies things may be easier, because the owner—manager can directly take decisions.

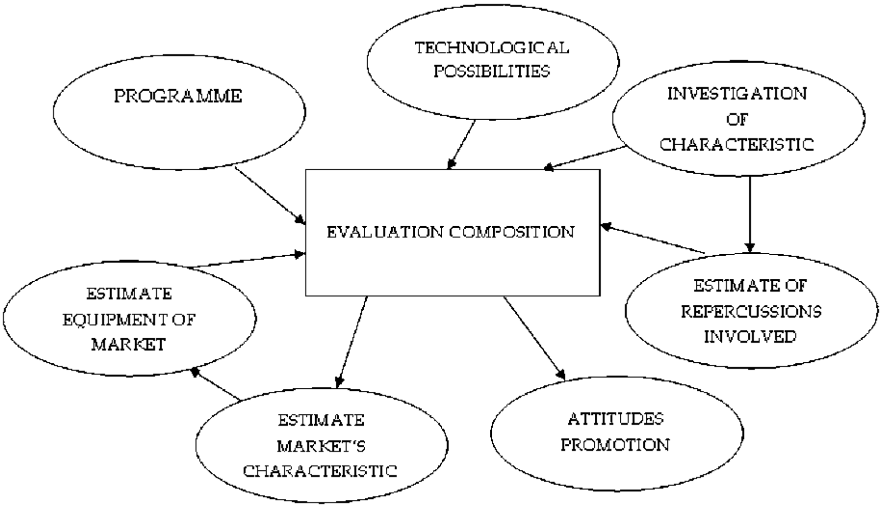
To convince them all—large and small businesses—that must permanently exercise a policy of control and suppression of energy costs, we have to assess the benefits arising from a standard and adjustable policy depending on the conditions of energy management.

Thus, the first step of a business administration—regardless of the size—is to take the decision to implement a policy of energy management.

To ensure commitment to a consistent policy of rational use of energy, all the benefits that will result in a short or in a long term for the business must be presented and evaluated.

The personnel which is going to undertake the task of planning a policy of energy saving should collect important information and present the reasons and advantages for adapting such a policy.

Based on the data available on trends in energy costs, especially electricity, to domestic and international market we can present the following:



The fast growth in international demand for energy raw materials (oil, gas, coal) compared to the total supply, inevitably leads to a continuous increase in electricity costs as well in the price of electricity.

- The EU policy to reduce emissions of carbon dioxide (CO_2) will create new additional price increases in electricity prices in 2013.
- The constantly growing environmental awareness of public opinion will benefit those companies that follow "green policies" in comparison to the pollutants ones and will contribute to energy saving.

Therefore, the benefits that will be obtained for the companies, regardless of size, from an energy saving policy are:

1. Reduction or maintenance of the total energy expenses as a percentage of the total expenses of the company.
2. Reduction or maintenance of the energy cost as a part of the average production cost of a product or a service.
3. Reinforce competitiveness against companies who are not following energy saving policies.
4. A strong proof of the environmental awareness of businesses through their participation in joint efforts for an effective protection of the environment by saving energy.

This argument can fully support a report to the management of the company for the adaptation of a standard energy saving policy and ensure the necessary commitment.

Thus, the first step of the management of a business—regardless of the size—is to take the decision to pursue a policy of energy management.

The key activities involved in the process are outlined below:

2.3.1 Identify a Strategic Corporate Approach

The starting point in energy management is to identify a strategic corporate approach to energy management. Clear accountability for energy management needs to be established, appropriate financial and staffing resources must be allocated, and reporting procedures initiated. An energy management program requires commitment from the whole organization in order to be successful.

Depending on the productive activity of the company, and on the energy expenses as a part of the total expenses, the pursued targets should be defined. Such targets may be:

- Development of an efficient energy management in a central level as well as in various activity fields of the company.
- Reducing overall energy costs over time.
- Direct reduction of the current energy expenses in the production levels, central offices, branches etc.
- Potential finding of substitutes of the supplied electric power through investments for self generating energy.
- Planning new investments in a less energy wasting equipment. Such planning is very important as it is connected to the artisanal and industrial businesses with future purchases of expensive machinery and equipment.
- Continuous improvement of environmental performance with significant reduction of pollutant emissions, etc.
- Reducing the cost of energy consumption per product and Services.

2.3.2 Commitment of the Personnel and Appoint Energy Manager

The most important step in designing and implementing a policy of energy saving management is the commitment of the executives who will be assigned to perform the operation. The executives should have a high level of technical knowledge and wider knowledge of the company's activities as well as a proved interest in introducing new innovations providing best technical performance with the lower costs for the business.

In large companies the employee who is designated to plan and execute this project should work within a strict timetable informing the administration of the company about the progress of the undertaken task during every step.

The administration of the company should monitor the relative works so as to be sure that the best practices are adopted. This is necessary because the decisions taken must be fully aligned with the future investment plans of the company.

The administration must also ensure that:

- All of the executives will contribute to the implementation of the undertaken project.
- All of the executives will contribute with their knowledge so as to adopt common solutions to promote short and long-term investments relying on a continuous cost reduction of the consuming energy.

Therefore it is necessary to create a working group with someone on top, who will be responsible for coordinating the actions of all team members.

All these procedures require decisions, reports, assignment of responsibility tasks and most of all a strict timetable of actions.

The energy manager, who should be a senior staff member, will be responsible for the overall coordination of the program and will report directly to top management. Energy managers need to have a technical background, need to be familiar with the organization's activities and have appropriate technical support.

2.3.3 Set up an Energy Monitoring and Reporting System

Successful energy management requires the establishment of a system to collect analyze and report on the organization's energy costs and consumption. This will enable an overview of energy use and its related costs, as well as facilitating the identification of savings that might otherwise not be detected. The system needs to record both historical and ongoing energy use, as well as cost information from billing data, and be capable of producing summary reports on a regular basis. This information will provide the means by which trends can be analyzed and tariffs reviewed.

The cost of electricity is the main energy cost and its share to the final product or service differs from company to company.

While the annual cost for electricity can be calculated based on current prices, there are difficulties in assessing long-term costs based on future prices of electricity. Here, we must take into account various factors such as:

The variation of energy prices in energy-wasting industries and in large or small businesses

- The benefits for the companies will emerge through the competition between suppliers of electricity or gas.
- The business plans for new investments to modernize or (and) for the expansion in the area of Renewable Energy sources, as well as the development of collaborations with other businesses for the development of self generating electricity systems.

All these parameters should be taken into account in order to form a long-term planning for the development of European Industries of any size.

2.3.4 Conduct Energy Audit

An energy audit establishes both where and how energy is being used, and the potential for energy savings. It includes a walk-through survey, a review of energy using systems, analysis of energy use and the preparation of an energy budget, and provides a baseline from which energy consumption can be compared over time. An audit can be conducted by an employee of the organization who has appropriate expertise, or by a specialist energy-auditing firm. An energy audit report also includes recommendations for actions, which will result in energy and cost savings. It should also indicate the costs and savings for each recommended action, and a priority order for implementation.

An effective energy saving policy has as a base the creation of a system of continuous monitoring of all the activities designed and already taking place during an implementation phase of the project.

A very common phenomenon is to take decisions at a highest level for the implementation of an energy saving policy and then, these decisions are fading away because there is always a focus on the daily operation and production of products and services. Energy management policies are concerning long-term future planned activities and therefore are in a lower level in the agenda of the administration.

In order to avoid the possibility of fading away the energy saving policy it is necessary to inform the administration on a regular, monthly or other time, basis.

These information reports will include:

1. Actions implemented since the beginning of the integrated program.
2. Identify problems or delays, analyzing the causes and finding the necessary solutions. While remaining problems are gathered, there is a danger of a failure for the long-term program.
3. Short and long-term actions that have not been implemented yet. Practically this procedure allows not only the evaluation of the progress of the energy saving and environment protection program, but also the evaluation of the work undertaken to implement by the authorized executive and the committee that has been established for the same reason.

The controlling mechanism of the energy management effectiveness should be in a continuous operation and give clear answers to the following key issues:

1. Report on the developing costs of the provided energy overall and by the supplying source, with a comparison of the relevant data through time. Analysis of the results that come out of these comparisons.
2. The level of implementation of the overall policy that has been scheduled so as to be clear and understandable if there are small or large delays concerning the program.

3. Evaluation of the current relation of the financial efficiency of the desired objectives. At this point, it is investigated whether the policy followed is efficient and reduces the energy costs in relation to the total expenses for this purpose (payments, energy/environmental managers, investment costs etc.)
4. Performance in environmental terms in accordance to the goals that have been achieved.
5. Evaluation of the participation of managers and personnel in the efforts to reduce energy costs by product, service, activity sector, etc.
6. Data on current prices and predictions of future prices of energy raw materials and electricity, based on the latest reports collected from various sources.
7. The level of implementation of educational programs that have been planned for energy saving.
8. Detailed presentation of the investment program that has been scheduled and approved by the administration of the company. With quantification of all the elements so as the level of implementation to be understood and easily identify deviations from the original program.
9. Report by the energy manager on the effectiveness of the external consultant and evaluation of his participation based on what is stated in the contract agreement that has been signed with the company.
10. Report by the external consultant on the progress of the project, the effectiveness of his cooperation with the work team for the energy saving and the head energy manager. This report is very important for the administration so as to have an independent opinion on the difficulties faced for the implementation of the long-term planning.

Based on the reports and data that will be presented, it is responsibility of a company's administration to make a total and individual evaluation of all the participants that have been assigned to implement the project of energy saving.

The administration must undertake all these activities that will allow overcoming any delays or to adopt changes that are feasible or necessary because of significant changes to key parameters.

If necessary, changes may be required concerning persons if found failing in performing their obligations or concerning the external partner if he has not fully met his obligations.

2.3.5 Formalize an Energy Management Policy Statement

A written energy management policy will guide efforts to improve energy efficiency, and represents a commitment to saving energy. It will also help to ensure that the success of the program is not dependent on particular individuals in the organization. An energy management policy statement includes a declaration of commitment from senior management, as well as general aims and specific targets relating to:

- Energy consumption reduction (electricity, fuel oil, gas, petrol etc.)
- Energy cost reduction (by lowering consumption and negotiating lower unit rates)
- Timetables
  - Budgetary limits
  - Energy cost centers
  - Organization of management resources.

2.3.6 Prepare and Undertake a Detailed Project Implementation Plan

A project implementation plan should be developed as part of the energy audit and be endorsed by management. The plan should include an implementation time table and state any funding and budgetary requirements. Projects may range from establishing or changing operational procedures to ensure that plant and equipment use minimum energy, renegotiating electricity supply arrangements etc. to adopting asset acquisition programs that will reduce energy consumption. An overall strategy could be to introduce energy management projects, which will achieve maximum financial benefits at least cost to the organization.

2.3.7 Implement a Staff Awareness and Training Program

A key ingredient to the success of an energy management program is maintaining a high level of awareness among staff. This can be achieved in a number of ways, including formal training, newsletters, posters and publications, and by incorporating energy management into existing training programs. It is important to communicate program plans and case studies that demonstrate savings, and to report results at least at 12-month intervals. Staff may need training from specialists on energy saving practices and equipment.

2.3.8 Financing of the Investment Cost

Savings in recourses through the development of a policy for rational use of energy can be achieved through simple acts such as the awareness among executives and employees to reduce the consumption of electricity or other types of energy to the minimum.

However, in the case where it is intended to make investments with an additional target to reduce the cost of the consuming energy per produced product, a key factor is to find the necessary capital.

Here, the entrepreneur must consider a number of factors relating to the benefits resulting from an investment made which will ensure a significant reduction of the energy cost of the produced product.

The specific issues to be resolved are:

- The total amount of the capital need to be invested in order to replace the mechanical equipment, upgrade the electronic and electrical equipment, etc.
- Coverage of part of the total capital requirements by equity capital and bank loans.
- Estimations for the variance of the interest rates in the case it is designed to take out a very large bank loan.
- Market research among banks to identify those offering better loan conditions.
- Annual and monthly calculation of the financial burden from the interest rates until the fully repayment of the loan.
- Calculation of the financial benefit that will arise for the company after obtaining a bank loan for the future profitability of the company.
- Calculations of the economic benefits resulting per produced product after making an investment for the purchase of new machinery etc., in comparison with the current cost which is particularly aggravated by the cost of energy consumed.

2.3.9 Annual Review

An energy management program will be more effective if its results are reviewed annually. Review of energy management policy and strategies will form the basis for developing an implementation plan for the next 12 months.

2.3.10 Communicative Policy

Once a decision is taken by the administration of the company to undertake an energy saving program, key success factor is the promotion in two levels:

2.3.10.1 Internal Communication

The administration of the company informs the executives and the personnel about the advantages that will arise from implementing a series of measures to save energy. The extension of this communication will depend on the importance of the actions that will be developed, especially if the company is planning to become a "green company" by extending its operations not only in saving energy but also in waste recycling areas, etc. contributing in that way to the saving of various raw materials.

Thus, based on the scale of these actions they can take various forms such as:

- Simple instructions for more limited use of air conditioning, personal computers, lights, etc.
- Circulars for participation of the staff in specific investment plans related to savings in order to be trained in new systems, machinery etc. that are less energy consuming.
- Motivating the executives and the technical or other type of personnel to suggest practical ideas for the reduction of the energy cost.
- Put up posters with slogans, exhortations, etc. for the rational use of energy.

2.3.10.2 External Communication

The announcement of decisions made by the administration about energy saving, takes place when these decisions are related with new investments that ensure better environmental and energy performance. These announcements made by large companies are mainly addressed to:

- Mass media
- Customers, particularly sensitive to environmental issues.
- Shareholders, who weigh the benefits from investments in energy saving and environmental protection.
- International institutional investors who invest great amounts in "green companies" based on internationally accepted indicators.
- Local communities where the company has a heavy productive activity that cause environmental pollution which are going to be limited through the new actions and investments.

ATTENTION:

Since there is publicity through the external communication of the activities for large energy savings and environmental protection, the company is committed to implement them within the determined deadlines. Otherwise, any delays are creating a negative image for the company. Accordingly, the public announcement is made under the following basic requirements:

1. To provide a fully integrated energy saving program.
2. To be fully compatible with the overall investment and operational plan of the company.
3. To have ensured the funding for the relevant investment.
4. The working group to be fully operational and have the necessary skills and experience to carry out the operation.

2.4 Questions

1. Define the Energy Management.
2. What is the objective of Energy Management?
3. What are the principles of Energy Management?
4. What characteristics can be used to describe the commitment of the personnel?
5. Define financing of the investment cost and indicate how it is calculated.
6. Briefly describe the major stages in controlling mechanism of the energy management effectiveness.
7. What factors can influence an organization's choice of appoint energy manager?
8. Give a brief description Energy Saving Management Strategy.
9. Identify the benefits that will be obtained for the companies, regardless of size, from an energy saving policy.
10. How an organization does conduct energy audit?
11. Identify a Strategic Corporate Approach.
12. How does an organization formalize an Energy Management Policy Statement?
13. Prepare and Undertake a Detailed Project Implementation Plan.
14. Implement a Staff Awareness and Training Program.
15. What are internal and external communication policy?

Chapter 3
Environmental Management

3.1 Develop an Environmental Strategy

The administrations of modern business—regardless of their financial size—have to deal with issues of energy saving as a part of their environmental strategy.

For a large number of companies especially for those which are small and provide services, it is most likely that they don't need an integrated environmental policy and they can just take into consideration energy saving issues.

Therefore, administrations of companies decided to develop a long-term environmental policy, which is linked to the energy saving, need to achieve the following targets:

- Adoption of a "new philosophy" that has to do with the development of "environmental consciousness" at all levels of the hierarchy,
- Right planning to implement an environmental policy that is linked to energy saving.
- Assignment of the planning project in a particular team with members that have the necessary knowledge and experience.
- Calculation of costs that will be required over time to implement this program.
- Choosing an appropriate external partner who will offer his experience for the implementation or for the appropriate adjustment to the original program.
- Design the suitable mechanisms and energy saving systems and better protection of the environment.
- Design a mechanism for constant monitoring of the progress of the program.
- Finalization of the environmental program and the funds will be required.

3.2 Environmental and Energy Management

An energy saving policy by enterprises is an important starting point for pursuing a systematic policy on environmental management.

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Here, we must highlight the “differences” between energy and environmental management:

- Energy management can be restricted only on energy savings without an integrated environmental program. For example, a company can be interested only to ensure the supply of energy through cooperation with the supplier who offers better agreement conditions.
- Environmental management covers a range of issues concerning the procedures for converting the company into a “green business”, with energy saving being only a part of its total environmental program.

A company, in order to design and implement an integrated environmental policy needs, first of all, to define those individuals who have the necessary—less or more—knowledge to carry out the operation.

This requires:

- The establishment of a working team with the task to develop an environmental policy.
- Assignment of clear roles for each member of the working team by the administration, which is a key factor for the success of the team.
- Determine a head member to coordinate the team and to constantly monitor the implementation progress of the undertaken project as well as to be responsible to inform the administration.
- Active participation of the personnel in every productive activity of the company that is connected with consumption of great amounts of energy. Incorporate executives from other sectors of the company to the team, such as the head members of the financial services, if there is planning to make large investments to upgrade the installed productive capacities or for a full modernization of them, which, in this case, requires significant amount of money.

In this way, the development of a large program that allows the coordination of all key areas of activity associated with large energy consumption is achieved. What should be studied closely is whether the various areas of activities are parts of a production chain or not. It is likely that some activity sectors to rely on sophisticated environmentally friendly machinery with very good energy performance and others, that have been developed several years ago, and need a complete productive restructuring or to be stopped if they are not economic.

Therefore, the total number of the team members will depend on the number and degree of involvement in various productive or other kinds of a company’s activities in energy saving policies. However, the head executives of the sectors who are directly involved to energy saving actions should know in detail the progress of the implemented updating and modernization projects. So far, the composition of the environmental and energy saving team was examined from the side of the energy management.

However, since the investment needed is of significant value, it is possible other more specialized teams to be created, with more specific tasks.

For example, a team may be created and be composed of persons related to the financial field of the project while funding and cost-benefit analysis is a very important aspect.

3.3 Environmental Management Systems

Effective environmental management can lead to the adoption of Environmental Management Systems (EMS). This will depend on taking into account and weighing all the advantages and disadvantages of such an option.

Additionally, an effective policy of rational use of energy can significantly contribute to the adoption of the European Environmental Management System under the name of "Eco-Management and Audit scheme (EMAS)" which is under the regulation 1863/93 of the European Council.

The Eco-Management and Audit scheme is very important for European companies because it contributes to the common European effort which intends to protect the environment within the Member States of EU.

Since 1996 a series of standards ISO 14000 implemented, conducted by the International Organization for Standardization ISO, which are referred to products of a business as well as to management procedures.

The implementation of these standards in terms of energy saving should ensure that they are achieving the following specific objectives:

- The company saves energy and this has positive effects on the environment.
- Through the Environmental Management System a continuous effort for energy saving through specific responsibilities of the executive members of the company is certified.
- Constant Internal controls are being held which proves that they certify actions for energy saving. The adopted standards are fully followed and there are continuous efforts to identify new problems and face them. The adoption and implementation of a recognized environmental management system, allows a company to gain an environmental label for its products and services.

3.4 Mechanical Equipment Selection

For manufacturing companies the machinery and technological equipment is a major cost and energy consumption factor. So, in an Environmental Management System, the electromechanical and mechanical equipment should be selected based on the cost of the energy required for the production of a specific final or intermediate product. Companies that estimate the electricity they consume as a total variable cost and they don't break it down per produced product may have difficulty managing to make substantial reductions in energy costs.

In order to achieve reduction of the total energy cost during the manufacturing phase, they should try to use those machines that ensure:

- Reduced energy cost per unit of produced product combined with the efficiency of the machine which ensures the reduction of the raw and auxiliary materials needed in the manufacturing process.
- Production of products or parts etc. with longer lifetime, that require less amount of energy during the production process concerning their lifetime.
- Use of systems that ensure efficient use of electricity by improving and stabilizing the 3-phase voltage, improving the power factor, protection from temporary fluctuations of voltage, etc.
- Measurements from specialized companies to identify energy losses in order to make the necessary improvements.
- Proper maintenance of the high energy consuming equipment in order to ensure longer life and better production performance.
- Reducing the volumes of wastewater, etc. during the manufacturing process.

3.5 Eco-Label Award

By implementing an Integrated Environmental Management System the manufacturing companies can set as a target the production of products that will be validated through an environmental label.

Gaining an eco-label indicates that the products provided to the market have limited environmental impacts throughout their life cycle and they offer consumers accurate and scientifically based information on the impact of these products on the environment.

We note that the EU legislation on the award of ecological labels aims to make consumers prefer products with potential to reduce environmental impacts throughout their life cycle by giving information about the environmental characteristics of the products that have the relevant label.

It is very important to mention that:

- The eco-label on a product indicates that this product compared to other similar products, can help contribute to the reduction of certain negative environmental impacts.
- According to EU legislation it is necessary to give more information on the label, about the reasons for the award, so that consumers can understand the importance of the award.
- As it is required by EU legislation about the award of an eco-label, the effects from the adoption of procedures that contribute to the energy saving are taken into account.

The rational use of energy could be considered as the faster, most effective and cost efficient way to control energy consumption, as well as fuel consumption.

Also, the energy saving, guarantees the limitation of greenhouse gas emissions which is an issue that has been strictly regulated under a legislation framework.

The continuous increase of fuel prices, the problems appear in fuel supplying with a possible decrease of the sources as well as the environmental constraints made an urgent need for an organized and continuous activity for a more efficient use of energy without reducing the production levels of a business and without sacrificing safety or environmental quality.

The cost-effective energy saving means for the European Union a less dependence on imports, greater respect for the environment as well as reduced cost for the EU economy in a period of increased competitiveness.

The building facilities are important assets and a required rational energy policy would contribute in a positive way to the general effort for a reduction of the energy dependence.

In addition, the energy saving within the buildings in addition to social benefits that will result will also have direct positive benefits to businesses themselves.

3.6 Energy Management Policy for Industrial Application

The purpose is to clearly define the goals and objectives for Industry, in respect to the reduction of energy consumption on industrial buildings in a manner consistent with the Sustainability Policy of each industry and to:

- reduce energy consumption;
- reduce waste and emissions;
- seek environmentally neutral sources of heating, cooling, and energy; and to
- reduce pollution.

The energy management programme must be based on a policy fully backed by the industrial's management team. A formal policy shows the organization's commitment and increases its chances of meeting energy savings goals. The policy is a public document can put in the annual report.

The policy should cover things like:

- Who is accountable for energy management
- What energy savings targets are
- How will monitor, review and report on progress
- Staffing and training to support the policy
- How it will be integrated into wider business processes
- Criteria for energy management investment
- Working energy efficiency into new capital investments
- Working in with environmental policies and programmes.

3.7 Planning the Policy for the Industry

Ideally, the main goals of an industrial policy will be worked into company's vision statement. Plan for adapting business processes and company's culture and structure to achieve the energy goals.

The energy management strategy shows how the energy management policy works. So, it should regularly review it to keep it in line with the business plan. The strategy needs to consider:

1. Strategic issues
    - Long-term issues and how they will be addressed
    - Links with the business plan
    - Viability of future energy resources
2. Management
    - Energy manager and their roles
    - Energy committees
    - How energy savings will be integrated with other management processes
    - Responsibility and accountability
    - Reporting and communication
3. Resources
    - Staffing and duties
    - External consultants and energy suppliers
4. Implementation
    - Budget
    - Investment criteria and life-cycle costing
    - Funding
5. Reporting
    - Within local workgroups
    - Board and external reports
6. Information
    - Monitoring energy use
    - Separating energy cost centers
    - Audits
    - Accounting systems

3.7.1 Action Planning

Energy management program needs:

- management team commitment
- clear responsibility and accountability
- specific, realistic goals
- planning
- performance monitoring.

3.7.2 Management Team Commitment

Senior management support is essential from the start of the programme and right through. Launch the programme with endorsement from the chief executive and follow up with a presentation to staff on the benefits of efficient energy use.

3.7.3 Clear Responsibility and Accountability

The management team needs to visibly support the programme and ensure it is adequately resourced.

The energy manager is responsible for the programme's implementation and effectiveness. They report to and work with the management team to set energy targets. They also set up an energy team made up of staff from different divisions.

Smaller organizations can make energy saving part of regular management duties, and something all staff can have a role in.

3.7.4 Specific, Realistic Goals

All goals should be realistic and measurable. Measuring energy savings against targets is easier than measuring changing organizational views on energy use—but both are important.

3.7.4.1 Setting Energy Savings Targets

Energy managers have come from a wide range of backgrounds, from engineering to accountancy and administration. The energy manger should be someone who has authority and is respected by staff across the company.

The industry needs a full time person to manage the energy programme if the business spends more than 2 million euro per year on energy.

The energy manager's role changes as the company's energy management activities change. The phases below show how the energy manager's role evolves with the programme.

3.7.5 Energy Program

3.7.5.1 Assess Energy Use

At the start, the energy manager identifies the business' main energy uses and introduces 'no cost' ways to save.

This involves:

- measuring energy use by each business area
- checking that the right type of energy is used, and at the right prices
- checking that plant and office equipment are running efficiently
- Training staff in energy efficiency.

At this stage the energy manager needs:

- energy management skills
- an understanding of how energy efficiency technologies relate to the business
- the respect of management
- Suitable education and training.

3.7.5.2 Invest in Energy Saving

The energy manager competes with other projects for funds. They need well developed skills in predicting benefits and calculating returns.

They will need expertise in accounting and investment, and experience in managing energy efficiency projects. The first two units will suit someone who enjoys working to shorter-term goals.

3.7.5.3 Control Energy Use

Here the energy manager sets up an energy management information system. They will need experience in the design and operation of management information systems, or managing the outsourcing of them.

3.7.6 The Right Place for the Energy Manager

Options for where to place the energy manager include:

- Technical department—Good in the early phases but less appropriate for training and energy information activities.
- Human resources—Motivation and training is made simpler from a base here but there may be a problem with technical support and credibility.

- Finance—A good base to run the financial controls and accounting procedures from. Technical support and credibility can be an issue.
- Chief executive's office—In the early stages the high profile and access can help kick-start the programme but long-term the role needs to be part of an operational role.
- Corporate services—This location is suitable in a large business with operations spread over a large area. Energy initiatives can be centrally coordinated and supported company-wide.

3.7.7 Choosing an External Partner

A key success factor for implementing a program of rational use of energy is to use a reliable and very experienced, in relevant matters, external partner. Such a need becomes much greater when the firm plans to make major new investments in production equipment or in any other kind of equipment which requires big expenses and find the necessary funds to finance them.

In addition, due to the development of Community or national programs related to energy saving projects, the specialized partners can contribute with their experiences to the successful business involvement in activities which ensure grants reducing the total investment cost.

In the specific investment sector, the choice of a partner, able to help with the implementation of programs that ensure better energy efficiency at the lowest cost in order to benefit the firm's competitiveness, is particularly important.

Efficient use of external partners can be ensured by a plan that will implement the company through the following phases:

- Market research among consultants dealing with saving or (and) rational energy usage issues.
- Meetings of managers or designated for this purpose executives (production technicians etc.) with the external consultants.
- Submission of informative notes by the consultants about their experience in the area of providing services on energy saving, their suggestions etc.
- Evaluation of the information provided by the external consultants and ranking them according to certain criteria.
- Investigating the effectiveness of the candidates through questions addressed to other companies that already have used the services of those consultants.
- Connecting the cost of the providing services of external consultants with the expected added value for the benefit of the company.
- Final choice of the external consultant.
- Starting a cooperation between the external consultant and the company through an authorized company executive in order to study and examine together various scenarios for energy saving.

- Define a contract schedule for the amount of the payment of the external consultant, etc., depending on the completion degree of the work he was assigned to perform.
- An Approval of the contract by the management board or by the entrepreneur and setting the implementation under the supervision of a specific person or group of persons, depending on the amount of work assigned to implement.
- Monitoring the progress of the work by the authorized person and providing information to the company administration on a regular basis.
- Completion of the project by the external consultant.

3.7.7.1 Energy Policy

Any industry which applies energy police is to control energy consumption in order to:

- avoid unnecessary expenditure
- protect the environment, and
- prolong the useful life of fossil fuels

3.7.8 Objectives

The industry's long term objectives are to:

- buy fuels at the most economic cost;
- burn and use fossil fuels as efficiently as practicable enabling future generations more time to research alternative energy sources;
- reduce the amount of pollution, particularly CO_2 emissions, caused by its energy consumption;
- reduce, wherever possible, our dependence on fossil fuels through the use of ambient and renewable energy;
- reduce the loss of energy from its buildings to the minimum practical level
- install a renewable energy system

Energy use patterns in European Industry are based fundamentally upon business behavior. Enhancing the ability of electric and gas utilities to shape consumer energy consumption and use the most efficient equipment on both ends of the transmission line could create an effective energy saving dynamic.

Encouraging utilities to draft comprehensive plans for demand-side management and energy efficiency programs could stimulate greater regional savings. In a region where the demand for energy outpaces population growth rates in some areas, an increasing number of utilities are actively pursuing demand-side management programs to reduce load growth.

3.8 Questions

1. What is the Eco-Management?
2. What indicates gaining an eco-label?
3. Identify differences” between energy and environmental management.
4. Which is the purpose of energy management policy for industrial application?
5. What characteristics should cover he policy of energy management policy for industrial application?
6. What strategy needs to consider an energy industrial policy?
7. What energy management program needs?
8. How the energy manager’s role evolves with the energy policy programme?
9. Which is the right place for the energy manager?
10. Briefly describe how an industry applies energy police to control energy consumption.
11. Briefly describe the major stages of setting energy savings targets.
12. What factors can influence an organization’s choice of external partner?

Chapter 4
Photovoltaic Energy

The sun's energy is the primary source for most energy forms found on the earth. Solar energy is clean, abundant, and renewable. Although solar energy is clean and abundant, it is diffuse and must be captured, concentrated, stored, and/or converted to be used in the highest value energy forms. The solar energy industry has grown steadily in just two decades and currently markets more than 2 billion Euros annually in products.

'Photovoltaic' is a marriage of two words: the Greek word 'photo', meaning light, and 'voltaic', meaning electricity. Photovoltaic technology used to describe the hardware that converts solar energy into usable power, generates electricity from light. Photovoltaic is the direct conversion of light (photons) into electricity (voltage) using semiconductor materials. The photovoltaic (PV) modules that perform this conversion have many benefits. They are durable and reliable, and require minimal maintenance as they have no moving parts. They are also completely silent and require only sunlight as fuel.

At the heart of photovoltaic (PV) technology is a semi-conductor material which can be adapted to release electrons, the negatively charged particles that form the basis of electricity. The most common semi-conductor material used in photovoltaic cells is silicon, an element most commonly found in sand. There is no limitation to its availability as a raw material; silicon is the second most abundant material in the earth's mass.

All PV cells have two layers of semi-conductors, one positively charged and one negatively charged. When light shines on the semi-conductor, the electric field across the junction between these two layers causes electricity to flow, generating DC (direct current). The greater the intensity of the light, the greater the flow of electricity.

A photovoltaic system therefore does not need bright sunlight in order to operate. It can also generate electricity on cloudy days. Due to the reflection of sunlight, days with slight cloud can even result in higher energy yields than days with a completely cloudless sky.

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Generating energy through solar PV is quite different from how a solar thermal system works, where the sun's rays are used to generate heat, usually for hot water in a house, swimming pool etc.

The advantages of PV technology:

- The fuel is free.
- There are no moving parts to wear out, break down or replace.
- Only minimal maintenance is required to keep the system running.
- The systems are modular and can be quickly installed anywhere.
- It produces no noise, harmful emissions or polluting gases.

4.1 Photovoltaic Technology and Systems Information

The era of the modern photovoltaic technology and systems began in the early 1940s when Russell Ohl simultaneously discovered the p–n junction and the silicon photovoltaic or solar cell, while using an ohmmeter at Bell Labs to test the electrical resistance of a cracked silicon sample. On one side of the crack, which was eventually dubbed "n" for negative type, had extra electrons. The other side had a shortage of electrons (abundance of positively charged holes) and was eventually dubbed "p" for positive type. The interface was dubbed a p–n junction. Incident light striking the sample precipitated a photovoltaic or photoelectric effect when it was absorbed by electrons in the p-region and enabled them to flow across the intrinsic electric field set up by the p–n junction (Fig. 4.1).

Photovoltaic cells had been created previously using pure selenium that had not been "doped" with impurities to create p–n junctions. But those cells lacked the photovoltaic conversion efficiency of the p–n junctions in silicon, which ushered in the capability for powering electrical equipment with photovoltaic systems, and essentially paved the way for the modern photovoltaic industry. It still took

Fig. 4.1 PV module production line

Fig. 4.2 Large PV power plant with thin film solar modules

15 years from the time of Ohl's seminal discovery before Bell Labs researchers developed the 6% efficient solar cells that began widespread industrial use. Of course the p–n junction plays an essential role in providing diodes and transistors for the electronics industry also. And the reverse of the photovoltaic process, pumping electricity through a p–n junction to create light, is the mechanism behind light emitting diodes (Fig. 4.2).

Today photovoltaic cells come in a variety of sizes and are often connected to form photovoltaic modules that in turn, can be connected to form photovoltaic arrays or solar panels of different sizes and power output. The modules of the array make up the major part of a photovoltaic system, which can also include electrical connections, mounting hardware, power-conditioning equipment, and energy-storing batteries. Simple photovoltaic systems provide power for small items, such as calculators and wristwatches. More complex photovoltaic systems have been used to power communications satellites, water pumps, as well as lights, appliances, and machines in buildings. Declining manufacturing costs are expanding the range of applications to include road signs, home power generation and even grid-connected electricity generation. Large-scale incentive programs, offering financial incentives like the ability to sell excess electricity back to the public grid, have also contributed to the pace of solar photovoltaic installations around the world.

The crystalline silicon that Russell Ohl used and that is also fundamental to the microelectronics industry has been and remains the primary photovoltaic material for creating photovoltaic cells. But relatively high material and processing costs have led to research and development of alternative photovoltaic materials that might prove more amenable to large area manufacturing processes. One of those is the thin-film approach based on either amorphous silicon or polycrystalline materials such as cadmium telluride (CdTe) or copper indium gallium diselenide (CIG or CIGS). The semiconductor junctions are formed as a p–i–n device in amorphous silicon or as a hetero-junction for CdTe and CIS. Another alternative approach is to use organic photovoltaic cells that use electrochemical, polymer or

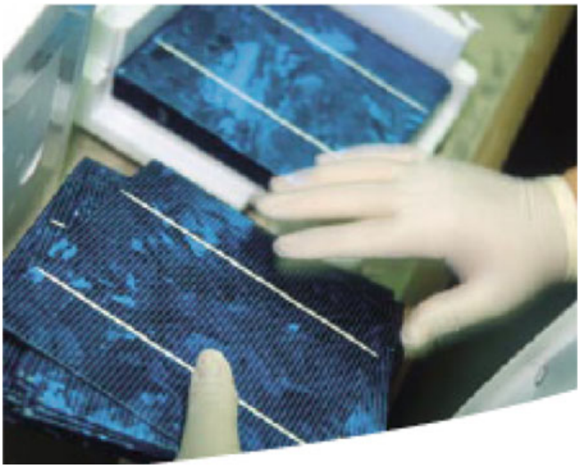


Fig. 4.3 Multicrystalline cells at Q-cells

nanocrystalline approaches rather than a traditional p–n junction to create a photovoltaic or photoelectric effect (Fig. 4.3).

The semiconductor junctions are formed as a p–i–n device in amorphous silicon, or as a hetero-junction for CdTe and CIS. Another alternative approach is to use organic photovoltaic cells that use electrochemical, polymer or nanocrystalline approaches rather than a traditional p–n junction to create a photovoltaic or photoelectric effect.

4.2 The PV Cell

Since over one hundred years (Becquerel, in the middle of the nineteenth century) it is known that under a few certain conditions solar radiation can alter the electrical behaviour of certain materials, originating an electrical current. Since then the efficient ways of generating electric power from the solar radiation have been widely investigated, being called "photovoltaic cell" (or "solar cell") the basic device used to obtain electricity (Fig. 4.4).

The functioning principle of solar cells is the photovoltaic effect:

- The union of two semiconductor materials, one type n and another type p, provokes a potential difference in the proximities of this union.
- Photons transfer the energy of the solar incidental radiation to semiconductor's electrons, liberating them from the crystalline net they were joined to.
- The existing potential difference inside the union provokes an arranged flow of carriers (electrons and hollows) photo generated, originating a clear difference of potential in the cell.
- By means of the existing contacts in the cell, can be assembled an exterior circuit where an electrical current able to provide electrical useful power will circulate.

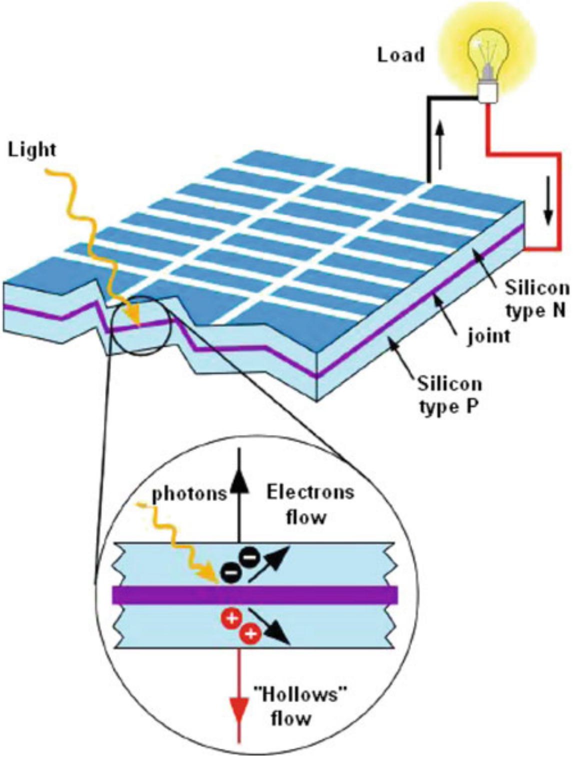


Fig. 4.4 Solar cell performing

Before going on, it is worth emphasizing the fact that PV cells are not electrical accumulators. Their electric power generation capacity is subordinated to the presence of solar incidental radiation on them, so the variability, discontinuity and randomness that characterize this radiation will also constitute the signs of identity defining photovoltaic electric power.

4.3 The PV Panel

Solar cells based on crystalline silicon are characterized by their limited capacity to generate electrical power and their fragility and vulnerability to external agents. For their managing and practical utilization several of them are joined together setting up what is called a photovoltaic panel, turning out a compact, manageable and resistant structure. Silicon-made PV panels are used to become commercialized as devices of 12 or 24 V and up to 100 W, or more, so that in several applications will be necessary the association of various unities to satisfy electrical requirements on voltage, current and power.

4.3.1 Electrical Characteristic

A solar cell can be represented as the electrical equivalent circuit showed in the Fig. 4.5. This is just the electrical simplified representation of the functioning described previously: a current of photo-generated carriers, the resultant diode of the union of semiconductors, a tension provoked by the photovoltaic effect and a few resistances that include the existing losses during the functioning (leakage currents, contacts, etc.).

This electrical equivalent circuit can be applied to a PV panel formed by NP rows in parallel and each one with NS cells in series, turning out to be the relation tension—current that appears following:

$$I = I_{sc}\left[1 - \exp\frac{(V - V_{oc} + IR_{SG})}{N_S V_T}\right]$$

I: Current provided by PV panel. It is equal to the current provided by one cell, multiplied by the number of cells in parallel.

I_{sc}: Current provided by PV panel under short-circuits condition. It can be considered equal to the current of photocurrent carriers (IL in Fig. 4.5).

V: Existing voltage inside PV panel terminals. It is equal to the existing one in a cell multiplied by the number of cells in series.

V_{OC}: Existing voltage inside PV panel terminals when open-circuit (which means lack of current).

RSG: Total series resistance of the PV panel, equal to RSNS/NP.

The electrical characteristic of the PV cell is generally represented by the current versus voltage (I–V) curve. Figure 4.6 shows the I–V characteristic for a

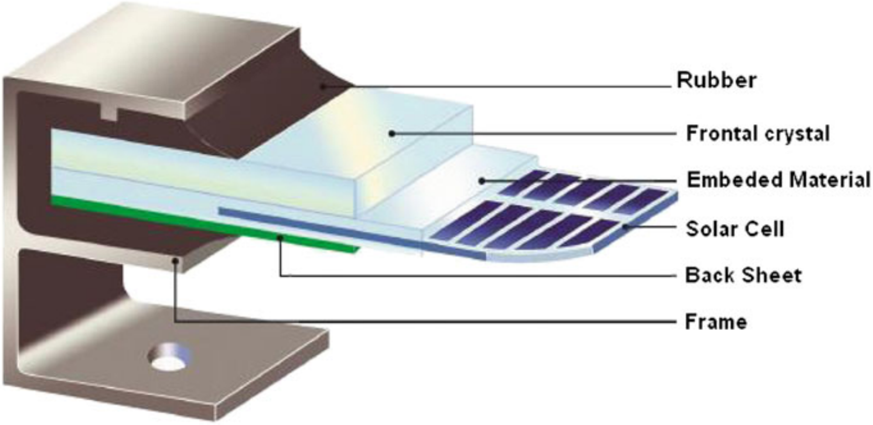


Fig. 4.5 General purpose PV panel cross-section

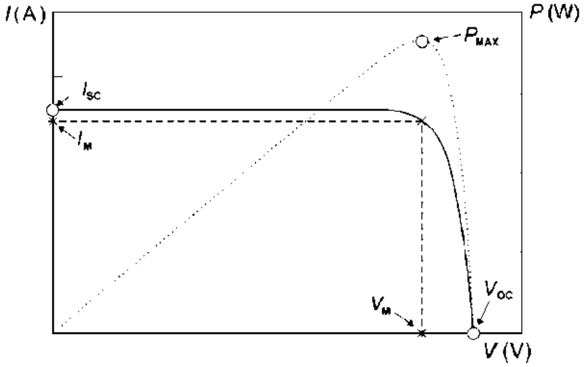


Fig. 4.6 I–V characteristics

PV module. At the same time, it is indicated by means of points the power curve of the module. Both I–V characteristic and power curve must be provided by module manufacturer.

Considering the I–V characteristic, it is necessary to indicate some requirements on how a PV module works:

Working point of PV panel (pair I–V) can be anyone in the V–I curve, being determined by the intersection of panel's I–V curve and the load to it connected.

There is only one pair of values VM, IM providing maximum power. From now on these values will be called as VMP and IMP (current and voltage at Maximum Power Point). A rough estimation of VMP, valid for most crystalline silicon-made panels is:

$$V_{MP} = 0.8V_{OC}$$

The current generated by a module is limited by nature, so that a short-circuit scenario is not a risky situation.

Besides described voltage and current parameters, there exist three more parameters of interest:

4.3.1.1 Shape factor

It is defined as:

$$FF = P_{MAX}/I_{SC}V_{OC} = I_M V_M/I_{SC}V_{OC}$$

and its name is due to the fact that mentioned factor is a measure on how I–V curve is close to a rectangle with V_{OC} and I_{SC} sides. This factor will be better as nearer it is to the unit.

4.3.1.2 Efficiency

The efficiency, as in case of a solar cell, is the quotient of the electrical power generated by the module and the power of the incidental radiation over it.

4.3.1.3 Nominal Operating Cell Temperature

Nominal operating cell temperature (NOCT) indicates the temperature reached by cells when they are under following working conditions:

- Radiation intensity: 800 W/m^2
- Spectral distribution: AM 1.5
- Cell temperature: 25°C

4.3.1.4 PV Panels Association

Individual electrical characteristic of PV panel not always allow satisfying system requirements on voltage and current. To get it, we have to associate the necessary number of panels joining properly their positive and negative terminals. The junction of two or more panels in series causes a voltage equal to the addition of individual voltages of each module, keeping invariable the current. On the contrary, when connecting in parallel it is current what it is summed, keeping invariable the voltage? Previously it was stated the effect reached when associating modules in series and in parallel, but such expected effects and real ones only match when every cells in a panel, and every panel, have the same electrical characteristic and work under identical temperature, lighting, etc. conditions, what in practice is not always true.

4.3.1.5 Stand-Alone Systems

The major application of the stand-alone power system is in remote areas where utility lines are uneconomical to install due to terrain, the right-of-way difficulties or the environmental concerns. Even without these constraints, building new transmission lines is expensive. A 230 kV line costs about $1 million per mile. For remote villages farther than two miles from the nearest transmission line, a stand-alone PV system could be more economical. The solar power outputs can fluctuate on an hourly or daily basis. The stand-alone system must, therefore, have some means of storing energy, which can be used later to supply the load during the periods of low or no power output. Alternatively, PV can also be used in a hybrid configuration with diesel engine generator in remote areas or with fuel cells in urban areas. According to the World Bank, more than 2 billion people live in villages that are not yet connected to utility lines. These villages are the largest potential market of the hybrid stand-alone systems using diesel generator with PV for meeting their energy needs. Additionally, PV systems create more jobs per dollar invested, which help minimize the migration to already strained cities. Because power sources having differing performance characteristics must be used in parallel, the stand-alone hybrid system is technically more challenging and expensive to design than the grid-connected system that simply augments the existing utility system.

The typical PV stand-alone system consists of a solar array and a battery connection. The array powers the load and charges the battery during daytime. The battery powers the load after dark. The inverter converts the DC power of the array and the battery into 60 or 50 Hz power. Inverters are available in a wide range of power ratings with efficiency ranging from 85 to 95%. The array is segmented with isolation diodes for improving the reliability. In such designs, if one string of the solar array fails, it does not load or short the remaining strings. Multiple inverters, such as three inverters each with 35% rating rather than one with 105% rating, are preferred. If one such inverter fails, the remaining two can continue supplying essential loads until the failed one is repaired or replaced. The same design approach also extends in using multiple batteries. Most of the stand-alone PV systems installed in developing countries provide basic necessities, such as lighting and pumping water. For determining the required capacity of the stand-alone power system, estimating the peak load demand is only one aspect of the design.

The system sizing starts with compiling a list of all loads that are to be served. Not all loads are constant. Time-varying loads are expressed in peak watts they consume and the duty ratio. The peak power consumption is used in determining the wire size for making a connection to the source.

The battery Ah capacity required to support the load energy requirement of Ebat is determined using:

$$A_h = \frac{E_{bat}}{\eta_{disch}[N_{cell}V_{disch}]DOD_{allowed}N_{bat}}$$

where:

E_{bat} = energy required from the battery per discharge
η_{disch} = efficiency of discharge path, including inverters, diodes, wires, etc.
N_{cell} = number of series cells in one battery
V_{disch} = average cell voltage during discharge
$DOD_{allowed}$ = maximum DOD allowed for the required cycle life
N_{bat} = number of batteries in parallel

PV array sizing: The basic tenet in sizing the stand-alone “power system” is to remember that it is really the stand-alone “energy system.” It must, therefore, maintain the energy balance over the specified period. The energy drained during lean times must be made up by the positive balance during the remaining time of the period. A simple case of a constant load on the PV system using solar arrays perfectly pointing toward the sun normally for 10 h of the day is shown in Fig. 4.7 to illustrate the point.

The solar array is sized such that the two shaded areas on two sides of the load line must be equal. That is, the area *oagd* must be equal to the area *gefb*. The system losses in the round trip energy transfers, e.g., from and to the battery, adjust the available load to a lower value as shown by the dotted line.

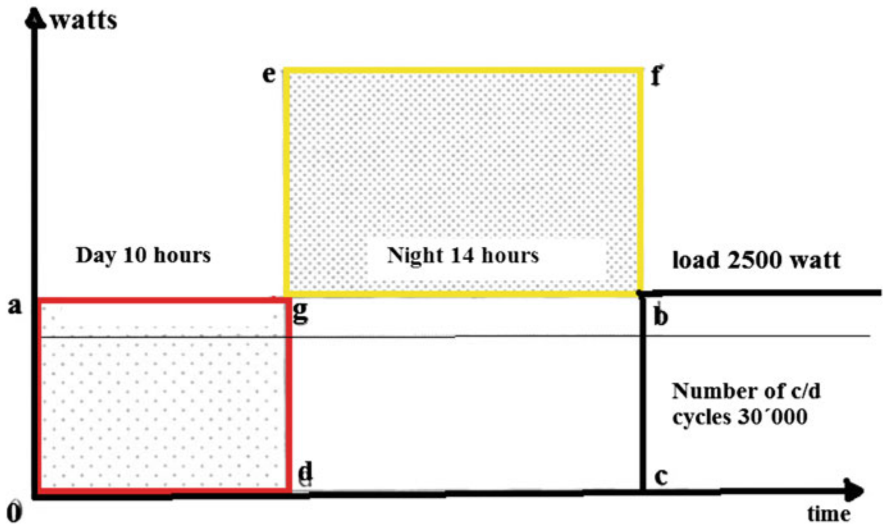


Fig. 4.7 Energy balance analysis over one load cycle

4.3.1.6 Grid-Connected Systems

PV power systems have made a successful transition from small stand-alone sites to large grid-connected systems. The utility interconnection brings a new dimension in the renewable power economy by pooling the temporal excess or the shortfall in the renewable power economy by pooling the temporal excess or the shortfall in the renewable power with the connecting grid. This improves the overall economy and the load availability of the renewable plant; the two important factors of any power system. The grid supplies power to the site loads when needed, or absorbs the excess power from the site when available. One kWh meter is used to record the power delivered to the grid, and another kWh meter is used to record the power drawn from the grid. The two meters are generally priced differently. Figure 4.8 is a typical circuit diagram of the grid-connected photovoltaic power system.

It interfaces with the local utility lines at the output side of the inverter as shown. A battery is often added to meet short term load peaks.

In recent years, large building-integrated PV installations have made significant advances by adding the grid-interconnection in the system design.

PV systems interface the grid at the output terminals of the synchronizing breaker at the output end of the inverter. The power flows in either direction depending on the site voltage at the breaker terminals. The fundamental requirements on the site voltage for interacting with the grid are as follows:

The voltage magnitude and phase must equal to that required for the desired magnitude and direction of the power flow. The voltage is controlled by the transformer turn ratio and/or the rectifier/inverter firing angle in a closed-loop control system.

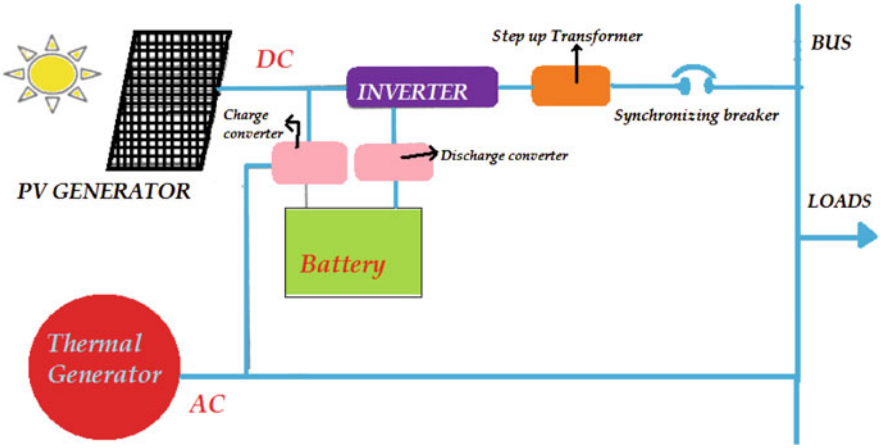


Fig. 4.8 Electrical schematic of a grid-connected photovoltaic system

The frequency must be exactly equal to that of the grid, or else the system will not work. To meet the exacting frequency requirement, the only effective means is to use the utility frequency as a reference for the inverter switching frequency.

The synchronizing breaker has internal voltage and phase angle sensors to monitor the site and grid voltages and signal the correct instant for closing the breaker. As a part of the automatic protection circuit, any attempt to close the breaker at an incorrect instant is rejected by the breaker. Four conditions which must be satisfied before the synchronizing switch will permit the closure are as follows:

The frequency must be as close as possible with the grid frequency, preferably about one-third of a hertz higher.

The terminal voltage magnitude must match with that of the grid, preferably a few percent higher.

The phase sequence of the two three-phase voltages must be the same. The phase angle between the two voltages must be within 5 degrees.

In this way, any small mismatch between the site voltage and the grid voltage will circulate an inrush current between the two such that the two systems will come to perfect synchronous operation.

4.4 Power Fitting-Out: The PV Inverter

The component responsible of making the appropriate electrical conversion DC/AC is the inverter. The most common waves generated by inverters are called “pure sine” and “modified sine” (or trapezoidal). In Fig. 4.9 both sort of waves are shown.

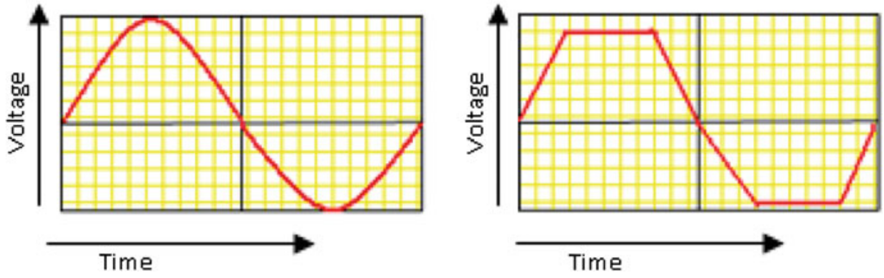
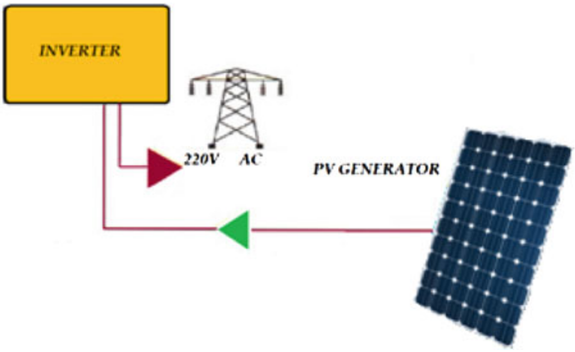


Fig. 4.9 Pure sine wave VS modified sine wave

Fig. 4.10 Typical schema for grid-connected PV systems



For PV systems grid-connected the energy generated is transferred to conventional electric power network, so mentioned energy must be "pure sine" with the same electrical characteristics (voltage and frequency) than Company provider. In Fig. 4.10 shown the typical schema for grid-connected inverters.

The efficiency of the inverter is a parameter of great importance, as long as it shows how the inverter behaves for different power levels (apart from nominal). The efficiency of the inverter varies with the load level. Although this relation is different for each inverter, a conventional model has a load/efficiency curve similar to Fig. 4.11. Therefore, a key consideration in the design and operation of inverters is how to achieve high efficiency with varying power output.

So when talking about efficiency, the main difference between inverters is its performance at low power (apart from existing losses, inverters need to use some power to execute conversion process).

Another important characteristic for grid-connected inverters is its capacity for tracking Maximum Power Point.

4.5 Maximum Power Point Tracker (MPPT)

The electric power supplied by a photovoltaic power generation system depends on the solar radiation and temperature. But designing efficient PV systems heavily emphasizes to track the maximum power operating point.

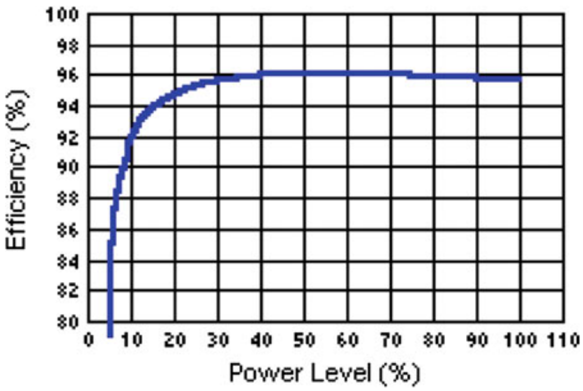


Fig. 4.11 Typical inverter efficiency curve

The amount of power generated by a PV depends on the operating voltage of the array. A PV's maximum power point (MPP) varies with solar insulation and temperature. It's V–I and V–P characteristic curves specify a unique operating point at which maximum possible power is delivered. At the MPP, the PV operates at its highest efficiency so many methods have been developed to determine MPPT.

Inverters/converters must guarantee that the PV module(s) is operated at the MPP, which is the operating condition where the most energy is captured. This is accomplished with an MPP tracker (MPPT).

To understand how MPPT works, following we will explain a simple but efficient method used for this purpose, based on a DC/DC converter as shown in the Fig. 4.12.

This circuit is based on a P&O technique (Perturb and Observe). The key of this circuit consist of a switcher that can be opened and closed thousand times per second, so the voltage between coil's terminals (V_L) when switcher is closed depends on the voltage V_B and the working cycle (m) of switcher.

$$\text{ON} : v_L = L(di/dt) = V_s - V_B = \text{cte.} = V_{L1} \Rightarrow i = t(V_{L1}/L)$$
$$\text{OFF} : v_L = L(di/dt) = -V_B = \text{cte.} = V_{L2} \Rightarrow i = t(V_{L2}/L)$$
$$V_{L1}(t_{ON}/T) + V_{L2}(t_{OFF}/T) = 0 \Rightarrow mV_{L1} = -V_{L2}(1-m) = V_B$$
$$(1-m) \Rightarrow V_{L1} = V_B(1-m)/m \Rightarrow V_s - V_B = V_B(1-m)/m \Rightarrow V_s = V_B/m$$

This working cycle is defined as the time the switcher is closed and its switching period, this means:

$$\mathrm{m} = \mathrm{T_{ON}/T}$$

When switch is closed, voltage in PV panel (V_S) is equal to:

$$\mathrm{V_S = V_L + V_B}$$

So with a suitable working cycle we could make this sum was equal to the voltage at the MPP and the problem would be solved.

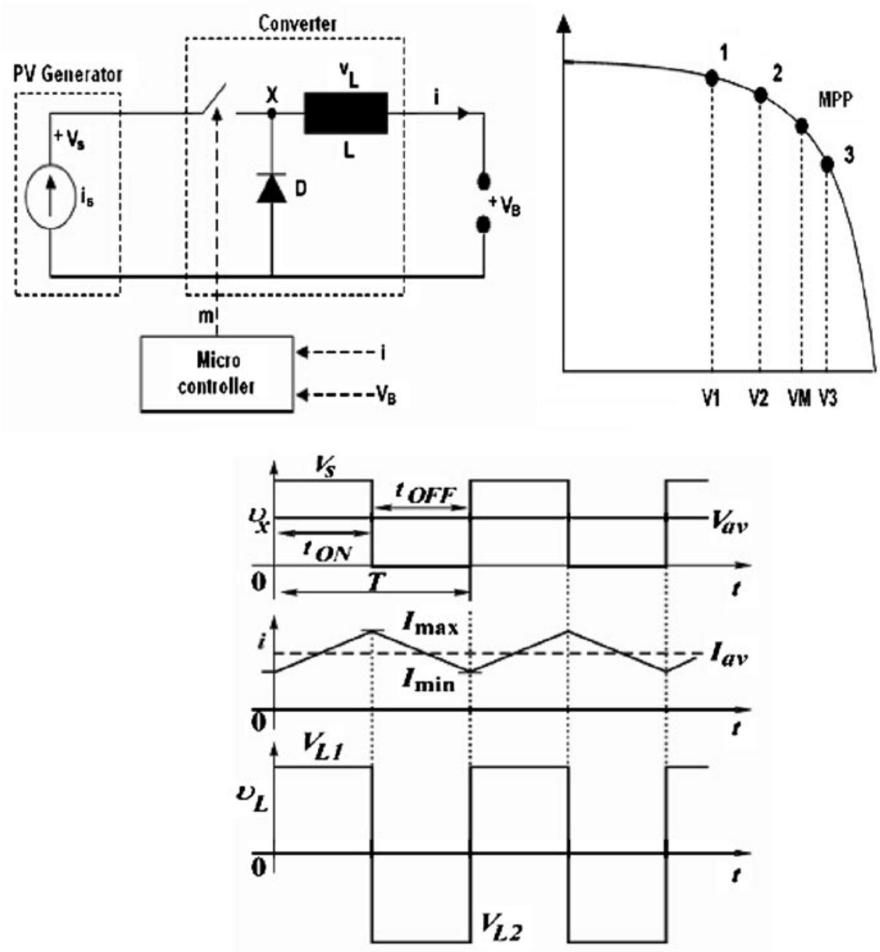


Fig. 4.12 MPPT circuit based on P&O technique

An easy way of determining the appropriate working cycle could be:

1. Start with m = 1, so V_L (switch closed) is 0, and therefore $V_S = V_B$
2. With this voltage, PV panel produces a current corresponding with working point “1”.
3. The micro-controller calculates power generated by panel ($P = I \times V_B$), and decreases a little the working cycle of switcher. This decrease means an increase in coil’s voltage (V_L) and therefore in panel’s voltage (V_S). So the working point moves to “2” (with a new load current).
4. The micro-controller calculates power generated by panel again, and if it is bigger than before, it decreases once more switcher’s working cycle, increasing V_L and passing to a working point between “2” and MPP. This process would keep repeating till the system gets to the point MPP.

5. Once reached the point MPP, the next decrease in working cycle would take us to the point “3” and therefore would cause a decrease in the power calculated by micro-controller, who will react increasing slightly the cycle (and so decreasing Vs and rising again through V–I characteristic).
6. With this easy procedure, variations in MPP caused by deviations in temperature or irradiance can be followed so the PV panel would be producing always the maximum power available.

The converter just depicted is called “voltage reducer” (or current increaser). It is the most frequent as long as MPP of PV generator is usually bigger than the voltage in the battery. But there exist “voltage increaser” converters too.

Through MPPT control the power provided by PV panels can be increased around 30%. However it is necessary take into consideration that it would not be useful getting 30% additional power if MPPT’s efficiency is just 70%. Fortunately, most MPPT nowadays exceed 90% efficiency.

4.6 Applications of Photovoltaic Cells

PV systems are highly modular and therefore offer a dynamic range of applications. Photovoltaic power systems today generate the electricity used to pump water, light roadside lights provide power to emergency phone systems, activate switches, charge batteries, supply the electric utility grid, and a plethora of other applications as well. Today photovoltaic technology powers virtually all communication satellites. Photovoltaic systems provide energy to the Hubble space telescope and the International Space Station. The practical transition of PV technology from calculator to satellite is obviously incredible.

4.6.1 PV for Households

Today PV systems for communications and solar home systems have the largest market share (21 and 15%, respectively) in the PV industry. The application of building-integrated PV systems is particularly interesting because it demonstrates several advantages compared with conventional PV power plants (Fig. 4.13).

First, the occupation of surfaces already used for other purposes substantially reduces the main environmental obstacle to the adoption and diffusion of PV, namely land requirements. As a consequence, it greatly increases the potential applicability of PV in areas of high population density. Second, integration into already existing or planned supporting structures and the substitution of building envelope materials reduce total system costs.

Because total energy consumption during the manufacturing and installation of the systems is reduced, the energy payback time of the PV system is also

Fig. 4.13 Grid on PV System at athletic center

reduced and its (indirect and low) environmental impacts are also lowered. Finally, this application actually expands technological potential of PV systems even further, because in buildings, they can play more roles than solely producing electricity. Building integrated PV panels, in theory can save energy when used as sun shading systems. Moreover, in buildings, there is the possibility of recovering a significant fraction of the thermal energy dissipated by solar panels. This thermal energy can be used directly for room heating in winter and for heating of water in all seasons. The coupling of PV building-integrated systems with solar-passive, bioclimatic architecture and energy-saving measures has enormous potential. The phenomenon of integrated-building PV systems raises the number of interested and involved actors by orders of magnitude on both the demand and supply side. The result will both promote competition and investment in the PV sector.

The number of photovoltaic powered households is increasing. Typically there are two types of Photovoltaic technology used for household applications: Stand Alone, and Grid-connected systems. Stand-alone PV systems are typically referred to as autonomous photovoltaic systems that operate independently from any electricity grid. This system generates electricity to run the application and store any extra energy in batteries. The batteries take over whenever the solar power cannot sustain the need of the application. Conversely, if there is an excess of solar power and the batteries are full, this power is lost. Grid-connected photovoltaic systems are directly connected to the electricity grid. The system can supply any surplus of energy to the grid, or extract energy if the generator does not meet the demand. Grid-connected photovoltaic systems can be used if the building is very close to an electric grid. Otherwise, under the assumption that the building is located in a remote area, where distribution lines difficult and in efficient to use, stand-alone photovoltaic systems are better suited. Since PV systems are installed by modules, the entire system itself can be constructed to any size based on the energy requirement (Fig. 4.14).

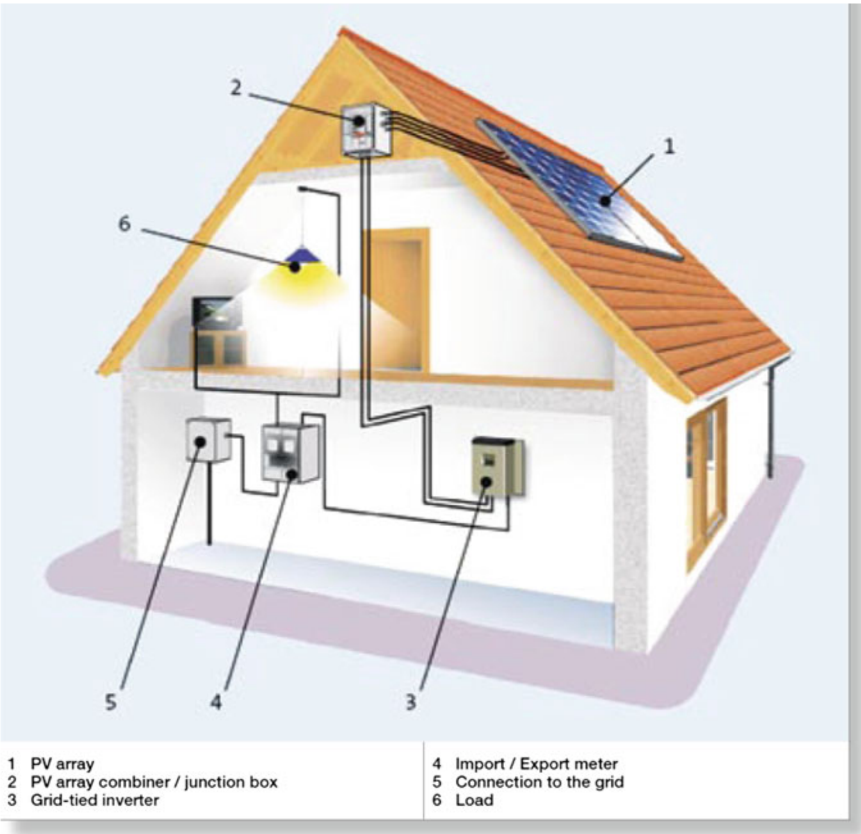


Fig. 4.14 Electricity generated by solar cells in roof-mounted PV modules is transformed by an inverter into AC power suitable for export to the grid network

Hence, the energy extracted from the sun can be used to supply all building's electricity needs, or synergize with other forms of electric generation to reduce costs and to increase conservation (Fig. 4.15).

4.6.2 Application of PV in Urban and Rural Areas

One of the simplest applications of photovoltaic cells is found on every day calculators. These calculators are dependant solely on light. This of course is a matured market in the small electronics industry.

However, the exposure people have had to such a product has not been enough to introduce PV on large scale projects. Much more education is required to supplement such a success in the PV industry. Also in countries like the Netherlands photovoltaic systems are commonly used to power water-pump and water management systems.

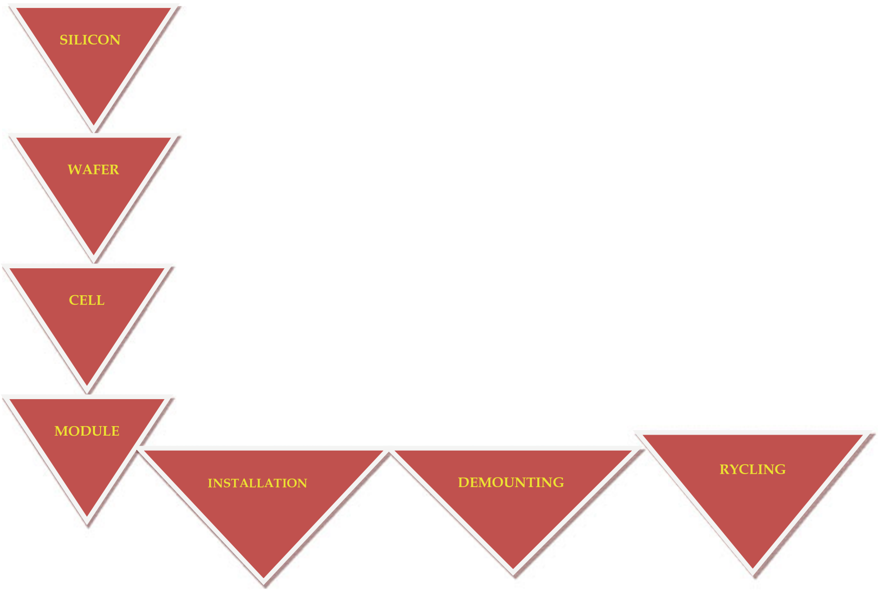


Fig. 4.15 Lifecycle of a PV system

Today more than 10,000 photovoltaic power water pumps have been installed worldwide. PV water-pumps are preferable because of their high reliability and low operating cost. Photovoltaic technology also powers the electric motors of ships. Such systems have become very popular because they are very quiet when operating, produce no air pollution and prevent water pollution otherwise present with the spilling of fuel.

In Portugal, photovoltaic systems have been used to power parking meters. Advantages of such an innovation include the little maintenance required, flexibility in location and placement considerations as such a device is independent of the electric grid, and finally it's economic dominance over grid connected parking meters and battery powered parking meters. In Sweden and Switzerland, photovoltaic systems have been used to power bus shelters in the winter, and to provide illumination.

The system has low operating costs, simple installation and its freedom from the utility grid is welcomed.

4.6.3 Application of PV in Rural Areas

Photovoltaic technology is already seeing increased applications in rural areas all over the world. The cost of extending the power lines to a remote area can be enormous and gasoline or diesel generators are noisy and inefficient.

Also, customers in rural areas tend to pay exponentially more on their electric bills, strictly because of distribution charges. These charges are composed of the cost of delivering, maintaining, and compensating for these lines.

Distribution line loss, the amount of energy lost as heat as a result of the resistance in the wires themselves, end up being billed completely to the customer.

Photovoltaic systems have become a reliable and very handy for delivering power to places that the electric power-grid cannot reach. The advantages of such a system include its low life-cycle cost, high reliability and low pollution.

In Japan, photovoltaic systems are being used to power entire remote islands.

Japan relies quite heavily on imported energy supplies. PV systems, as an alternative have now allowed Japan to crawl out of economic bankruptcy and begin leading the world in the development of a plausible PV industry.

In these remote islands a centralized power plant generates electricity by thousands of photovoltaic arrays and delivers the power to households.

Such a system is very cost efficient, highly reliable, environmental friendly, and its existence worked to significantly lower Japan’s and many of these islands’ need for electricity from abroad (Figs. 4.16, 4.17).

4.7 The Current Energy Payback Time of a PV Panel

A square meter of PV panel will require 90 solar cells with a total mass of 725 gm and an area of 0.9 m^2. Allowing for the yield of the Czochralski growth (72%), ingot slicing (54%), cell fabrication (90%) and cell trimming (90%) processes, a total mass of 2,300 gm of EG-Si is required. A mass of 2,400 gm of MG-Si is required (excluding the silicon that is incorporated into the $SiCl_4$).

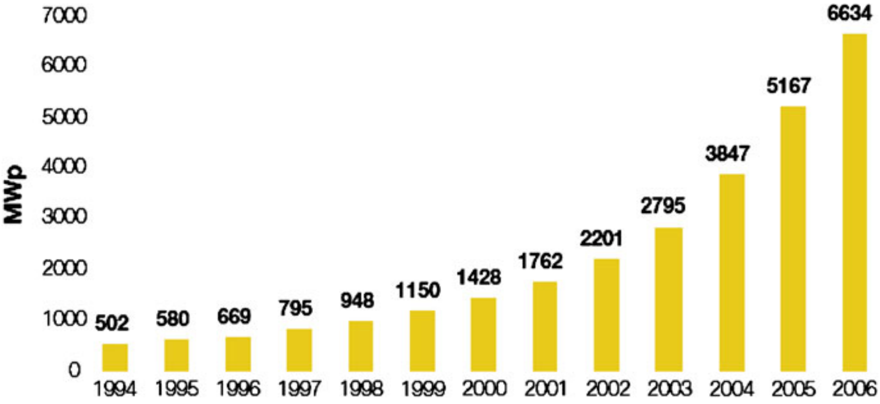


Fig. 4.16 Global cumulative PV capacity

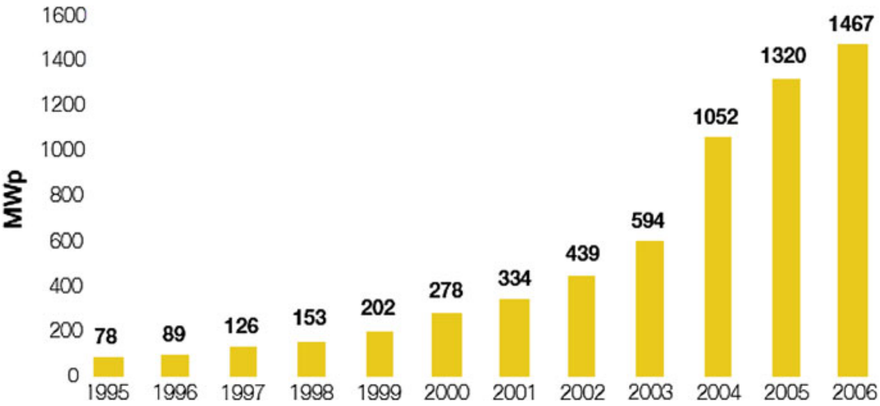


Fig. 4.17 Global annual PV market

Energy requirements for each step are assumed to be as follows:

1. Production of MG-Si: 20 kWh per kg of MG-Si produced (15 kWh of electricity is required; the carbon sources are equivalent to a further 5 kWh of electricity)
2. Production of EG-Si: 100 kWh per kg of EG-Si produced
3. Production of Czochralski silicon: 210 kWh/kg of EG-Si loaded into the crystal grower
4. Cell fabrication: 120 kWh/m^2 of silicon
5. Panel assembly: 190 kWh/m^2 of panel
6. Support structure and other BOS costs (open field): 700 kWh/m^2 of panel (open field) or 200 kWh/m^2 of panel (rooftop)

The total energy requirement to produce a PV panel is 1,060 kWh/m^2. In Sydney the useable panel output will be 153 kWh/m^2/year, giving an energy payback time (EPBT) for the panel of 6.9 years. After mounting in an open field or on a roof the EPBT will be 11.5 or 8.3 years, respectively. These energy payback times are well short of the likely system lifetime of 30 years. Production of the silicon wafers accounts for 60% of the total energy payback time.

4.7.1 The Energy Payback Time of a PV Panel in 2010

The energy payback time of a PV system in 10 years time is likely to be far lower than the current Fig. 4.18. Large-scale deployment of PV systems will force costs down and hence also the energy content of PV systems. The following assumptions have been used to derive the likely energy payback time for PV systems in the year 2010:

- Thin crystalline silicon solar cells are used, with a silicon consumption of 10% of the current silicon wafers

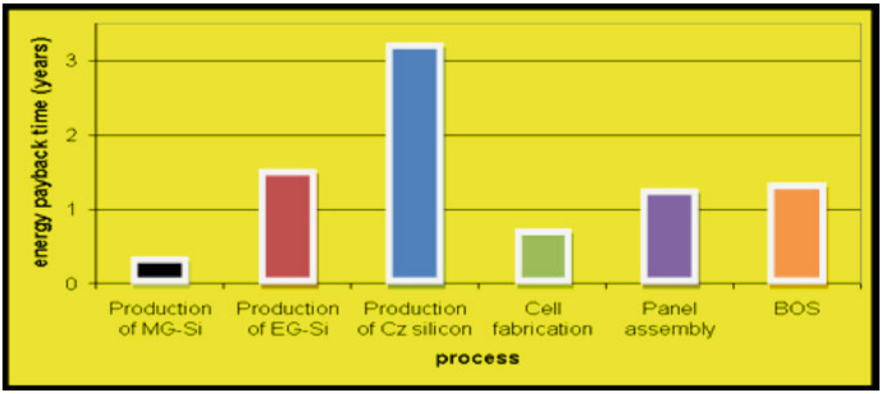


Fig. 4.18 Energy payback time (years) for currently produced roof mounted PV systems. The total energy pay back time is 8.3 years

- No aluminium frame is used
- Cell processing energy is reduced to 75% of the current value
- Direct production of square wafers allows for the elimination of wafer trimming and a packing factor of 98%
- Cell efficiency increases to 18% under standard testing conditions
- The PV roof system mounting embodied energy decreases to 75% of the current value

After mounting on a roof the Energy Pay Back Time will be 2 years. The PV module alone has an Energy Pay Back Time of 1.7 years. The PV module is likely to have a similar embodied energy to a currently produced amorphous silicon module, in which the silicon thickness is only a few microns. The efficiency of the crystalline silicon panel will be much higher. The energy payback time in Sydney of an amorphous silicon module (United Solar UPM-880) is estimated to be 2.5 and 1.5 years with and without an aluminum frame, respectively, assuming that the efficiency can be improved from 5 to 9%.

The cost of a PV systems will have dropped sharply by 2010, although not as sharply as the embodied energy because material costs will be less important in future PV systems. Figure 4.19 shows the energy payback time of the various process steps for a roof-mounted panel. Embodied energy in the balance of systems now dominates system embodied energy.

The most important parameter in the determination of the energy payback time of a PV system is the thickness of the crystalline silicon layer and the method of mounting the panels. Other important parameters are:

- The presence or absence of aluminum components such as panel frames;
- The efficiency of the solar cell;
- Solar radiation availability;
- The ability to use recycled silicon wafers or aluminum;
- The details of the cell fabrication process.

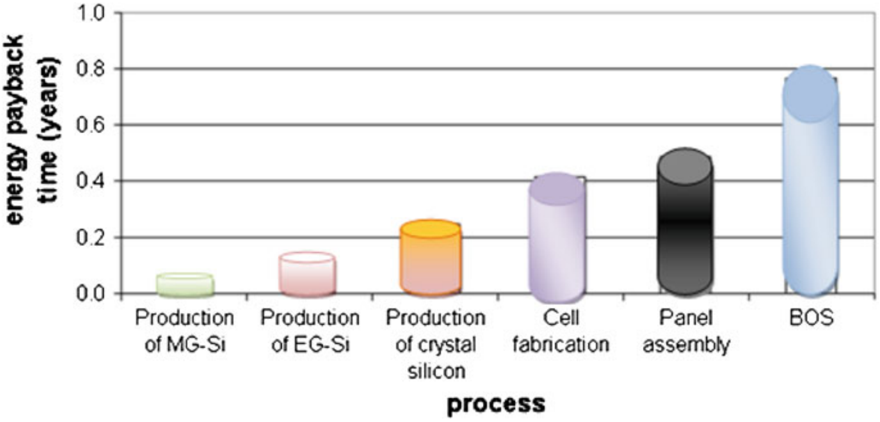


Fig. 4.19 Energy payback time (years) for a roof mounted PV system in the year 2010. The total EPBT is 2.0 years

Typical energy payback time at present is around 7 years. Mounting and installation of the system adds a further 1–4 years, depending upon whether it is on a roof or in an open field. This gives a total energy payback time for a PV system of 8–11 years.

Future PV panels that use thin films of crystalline silicon or other materials will have greatly reduced energy payback times. Such panels will be required if cost targets for large-scale production are to be met. The expected energy payback time will be in the vicinity of 2 years. The PV industry is enjoying production growth rates of about 30% per year, which is likely to bring substantial investment into the industry. It is expected that thin film PV panels will be in widespread use by around 2010.

Fossil fuel use during PV system operation and decommissioning is negligible. Virtually all of the fossil fuel energy and carbon dioxide production associated with PV systems arises from the initial production and installation of the system (Fig. 4.20).

4.8 Solar Energy Costs/Prices

The oil industry uses price per barrel as its unit of price measurement. The solar energy industry typically uses price per Watt Peak (Wp) as its primary unit of measurement. The prices for high power band (>125 watts) solar modules has dropped from around 18.7 €/Wp in 1982 to around 2.7 €/Wp today. Prices higher and lower than this are usually dependent upon the size of the order.

In order to translate, kWp (a standardized measure excluding solar conditions) to kWh (a measure which takes account of solar conditions), an adjustment for the

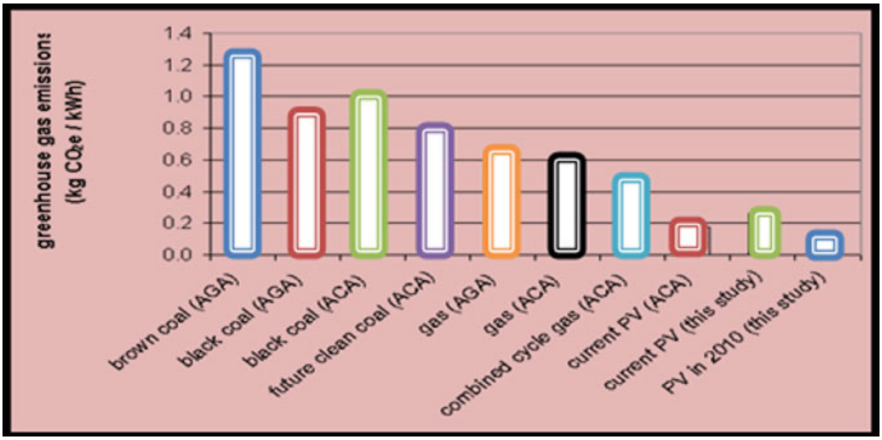


Fig. 4.20 Greenhouse gas intensities for the production of electricity from coal, gas and photovoltaic

actual location of the solar panel is necessary in order to take into account how much sunlight would be expected in that location over the period of a year.

Some simple examples are that a 1 kWp System will produce approximately:

- 1800 kWh/year in Southern California
- 850 kWh/year in Northern Germany
- 1,600–2,000 kWh in India and Australia

Solar Electricity Prices are today, around 30 cents/kWh, which is 2–5 times average residential electricity tariffs (Fig. 4.21).

This precise calculation will depend on the location of the solar installation and the local electricity tariff rates (see section below regarding the latter). Then in order to determine what proportion of total energy solar will provide, one has to take into account the size of the solar energy system and the energy demand of the customer.

Around 59% of world solar product sales installed the last 5 years were in applications that are tied to the electricity grid. Solar Energy prices in these applications are 5–20 times more expensive than the cheapest source of conventional electricity generation, although they may only be 3–5 times the electricity tariff that utility customers pay. By contrast, PV can be fully cost competitive on economic grounds in remote (off-grid) industrial and habitational applications.

The cost structure of solar energy has already created significant economic penetration in remote industrial applications (such as remote rural telecommunication, navigation lighting and cathodic protection systems) and in remote habitational markets (developing world village power or home lighting, TV, radio and off-grid homes in industrialized countries). These two market segments have driven the rapid growth rate in solar energy over the last 15 years, because solar PV has been economically competitive.

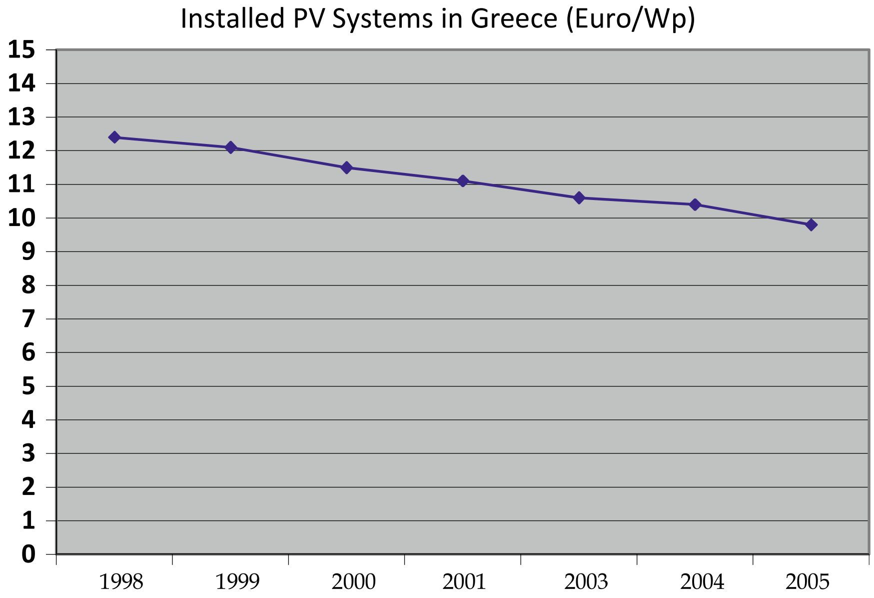


Fig. 4.21 Installed PV systems in greece

In remote industrial applications, solar PV can be a cheaper alternative to diesel power generation, especially to power small electrical loads of up to hundreds of Watts. The economics are driven by a balance between the high initial cost of a solar PV system and very low subsequent running costs compared to the low initial cost of a diesel generator but very high on-going fuel and maintenance costs. The latter are especially high if site access is difficult (e.g., on a mountain).

Off-grid buildings have an economic reference point in the cost of installing a grid connection to the location. As a guideline, if a building is further than 1 km from the nearest grid line then it is likely to be cheaper to install a PV system. In developing countries, the source of power for lighting may be limited to candles or kerosene burners. In this case, solar provides a highly cost effective option and can provide power for a wider range of uses too. The difficulty comes with the high up-front cost of solar which can make it unaffordable without the provision of funding from developmental aid or micro-finance to provide credit.

However, it is the grid-connected market that remains the major prize for the solar industry because of the huge scale of the electricity supply market. Indeed, this is where growth has been strongest recently. While solar is a long way from competing with conventional power generation costs at 3–5 cents/kWh, it is much closer to reaching electricity tariffs charged to residential, commercial and industrial consumers. This is especially relevant because when the PV is sited at the consumers' premises then the comparison for the customer is between the tariff rate and the cost of PV electricity from his system. Precise calculation of solar electricity costs depend on the location and the cost of finance available to the

Fig. 4.22 Photovoltaic panels for residential or commercial applications

owner of the solar installation, but with the best PV electricity prices (in the sunniest locations) approaching 30 cents/kWh and the highest tariffs now exceeding 20 cents/kWh, the gap is now close. Funding programs that bridge this gap are causing rapid growth in sales of solar PV, especially in Japan and Germany (Fig. 4.22).

4.9 Questions

1. What are the advantages of PV technology?
2. Name the types of PV system.
3. Define sizes of photovoltaic cells.
4. Define solar energy costs and indicate how it is calculated.
5. Briefly describe the major stages in the evolution of PV array sizing.
6. What factors can affect the energy payback time of a PV panel?
7. Give brief description Stand-alone systems.
8. Describe briefly a Grid-connected system.
9. Identify the principles of solar cells.
10. What are the electrical characteristic of the PV cell?
11. What is an inverter?
12. How does calculate the efficiency of the inverter?
13. What is Maximum Power Point Tracker (MPPT)?
14. Describe briefly the applications of photovoltaic cells.

Chapter 5
Installed PV System at Industrial Buildings

5.1 European Policy for RES

During the last decade a continuously increasing interest in renewable energy technologies, was noted in European Union. This was a combined effect of: (a) the favorable legal and financial measures that were implemented, (b) the rich potential of Renewable Energy Sources (RES) that exists and (c) the rising environmental awareness.

The development of Renewable Energy Sources has been among the major energy policy lines of European Union for the last 20 years.

It is seen as an important contribution to the improvement of the European environmental indicators and, in particular, to the abatement of CO_2 emissions.

Legal and financial incentives are the tools of the European governments' strategy to support renewable energy technology (RET) investments (Fig. 5.1).

For the European Union, the Directorate General for Transport & Energy (DG TREN) is responsible for the energy policy. Although the promotion of renewable energy has been an integral part of the EU energy policy, renewable energy sources (RES) are currently insufficiently exploited in the EU. The promotion of renewable energy has become a European Union priority policy objective, with the following ambitious targets:

- The share of renewable energy in gross domestic energy consumption in the EU should be doubled (from the present 6–12%) by 2010.
- Electricity produced from renewable energy sources should represent 22% of electricity consumption by 2010 (in 1997, it represented 14% of electricity consumption).

Overall emissions of greenhouse gases should be reduced meeting the Kyoto objectives by at least 8% below 1990 levels for the period 2008–2012.

E. V. M. Papadopoulou, *Photovoltaic Industrial Systems*,
Green Energy and Technology, DOI: 10.1007/978-3-642-16301-2_5,

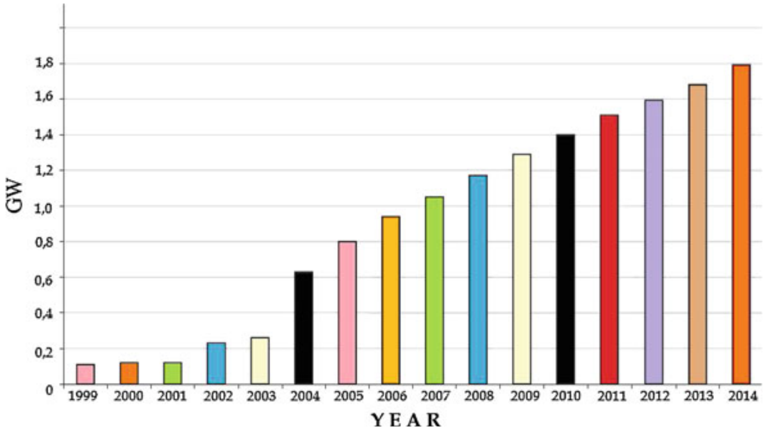


Fig. 5.1 Projection of installed capacity of Renewable Energy Sources in Greece for electricity generation

The main objectives of the EU renewable energy Action Plan are:

- Internal Market measures (fair access for renewable energy to the electricity market; fiscal and financial measures, such as tax exemptions for RES; new bioenergy initiative for transport, heat and electricity; improving building regulations).
- Reinforcing Community policies (environment; growth, competition and employment; competition and state aid; research, technological development and demonstration; regional policy; common agricultural policy (CAP); external relations).
- Strengthening co-operation between Member States.
- Support measures (targeted promotion, such as the ALTENER programme; market acceptability and consumer protection; increased visibility of RES on the finance market; renewable energy networking). Proposal for a directive on the energy performance of buildings.

The Commission has adopted a proposal for a directive (Directive 2002/91/EC), which aims to promote improvements in the energy performance of buildings. This proposal focuses to a large extent on energy efficiency issues but also has relevance for the supply side. It includes a methodology for establishing integrated energy performance standards for buildings that takes into account on-site energy production, for example through the use of PV electricity or solar heating/cooling technologies.

Implementation of the new directive would provide a valuable opportunity for the PV industry to demonstrate to a wide range of building owners and users how PV can contribute to reducing the share of energy consumption in the EU attributable to buildings, which currently stands at 40%. Financing the installation of renewable energy technologies remains a major concern. The Government should try to ensure that environmental externalities are fully included in the operating costs of energy companies, both private and public. All external costs or benefits borne by state-owned energy companies should be made explicit for all market participants through regulation or market-based policy instruments such as taxation of pollutant emissions of fuels. Ensuring that energy costs include the costs of reducing emissions of sulphur dioxide and particulate matter, or even CO_2, will tend to encourage the use of cleaner liquid or gaseous fuels and will aid the Government's efforts to speed the introduction of renewable energy into the energy mix. To help the market there are also several types of innovative marketing and financing schemes to promote the increased penetration of renewable energy technologies.

Renewable energy technologies tend to have higher capital costs and longer payback periods than conventional energy technologies, although overall rates of return may be higher.

Capital markets traditionally favor projects with lower payback periods, which tie up capital for a shorter period and are seen as lower risk. At the same time, conventional fuel prices do not reflect their full cost, due to the failure to include the additional external costs associated with these fuels. Current fuel prices do not reflect the true social cost, while renewable energies have a market price above their social cost. While the economic conditions all over EU in the eighties militated against ESCO (dramatic fall in energy prices, capital budgeting rules restricting third party financing etc.), five major elements of this period may in fact be responsible for the current comeback of ESCO. These five elements are:

1. Environmental degradation.
2. Limits to growth in the energy supply industry.
3. The quest for economic efficiency in the public sector.
4. The deregulation and globalization of energy market.
5. Development of e-energy services.

Effective promotion of renewable electricity will be facilitated if it is examined in the context of the whole electricity market. Market reforms in the electricity sector are influencing the policies used to promote renewable electricity. These new policies increasingly contain an element of intra-renewable competition. Possible means of using market mechanisms to promote renewable electricity include:

- Ensuring that independent power producers and non-utilities have fair access to the electricity grid;
- Allowing distributed generators to feed into and take from the grid;
- Creating supply-side incentives, such as favorable buy-back rates, to make renewable electricity generation economically attractive for potential generators;
- Creating a market for renewable electricity by requiring a certain proportion of total electricity to come from renewable sources;
- Making demand-side incentives such as "green pricing" as widespread as possible.

5.2 Installing PV System

There are two PV offerings available for roof system applications—amorphous and crystalline silicon systems.

PV cells in amorphous systems can be used with glass, membrane and roof-mounted tile products to provide direct current (DC) electricity. There also are flexible thin-film generations available, which allow a PV system to be installed directly over a roof membrane. These PV systems provide an efficiency rate of only 9% and typically need more surface area to generate the same amount of energy provided by crystalline systems.

Crystalline systems can be installed directly over a rooftop or by penetrating a roof substrate. With a 34% efficiency rate, these PV systems are durable and lightweight, making them easy to install on any low-slope roof system. Crystalline systems that require rooftop penetration also require extra waterproofing.

The workhorse of any solar electric (PV) system is the module, which is usually mounted upon the roof.

There are four kinds of photovoltaic solar 'panels' commercially available today:

Single crystal modules are the most efficient (10–17%) and the most expensive. This kind of technology has been around longer than any other and is most frequently used for outer space (satellites) and remote or off grid tracking applications. It has demonstrated long term (30 year) stability in its ability to produce power in hot desert to marine environments. They are usually recognizable as the modules with polka dots or octagons (Fig. 5.2)

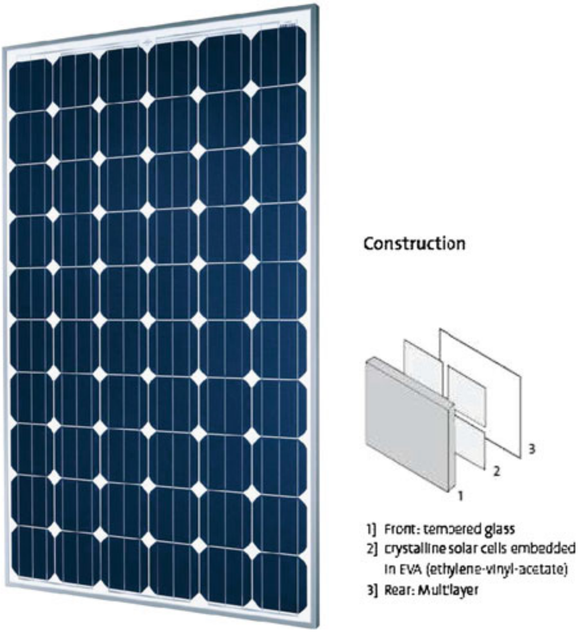


Fig. 5.2 PV module

Poly or Multicrystalline units are less expensive but demonstrate lower efficiencies (9–14%). Polycrystalline modules are pure blue in appearance and since there are no gaps or openings in the face of the collector, its size is about the same as its more efficient polka-dotted single cell cousin.

Amorphous (Thin Film) cells are manufactured by vaporizing and depositing silicon on either glass, ceramic or steel. The process to manufacture this module is simple and cheap, but efficiency (7–12%) is so low that a very large area is required to produce the same kind of power made by the single or polycrystalline modules. This technology is most often seen in toys and calculators as well as in Building Integrated PV (BIPV) where the solar module is actually built into the roof or structure.

String Ribbon manufacturing produces efficiencies of 7–8% but are relatively inexpensive. Long term performance is similar to other polycrystalline technologies, but low efficiency requires relatively larger systems to produce the same energy as single or polycrystalline modules.

Inverters are the most important part of PV systems. An inverter converts DC electricity to an alternating current that is commonly used in residential and commercial buildings. Also, inverters keep complete records of the time, day and how much energy is produced. These records are necessary because most rebates depend on the energy produced versus the total energy systems installed (Fig. 5.3).

Electricity output depends on an inverter's efficiency. The more efficient the inverter, the more energy it can produce.

Positioning PV panels also is important to ensure a PV system receives maximum sunlight. Currently, PV systems only collect one color and/or wavelength of rays from the spectrum of the sun's rays that reach Earth (Fig. 5.4).

Although a sunny day provides maximum efficiency for a PV system, some electricity can be generated on cloudy days, as well. Shadows of surrounding equipment can harm PV systems' energy production; therefore, shadowing a panel should be avoided. Although PV systems can be more expensive than traditional roof membrane systems, according to the World Business Council for Sustainable Development's 2007 Building Efficiency report, perceptions for the costs of

Fig. 5.3 Inverter

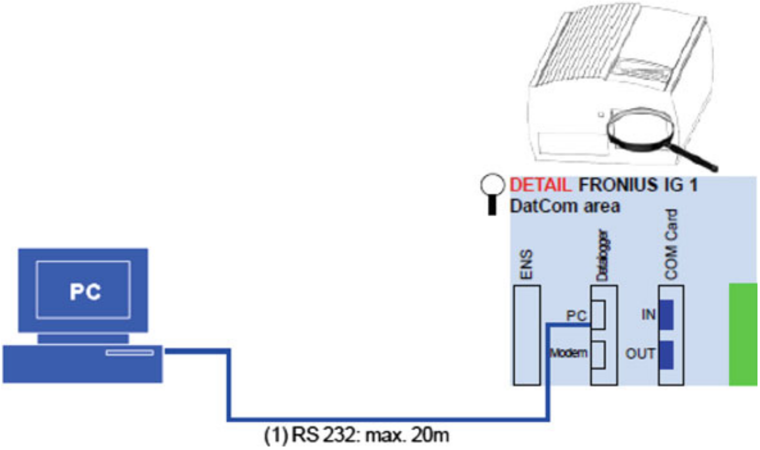
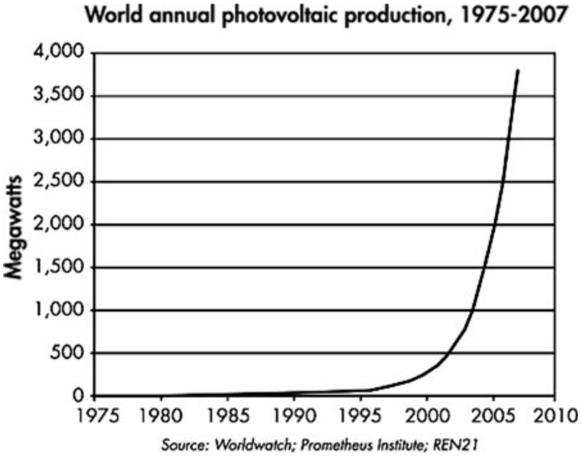


Fig. 5.4 Inverter with direct connection to the PC

Fig. 5.5 According to the Earth Policy Institute, Washington, D.C., photovoltaic production in 2007 increased to 3,800 MW, an estimated 50% increase from 2006



adding green enhancements to a building are significantly higher than the actual costs.

When considering installing a PV system, it is important to evaluate how it will work with a roof system. Because of heavy foot traffic on rooftops, PV systems are ideal for use with fully adhered commercial roof membranes with protective walkway mats. Other roof system types, such as those that are mechanically attached, can cause wind flutter on a roof membrane and affect a PV system's performance. It is also key to note that dissimilar materials expand and contract at different rates, so be aware of differential movement between a PV system and roofing materials (Fig. 5.5).

Although minimal maintenance is required for PV systems, it is important to work with customers to set up maintenance programs to manage their roof assets.

Fig. 5.6 PV arrays roof mounted in industrial building

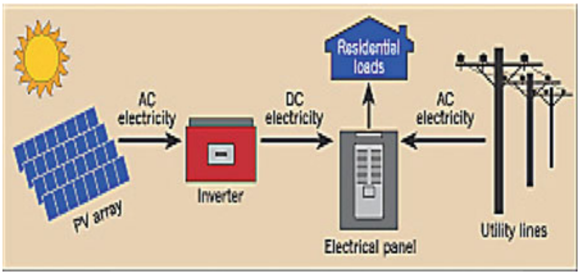


Fig. 5.7 PV system installation

The most important step to protect a roof is to conduct biannual spring and fall inspections. Also, many roofing manufacturers require that roof systems be maintained to uphold warranty agreements (Fig. 5.6).

With proper ongoing maintenance, some manufacturers will allow customers to extend their warranty coverage.

In some cases, it is recommended PV systems be installed in conjunction with a new roof system. It is also recommended that PV systems be used with fully adhered roof systems backed by dependable 20- to 25-year warranties. This ensures a roof membrane lasts as long as a PV system (Fig. 5.7).

If a roof system is less than 7 years old, maintenance can ensure the system works properly for several years to come. Keep in mind the cost of a new roof system compared with a PV system is minimal; therefore, greater judgment should be used when deciding not to reroof.

Presently, few commercial roofing contractors are trained to install PV systems. However, some roofing materials manufacturers work directly with solar panel manufacturers to train roofing contractors to install PV systems.

Also, it is important to have substantial financial backing when working with PV systems. Unfortunately, it only makes sense to install PV systems in key states with rebates to be profitable. Once the prices of solar cells decrease and standardized

Fig. 5.8 PV roof mounted and grid connected

installation systems enter the roofing market, most roofing contractors will be able to install these systems.

Although roofing contractors have all the necessary equipment to install PV systems, they still have to hire electricians to install wiring and make a connection to junction boxes and the inverter. When working with a PV system and electricity, you should know how to get a building permit for a PV system; be well-versed in electric generation, installation and efficiency of the system; and, most important, be aware of safety issues (Fig. 5.8).

5.3 Basic Steps for Installation

5.3.1 Sizing the Organization Photovoltaic System

To size the solar photovoltaic (PV) system for an industrial building need to take a look at industry's building. For PV system to work best, the system should face south or southwest, but they also work well on flat roofs.

In addition to roofs, parking lots or other open spaces make good locations for PV systems. The roof should have minimal to no shading from trees, mechanical equipment, or other buildings. The shade-free area of roof will limit how large your PV system will be, and electricity usage (as measured by electricity bill) will dictate how much solar power need.

Before soliciting bids it will be helpful to know:

- What is the organization's budget for PV installation?
- During what hours of the day do you consume the most electricity?
- Have the organization made efforts to improve any energy efficiency?

5.3.2 Choosing the Solar PV Installer

The installer must be in good standing with the domestic land and must have experience. The installer should have specialized in industrial PV systems and should have experience with grid-tied systems and should be familiar with local codes, regulations, and rebates.

The installer should provide with a portfolio or a list of recent projects as well as several references to contact.

It is very important the kind of system warranty which the installer provide. The solar panels should have a manufacturer warranty of at least 25 years. Some panels are now warranted for 30 years. It should expect the system's inverter to have at least a 5-year warranty, but a 10-year warranty is not uncommon.

Another target is the kind of operation and maintenance training the installer provides.

Note that dust and bird droppings can negatively affect system performance. So it is important to keep the PV system clean. Who will the clean and maintain the system?

The installer mounts the solar panels to the roof without the solar panels cause leaks in the roof.

Solar installers should give a range of system sizes, costs and savings that are appropriate for the building. The organization should try to compare bids by similar parameters, such as nameplate system power (DC) rating (in kilowatts or watts) and expected annual energy (kWh) production.

5.4 Reaping the Benefits

As energy costs escalate, it needs to be knowledgeable of new energy-efficient roofing options for the industries. As more states pass legislation for rebates and incentives for solar power, PV systems are slated to have enormous growth within the next few years. Installing PV systems can offer to industries an eco-friendly and aesthetically pleasing roofing option with a 25- to 40-year life expectancy while providing with a lucrative business.

Environmentally friendly: The PV modules are made out of silicon which is entirely benign, and available in abundance. No noise pollution or harmful gases are emitted during the operation.

Immediately available: PV utilizes the most abundant energy source on the planet—the sun.

No barriers to installation: PV is not affected by 'Nimbyism' or affected by planning delays.

Minimal maintenance: PV has no moving components and is virtually maintenance free.

Flexible: PV systems can be incorporated into all types of building, and retrofitted on existing roofs or as part of the building envelope at construction stage. It can be curved and shaped to the building design.

Cost effective: In grid locations where grid connection is too expensive.

Reduces energy bills: Having a solar roof provides you with a power source that can be used to augment your grid connected electricity supply subsequently reducing your electricity bills. In addition, having PV as an energy resource increases your awareness of electricity use and encourages more efficient energy behavior. This in turn leads to lower energy bills.

5.5 Estimating Electrical Energy Savings

One of the key benefits of industrial solar power systems is a lower electric utility bill resulting from the energy that the solar system produces. The energy savings to an industry can be estimated by simply multiplying the annual energy in KWh that a PV system might produce times the utility electric energy rate.

5.5.1 Costs and Competitiveness

One of the main arguments heard from critics of solar electricity is that its costs are not yet competitive with those of conventional power sources. This is partly true. However, in assessing the competitiveness of photovoltaic power a number of considerations should be taken into account:

- The type of PV application—grid-connected, off-grid or consumer goods.
- What exactly is PV competing with? What are the alternatives?
- The geographical location, initial investment costs and expected lifetime of the system.
- The real generation cost, bearing in mind that conventional sources are heavily subsidised and their ‘external’ costs from pollution and other effects are not accounted for.
- Progress being made in PV cost reduction.

5.5.2 Competitiveness of Off-Grid Applications

Off-grid applications are mostly already cost-competitive compared to the alternative options. PV is generally competing with diesel generators or the potential extension of the public electricity grid. The fuel costs for diesel generators are high, whilst solar energy’s “fuel” is both free and inexhaustible.

The high investment costs of installing renewable energy systems are often inappropriately compared to those of conventional energy technologies. In fact, particularly in remote locations, a combination of low operation and maintenance costs, absence of fuel expenses, increased reliability and longer operating lifetimes are all factors which offset initial investment costs. This kind of lifecycle accounting is not regularly used as a basis for comparison.

The other main alternative for rural electrification, the extension of the electricity grid, requires a considerable investment. Off-grid applications are therefore often the most suitable option to supply electricity in dispersed communities or those at great distances from the grid. However, although lifetime operating costs are much lower for off-grid PV than for other energy sources, initial investment costs can still be a barrier for people with little disposable income.

5.5.3 Competitiveness of Grid-Connected Applications

Grid-connected applications, currently the biggest market segment, are expected to remain so for the foreseeable future. The generation costs are in most cases, not yet competitive with electricity prices, unless there are support programmes. Electricity prices vary greatly, even within the 27 EU countries, with 2006 prices ranging, according to Eurostat, from between 7 and 24 Eurocents/kWh (including all taxes). The most recent trend has also been a steady increase. From 2005 to 2007, electricity prices in the 27 EU countries increased by an average of 16%. At the same time, PV generation costs have been decreasing, a trend expected to accelerate over the coming years.

The simplest way to calculate the cost per kWh is to divide the price of the PV system by the number of kWh the system will generate over its lifetime. However, other variables such as financing costs may have to be taken into consideration. Figures for the cost per kWh of grid-connected systems frequently differ, depending on what assumptions are made for system costs, sunlight availability, system lifetime and the type of financing. Table 5.1, includes financing costs (at a 5% interest rate) and a lifetime of 25 years, which is the same as the performance warranty period of many module producers. The figures are based on the expected system prices under the Advanced Scenario, where strong industrial growth is expected to drive down prices.

The figures, giving PV generation costs for small distributed systems in some of the major cities of the world, show that by 2020 the cost of solar electricity will have more than halved. This would make it competitive with typical electricity prices paid. One reason is that whilst PV generation costs are consistently decreasing, general electricity prices are expected to increase. As soon as PV costs and electricity prices meet, ‘grid parity’ is achieved. With grid parity, every kWh of PV power consumed will save money compared to the more expensive power from the grid. Grid parity is expected to be reached first in southern countries and then spread steadily towards the north.

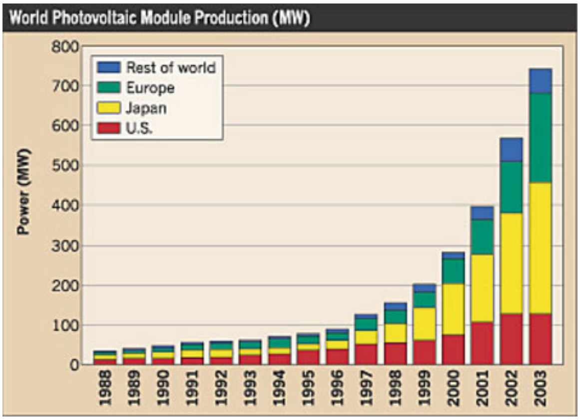


Fig. 5.9 World photovoltaic module production (MW)

Table 5.1 Expected PV generation costs for roof-top system at different locations

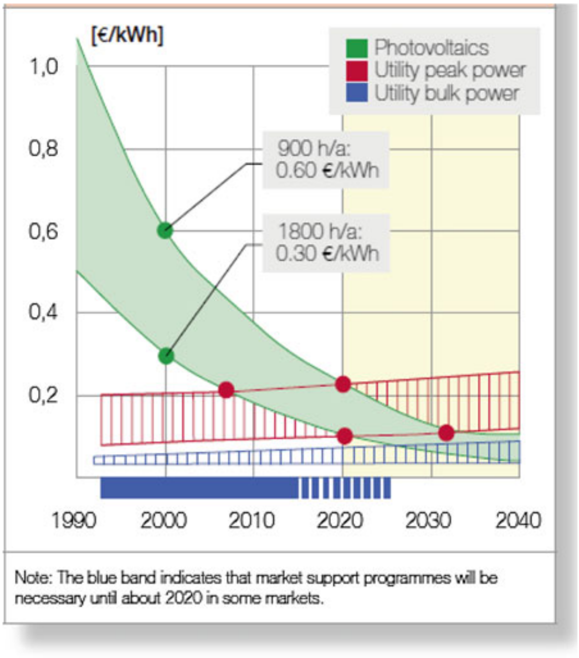
	Sunshine hours	2006	2010	2020	2030
Berlin	900	0.45 €	0.35 €	0.20 €	0.13 €
Paris	1,000	0.40 €	0.31 €	0.18 €	0.12 €
Washington	1,200	0.34 €	0.26 €	0.15 €	0.10 €
Hong Kong	1,300	0.31 €	0.24 €	0.14 €	0.09 €
Sydney/Buenos Aires/Bombay/Madrid	1,400	0.29 €	0.22 €	0.13 €	0.08 €
Bangkok	1,600	0.25 €	0.20 €	0.11 €	0.07 €
Los Angeles/Dubai	1,800	0.22 €	0.17 €	0.10 €	0.07 €

The calculation method has been changed from the previous edition of 'Solar Generation'

Figure 5.9 shows the historical and expected future development of solar electricity costs. The falling curves show the reduction in costs in the geographical area between central Europe, for example northern Germany (upper curve), and the very south of Europe (lower curve). In contrast to the falling costs for solar electricity, the price for conventional electricity is expected to rise. The utility prices for electricity need to be divided into peak power prices (usually applicable around the middle of the day) and bulk power. In southern Europe, solar electricity will become cost-competitive with peak power within the next few years. Areas with less irradiation, such as central Europe, will follow suit in the period up to 2020 (Table 5.1; Fig. 5.10).

In some countries with a more liberalized power supply market, electricity prices are more responsive to demand peaks. In California and Japan, for example, electricity prices increase substantially during daytime, especially in the summer, as demand for electricity is highest during that period. Daytime, in particular in summer, is also the period when the electricity output of PV systems is at its highest. PV therefore serves the market at exactly the point when demand is greatest.

It should also be pointed out here, that the prices for conventional electricity do not reflect the actual production costs. In many countries, conventional electricity



Note: The blue band indicates that market support programmes will be necessary until about 2020 in some markets.

Fig. 5.10 Development of utility prices and PV generation costs

sources such as nuclear power, coal or gas, have been heavily subsidized for many years. The financial support for renewable energy sources such as PV, offered until competitiveness is reached, should therefore be seen as a compensation for the subsidies that have been paid to conventional sources over the past decades.

5.6 External Costs of Conventional Electricity Generation

The external costs to society incurred from burning fossil fuels or from nuclear generation are not included in most electricity prices. These costs have both a local and a global component, the latter mainly related to the consequences of climate change. There is uncertainly, however, about the magnitude of such costs, and they are difficult to identify. A respected European study, the “Extern E” project, has assessed these costs for fossil fuels within a wide range, consisting of three levels:

- Low: 2,5 € per ton of CO_2
- Medium 12,18–31,12 € per ton CO_2
- High: 94,12 € per ton CO_2

Taking a conservative approach, a value for the external costs of carbon dioxide emissions from fossil fuels could therefore be in the range of 5,8–11,76 € tone CO_2.

PV reduces emissions of CO_2 by an average of 0.6 kg/kWh. The resulting average cost avoided for every kWh produced by solar energy, will therefore be in the range of 0.15–5,65 € per kWh.

5.7 Factors Affecting PV Cost Reductions

The cost of producing photovoltaic modules and other system inputs has fallen dramatically since the first PV systems entered the market. Some of the main factors responsible for that decrease have been:

- Technological innovations and improvements
- Increasing the performance ratio of PV
- Extension of PV systems' lifetime

Another very important driver for PV cost reduction is economies of scale. Larger production volumes enable the industry to lower the cost per produced unit.

Economies of scale can be realized during the purchasing of raw materials through bulk buying, and during the production processes by obtaining more favorable interest rates for financing and by efficient marketing.

Whilst only a decade ago cell and module production plants had capacities of just a few MWp, today's market leaders have 1 GWp capacity plants within their reach. This capacity increase is expected to decrease costs per unit by approximately 20% for each time production output is doubled.

The rapid rise in the price of crude oil in recent years, and the subsequent knock-on effect on conventional energy costs across the global domestic and industrial sectors, has once again highlighted the urgent need for both industrialized and less developed economies to rebalance their energy mix. This increase in oil price is not just the result of concerns about security of supply. It also reflects the rapidly rising demand for energy in the emerging economies of Asia, particularly China. Oil production can no longer expand fast enough to keep up with demand. As a result, higher oil prices—and consequently higher energy prices in general—are here to stay and world economies will have to adjust to meet this challenge.

It is against this background of runaway energy prices that those economies which have committed themselves to promoting the uptake of solar electricity are starting to differentiate themselves from those countries that have relied heavily or almost exclusively on conventional energy sources. There are clear signs that the next decade will see many countries having to rapidly reduce their dependence on imported oil and gas. This abrupt transition will be felt hardest by those that have paid little attention so far to the role that solar electricity can play. However, on the positive side, there is still time for them to catch up if they introduce innovative policies quickly to promote solar electricity use.

The speed with which the solar electricity sector is increasing its market share in those economies that have committed themselves to promote this clean power source, coupled with the transformation of its customers from power recipients to power generators, represents a revolution comparable to that in the telecommunications market over the past decade. Such industrial revolutions produce winners and losers.

The undisputed winners in such industrial revolutions are the customers who have access to greater choice. Other winners include the market players who recognize the potential of such an expanding market, and those who have committed themselves to investment in the sector.

However, there are also many examples of innovative products and services where offering customer choice has led to their popular uptake at a price considerably higher than that previously available.

Two examples of such innovative market entrants are mobile phones, offering a service at a far higher price than conventional fixed-line networks, and bottled mineral water, a product which in the middle and higher price ranges costs more per liter than petrol. With the right product—offering customers the type of added value they are looking for, coupled with innovative marketing—technologies such as solar electricity should be able to compete with conventional grid supplied power in industrialized countries.

The extension of customer choice in the electricity sector to embrace solar power, however, requires a commitment to creating an appropriate framework to allow consumers to access solar power in an efficient and cost-effective way.

5.7.1 Feed-in Tariff

In the past, in order to encourage solar electricity, many programmes were financed through government budgets. The disadvantage of this method has been that if the state money ran out, or was curtailed, the programme could be stopped. Therefore, some feed-in tariff models take a completely different approach. In Germany in 2007, the utilities pay a premium tariff of between € 0.38/kWh and € 0.54/kWh (depending on the size and type of system) for solar electricity from newly-installed PV arrays.

The utilities are authorized to pass on this extra cost, spread equally, to all electricity consumers through their regular electricity bill. This means that the feed-in programme works independently from the state economy, and the extra cost which each electricity consumer has to pay, in order to increase the share of renewable energy in the national electricity portfolio, is very small. In Germany, the monthly extra costs per consumer due to the premium tariff for solar electricity are currently €0.20.

The result is also that every electricity consumer contributes to the restructuring of the national electricity supply network, away from a fossil-based one, and towards a sustainable and independent structure.

5.7.2 *Feed-in Tariff: The Driver of Cost Reduction*

The costs for solar electricity have been reduced consistently since the technology was first introduced to the market. Even so, in most cases solar electricity cannot yet compete with grid electricity generated from fossil fuels. Whilst it is expected that prices for electricity generated from fossil fuels will keep rising, it is still very important to maintain a strong momentum in bringing down the costs for solar electricity.

For this reason, the feed-in tariff in Germany is reduced each year by 5%, but only for newly-installed PV systems.

Once a PV system is connected to the grid, the tariff remains constant over the complete period of 20 years. Through this 5% annual reduction, there is therefore constant pressure on the PV industry to bring the costs for solar electricity down by 5% each year in order to keep the market alive. At the same time, the customer can easily calculate the return on investment in their PV system.

This planning security is an essential element of the success story of the feed-in tariff.

5.7.3 *Feed-in Tariff: The Driver of High-Quality Solar Electricity Systems*

Many solar electricity support programmes are based on an investment subsidy in order to reduce the barrier of high up-front capital costs. The drawback of such an approach is the missing incentive to invest in high-quality solar electricity systems and to ensure their efficient operation and maintenance.

If the customer receives a fixed payment per installed capacity unit, there is no incentive to go for high-quality products, which usually mean a higher price, or to operate the system at the highest possible level. With the feed-in tariff, the return on investment is heavily dependent on the performance of the PV system. The customer gets his return on investment with each kWh that is fed into the grid. Therefore, maximizing the power output of the PV system over its whole lifetime is essential to the customer, ensuring that the PV system will be well operated and maintained.

The feed-in tariff is the only system that rewards the generation of solar electricity appropriately and not simply for installing a system.

5.7.4 *Feed-in Tariff: The Driver of Easier Financing*

The up-front costs for solar electricity systems are a clear barrier to wider market penetration. As already explained, investment subsidies have been implemented in many countries in order to overcome this barrier, but this approach has significant disadvantages. A feed-in tariff guaranteed by law over a sufficient period of time, serves as an excellent security for the customer's bank in order to finance the system.

The PV system itself, combined with the guaranteed feed-in tariff over 20 years in Germany, is usually sufficient to receive a loan from the bank. Of course, it took some time until banks became familiar with PV systems and the implications of the feed-in tariff, but nowadays the financing of PV systems via a bank loan in Germany is no longer an unusual and time-consuming activity, but very common and straightforward.

5.8 Questions

1. Which is the European Union Policy about RES?
2. Name the types of PV modules.
3. What characteristics can be used to describe an inverter?
4. Define the steps for installation a PV system at industrial building.
5. Briefly describe the major stages of effective promotion of renewable electricity.
6. Identify the PV benefits.
7. Briefly compare the competitiveness of grid-connected applications and grid-off applications.
8. Describe the factors affecting PV cost reductions.

Chapter 6
Installation Guide

The purpose of this chapter is to provide tools and guidelines for the installer to help ensure that industrial photovoltaic power systems are properly specified and installed, resulting in a system that operates to its design potential. This chapter sets out key criteria that describe a quality system and key design and installation considerations that should be met to achieve this goal. This chapter deals with systems located on industrial buildings that are connected to utility power and does not address the special issues of industries that are remote from utility power.

The following instructions aim primarily to the planning and implementation of the electrical installation of photovoltaic systems in buildings Grid Connected with the central electrical network of alternating current (AC).

Without being considered as strict regulations, these guidelines derive from international practice and experience.

6.1 Structure of the Connected Building Photovoltaic Systems

There are two general types of electrical designs for PV power systems; systems that interact with the utility power grid and have no battery backup capability; and systems that interact and include battery backup as well. For industrial use we always choose the utility power grid and have no battery backup capability.

Each connected building photovoltaic system (BAPV/BIPV—Building Applied/Integrated Photovoltaic) can be analyzed in two individual building blocks: the solar modules, which convert solar energy into electricity and the electronic converter to perform the adaptation of electricity to requirements of low voltage.

The number of the needed Photovoltaic Panels (P/V Panels) determines the maximum produced power, while, the series or parallel connection of these, determines the electrical characteristics (voltages and power) of the converters that

E. V. M. Papadopoulou, *Photovoltaic Industrial Systems*,
Green Energy and Technology, DOI: 10.1007/978-3-642-16301-2_6,

are going to be used. Additionally, the proper functioning of the whole installation requires the use of certain auxiliary systems (Balance of System, BOS), which guarantee both the safe connection of the inverter with the PV generators and electrical network and the resistance of the whole installation to mechanical stresses.

The electricity produced by photovoltaic panels is provided in the form of direct voltage and direct current. To make the supply of the electrical network of alternating current (AC) with the energy produced by the photovoltaic possible the mediation of appropriate inverters is required. These electronic devices are known as electric converters, while, their part that has as a task the connection to the electrical network and the conversion of the direct current to alternating current, is known as inverter.

Like every electrical installation of production and consumption of electric power that is connected to the alternating current network, in the same way, the electronic converters of the interconnected electric grid PV systems must fulfill the requirements specified by regulations and standards established or adopted by the operators of power systems and networks. Specifically, the connection of small dispersed power plants in the low voltage network is considered acceptable when the power supplied to the electrical network via electronic converters doesn't affect in a negative way the quality of the power which is supplied to other connected users (consumers or producers), does not disrupt the proper functioning of parts responsible for the regulation and protection of the network and does not put at risk persons and facilities. An important distinction between electronic converters connected to PV systems can be made depending on whether they include a transformer in one of their scales. In the case of using a transformer, it may be of high frequency (Ferrite Transformer) or of low frequency (iron-core transformer). The existence of a transformer offers the advantage of galvanic isolation of the PV equipment from the network of the alternating current. Although the low frequency transformers lead to an increase of the volume and weight of the total construction, their presence guarantees zero DC injection to the grid. Unlike the other topologies, any asymmetry of the circuit power or of the control circuit can cause the appearance of a small DC amount at the output of the inverter.

6.1.1 Classification of the Building Interconnected PV Systems

Depending on the way the above structural units are combined, the connected to buildings PV systems of low power (up to 10 kW) are classified into two main technological trends. The Array technology and the Multi-array technology. The differentiation of the above mentioned technological trends is depending on the number of the PV panels that are connected per electronic converter (power level of the converter) and on the way the PV panels are connected together (series, parallel connection or combination of them).

6.2 Building Connected PV Systems Under an Independent Producer

The Building Connected PV systems are under an Independent Producer (Feed in tariff). Therefore, all the energy produced by the power generating unit is sold to the public power corporation and is not used for a partial or a total power supply of the building (self-consumption of the building).

The implementation of the electrical installation (Fig. 6.1) requires the installation of two separate electrical panels (one for the building self-consumption and a second for the connection to the power generating plant), which are connected to the counters of the consumed and supplied power. Both the energy delivered by the producer to the electrical grid and the energy that is absorbed for building self-consumption, always moves through the same power supply system.

6.2.1 Configuration of the Connection Depending on the Maximum Power of the PV System

The building PV systems of power up to 5 kWp, are connected to the low voltage grid through a single-phase electric power supply as opposed to those whose maximum power exceeds the 5 kWp (but in no case up to 10 kWp). So, they are necessarily connected to the grid network through a three-phase electric power supply. In the case of the three-phase connection a symmetrical loading of the three-phases should be chosen.

It is mentioned that the percentage of asymmetry among the three phases of electric current must not exceed 20%.

6.2.2 Choosing the Right Location for Installing a PV System

6.2.2.1 Orientation of the PV Panels

In order to achieve the maximization of the productivity of the PV modules, the best utilization of the solar radiation must be achieved. Since the direction of the sun changes as the time of day and the days of the year pass, it is known that in order for a panel to produce the maximum quantity of electrical energy it should be able to rotate so that it can follow the direction of the sun and be kept perpendicular to the direction of the solar radiation.

Practically, the mechanical complexity and the cost of such a mechanism that allows the movement of the panels according to the way mentioned above, makes it extremely difficult and costly to implement in Building PV systems. So, the majority of building PV systems chooses an orientation of stable panels in order to achieve an average annual angle of 90° for the incoming solar radiation. This goal can be achieved with the right choice of the inclination and the right choice of the azimuth angle. The inclination of the module is expressed by the angle that is formed between the level of the surface of the PV panel and the horizontal level, while, the azimuth angle is formed on the horizontal level between the tilted side of the module and the local meridian with North–South.

For the northern hemisphere, the best inclination of the PV panel for the maximum production throughout the year is equal to the geographic latitude of the place and the azimuth angle is almost 0° (with direction to the south).

Since, in the case of building PV systems the best inclination degrees and the orientation of the PV panel may be unattainable (because of restrictions resulting from the available spaces of the building), a solar radiation assessment of the surface where is going to be placed the PV system should be done. The reduction of the annual solar radiation (on the surface of the PV system) compared with the maximum theoretical value (best inclination and orientation degrees) is recommended not to exceed the 10% in order to maximize the economic benefits of an independent producer. Taking into account the constraints arising from the available surfaces of the buildings, it is generally preferable to have surfaces with south orientation deviation up to 70° to the direction of the south and inclination in the range of 0°–50°. It is noted that inclination angles of more than 10°–15° makes the self-cleaning of the panels from dust and other pollutants through the rain easier.

The effect between the inclination angle degree and the orientation as it concerns the producing electrical capacity of a building PV system in absolute and percentage rates, respectively is presented. In all cases it is assumed that there is no shading.

6.2.3 Shading Problems

Another important factor which affects the energy efficiency of a building PV system is the presence of shading. Taking into account that in a PV module, the PV elements (or parts of them) as well as the PV panels of a array, are connected together in series, it is obvious that even the shading of a part of the array can cause a significant reduction of the produced power compared to the expected value. Specifically, the total current power of a PV module array is determined by the reduced power supply of the shaded part of the PV series. Of course, if the shading limits the voltage of the shaded panels so low that the deviation route comes into conduction then the panel is excluded from the electricity production.

From another point of view, permanent or repeated local shading during hours of high solar radiation may stress the shaded PV module causing its premature aging. Therefore it is important to avoid shading even from objects of low volume like poles, antennas or wires or even more from trees or nearby buildings, etc.

The choice of the placing position of the PV array should be done in such a way to ensure that there is no shading and that there will be no shading during the year and especially during the hours of the day with the highest solar radiation.

Finally, to ensure long term continuous performance of the PV system of any shadowing due to future construction of neighboring buildings should be considered.

In conclusion we can say that the general rule of choosing a location for the placement of the PV equipment is the horizon to the south to be free from obstacles. To check for possible shadowing throughout the year it is good to use a chart presenting the orientation of the sun as shown in Fig. 6.4. In this chart the position of the sun in angular coordinates, for latitude of 38° is designed. For different latitude in Greece, the diagram appears slightly different. The horizontal axis corresponds to the azimuth angle of the sun, which is the angle that is formed on the horizontal level between the direction of the sun and the local meridian north–south (Angular distance of sun from the direction of the South), while the vertical axis corresponds to the angle of the sun, between the direction of sun and its presentation to the horizontal layer. In the chart there are indicative designed the 21st of December, 21st of March and 21st of June, while on the tracks the position of the sun in every hour of the day (in Local solar time) is marked. The contours of the obstacles (in angular coordinates in the same system of axes) should be compared as they are seen from the worst point of the PV array. In this way we can check if obstacles are shading the PV array, therefore, if the angle of the obstacles is greater than the angle of the sun for the relevant azimuth angle.

6.3 Static Study Materials & Support Material

The placement of the PV modules in the building can be implemented either on an additional metal structure, or on the surface of the roof, or even with the integration of the modules to structural shell of the building. Although the PV array and the support base weight is unlikely to affect the static strength of the building, when the panels are installed on rooftops or roofs it is preferable to make a static research first (Or even a special study where required) so as to analyze the mechanical stress and the wind pressure of the surface where the panels are placed.

The PV modules are placed in a supporting system and ensure the proper function and the safety of the structure in extreme wind conditions, snowfall, ground quake and temperature variations. These extreme weather conditions or a combination of them as well as the safety coefficients are determined by Eurocodes together with additional checks exactly like it happens in every construction test. For the efficient static of the supporting system it can be asked from the supplier to provide the relevant certificate. The support system can be part of a glazing panel or a joint of a roof or to be an independent system placed in such a way that creates a sun shade. The supporting system can be even metallic made of aluminium or heated galvanized steel or made of plastic (especially in the case of support areas). There is a variety of supporting systems available in the market. In each case it must be paid attention if there is compatibility with the rest elements of the equipment, furthermore in the accuracy of the certificates of the static efficiency of the entire construction. The way the PV modules are tighten must be in accordance with the specification standards of the PV module and additionally the dimensions of the panel must be relevant (or smaller) compared to those that have been approved in the static study for the issue of the certificate of static efficiency (Fig. 6.1).

As it concerns the connection of the supporting system to the building especially when it is placed on a rooftop the proper support must be used. This can be achieved by adding extra weight or with the use of screws. In the first case, the extra weight that is going to be placed must be in accordance with the static study of the building. In the case of using screws, they must not damage the existent insulation. In both cases, like in the case of another system, the specification standards for the supporting procedure are provided by the supplier of the supporting system. However, the compatibility with the building should be checked by a mechanic. Finally, the installer should be aware of the diversity of the support systems and their advantages and disadvantages including the ease of installation, reliability and operational elements (such as the possibility or not of a natural ventilation of the module).

6.4 Selecting the Placement Area of the Electronic Converters

One of the issues that deserve attention when designing a building PV system is the choice of the placement area for the electronic converters. Usually, the converters of the power generating units are placed either inside the buildings or in a specially designed indoor space which can be close to the PV equipment. Indeed, if the latter case happens there is a significant reduction of the length of electrical

Fig. 6.1 PV panels' roof mounted at industrial building (Milk Diary Industry)

conductors of direct current (DC). With the direct result of reducing electrical losses, voltage drop and reduction of wiring cost.

Of course there are electronic converters which, according to the manufacturer's technical manuals, can be installed either under the PV panels or in their supporting mechanism if there is enough space. Taking into account that this type of installation has as a result the direct exposure of the converter at high temperatures during the summer months, while in some parts of Greece there is an exposure in quite low temperatures during the winter, it is proposed to be applied only in the cases suggested by the manufacturer. Specifically, in the manufacturer's manual the degree of the protection factor (IP) of the converter from dust and water, as well as the temperature limits within which the safe and smooth operation is not affected should be sought. Otherwise, the adoption of this type of installation can cause a reduction in the life expectancy of the converter. Also, taking into account the fact that the electronic converter cooling is strongly influenced by the climatic conditions of the region in which the PV system is installed (weather temperature, conditions of sunlight, humidity and wind), it is understood that when the converter is placed in an indoor space, near the PV equipment may be necessary to place a cooling mechanism (fans). The following are specific instructions regarding the proper installation and the safe operation of the PV system. The guidelines are based on the international practice and experience as well as in standards such as IEC and ID384 364-7-712.

6.5 Designing the PV System

6.5.1 Basic Principles to Follow When Designing a Quality PV System for Industrial Use

First of all must select a packaged system that meets the Industry's needs. Industry's criteria for a system may include reduction in monthly electricity bill, environmental benefits, desire for backup power, initial budget constraints, etc. Size and orient the PV array to provide the expected electrical power and energy.

We have to ensure the roof area or other installation site is capable of handling the desired system size, to specify sunlight and weather resistant materials for all outdoor equipment and to locate the array to minimize shading from foliage, vent pipes, and adjacent structures.

The system in compliance with all applicable building and electrical codes should be design with a minimum of electrical losses due to wiring, fuses, switches, and inverters. The design should meet local utility interconnection requirements.

The proper design of a PV system and the proper installation are required to ensure the smooth operation of power plants, both in terms of safety and energy efficiency.

6.5.1.1 Typical Electrical Values of a PV System

Voltage The maximum voltage expected from a PV array is the total voltage of an open circuit of panels connected in series, regarding the lower expected operating temperature.

Amperage (Current) The maximum expected value of a PV array current is calculated from the current value of a panel multiplied by the factor of 1.25. In parallel channels, the maximum expected value of the total current arises by multiplying the value of one channel with the number of the parallel channels. The safety factor of 1.25 covers specific atmospheric conditions and reflections that can occur in clear skies after rain (Solar Irradiance greater than 1,000 W/m^2).

The value of electricity calculated in this way should be taken into account in the sizing of cables and protections.

Temperature The maximum expected operating temperature of PV modules and connecting boxes can reach the 70°C, in structures that allow the free circulation of air in the back side of the PV modules. In cases where the free circulation of air is prevented higher temperatures up to 80–90°C are expected. In the case where the interconnection conductors of the PV modules are very close to the PV module, their temperature should be seriously taken into account both for the correct choice of insulation of the conductors, as well as for the appropriate choice of their cross section (select the proper growth section corrective rate).

6.5.2 Grid-Interactive Only (No Battery Backup)

As it is referred above this type of system only operates when the utility is available. Since utility outages are rare, this system will normally provide the greatest amount of bill savings to the customer per euro of investment.

However, in the event of an outage, the system is designed to shut down until utility power is restored.

Typical System Components:

PV Array: A PV Array is made up of PV modules, which are environmentally-sealed collections of PV Cells—the devices that convert sunlight to electricity. The most common PV module that is 1–3 m^2 in size and weighs about 10–20 kg/m^2. Often sets of four or more smaller modules are framed or attached together by struts in what is called a panel. This panel is typically around 2–4 m^2 in area for ease of handling on a roof. This allows some assembly and wiring functions to be done on the ground if called for by the installation instructions.

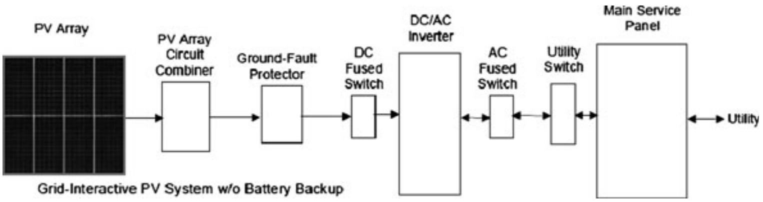


Fig. 6.2 Grid-connected PV system

Balance of system equipment (BOS): BOS includes mounting systems and wiring systems used to integrate the solar modules into the structural and electrical systems of the home. The wiring systems include disconnects for the DC and AC sides of the inverter, ground-fault protection, and over current protection for the solar modules. Most systems include a combiner board of some kind since most modules require fusing for each module source circuit. Some inverters include this fusing and combining function within the inverter enclosure.

DC–AC inverter: This is the device that takes the DC power from the PV array and converts it into standard AC power used by the house appliances.

Metering: This includes meters to provide indication of system performance. Some meters can indicate industry energy usage.

Other components: utility switch (depending on local utility) (Fig. 6.2).

6.5.2.1 Cooperation Between the PV System and the Inverter

During the designing of the system special attention to the cooperation between the PV array and the electronic inverter is required. The inverter requires a specific voltage range in its entrance for its operation, having a maximum input voltage limit. This maximum limit must not be exceeded in order to avoid any risk of damaging the inverter. Therefore, the number of PV panels that can be connected in series (an array) must be estimated so as not to exceed these limits in every operating condition.

The voltage of a PV module depends highly on its operating temperature. The voltage, current and power values given by the manufacturer is mentioned to the standard test conditions (STC). The electrical characteristics of PV modules must be corrected based on the extreme temperature operating conditions of the PV system. Specifically, from the minimum operating temperature of the modules, the maximum voltage value of the chains is calculated, and from the maximum operating temperature of the modules, the maximum value of the current of the parallel chains (branches) is calculated.

The maximum number of PV modules in series is calculated in a way that the total voltage of the open circuit of the array, within the lower operating temperature, must not exceed the maximum input voltage of the inverter. For the lowlands of Greece the minimum temperature can be determined from −5 or −10°C. (Operating temperature of the active material of PV module). At the same time, the maximum operating voltage of the PV module, which must be greater than the open circuit voltage of the array within the lower expected operating temperature, must be checked in order to avoid a problem in the isolation of the PV module.

The minimum number of PV modules in series is determined so that the total voltage for an optimal functioning of the array to the maximum expected operating temperatures must not exceed the minimum input voltage of the inverter in order to be activated.

If the manufacturer provides only the value of the thermal coefficient for the voltage of an open circuit (V/°C), then the same value can be used for the voltage of the maximum produced power of the PV module without significant errors.

The minimum number of PV modules in series is determined so that the total voltage of excellent performance in the maximum expected working temperature to exceed the minimum voltage of the inverter's entrance width in order for it to be activated.

If the manufacturer only provides the value of the thermal coefficient for the open circuit voltage (V/°C), then the same value can be used for the voltage in the point of maximum produced power of the PV module, without any significant errors.

If from the series connection of the PV modules a power approximately as the nominal power of the inverter is not produced, then more parallel branches (acceptable number of series modules) must be connected so that the total power of the PV module array approaches the one of the inverter.

The operating current of the parallel branches must be lower than the maximum entrance current limit of the inverter. The total power of the PV array may exceed the nominal power of the inverter.

For the weather conditions of Greece it is recommended the nominal power of the PV array not to exceed the 110% of the nominal power of the inverter.

Finally, one important issue that must be taken into account is the compatibility between the type of the PV modules and the inverter which is relevant with the demand or not for grounding of the array in the side of the DC current. To be more specific, some types of PV modules according to the manufacturer demand grounding either of the negative (thin-film) or of the positive (back contact) pole.

The grounding must be either directly made, either through big resistance aiming to avoid functional problems that the above mentioned types of PV modules have when they are not grounded (problems of corrosion and performance demission). Therefore, in such cases the use of inverters without galvanized insulation must be avoided, due to occurrence of leak currents, unless it is certified by the inverter's manufacturer that the chosen type of the inverter is appropriate for use with the modules we have chosen.

6.5.2.2 System Installation

General

For the full completion of the power generation plant the rules of the international experience and the existing regulations must be followed in order to avoid situations where human lives could be put at risk or material damages could be caused.

In detail, to complete the installation from the side of the AC current, the regulations deriving from the HD384 regulation must be followed. It is noted that the PV modules have different properties than those of the compatible sources. Those characteristic features come from the nature of the construction materials of PV modules and must be seriously taken into account in order to correctly design and complete a PV system.

In detail:

Taken into account the nature of the PV modules, it is proven that the PV modules act as electricity sources controlled by voltage. In fact, the maximum value of the current of a PV module is slightly bigger than the value of the nominal current of the module. Therefore, the use of safety fuses does not guarantee the pause of the system in case of error (module short-circuit). A short-circuit error on the side of the DC current may still exist despite the use of safety fuses, except in the case where the PV system is consisted of more than three parallel module series. In such a PV system structure the safety fuses may be used to protect each module series separately.

Unlike most power generation plants where the electricity production may be interrupted with the help of a general decoupling medium, the PV modules produce voltage on their edges as soon as they are exposed to sun light. Consequently, the installation of a PV module system is completed under voltage circumstances from the side of the modules.

During the completion of the electrical installation from the side of the DC current undesired situations may come up when:

(a) Bad or loose connections exist (formation of an electrical arc)
(b) Error regarding the grounding (insulation damage and contact of active pipe with grounded metallic module or its support equipment)
(c) Short-circuit error (insulation error and contact of active pipes)

The installation of PV system should follow the next steps:

- Ensure the roof area or other installation site is capable of handling the desired system size.
- If roof mounted, verify that the roof is capable of handling additional weight of PV system. Augment roof structure as necessary.
- Properly seal any roof penetrations with roofing industry approved sealing methods.

- Install equipment according to manufacturers specifications, using installation requirements and procedures from the manufacturers' specifications.
- Properly ground the system parts to reduce the threat of shock hazards and induced surges.
- Check for proper PV system operation by following the checkout procedures on the PV System Installation Check List.
- Ensure the design meets local utility interconnection requirements
- Have final inspections completed by the Authorities, if required.

Error Investigation

In Fig. 6.3 an example of installation with the negative pole of the PV series modules grounded, so as to investigate possible unwanted situation due to error, is shown. It is supposed that the negative pole is grounded. This can happen deliberately by the design of the system, meaning grounded system or use of an inverter without isolation.

If an error regarding the ground occurs in a parallel branch, then the current of all the other branches will supply the error, creating an alternative current in the modules of the branch with the error.

A similar situation occurs when short circuit fault is created by the parallel branch or when the negative pole is grounded unintentionally by a first error in the ground that has emerged, followed by the second error in the ground.

The current error is fed by the PV modules and can remain even if the PV array is isolated from the converter, without having to interrupt the loop of the current error. This current can destroy the wires and the PV modules.

You can deal with the problem in the following ways:

(a) With the dimensions determination of any parallel conductors' branch to withstand the current of $N - 1$ parallel branches, as long as the current is lower than the maximum allowed AC current of the PV module. For most of the commercial PV modules the maximum allowed current may be considered the one equal to 3 times the short circuit current value.

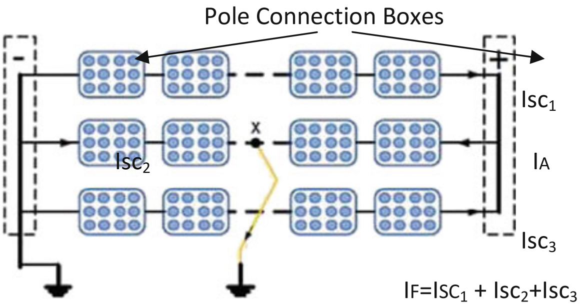


Fig. 6.3 PV installation with the negative pole grounded

(b) With the installation of safety fuses on each side (positive or/and negative at the same time according to the location of the inverter) of each parallel branch

The use of diode-return can solve the problem mentioned above, but it will burden the energy performance of the power generation plant because of power losses (Fig. 6.4).

Protection

Regarding protection issues, the method of automatic feed disruption is not possible because of the special features of the PV modules. To protect them against direct or indirect contact, the use of very low voltage is possible (SELV or PELV systems). A PV module system is characterized as very low voltage system when the voltage of an open circuit in standard test conditions does not exceed 120 VDC. This case though, is special and of low interest since most market products operate in higher voltages. Taking into account the fact that the PV modules that are used must be Class II regarding the insulation (according to standards EN 61730, in the application category [Application Class A] of continuous voltage of the system over 120 V), the insulation of the PV modules of this category must be insulated by Class II. The recommended practice for protection against indirect contact is the minimization of the possibility of error occurrence, beyond the use of PV modules Class II, and with materials and installation practices that ensure

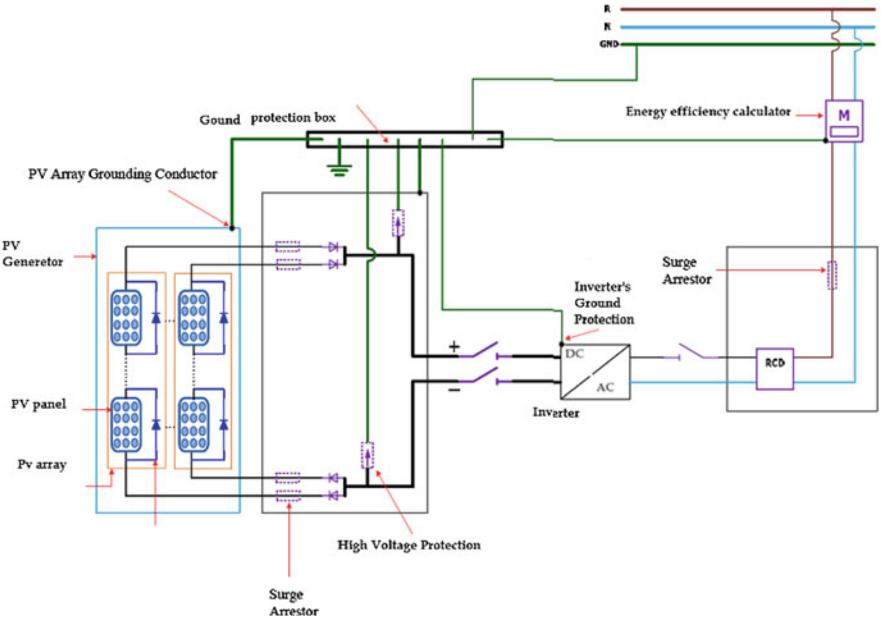


Fig. 6.4 PV installation

protection Class II or equal (“ground fault and short circuit proof installation”). The protection with material of category II, with enhanced insulation, is based on the fact that it is so strong that practically cannot be destroyed. The standard IEC EN 61730 consists of two parts. The first is about the minimum standards regarding the good construction of the PV modules, including the electricity insulation, for facilities where the maximum AC voltage may come up to 1,000 V. As it concerns the insulation, the standards of Class II must be fulfilled. The second part of the IEC EN 61730 refers to the test standards of the PV modules.

6.5.2.3 Grounding of the inverter

The grounding (direct or neutral, depending on the area) aims at the protection of the production facilities and the safety of the individuals and must be performed according to the relevant regulations (HD384). In Fig. 6.6 the possible grounding ways of the connected building PV modules are presented. At this point it must be noted that the grounding of one of the edges of the inverter on the side of the DC current is not compulsory in the European countries, unlike the USA.

It is pointed out that the grounding or not of the DC current side depends on the PV modules technology and the topology of the inverter. The PV arrays that are formed by specific kinds of modules (thin film, back—contact), are grounded according to the manufacturer’s recommendation so as to ensure their unobstructed function as well as their maximum performance. To be more specific, the PV modules of thin film with materials like a-Si and CdTe, due to their manufacturing technology (superstrate technology), usually show high danger of corrosion of the TCO layer, fact that causes damaging effects. To avoid such incidence, the negative edge of the PV source is grounded. This does not appear, according to studies, in thin film PV modules with other materials (e.g., CIS). In PV module systems with back-contact technology, it is compulsory (by the manufacturer) the grounding of the positive edge on the side of AC current so as to optimize their performance. In this case, the grounding must be done through high resistance. Under these circumstances, the use of inverter with converter is compulsory, unless it is certified by the manufacturer that the chosen type of the inverter (without insulation converter) is suitable for the modules that we have chosen. As it concerns the usual crystal modules, no specific demands have been put by the manufacturers regarding the grounding (or not) of the edge of the DC current side. In such cases, since active parts of the DC current side are not grounded, the use of inverter without isolation converter is possible. At anytime, the studier of the system must follow the instructions of the manufacturer regarding the demands that arise depending on the technology of the PV modules. Usually, the inverters’ manufacturers, taking the above mentioned into account, suggest the suitable equipment according to the module type. It is stressed that, if the inverter does not include isolation transformer, the DC current side is not grounded. On the other hand, other exposed metallic parts of the PV module equipment (e.g., support base and metallic parts of the PV modules) must be grounded. In Fig. 6.5a the case of a PV module system where an inverter with a transformer and grounding of it on the side of the AC current is presented. In a system like that the occurrence of an error between one of the two DC current conductors and ground does not lead to current flow. In general, the same applies when a human (in contact with the ground) touches one of the two active conductors of the DC current. Of course, if the modules are not grounded and they do not have proper insulation, discharging of the parasitic capacity of the modules may occur through human towards ground (leak current). For this reason, it is necessary to use modules of insulation category “Class II” according to the standard IEC EN 61730. Finally, in the above mentioned modules the use of special error observation systems to ground and inverter disconnection systems (on the side of the DC current) is compulsory, in order to avoid accidents due to deliberate (or not) grounding on the side of the DC current.

In Fig. 6.5b the case of a PV module system where an inverter with a transformer and grounding on the side of the DC current as well as on the side of the

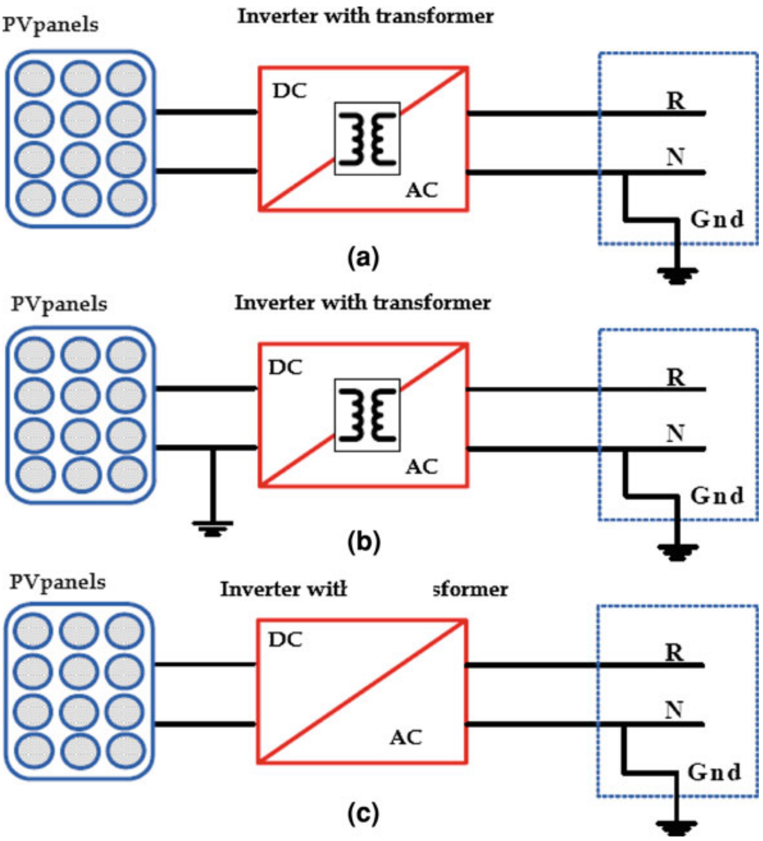


Fig. 6.5 PV installation with difference cases grounded

AC current, is presented. Unlike the previous case, the formation of an error between the ungrounded conductor of the DC current and ground leads to current flow, as well as the contact of a human(who is in contact with the ground) with the ungrounded conductor of the DC current. The only way to interrupt the current flow towards ground (error case) is to disconnect the side of the DC current. For the safety of humans, the use of current (flowing to ground due to the deliberately grounded conductor) detection system is necessary. Finally, the leak currents due to parasitic capacity of the modules may negatively affect the credibility of the mentioned set out.

In Fig. 6.5c the case of a PV module where an inverter without a transformer and grounding of it on the side of the AC current is presented. Although the side of the DC current is not directly grounded, in some cases (depending on the topology of the inverter) the grounding on the side of the AC current is "visible" on the side of the DC current. If, either the modules are grounded and they do not have proper insulation or due to an error undesired grounding of them happens, then discharging of the parasitic capacity of the modules through the inverter towards ground takes place (leak current). For the safety of humans the use of a leak current detection system is necessary. Of course, the setting of the activation limit of such a system is critical (upper-lower limit, abrupt variations).

Taking into account the fact that in all cases the voltage on the ends of the PV array may be too high (so that according to the IEC 364-4-41 standard there is need to take measures to protect the public), and also the output of the inverter is connected to low voltage network, it is proven that the voltage on some parts of the inverter may be two or three times higher than the nominal voltage of the network. Consequently, the need to ground the metallic wrapping of the converter is necessary in order to avoid electrocution.

Furthermore, this way the potential electromagnetic harassment that may occur due to intermittent operation of the circuit's power in nearby electrical devices may decrease.

Finally, it is stressed that the grounding of the PV equipment may cause serious problems in case the insulation of the modules is not proper. On the other hand, although the use of ungrounded PV modules limits the above mentioned risk, it increases the risk of damage of the modules caused by a potential lighting strike. In some cases the grounding of the modules is mandatory according to the manufacturer.

Wiring DC Current Side

On the side of the P/V the design and implementation of the wiring installation should provide protection equivalent to insulation of Class II.

The wiring includes connections between the PV panels, the connections from the edges of each P/V module of the array to the parallelism box, if it is used, as well as the connections from the edges of the P/V array, for example the parallelism box, to the inverter.

All the cables that are exposed to the solar radiation should be resistant to UV radiation (excluding common wires with PVC insulation).

Cables that are used in the modules' connection should have resistant insulation for at least 70° or higher if there is not free circulation of air.

Choosing the right type of cables is important for the safety and the longevity of the installation as well as for the satisfaction of the requirement for insulation equivalent to class II. For the connections between the modules, flexible single core cables which fulfill the minimum requirements mentioned above with increased insulation are usually used. The combination of these requirements is difficult to be satisfied by using common wiring and requires the use of special blends of plastics for insulation.

The cables can be aerial, but must be supported so as not to strain the connections. The support is achieved with the use of materials resistant to ultraviolet rays, moisture, high temperatures and corrosion.

The P/V modules must have (bypass diodes), for alleviating the effects of shadowing. For the connections between the cables it is recommended to use the appropriate special connectors for a fast connection. The pre-installed cables of PV panels must not be removed or replaced by cables of other type or cross section. The routing of cables from the parallelism box to the inverter should ensure protection equivalent to Class II. The cables must be of single core with double or reinforced insulation. Otherwise, they should be placed in different channels. In the connection boxes different areas with insulating separator must be used for connecting the negative and positive conductors. Alternatively separate boxes for positive and negative conductors can be used. The boxes to be used should be insulated and opening with a special key or tool.

The cross section of a cable is determined by the maximum expected current of a branch. The correction due to the temperature, which can reach the 70°C for the wires near the PV modules, should be taken into account.

It is noted that in a temperature of 70° the correction factor for wiring insulation resistant up to 90° must be 0.58. In this case, the cross section of the cable must be calculated based on the expected value of the maximum current multiplied by 1.72 (=1/0.58) in order to not exceed the limits of the insulation resistance. Another factor that must be taken into account in order to determine the right dimensions of the cable is the energy losses. It is generally considered that the energy loss through the length of the DC cables based on the nominal values must not exceed the 1% of the nominal value of the PV system. This criterion usually leads to the choice of larger cross section.

In the side of the DC current a switch (when it is not included to the inverter) which is going to isolate the inverter from the P/V array should be installed. This switch should have the ability to isolate the loaded inverter (thus, the fast connectors do not fulfill this requirement as a means of isolation). The switch must be designed in order to work for DC current so as to isolate the two cores (ungrounded system).

AC Current Side

The general rules that derive from HD384 must be followed on the side of the AC current.

The output of the inverter is connected to a different electrical board, where the protection and control measures are installed. The feed of the electrical board must come directly from the Supply that the network's administrator has provided to the building.

The electronic inverters must provide isolation ability of their output from the AC current network.

The installation of the escape relay to the output of the inverter (AC current side) is made according to the demands of the HD384 standard. To be more specific, in case the inverter does not include galvanic insulation or includes high frequency converter, protection through escape relay type B (according to the IEC 364-7-712 standard) must be provided. The chosen inverter is best to already have this option without the need to install extra electrical equipment. The inverters of this type may have a certificate of measurements for the non infusion of DC current; therefore escape relay type A may be installed. For the selection of IΔn current, besides the demands of the HD384 standard, it must be taken into account the fact that in PV installations with inverter without converter a leak current exists in the normal function of the system, the value of which cannot be accurately predicted (depending on the type of the modules, the inverter and the weather conditions). In those cases, the installation of an escape relay with stimulation current 30 mA may cause undesirable pauses to the function of the PV system.

It must be stressed that the minimization of the routing is undesirable; on the side of the DC current as well as on the AC current in order to achieve reduction of electrical loses.

Markings Warning signs that all active parts inside the boxes remain active even after the isolation of the PV modules from the converter must exist in all connection boxes. The signs must be resilient to the environment where they are installed.

Mounting Options There are several ways to install a PV array at an industry. Most PV systems produce 50–100 W/m^2 of array area. This is based on a variety of different technologies and the varying efficiency of different PV products. A typical 2-kW PV system will need 20–40 m^2 of unobstructed area to site the system. Consideration should also be given for access to the system. This access space can add up to 20% of needed area to the mounting area required.

Roof Mount Often the most convenient and appropriate place to put the PV array is on the roof of the building. The PV array may be mounted above and parallel to the roof surface with a standoff of several cm for cooling purposes. Sometimes, such as with flat roofs, a separate structure with a more optimal tilt angle is mounted on the roof.

Proper roof mounting can be labor intensive. Particular attention must be paid to the roof structure and the weather sealing of roof penetrations. It is typical to have one support bracket for every 100 W of PV modules. For new construction, support brackets are usually mounted after the roof decking is applied and before the roofing materials is installed. The crew in charge of laying out the array mounting system normally installs the brackets. The roofing contractor can then flash around the brackets as they install the roof. A simple installation detail and a sample of the support bracket is often all that is needed for a roofing contractor to estimate the flashing cost.

Masonry roofs are often structurally designed near the limit of their weight-bearing capacity. In this case, the roof structure must either be enhanced to handle the additional weight of the PV system or the masonry roof transitioned to composition shingles in the area where the PV array is to be mounted. By transitioning to a lighter roofing product, there is no need to reinforce the roof structure since the combined weight of composite shingles and PV array is usually less than the displaced masonry product.

6.5.2.4 Shade Structure

An alternative to roof mounting is to mount the system as a shade structure. A shade structure may be a patio cover or deck shade trellis where the PV array becomes the shade.

These shade systems can support small to large PV systems.

The construction cost with a PV system is a little different than for a standard patio cover, especially if the PV array is acts as part or the entire shade roof. If the PV array is mounted at a steeper angle than a typical shade structure, additional structural enhancements may be necessary to handle the additional wind loads. The weight of the PV array is 3–5 lb/ft^2, which is well within structural limits of most shade support structures. The avoided cost of installing roof brackets and the associated labor could be counted toward the cost of a fully constructed patio cover. The overall cost of this option will likely be higher than roof mounting, but the value of the shade often offsets the additional costs. Other issues to consider include:

- Simplified array access for maintenance
- Module wiring, if visible from underneath, must be carefully concealed to keep the installation aesthetically pleasing
- Cannot grow vines, or must be diligent about keeping it trimmed back from modules and wiring

6.5.2.5 Building-Integrated PV Array (BIPV)

Another type of system displaces some of the conventional roofing product with building integrated PV modules. Commercially available products currently include roof slates (similar to masonry roofing) and standing seam metal roofing products. Special attention must be paid to ensure that these products are installed properly and carry the necessary fire ratings.

Dimensional tolerances are critical and installation requirements must followed precisely to avoid roof leaks.

Dimensional tolerances are critical and installation requirements must follow precisely to avoid roof leaks.

6.5.2.6 Estimating System Output

PV systems produce power in proportion to the intensity of sunlight striking the solar array surface. The intensity of light on a surface varies throughout a day, as well as day to day, so the actual output of a solar power system can vary substantial. There are other factors that affect the output of a solar power system.

These factors need to be understood so that the industry's general has realistic expectations of overall system output and economic benefits under variable weather conditions over time.

6.5.2.7 Factors Affecting Output

Standard Test Conditions Solar modules produce DC electricity. The DC output of solar modules is rated by manufacturers under Standard Test Conditions (STC). These conditions are easily recreated in a factory, and allow for consistent comparisons of products, but need to be modified to estimate output under common outdoor operating conditions. STC conditions are: solar cell temperature = 25°C; solar irradiance (intensity) = 1,000 W/m^2 (often referred to as peak sunlight intensity, comparable to clear summer noon time intensity); and solar spectrum as filtered by passing through 1.5 thickness of atmosphere (ASTM Standard Spectrum). A manufacturer may rate a particular solar module output at 100 W of power under STC, and call the product a "100-watt solar module." This module will often have a production tolerance of ±5% of the rating, which means that the module can produce 95 W and still be called a "100-watt module." To be conservative, it is best to use the low end of the power output spectrum as a starting point (95 W for a 100-watt module).

Temperature Module output power reduces as module temperature increases. When operating on a roof, a solar module will heat up substantially, reaching inner temperatures of 50–75°C. For crystalline modules, a typical temperature reduction factor recommended by the CEC is 89% or 0.89. So the "100-watt" module will typically operate at about 85 W ($95 \text{ W} \times 0.89 = 85 \text{ W}$) in the middle of a spring or fall day, under full sunlight conditions.

Dirt and Dust Dirt and dust can accumulate on the solar module surface, blocking some of the sunlight and reducing output. Although typical dirt and dust is cleaned off during every rainy season, it is more realistic to estimate system output taking into account the reduction due to dust buildup in the dry season. A typical annual dust reduction factor to use is 93% or 0.93. So the "100-watt module," operating with some accumulated dust may operate on average at about 79 W (85 W × 0.93 = 79 W).

Mismatch and Wiring Losses The maximum power output of the total PV array is always less than the sum of the maximum output of the individual modules. This difference is a result of slight inconsistencies in performance from one module to the next and is called module mismatch and amounts to at least a 2% loss in system power. Power is also lost to resistance in the system wiring. These losses should be kept to a minimum but it is difficult to keep these losses below 3% for the system. A reasonable reduction factor for these losses is 95% or 0.95.

DC to AC Conversion Losses The DC power generated by the solar module must be converted into common AC power using an inverter. Some power is lost in the conversion process, and there are additional losses in the wires from the rooftop array down to the inverter and out to the panel. Modern inverters commonly used in residential PV power systems have peak efficiencies of 92–94% indicated by their manufacturers, but these again are measured under well-controlled factory conditions. Actual field conditions usually result in overall DC-to-AC conversion efficiencies of about 88–92%, with 90% or 0.90 a reasonable compromise.

So the "100-watt module" output, reduced by production tolerance, heat, dust, wiring, AC conversion, and other losses will translate into about 68 W of AC power delivered to the panel during the middle of a clear day (100 W × 0.95 × 0.89 × 0.93 × 0.95 × 0.90 = 67 W).

Building Protection of PV Modules Against High Voltage and Lightning Strikes

The protection of building PV systems against high voltages and lightning strikes is an issue that aims to protect the production facilities but mostly to protect humans.

With every precaution, based on the existing experience of hundreds of PV systems smaller than 10 kWp that were installed in European countries and do not project significantly from the building, the risk of direct lightning strike does not increase. Therefore, it is recommended to evaluate the risks of lightning strikes and the high voltages they create in order to ensure the safety of humans and building electrical facilities. In Fig. 6.6 a recommended indicative form of protection facilities' installation for protection of the PV system is shown. At the same time, the protection of the below existing electrical facilities (e.g., protection of the main board and sub boards) must be predicted.

It is recommended that the facilities must avoid forming large current loops, because a possible lightning strike will lead to the appearance of induction high

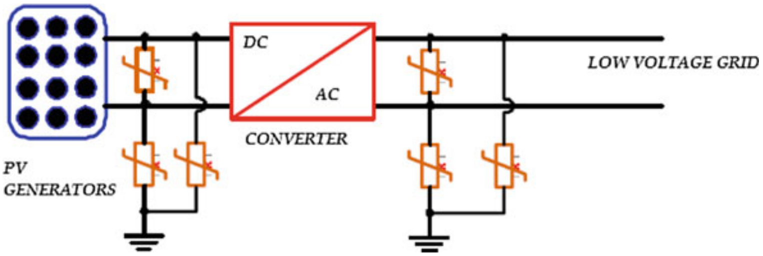


Fig. 6.6 Typical protection facilities' installation for protection of the PV system

voltages. If the PV system is installed in a building that already has lightning protection and a safety distance (0.5–1 m) can exist between the PV system and the conductors that collect and descent the lightning current, then the PV system is considered being within the protection area of the lightning rod must not be connected conductively to the lightning protection system (as long as it is about integration in below existing buildings). If a safety distance cannot be maintained then a conductive connection with the conductors of the lightning protection system is necessary.

6.6 Connection of the Network

6.6.1 Connecting the Building PV Systems to a Low Voltage Electrical Network

The choice of connecting a domestic photovoltaic (PV) system to a low voltage network should be done in a way to avoid violating the disturbance limits set by the network administrators.

6.6.2 Configuration of the Connection of Building PV Systems: Electrical Network

In Fig. 6.7a typical simplified connection form of the mentioned electricity producing facilities with the low voltage network is presented. The general connection form of DC current, the protection against short circuit current in the side of the DC current and the automated switcher of the generator ensures the parallelism and the connection to the network.

The protection of the PV module generators in a case of network disruptions as well as the isolation in a case of a complete shutdown should be achieved through the automatic switch of the generator or through other suitable protection methods incorporated in the controlling system of the converter so as to avoid damages of

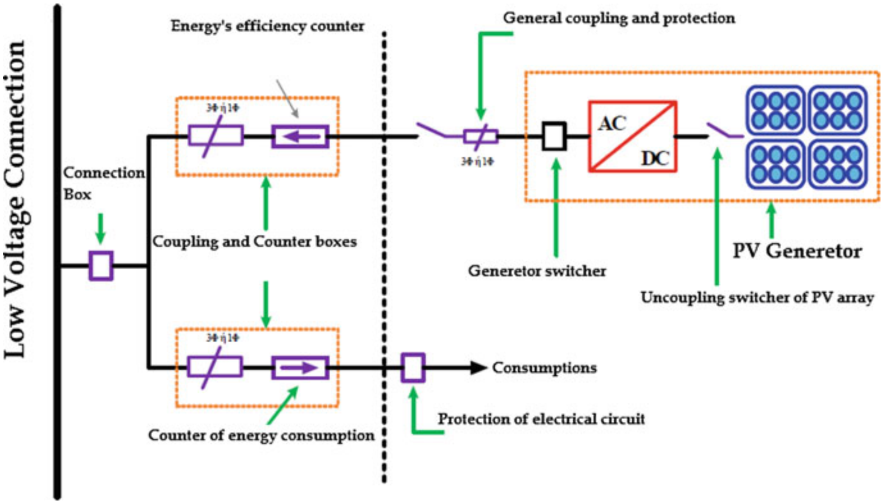


Fig. 6.7 Typical simplified connection form

the installed equipment and avoid the appearance of risky situations for other users of the network.

For the secure and proper execution of works through the network, the personnel of electricity suppliers should be provided with the ability of a manual disconnection of the installation from the network, through the free access to the measuring arrangement.

On the other hand, the connection and protection means, should have the ability to disrupt short circuit current voltages and to ensure the direct disconnection of the power generation plant. The regulation of time delay values concerning the protection devices requires special attention because extremely small values may cause an increased number of undesirable disconnections of the production facilities, while great time delays can cause damages to the installed facilities as well to adjacent voltages or producers.

The requirements that must be met for the interconnection of a PV system on the network, in accordance with the instructions of the Network Administrator, summarized in as follows:

Parameter	Requirement
Voltage	The value of the AC current to the edges of the electronic inverter should not exceed the −20% (184 V or the +15% of the nominal value of the network voltage. In a case of exceeding the above mentioned limits the disconnection should be made within 0.5 s
Frequency	The frequency of the output electrical values of the inverter should not be more than ±0.5 Hz of the nominal value of the network frequency. In a case of exceeding the above mentioned limits the disconnection should be made within 0.5 s

(continued)

(continued)

Parameter	Requirement
Automatic reconnection	The reconnection should be made within 0.5 s
Harmonics	The total distortion of the output current should not exceed the 5%
Infusion of DC current	The maximum value of the infused DC current should be at the most equal to the 0.5% of the nominal values of the facilities

6.6.2.1 Harmonic Distortion and Acceptable Limits of Harmonic Constituents' Infusion

The high frequency intermittent function of the inverters used in building PV modules causes the appearance of higher harmonic constituents to the waveform of the current that is provided to the electrical network. These higher harmonic constituents are possible to cause problems to the network as well as to facilities that are connected to it and adjacent electronic devices. To be more specific, the infusion of harmonics from the production facilities causes voltage distortion, which directly results to the malfunction of electrical systems (e.g., converters, electrical machines), electronic devices (e.g., network protection systems), as well as adjacent electrical loads (e.g., amplifier, power pack of electronic machinery), which are connected to the same electrical line. On the other hand, the existence of harmonics in frequencies higher than 1 kHz obstructs the use of the network to transfer high frequency telecommunicative signals which serve the duplex data transfer between dispersed energy sources and the control center of the Electrical System. Finally, the existence of higher harmonics may cause the harassment of nearby devices, which are not directly connected to the electrical network (through radiation). This results to appearance on noise and malfunctions to all the devices, if there is no proper magnetic armor.

To avoid all the above mentioned undesirable situations the compliance of the used converter's function with the existing regulations is necessary.

In detail, the infusion of harmonics from the electronic converters of the building PV modules must be in accordance with the conditions that are predicted by the IEC 61000-3-2 standard. This standard is about the permissible emission limits of harmonic devices and facilities with nominal current lower or equal of 16 A/phase which are connected to the X.T networks. Therefore the limits that are set according to this are also suitable for the evaluation of electrical inverters that are used in house PV systems. It must be noted that the control of the harmonic is made only for the standard function of the facilities and not during transitive periods, which usually last few seconds (e.g., during parallelism with the network). Finally, the EN 50081-1 put a limit to the permissible radiation emission limits and conductive emissions of electronic converters and the EN50082-1 defines the protection of the mentioned converters from radiation emissions in domestic, commercial and light industrial environment.

Beyond the above specifications, the Network's Administrator imposes, as necessary requirement for the connection of production facilities to the distribution networks, the achievement of a Total Harmonic Distortion, THD coefficient of the current output lower or equal to 5%, Power Factor, PF higher than 0.95 for inductive and capacity behaviour for power over 50% of the nominal and maximum value of the infused DC current (as long as the electronic converters do not have low frequency inverter) at the most equal to 0.5% of the nominal facility current. The goal of these two specifications is the economic operation of the electrical system (through limiting the losses in the network's conductors) and the avoidance of repletion to the network inverters.

In countries with greater experience on the field of PV systems, the limits of the above mentioned specifications are stricter in some cases, due to the increased insinuation of these systems to their energy supply. The following table shows the predicted limits according to IEC 61727 standards which is based mostly on regulations that were formed by the extensive application of PV systems in Germany.

Maximum permitted intensity of odd class harmonics (A)		Maximum permitted intensity of even class harmonics (A)
Harmonic class		The even class harmonics must be at least 25% lower of the corresponding of odd class
3rd–9th	4% of the output current	
11th–15th	2% of the output current	
17th–21st	1.5% of the output current	
23rd–33rd	0.6% of the output current	
Maximum value of THD		5%
Coefficient power on the 50% of the nominal power		0.9
Maximum value of the infused DC current to the electrical network		Less than 0.5% of the facility's nominal output current
Maximum allowed variations of the facility's output voltage in the standard function		85–110% (196–253 V)
Maximum allowed variation of the facility's electrical output sizes in the standard function		(50+ to -0.5) Hz

6.6.2.2 Detection of Situations of Isolated Operation: "Island Phenomenon"

With the term "Island phenomenon" a non desirable situation in which a part of the electric network which contains both electrical loads and dispersed production units, remains electrified because of the above units while the remaining electric network is inactive is defined. Causes of this phenomenon may be the deliberate disconnection of a part of the network from the protection means, due to the detection of an error, or a scheduled interruption due to maintenance, or an electricity supply interruption due to external environmental causes, or due to a possible failure of a part of the equipment of the electrical installation system as well as due to human error.

The reasons that impose the detection of such situations are the assurance of a high quality produced power for the consumers and especially the safety for facilities and humans.

In detail, in cases of a scheduled maintenance, while the administrators of the network interrupt the operation of parts of the electrical system in order to make maintenance works, the potential power supply of this section from scattered sources (Due to inability to detect the interruption) puts at risk the personnel performing the necessary work. Additionally, if the protections of an electrical installation system turn on the security switches of a line (Due to detection of random errors, possible equipment damage, external environmental causes, human error, etc.) and it is not practicable possible the scattered sources to detect the interruption of electricity supply, they will continue to supply the loads that are connected to the same line with them.

This may cause two important problems:

(a) During the period of interruption, in the part of the deactivated line there is no central control of the frequency and the voltage, and this fact may cause serious damages to other connected users when the scattered sources are not able to supply the loads with the necessary amounts of active and reactive power.
(b) In the case where the scattered production units are able to meet the demands of the loads, when the switches of the protection system reconnect the line with the main electrical network, there may be significant differences between the voltage in the edge of the scattered sources and the voltage of the remaining electrical installation system. (Loss of synchronization with the main electrical network). These differences may have disastrous consequences for both the installed system itself as well as for the other connected consumers that use it.

The inverters of the building PV systems should have protection through the "islet phenomenon" with VDE 0126-1-1 or equivalent method or with IEC 62116. In the case of detecting an isolated operation (regardless of the method in use), the disconnection of the PV modules form the electrical network should take place in a time period shorter of 1 s (Time required for the clearance of random not serious errors) so as to minimize the consequences that may result from any rapid restoration of the network voltage.

In Germany, the PV generator is disconnected from the network if the limits for voltage and frequency are violated. The protection from the "island phenomenon" with VDE 0126-1-1 is mandatory for PV systems of power up to 30 kVA only when the connection point of the source with the network is accessible from the network administrator. The compliance with the standard VDE 0126-1-1 is proved by a certificate released by an independent laboratory.

6.6.3 General Safety Instructions

Unlike most power generation plants where the electricity production can be interrupted with the help of a general means of disconnection, the PV modules directly produce voltage in their edges when they are exposed to sunlight. Therefore, installing a PV system usually takes place under voltage conditions from the side of the modules. Also, taking into account that the maximum value of the current of a PV module is slightly larger than the nominal power of the module, it is assumed that the use of safeties does not guarantee the interruption of the system in the case of an error. (Short circuit of the module). This has as a result that a Short circuit error in the side of the DC current may continue to exist regardless of the use of safeties. Good design and proper selection of wiring materials is necessary for security against electric shock not only of the installer but also for any person coming into contact with the system.

Additionally, the selection of wiring with the proper section width guarantees prevention of a fire due to overheating of cables, in case of short circuit.

The PV modules that are going to be used must fulfill either all the technical specifications of the standard EN-IEC 61215 regulation (PV crystalline silicon) either the requirements of the standard EN-IEC 61646 regulation (PV thin-film technology).

6.6.4 Measures for the Risk Reduction of an Electric Shock During the Installation of a PV System

During the installation of the PV systems, the installer comes into contact with the edges of the module where there is DC current. Usually this value does not exceed the safety limits of continuous contact based to the standard IEC 364-4-41 regulation. The indicative values of the commercial modules' voltage vary between 17 and 100 V (depending on the technology and the numbers of cells). Despite this fact, the electronic inverters that are used in PV systems usually demand the series connection of two or more modules and as a result the series voltage often exceeds the safety limits. The voltage of the series can be calculated if we multiply the number of the series modules with one's maximum voltage.

Consequently, the installation of the system must be performed by authorized staff and according to the following measures:

- Proposed method of installation: Significant part of the cabling must be done before the installation of the PV modules. Indicatively, firstly we put the general disconnection medium of the DC current side and the connection boxes. Afterwards we connect the positive and negative pole of the whole array with the general disconnection medium without performing the intermediate module connections. Then the series connection of the array's modules is performed, while finally the general disconnection medium is connected to the input of the electronic inverter. The proposed methodology aims at avoiding dangerous voltages during installation.

- Installation with no sunlight: To avoid the occurrence of high voltages the system installation can be done either by completely covering the modules or at night whenever possible. The use of special gloves and insulated tools it also recommended.
- Warning signs: During the installation of the PV system a special warning must be used to warn about the risk of electric shock.
- Choice of insulation cables and connection boxes: The use of cables and connection boxes with double insulation minimizes the risk of electric shock. For this reason the use of materials and modules of class II (Class II construction) is recommended. Since the class of materials and modules may not be apparent, the installer must confirm by contacting the manufacturer.
- Choice of PV modules with preinstalled connection system: The PV modules with insulated connectors minimize the possibility of the installer being exposed to dangerous voltages. This option is necessary if the installation is done by unqualified personnel.
- Avoid grounding of the DC current side during installation: A system in which neither of the two poles is grounded poses fewer risks (compared to a grounded system) because it minimizes the number of possible routes of electric current. For example, suppose in a system grounded to the negative pole the installer comes into contact with any part of the array—and is also in contact with the ground—a current route through him and the ground is created. In such case, the voltage in which the installer will be exposed to equals the sum of voltages of the series connected modules between the contact point and the negative pole of the array.

Note: It should be noted that the proposed connection methodology cannot fully eliminate the possibility of electric shock.

6.6.4.1 Minimum Necessary Equipment Requirements

PV modules

- IEC-EN 61215 *η* 61646,
- IEC 61730—Class A (with Class II insulation)

The above certificates must always be provided by accredited Laboratories

- Electronic converters

Assurance that they have protection against nisidopoiisis (anti-islanding) according VDE 0126-1-1 or equivalent method (type certificate by an independent laboratory)

- Protections of voltage and frequency limits (hypertension, hypotension, hyper frequency—hypo frequency)
- THD output current less than 5%, a certificate of manufacturer compliance (optional)

If the electronic converters do not have iron inverter then the maximum value of the infused DC current in the electrical network must be less the 0.5% of the value of the inverter's nominal output current, certificate of manufacturer compliance (optional).

6.6.4.2 Materials Recommendations

Materials used outdoors should be sunlight/UV resistant

Urethane sealants should be used for all non-flashed roof penetrations.

Materials should be designed to with stand the temperatures to which they are exposed.

Dissimilar metals (such as steel and aluminum) should be isolated from one another using non-conductive shims, washers, or other methods.

Aluminum should not be placed in direct contact with concrete materials.

Only high quality fasteners should be used (stainless steel is preferred).

Structural members should be either:

corrosion resistant aluminum, 6061 or 6063, hot dip galvanized steel per ASTM A 123, coated or painted steel (only in low corrosive environments such as deserts), stainless steel (particularly for corrosive marine environments)

6.6.4.3 Equipment Recommendations and Installation Methods

All electrical equipment should be listed for the voltage and current ratings necessary for the application.

PV modules should be listed to UL 1703 and warranted for a minimum of 5 years (20–25 year warranties are available).

Inverters should be listed to UL 1741 and warranted for a minimum of 5 years.

All exposed cables or conduits should be sunlight resistant.

All required over current protection should be included in the system and should be accessible for.

6.6.4.4 Maintenance

All electrical terminations should be fully tightened, secured, and strain relieved as appropriate.

All mounting equipment should be installed according to manufacturers' specifications.

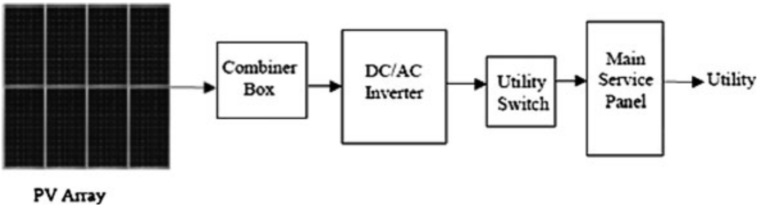


Fig. 6.8 Connection framework of a PV array

All roof penetrations should be sealed with an acceptable sealing method that does not adversely impact the roof warranty.

Integral roofing products should be properly rated (e.g., class A roofing materials).

All cables, conduit, exposed conductors and electrical boxes should be secured and supported according to code requirements.

PV Array should be free of shade between 9:00 a.m. and 4:00 p.m. This requirement includes even small obstructions such as vent pipes and chimneys. A small amount of shade can have a disproportionately high impact on system performance (Fig. 6.8).

6.7 PV Electric System Installation Checklist

6.7.1 *Before Starting Any PV System Testing: (Hard Hat and Eye Protection Recommended)*

1. Check that non-current carrying metal parts are grounded properly. (array frames, racks, metal boxes, etc. are connected to the grounding system)
2. Ensure that all labels and safety signs specified in the plans are in place.
3. Verify that all disconnect switches (from the main AC disconnect all the way through to the combiner fuse switches) are in the open position and tag each box with a warning sign to signify that work on the PV system is in progress.

6.7.2 *PV Array: General (Hard Hat, Gloves, and Eye Protection Recommended)*

1. Verify that all combiner fuses are removed and that no voltage is present at the output of the combiner box.
2. Visually inspect any plug and receptacle connectors between the modules and panels to ensure they are fully engaged.
3. Check that strain reliefs/cable clamps are properly installed on all cables and cords by pulling on cables to verify.

4. Check to make sure all panels are attached properly to their mounting brackets and nothing catches the eye as being abnormal or misaligned.
5. Visually inspect the array for cracked modules.
6. Check to see that all wiring is neat and well supported.

6.7.3 PV Array Circuit Wiring (Hard Hat and Eye Protection Recommended)

1. Check home run wires (from PV modules to combiner box) at DC string combiner box to ensure there is no voltage on them.
2. Recheck that fuses are removed and all switches are open.
3. Connect the home run wires to the DC string combiner box terminals in the proper order and make sure labeling is clearly visible.

6.7.4 Repetitive Source Circuit String Wiring (Hard Hat, Gloves, and Eye Protection Recommended)

The following procedure must be followed for each source circuit string in a systematic approach—i.e., east to west or north to south. Ideal testing conditions are midday on cloudless days March through October.

1. Check open-circuit voltage of each of the panels in the string being wired to verify that it provides the manufacturer's specified voltage in full sun. (Panels under the same sunlight conditions should have similar voltages—beware of a 20 V or more shift under the same sunlight conditions.)
2. Verify that the both the positive and negative string connectors are identified properly with permanent wire marking.
3. Repeat this sequence for all source circuit strings.

6.7.5 Continuation of PV Array Circuit Wiring (Hard Hat, Gloves, and Eye Protection Recommended)

1. Recheck that DC Disconnect switch is open and tag is still intact.
2. Verify polarity of each source circuit string in the DC String Combiner Box (place common lead on the negative grounding block and the positive on each string connection—pay particular attention to make sure there is NEVER a negative measurement). Verify open-circuit voltage is within proper range according to manufacturer's installation manual and number each string and

note string position on as-built drawing. (Voltages should match closely if sunlight is consistent.)

Warning: If polarity of one source circuit string is reversed, this can start a fire in the fuse block resulting in the destruction of the combiner box and possibly adjacent equipment reverse polarity on an inverter can also cause damage that is not covered under the equipment warranty.

3. Retighten all terminals in the DC String Combiner Box.
4. Verify that the only place where the AC neutral is grounded is at the main service panel.
5. Check the AC line voltage at main AC disconnect is within proper limits (115–125 V AC for 120 V and 230–250 for 240 V).
6. If installation contains additional AC disconnect switches repeat the step 11 voltage check on each switch working from the main service entrance to the inverter AC disconnect switch closing each switch after the test is made except for the final switch before the inverter (it is possible that the system only has a single AC switch).

6.7.6 Inverter Startup Tests (Hard Hat, Gloves, and Eye Protection Recommended)

1. Be sure that the inverter is off before proceeding with this section.
2. Test the continuity of all DC fuses to be installed in the DC string combiner box, install all string fuses, and close fused switches in combiner box.
3. Check open circuit voltage at DC disconnect switch to ensure it is within proper limits according to the manufacturer's installation manual.
4. If installation contains additional DC disconnect switches repeat the step of voltage check on each switch working from the PV array to the inverter DC disconnect switch closing each switch after the test is made except for the final switch before the inverter (it is possible that the system only has a single DC switch).
5. At this point consult the inverter manual and follow proper startup procedure (all power to the inverter should be off at this time).
6. Confirm that the inverter is operating and record the DC operating voltage in the following space.
7. Confirm that the operating voltage is within proper limits according to the manufacturer's installation manual.
8. After recording the operating voltage at the inverter close any open boxes related to the inverter system.
9. Confirm that the inverter is producing the expected power output on the supplied meter.
10. Provide the homeowner with the initial startup test report.

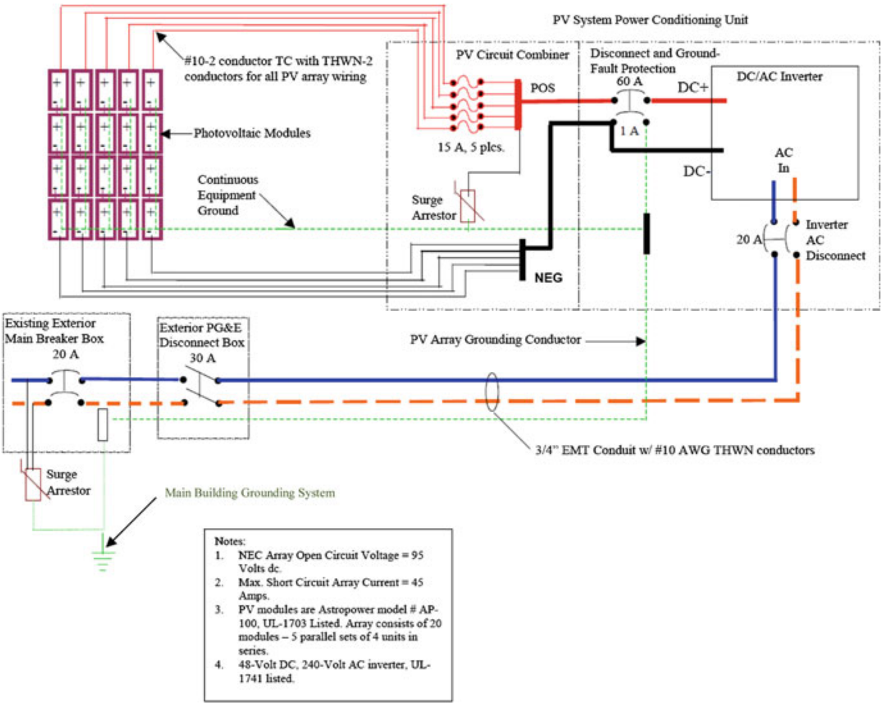
6.7.7 System Acceptance Test (Hard Hat and Eye Protection Recommended)

Ideal testing conditions are midday on cloudless days March through October. However, this test procedure accounts for less than ideal conditions and allows acceptance tests to be conducted on sunny winter days.

1. Check to make sure that the PV array is in full sun with no shading whatsoever. If it is impossible to find a time during the day when the whole array is in full sun, only that portion that is in full sun will be able to be accepted.
2. If the system is not operating, turn the system on and allow it to run for 15 min before taking any performance measurements.
3. Obtain solar irradiance measurement by one of two methods and record irradiance on this line: W/m^2. To obtain percentage of peak sun, divide irradiance by 1000 W/m^2 and record the value on this line. (Example: 692 W/m^2 $\div$ 1,000 W/m^2 $=$ 0.692 or 69.2%).

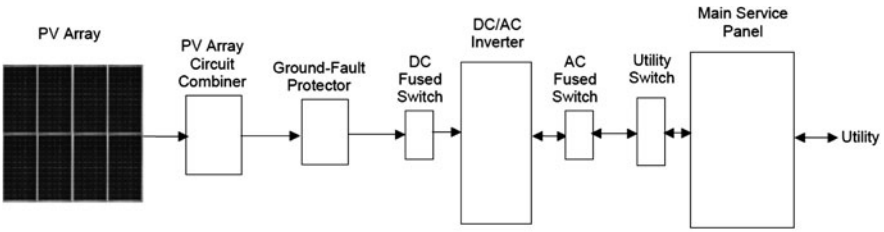
Method 1: Take measurement from calibrated solar meter or pyranometer.

Method 2: Place a single, properly operating PV module, of the same model found in the array, in full sun in the exact same orientation as the array being



Notes:
1. NEC Array Open Circuit Voltage = 95 Volts dc.
2. Max. Short Circuit Array Current = 45 Amps.
3. PV modules are Astropower model # AP-100, UL-1703 Listed. Array consists of 20 modules – 5 parallel sets of 4 units in series.
4. 48-Volt DC, 240-Volt AC inverter, UL-1741 listed.

Fig. 6.9 Electrical connection of a PV array



Notes:

1. PV Array contains five 48-Volt DC series strings of 100-Watt Modules (20-modules)
2. PV Array Circuit Combiner contains 15-Amp fuses rated at 125Vdc.
3. Ground-Fault Protection required only on roof-mounted PV arrays.
4. DC Fused Switch rated at 60-amps, 125-Vdc (may be circuit breaker)
5. DC/AC Inverter rated at 2 kW AC output at 240-Volts and is Listed to UL-1741 "Utility-Interactive"
6. AC Fused Switch rated at 30-amps, 240Vac (may be circuit breaker)
7. Utility Switch is visible open, lockable in open position, 240-Vac, 60-amp switch.
8. 100-Amp Main Service Panel with 20-Amp Two-Pole Circuit Breaker for Interactive Point of Connection (up to 3.5 kW, 240-Volt inverter)
9. Equipment ground equivalent to PV array conductor size on DC-side of system.
10. Equipment ground according to NEC Table 250-122 on AC-side.
11. Negative pole of PV array referenced to ground at the Inverter.

Fig. 6.10 PV array equipment connection

tested. After 15 min of full exposure, test the short circuit current with a digital multimeter and place that reading on this line: Amps. Divide this number into the short circuit current (Isc) value printed on the back of the PV module and multiply this number by 1,000 W/m^2 and record the value on the line above. (example: Isc-measured = 3.6 A; Isc-printed on module = 5.2 A; Irradiance = 3.6 A/5.2 A × 1,000 W/m^2 = 692 W/m^2).

4. Sum the total of the module ratings and place that total on this line Watts STC.
5. Multiply this number by 0.7 to obtain expected peak AC output and record on this line Watts AC-estimated.
6. Record AC Watt output from the inverter or system meter and record on this line Watts AC-measured.
7. Divide Watts AC-measured by percent peak irradiance and record on this line Watts AC-corrected. This "AC-corrected" value is the rated output of PV system. This number must be within 90% or higher of Watts AC-estimated recorded in step 4. If it is less than 90%, the PV system is either shaded, dirty, miswired, fuses are blown, or the modules or inverter are not operating properly (Figs. 6.9, 6.10).

6.8 Questions

1. Name the two types of electrical designs for PV power systems
2. What characteristics can be used to describe the typical electrical values of a PV system?

3. Briefly describe the major stages when selecting the placement area of the electronic converters.
4. Describe building protection of PV modules against high voltage and lightning strikes.
5. What steps may help the measures for the risk reduction of an electric shock during the installation of a PV system?
6. How do the geographical and temporal characteristics of
7. Give a brief description basic principles to follow when designing a quality PV system for industrial use
8. Identify the Factors Affecting Output
9. How can be implemented the placement of the PV modules in the building?
10. What steps should the installation of PV system?
11. Describe the grounding of inverter.
12. What includes the wiring's connections
13. Which are the mounting options?
14. How should mount the roof?
15. How can estimate the System Output?
16. Describe equipment recommendations and installation methods.
17. What is the "islet phenomenon"

Chapter 7
Installation of a 20 kW Grid-Connected PV System

Electricity generation from photovoltaic in Greece has been significantly increased in recent years. Legislations has been promoted for simplification of the licensing processes and development of PV systems. Greek government's target is to install at least 700 MWp by 2020. Within this framework, in July 2010 a new feed-in tariff system was launched in Greece, guarantying €0.40 to €0.50 per kWh for the next 20 years. Accompanied by a relaxation of the licensing procedure and the possibility for combination of these benefits with investment grants and subsidies between 30 and 55%, the payback time of PV investment becomes very interesting in this sunny country.

7.1 Greek Policy

According to law 3468/06, the photovoltaic stations under to 20 kWp have no need of any installation's permission paper from authorities. Photovoltaic stations must not install at the NATURA 2000' regions, National parks, traditional settlements and regions of archaeological interest.

An investment of this type is particularly attractive for companies that allocate unexploited spaces, suitable for PV systems installation as the roofs of stocking installations or factories. Installing a P/V System in an industry there will exist profits from the sale of electric power and also to present a friend-environmental profile.

The climatic change and the pollution of environment both constitute modern problems with frequent report in media. Consequently, the environmental action offers to companies the occasion to include the energies for the protection of climate and environment in their operational communications and to attract the interest of consumers and media.

E. V. M. Papadopoulou, *Photovoltaic Industrial Systems*,
Green Energy and Technology, DOI: 10.1007/978-3-642-16301-2_7,

7.1.1 Conditions of Space of Installation

- For an installation of 20 kWp are required about 300–500 m^2 of ground or 200 m^2 of gable or shed roof (e.g. industrial building) with southern orientation.
- The space of installation it should be the duration of time.
- In any case it is recommended is avoided the arrangement in:
- Regions Natura, Ramsar, aesthetic forests or even regions characterized as forests—to reject of need of publication of approval of forestall intervention, characterized traditional settlements etc.
- In archaeological interest regions.
- Near military regions.
- Far from the network (low tendency for up to 100 kWp) since the interconnection can be rendered time-consuming, costly and with unanticipated difficulties process.
- Rural ground characterized as "high productivity".
- Regions particularly tourist.

7.1.2 Cost of the PV Station

Indicatively, the cost of photovoltaic station is 6,000 €/kWp and includes:

- Basic equipment P/V generators, bases, cables etc.)
- Shipping cost.
- Plant layout, fencing etc.
- Connection cost (distance from the network: 50–100 m).
- Required studies.

The total cost of a photovoltaic station installation of 20 kWp, is 100,000 €.

7.1.3 Maintenance of a Photovoltaic Station: Cost

The only maintenance that has been required from a station is a periodical cleaning of surfaces of panels and of generators and the cost of insurance of station which however still has not been determined precisely in the Greek market.

7.1.4 Industry's Targets

7.1.4.1 Output

The medium annual production of electric energy from a P/V system is for Greek area 1,300 kWh/kWp, ±10% depending on the geographic width of region.

Consequently the annual production of energy will be:

$$20\,\text{kWp} \times \text{of } 1,300\,\text{kWh/kWp} = 26,000\,\text{kWh}$$

Faithfully yours sale 0.45 €/kWh for the grid on network (0.50 €/kWh for the grid of islands), the income that results per year are:

$\sim$ 11,700 € ($\sim$ 13.000 €) + VAT, before taxes and damping.

7.1.4.2 Form of Company

Any corporate form is suitable for an investment in PV station. It should it is stressed that the income of station, afterwards the damping and the expenses that are deducted, is taxed regularly, according to the factors that are in effect for the companies.

7.1.4.3 Getting the Most Out of Photovoltaic Power

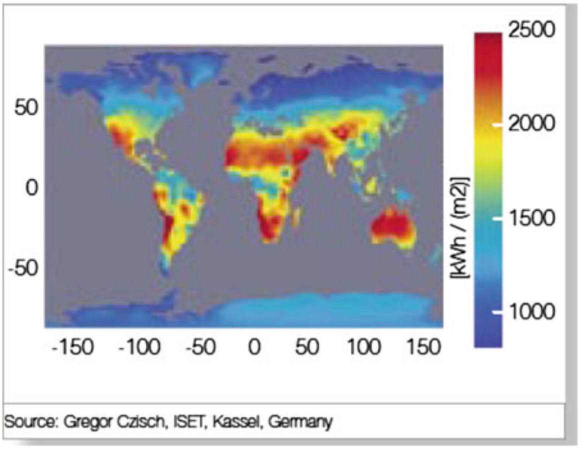
To get the most benefits from the installation of the PV system at the industrial buildings is to use the produced energy for lighting. The best results become if the lighting system is a LED lighting electricity system.

7.2 The Solar Radiation

To all practical effects, it is valid and it turns out useful to imagine that sun describes every day an arch on the celestial vault, from the rise up to the west, which length, elevation and duration throughout the time are different every day and in every geographical latitude of the planet (Fig. 7.1).

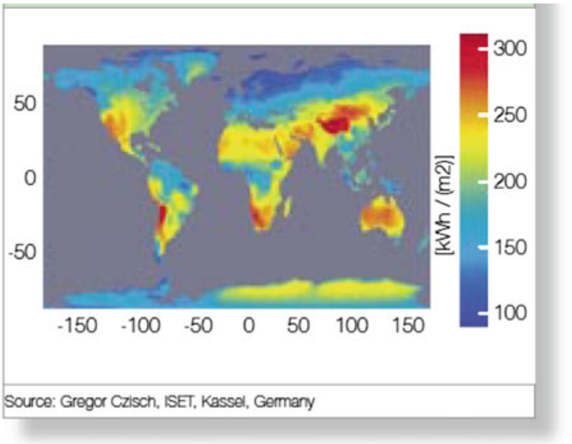
Sun position in every instant, seen from a certain place of the terrestrial surface, remains perfectly defined just knowing the value of two angular variables: the solar azimuth, Ψ, and the solar height, α. These two angles, which are referred to the straight line that joins the centre of the solar disc with the point in the terrestrial surface from which the observation is carried out, can be known accurately for every instant throughout the year depending on the geographical latitude (parallel of the place), using well-known formulae of Positioning Astronomy, which for major comfort are tabulated and also integrated as data in many computer programs. The interest of knowing the relative position of the sun-beam with regard to the horizontal soil is due to the fact that the energetic waves directly from the sun travel up to the terrestrial surface according to the direction of the above mentioned beam and, therefore, they affect on the soil (or another on flat surface arbitrary positioned as, for

Fig. 7.1 Global variations in irradiation



Source: Gregor Czisch, ISET, Kassel, Germany

Fig. 7.2 Energy potential from PV around the world



Source: Gregor Czisch, ISET, Kassel, Germany

example, a solar panel) forming an angle which value will concern the value of the intensity of the solar radiation on the surface in question (Fig. 7.2).

The position of a solar panel remains, likewise, perfectly determined just knowing also two angular values: the azimuth of the panel, γ (angle that forms the projection on the horizontal plane of the normal one to the surface of the panel with the local meridian), and the inclination, β, of the panel with regard to the horizontal plane.

The azimuth of the panel determines its orientation, being zero if it is orientated towards the equator which is the optimum in case of static systems.

The value of the duration of the day is used sometimes as estimation, in a comparative way, of the total irradiation that is necessary to wait to receive in 1 day with regard to other one of meteorological similar characteristics.

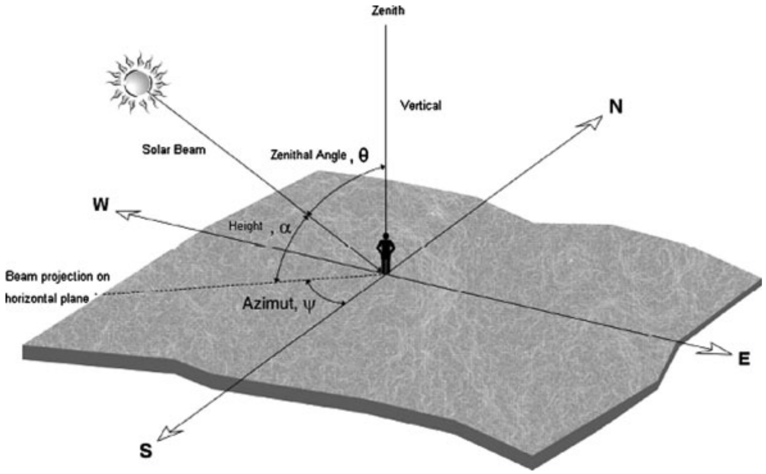


Fig. 7.3 Angles that define Sun position at any moment

For latitude of 40°, in the longest day of the year the sun shines for almost 15 h, whereas in the shortest day it hardly overcomes 9 h.

Nowadays there is information available of average irradiation on horizontally of many localities, which allow to establish a few generally enough trustworthy values on the quantity of solar power that it is possible to expect obtaining, as average, in every month of the year (Fig. 7.3).

From horizontal irradiation values it is possible to calculate the irradiation on a sloping surface using diverse models of temporary and spatial distribution of the solar radiation. Hereby, tables or algorithms easily adaptable to computer-programs can be obtained, showing the quantity of incidental solar power on the photovoltaic panels (generally orientated approximately towards the equator and with an angle of inclination determined).

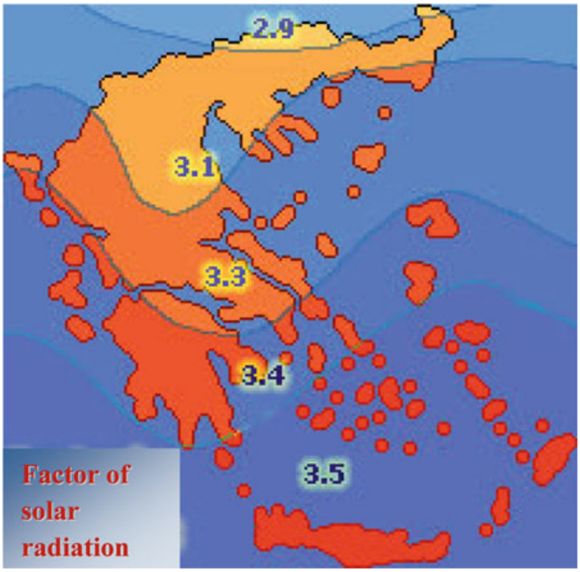
The above mentioned quantity evaluated month by month or for different epochs of the year, constitutes as we will see hereinafter the starting point for trustworthy design of the PV system.

7.3 System Description

Our 20 kW grid-connected system has been placed in Kozani, the capital of Kozani Prefecture (Western Macedonia, Greece) (Figs. 7.4, 7.5).

Fig. 7.4 Location of PV array installation

Fig. 7.5 Solar radiation in Greece



NASA surface meteorology and solar energy: Kozani area (Latitude 40.17/Longitude 21.47)

	Unit	Climate data location
Latitude	°N	40.17
Longitude	°E	21.47
Elevation	m	1,043
Heating design temperature	°C	−4.00
Cooling design temperature	°C	28.48
Earth temperature amplitude	°C	20.83
Frost days at site	day	70

Month	Air tempe-rature (°C)	Relative humidity (%)	Daily solar radiation—horizontal (kWh/m^2/d)	Atmospheric pressure (kPa)	Wind speed (m/s)	Earth tempe-rature (°C)	Heating degree-days (°C-days)	Cooling degree-days (°C-days)
January	1.3	77.5	1.94	94.2	3.4	0.8	511	0
February	2.2	72.9	2.68	94.1	3.5	2.3	441	0
March	5.5	67.3	3.77	94.0	3.3	6.5	382	9
April	10.5	59.2	4.53	93.8	3.0	12.1	224	47
May	16.3	51.2	5.44	93.9	2.8	18.6	72	191
June	21.0	44.9	6.64	93.9	2.6	23.9	8	318
July	23.8	40.2	6.62	93.9	2.8	27.0	0	417
August	23.6	41.5	5.82	94.0	2.9	26.4	0	415
September	19.1	48.6	4.49	94.1	2.8	21.2	21	271
October	13.4	60.2	3.07	94.3	3.0	14.3	145	124
November	7.1	74.3	1.99	94.2	3.3	7.0	322	18
December	2.3	78.9	1.55	94.2	3.6	1.8	483	0
Annual	12.2	59.7	4.05	94.1	3.1	13.5	2,609	1,810
Measured at (m)					10.0	0.0		

7.3.1 Electrical Diagram of the Grid-Connected PV System

The electrical diagram of grid-connected PV system under analysis is shown in Fig. 7.6.

7.3.2 Solar Array

The existing PV array is comprised of mono-crystalline silicon modules.

- E_r (kWh/day): required electrical energy

$$E_r = 14.5\,\mathrm{kWh/day}$$

- E_{sr} (kWh/m^2 * month): solar energy radiation

$$E_{sr} = 1.55 * 31 = 48.5\,\mathrm{kWh/m^2} * \text{month} \quad ή\, E_{sr} = 1.55\,\mathrm{kWh/m^2} * \text{day}$$

- $P_{p\Sigma}$ (kWp): power peak of PV array

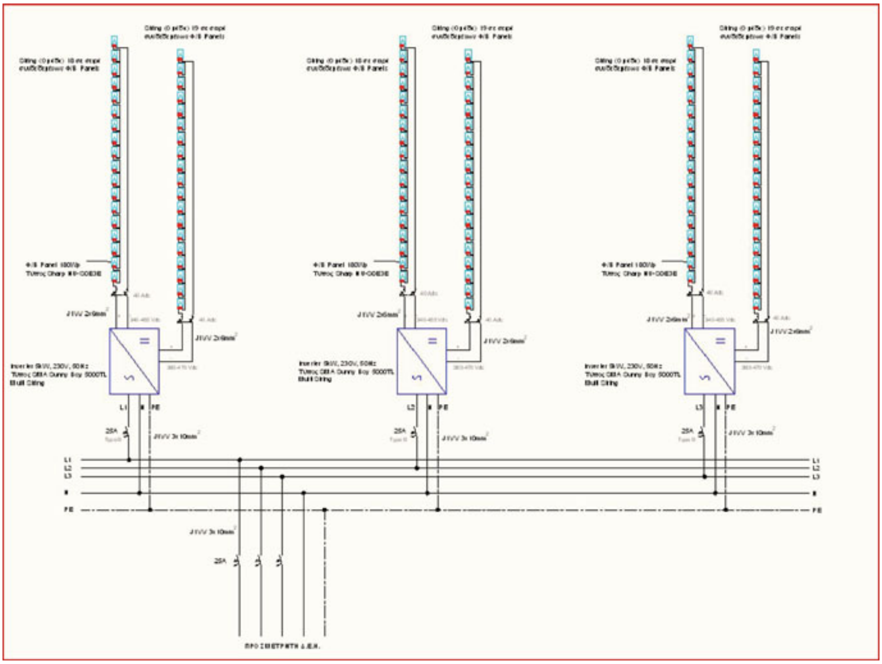


Fig. 7.6 Electrical diagram of the grid-connected PV system

$P_{\mathrm{STC}} = 1$ kW/m^2 (power of PV array on standard test conditions)
N: time period
n: number of sunny days
$m = 1.2$ (coefficient of energy request)
$\sigma_\mu = 0.92$ (coefficient of losses energy transport)
$\sigma_{\mathrm{A\Sigma}} = \sigma_\gamma \sigma_\rho \sigma_\theta \sigma_\delta \sigma_\alpha \sigma_\kappa = 0.65$ (coefficient of losses of PV array)

that:

σ_γ: factor of ageing (0.90)
σ_ρ: factor of pollution (0.80)
σ_θ: thermal factor with $\sigma_\theta = 1 - [(t_{\mathrm{a}} + 30) - 25] * 0.004 = 1 - [(12.2 + 30) - 25] * 0.004 = 0.93$
σ_δ: coefficient of losses of diode (0.99)
σ_α: inhomogeneousness factor (0.98)
σ_κ: wiring factor (0.98)

$\mathrm{E}\pi o\mu \acute{\varepsilon} \nu \omega \varsigma$:

$$P_{\mathrm{p\Sigma}} = \left[(E_{\mathrm{r}} * P_{\mathrm{STC}} * m)/(E_{\mathrm{sr}} * \sigma_{\mathrm{A\Sigma}} * \sigma_\mu)\right] * [N/(N-n)]\left\{\mathrm{kW_p}\right\} \approx 20\,\mathrm{kWp}$$

- Number of panels

  The panel's power is $P_{\mathrm{p\Pi}} = 185$ Wp

$$N = P_{\mathrm{p\Sigma}}/P_{\mathrm{p\Pi}} = 20{,}000/185 \approx 108 \ \text{panels}$$

- Link of PV array

  Max voltage $V_{\mathrm{m\Sigma}} = 235$ V
  Max voltage of the panel $V_{\mathrm{m\Pi}} = 30.2$ V
  Number of panel in parallel connection:

$$N_\sigma = V_{\mathrm{m\Sigma}}/V_{\mathrm{m\Pi}} = 8\,\text{panels}$$

Number of:

$$N_\pi = N/N_\sigma = 14\,\text{strings}$$

- DC-AC inverter with the following electrical characteristics

$$\text{Voltage input: } V_{\mathrm{INV}} = V_{\mathrm{m\Sigma}} = 235\,\mathrm{V}$$

$$\text{Voltage output: } V_{\Pi} = 1.73\,V_\varphi = 1.73 \, * \, 240 = 415\,\mathrm{V}.$$

The 108 panels of 185 Wp each one produce a total power capacity of 19.98 kWp. The solar installation is made up of three subarrays of 37 modules with 55° tilt (optimum for Kozani). Each subarray is arranged in two strings:

- String A: 18 modules connected in series
- String B: 18 modules connected in series

7.4 Grid-Connected Inverter

The grid-connected inverters used to convert DC power from PV subarray to AC power.

7.4.1 Inverter Sizing

During the design phase of 20 kW photovoltaic system, it was decided to allocate three inverters of 5 kW. It could seem that the system is under-sized from inverters point of view, because the sum of inverters capacity just provides 15 kW while the maximum generation capacity could reach to about 20 kW.

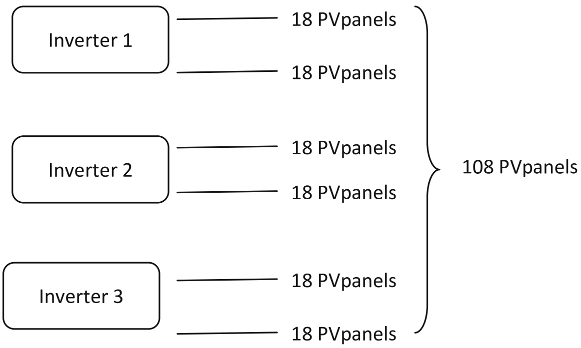
However, both general system design recommendations for grid-connected PV installations as well as particular previous studies focused on the north of Greece, lead to install inverters with a nominal capacity power considerably smaller than the PV array's nominal power, due to:

1. PV systems almost never have a direct current output equal to their nominal power, so inverters are usually sized with a nominal power some 25% below the PV array nominal power.
2. For partial loads under 20% of nominal power, state-of-the-art inverters operate at reduced peak efficiencies, needing loads over 30% of their nominal power to obtain acceptable efficiencies (as we have checked before in the present report). This means that oversized inverters (or excessively tighted to the array nominal power) might operate at low capacity levels for long periods of the day and therefore accumulate long intervals with performance levels below maximum.
3. Inverter sizing strategy followed during the design phase took into account site-dependent peculiarities previously analyzed, such as inverter operating temperature or solar irradiation distribution characteristics.

DC-AC (inverter):

$$\text{Input voltage: } V_{\text{INV}} = V_{\text{m}\Sigma} = 235\,\text{V}$$

Fig. 7.7 Three inverters connected with 108 PV panels



$$\text{Output voltage: } V_{\Pi} = 1.73\,V_{\varphi} = 1.73 * 240 = 415\,\text{V}$$

Voltage of opened circuit: $V_{\text{OCINV}} = k * N_{\sigma} * V_{\text{OC}\Pi} = 1.15 * 8 * 30.2 = 277.84\,\text{V}$, with $V_{\text{OC}\Pi}$ the voltage of opened circuit for each panel and k, the factor for the high (from the sea) of the installation's location ≤800 m.

$$\text{Output power: } P_{\text{INV}} = P_{\text{p}\Sigma}/1.3 = 20/1.3 = 15\ \text{kW}$$

Three inverters were employed, each one connected to a subarray (two strings), as shown in Fig. 7.7

Each inverter has two input areas, "String A" and "String B", each with their own MPP tracker. The inverter is designed for operation on 220–240 V grids at a grid frequency of 50 Hz.

The control of inverter operating function depends on the inverter itself. This means that the inverter will be turned on in the morning and will automatically synchronize to the electric grid. After being operative all day until the evening, it will just automatically shut down.

For the monitoring of the System, there exists a measurement device inside inverter which records all data related to system performance.

Thanks to this system of monitoring, we have compiled info of the PV installation during 6 months, time enough to draw conclusions after a detailed analysis on data available.

7.5 Inverters Efficiency

This section is intended to establish the conversion efficiency of the system inverters between the DC source (PV) input and the AC output. The series of analysis described in this section will characterize the unit's performance and efficiency as a function of array power.

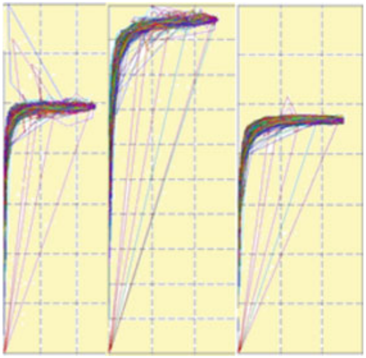


Fig. 7.8 Output power versus efficiency, for every available data per day

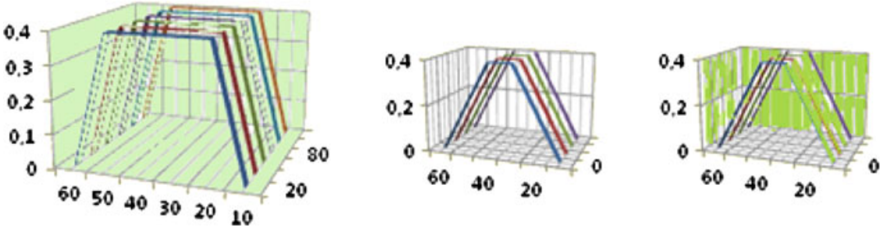


Fig. 7.9 3-D output power versus efficiency, for every available data per day

7.5.1 First Approach

The first approach to system consists on the graphical representation of inverters efficiency as a function of output power, for every available day (Fig. 7.8).

From Fig. 7.9 we can note at first sight how efficiency curves are, approximately, for every inverter. In mentioned figure, efficiency curve for every available day have been overprinted. To have a more clear view of the same graphic, plot it in a 3-D graphic, including in a new axis indicating the sequence of days.

In this point we can check that there are some punctual "erroneous data" due to operating failures of the system (inverter shutdown, grid disturbances, etc.).

7.5.2 Measurements

In order to have a global vision of the energy generated per day and per inverter, let's have a look at the next figure.

In Fig. 7.10 we can check that the energy generated per inverter is normally the same for the three inverters for a given day, even if this generation varies significantly depending on the period of the year (irradiance, temperature, sky clearness, etc.). So as it was predictable during March (first days of the graph) the production is lower than during summer months (about the range of days [30–80]).

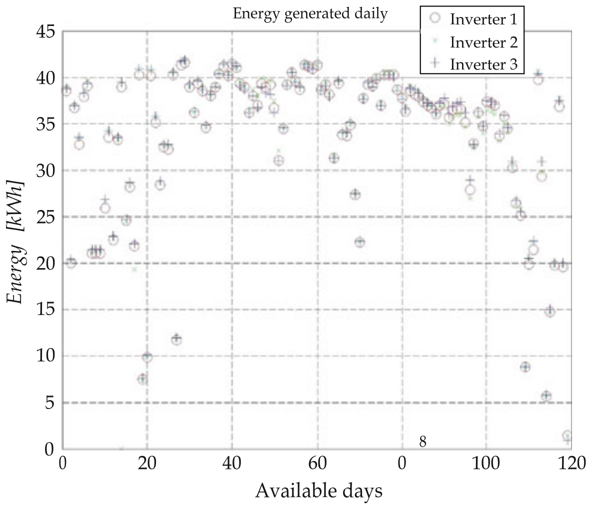


Fig. 7.10 Sequence of energy generated per available data day per inverter

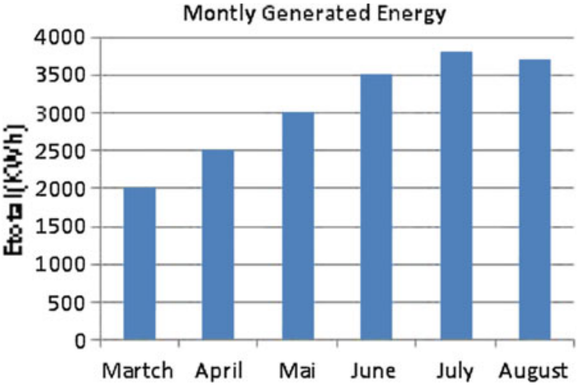


Fig. 7.11 Total energy generated per month

In previous figure we can check how the global energy production of our system gets to its maximum during sunny and sky-cleared months (May, June, July and August), meanwhile decreases significantly during the beginning of spring and beginning of autumn (March and September). During the month of April, measurements could not be collected (Fig. 7.11).

Considering individually the production of energy generated by each inverter, we can verify that the contribution of each inverter is similar every month, getting to maximum values during the mentioned sunny and sky-cleared months, as can be checked in next figure (Figs. 7.12, 7.13).

From figures shown above and according with all the results obtained till now, we can say that, even if the panels associated to each inverter string and their efficiencies vary from one to another, when talking about energy generation every inverter behaves in a very similar way.

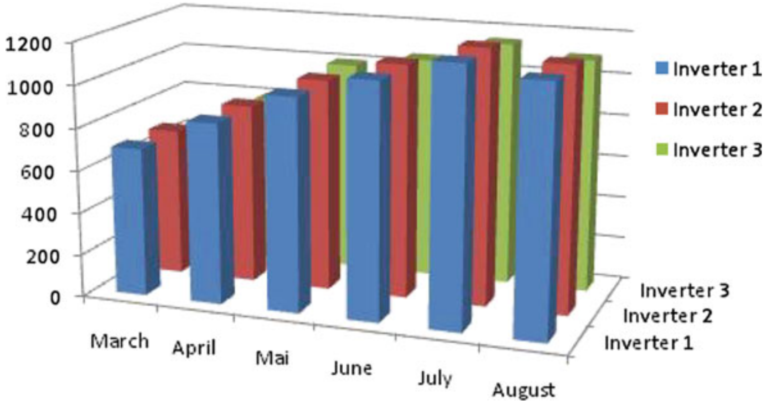


Fig. 7.12 Energy generated per month per inverter

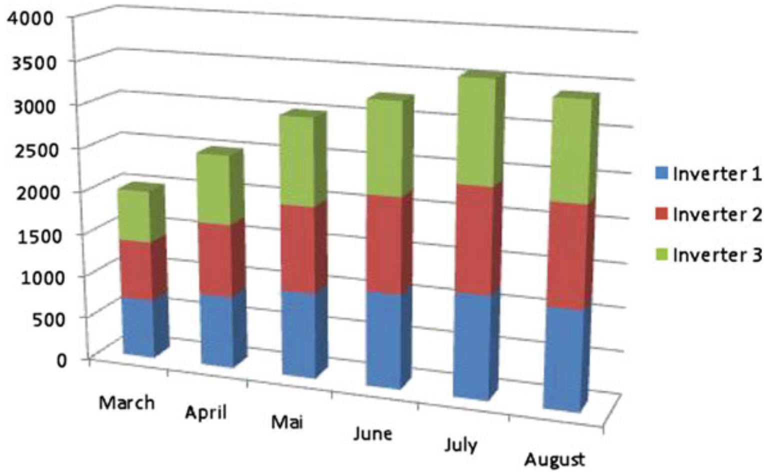


Fig. 7.13 Total energy generated by global system

To be more precise about how this energy distribution is as symmetrical as desired, we show in next pie diagram the percentage of global energy generation produced by each one of the inverters monthly, illustrating how energy generation is equally distributed amongst inverters (Fig. 7.14).

7.6 Conclusions

The placement of the installation in Kozani has turned out to be one of the most favorable places for solar production all over north of Greece, thanks to special irradiation conditions present in the area.

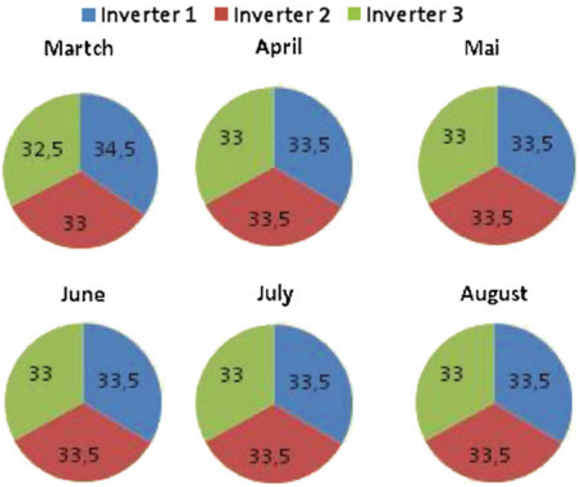


Fig. 7.14 Percentage of energy generated per month per inverter (regarding the whole system)

Beyond our particular system, results obtained throughout this case study are positive for the whole future of PV industry in Greece, especially now that Greece's Parliament has approved (15 January 2009 and 10 July 2010) Europe's most generous PV incentive program after a moratorium of almost 2 years. So results obtained in Kozani can be extrapolated (making always the required particular analysis) to other placements in Greece, as long as PV's potential and development in this sunny country has been shown.

Additionally, the actual international context in Europe makes Greek's situation even more encouraging. In 2008, the most important European PV markets (Germany, Spain, Italy, France and the newcomer Greece) registered a newly installed PV capacity of more than 3 GW. However, within the last years the situations has changed profoundly:

The number of market players in the PV business has been increased significantly, so promotions caps now control market growth.

On the other hand, regression rates of feed-in tariffs have been significantly elevated (especially in Germany).

Against this background, important indicators reveal that Greece can be expected to be in few years the next major photovoltaic market in Europe.

7.7 Questions

1. What characteristics can be used to describe a PV system?
2. Define a PV system and indicate how it is calculated.
3. Briefly describe the major stages in the evolution of PV system.

Appendices

Energy Savings

According to the Greek Department of Energy, 22% of electricity used in the Greece powers lighting. In a world with soaring energy prices based on the availability and control of fossil fuels, and with growing concern about sustainability of the environment, a revolution in lighting is long overdue.

Lighting uses more energy than cooling in the building's sector. This emphasizes the importance of breakthrough lighting technologies.

According to the European Department of Energy, in the next 20 years, the application of LED lighting in the European Union will change the followings:

- Reduce electricity demands from lighting by 62%
- Eliminate 258 million metric tons of carbon emissions
- Avoid building 133 new power plants
- Anticipate financial savings that could exceed 115 billion euro

Many indoor applications, especially residential and hospitality settings require a "warm" white light, instead of the cool or blue white light historically associated with fluorescent lights and with many LEDs.

Recent advances in LED technology have made possible high-efficiency, high-brightness LEDs that are available in a full range of warm and neutral white colors. These advances can allow lighting solutions providers to bring new products to market, helping meet consumers' demands for soft, warm-white light in indoor applications.

The long service life and efficiency of LED lighting delivers significant benefits for indoor applications, especially those currently using incandescent bulbs. Current-generation LEDs deliver approximately five times the efficiency of many incandescent bulbs, and effective light fixture design can improve these gains even further.

Since LEDs generate less heat than most light sources, and since the heat generated is not radiated into the work or living space as it is with light bulbs, LEDs can also reduce the load on air conditioning systems and hence reduce the electricity used to cool the area.

Industrial Lighting

Industrial Lighting represents an attractive application for LED lighting due to several factors:

- Large number of industrial lights.
- High maintenance costs due to height and location.
- Growing community pressure to implement; "full cut-off" solutions to minimize glare and light pollution.
- Desire for white light.

LED Industrial Lighting is now available from a variety of vendors and offer many advantages over traditional Industrial Lighting technologies.

- Long lifetimes and highly reliable service, greatly reducing maintenance costs.
- Highly efficient light source potentially reducing electricity consumption by up to 50% or more.
- White light available in color temperatures from "warm" to "cool" with high CRI providing high-quality white light.

Questionnaire

QUESTIONNAIRE ABOUT ENERGY POLICY AND PV SYSTEM IN INDUSTRIES

General elements

A. Name of Enterprise: ______________________________

Address: ______________________________

Telephone: ______________________________ Fax: ______________________________

E- mail: ______________________________

Legal Form: ______________________________ Number of employees: ______________________________

V. Full name of Author of Questionnaire: ______________________________

Attribute/Place: ______________________________

G. Sectors of Activity of Enterprise:

(You can you mark more from one answers.)

1. Offer of Services ☐
2. Sales ☐
3. Service ☐
4. Production ☐
5. Education ☐
6. Other activity ☐

You reported the precise activity of your enterprise:

____

____

Saving of energy

1. Do you consider important the subjects of saving energy?

$1^{ης}$ priority ☐

$2^{ης}$ priority ☐ after ....

$3^{ης}$ priority ☐ after .... before ....

Low priority ☐

2. If yes, for what reason do you think so?

Climate change ☐

Pollution ☐

Economy ☐

Marketing ☐

Quality of life ☐

3. Do you consider that you will have economy benefits applying energy management?;

YES ☐ NO ☐

4. Do you apply an energy management programme in your industry?

YES ☐ NO ☐

5. Does fuel's consumption is the first priority for your industry?

YES ☐ NO ☐

6. Which methods do you apply to make better the energy efficiency in your industry?

Saving energy from building's material (insulation, double crystal, etc) ☐

Replacement lamps with high power led ☐

Installation of roof fans ☐

Installation of solar thermal energy system ☐

Installation of photovoltaic system ☐

Wind energy ☐

Geothermal energy ☐

Automatic energy management system ☐

Other……………………………………………………………………

7. What kind of lamp has been used?

Conventional lamp ☐
Energy saving lamp ☐
Led ☐
High Power Led ☐

8. Which parameters are most important for energy saving?

Technical parameters ☐
Tax free parameters ☐
Subsidy ☐
Economical parameters ☐
Other ☐

9. Do you know the improvement possibilities of energy saving for your industry?

YES ☐ NO ☐

10. Have you energy manager;

YES ☐ NO ☐

11. Are you used to inform your employers about energy saving?

YES ☐ NO ☐

12. When you buy new equipment do you give the main important to energy consumption?

YES ☐ NO ☐

13. Do you spend any amount from annual budget for energy saving?

YES ☐ NO ☐

14. Is your industry certified for Eco Management Audit Scheme?

YES ☐ NO ☐

15. Is your industry certified for ISO-14001?

YES ☐ NO ☐

16. What is your industry energy consumption to kWh?

……………………………………………………………………………………………………

17. What kind of annual budget do you spend for energy bills?

……………………………………………………………………………………………………

18. Have you any energy consultant?

YES ☐ NO ☐

PV SYSTEM

1. Have you install any PV System at your industry?

YES ☐ NO ☐

2. If yes, please describe the installation

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

3. Year of PV System installation

……………………………………………………………………………………………………

4. Power of PV System

……………………………………………………………………………………………………

5. Cost of installation

……………………………………………………………………………………………………

6. Maintenance annual cost

……………………………………………………………………………………………….

7. Type of the PV System

……………………………………………………………………………………………….

……………………………………………………………………………………………….

……………………………………………………………………………………………….

……………………………………………………………………………………………….

8. Amount of energy saving

……………………………………………………………………………………………….

9. Consumption before the installation of the PV System

……………………………………………………………………………………………….

10. Consumption after the installation of the PV System

……………………………………………………………………………………………….

11. Time of pay-back

……………………………………………………………………………………………….

12. Profits for your company from the installation of the PV System

……………………………………………………………………………………………….

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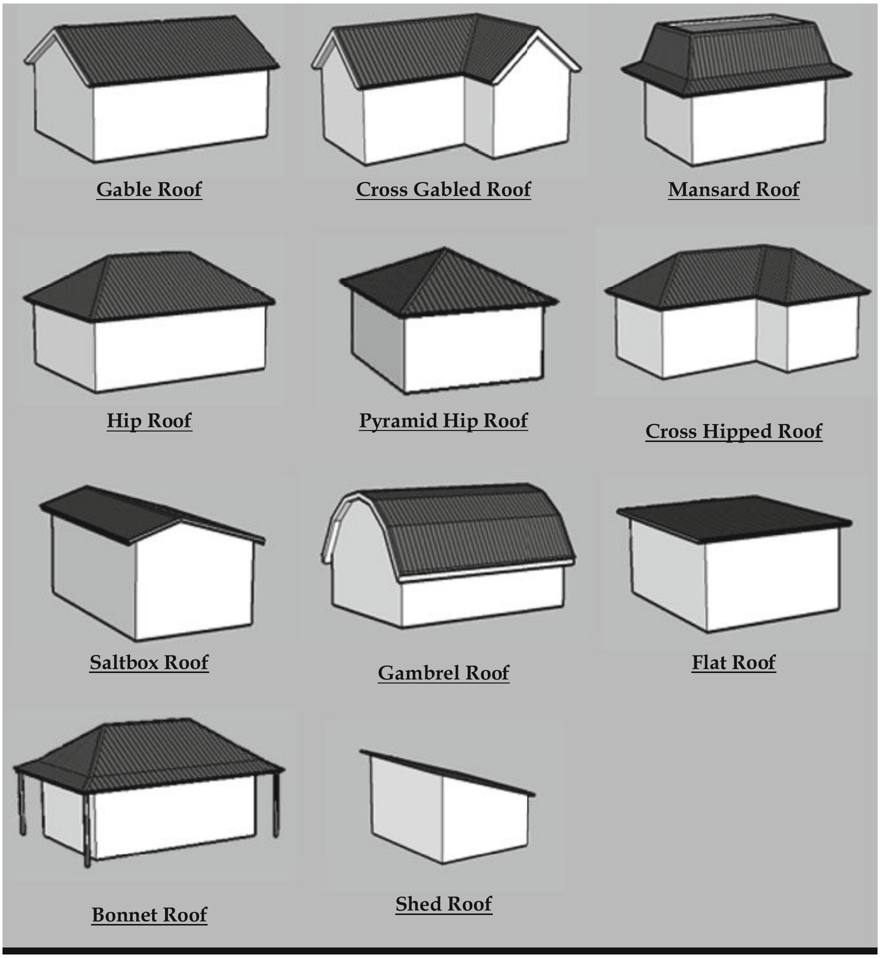
……………………………………………………………………………………………….

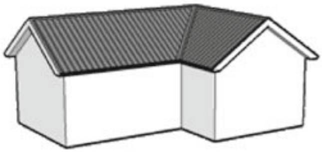
Roof Types



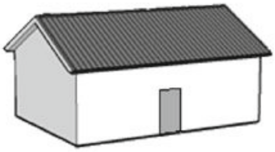
The Gable roof is one of the most popular choices when deciding a style of roof for your home. It has two roof surfaces of the same size, that are pitched at the same angle back to back, making a ridge at the top and forming a triangular roof. Its simple design makes it cheap and easy to build. It effectively sheds water, allows for good ventilation, and typically provides the most ceiling space.

The Gable roof is not ideal for high wind areas like the hip roof and is the most likely of roof types to suffer damage, usually with the end wall collapsing due to it not being properly braced.

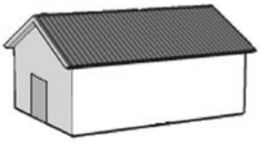
Common Variations of Gable Roofs:



Cross Gabled Roof



Side Gable Roof



Front Gable Roof

Dutch Gable (Hip) Roof

- Front gable roof: The gable end is placed at the front (entrance) of the house. Often used for Cape Cod and Colonial style houses.
- Side gable roof: One of the most common roofing styles because of its economy.
- Cross gabled roof: Simply two gable roof sections put together at a right angle. The two ridges formed by these gable roofs are typically perpendicular to each other. Lengths, pitches, and heights may or may not defer from each other. Often used for Tudor and Cape Cod style houses.
- Dutch gable: A hybrid type of gable and hip roof where a full or partial gable is located at the end of a ridge offering more internal roof space and/or increased aesthetic appeal.

The Mansard roof gets its name from architect Francois Mansart who popularized it in the 1600s in France. A mansard roof has two distinctly different slopes on each side. The lower portion of the roof has a very steep pitch often with dormers attached, while the upper portion has a low slope, just enough for water runoff to occur. Typically speaking the low slope portion of the roof cannot be seen from ground.

Mansard roofs offer so much attic space it is often used as an extra story for the house with the additional space known as “the garret”. This type of roof is not recommended for areas that have a great deal of snowfall. Heavy snow build up could occur on the low slope portion of the roof placing undo strain on the bracing.

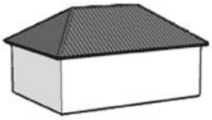
Buildings with Mansard roofs (sometimes referred to as Second Empire) enjoyed a popularity in North America in the mid to late 1800s as a part of Victorian style architecture.

A very common roof type the hip roof (or hipped roof) does not have flat sides like the gable roof instead all sides of the roof slope down to meet the walls of the house. Building a hip roof is more involved than a gable roof but building the walls for such a house is actually easier as they are all the same height.

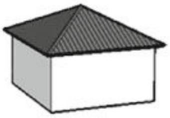
Hip roofs are very good for homes in high wind or hurricane areas as they offer better internal bracing and are less likely to be peeled from the house as a gable end. Given the roof is at a uniform height gutters can be easily attached around the entire house. Also, the roof protects more of the house from elements such as sun, wind and rain which over time can require increased maintenance for the structure.

Hip roofs offer less internal roof space making access for maintenance more difficult and offering less potential storage space. Cross hipped (and more complex hip roofs) need to have their valleys kept free from debris so that moisture and dirt don't cause a failure of the valley flashing.

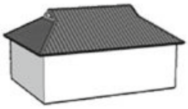
Common Variations of Hip Roofs:



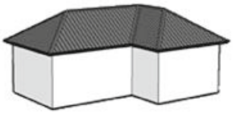
Simple Hip Roof



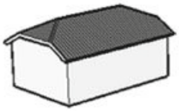
Pyramid Hip Roof



Dutch Gable (Hip) Roof



Cross Hipped Roof



Half Hipped Roof

- Simple hip roof: The most common hip roof has a ridge over a portion the roof creating two polygon sides and two triangle sides of the roof.
- Pyramid hip roof: Four equal triangular sides meet at a single point at the top of the roof.
- Cross hipped roof: Similar to putting two hipped roof buildings together. Where the two roof sections meet forms a seam called a valley.
- Half hipped roof: A standard hip roof that has had two sides shortened to create eaves.
- Dutch gable: A hybrid type of gable and hip roof where a full or partial gable is located at the end of a ridge offering more internal roof space and/or increased aesthetic appeal.

Most similar to a gable roof, the saltbox style rose from a need to create more space for cramped colonial houses. Early Americans looking for an efficient way to add space to a home soon realized that adding a one story lean-to (or shed roof) to the back of a one and a half or two story house saved materials and cost. The earliest examples of saltbox houses will sometimes show evidence of the addition by having a second "lean-to chimney/fireplace" or by changing the roof line (slope) on the addition to allow enough height for a useable ceiling. Eventually, the addition became so commonplace the lean-to was simply added into the original design of the house.

Saltbox houses were a variation of the early Colonial or Cape Cod style and were particularly popular during the late 1600s and into the early 1800s. The name saltbox was taken from the building's similarity in shape to wooden lidded boxes commonly used to hold salt at the time.

John Quincy Adams, the sixth President of the United States was born in a saltbox house that remains standing to this day.

The Gambrel roof, like the mansard roof, has two distinctly different slopes on each of its two symmetrical sides. The bottom slope has a steep pitch, sometimes nearly vertical while the top slope is lower. But unlike the mansard roof, the gambrel roof only utilizes this method on two sides of the structure rather than four.

The gambrel is often referred to as a barn roof; in that it is commonly seen on many hay barns for the ample space it provides for storage. Small structural additions called dormers may also be seen on gambrel roofs as to provide more head space or extra lighting. This allows for the extra space found in gambrel roofs to be used more effectively.

You can find gambrel roofs on a lot of Dutch Colonial architecture from the 1700s and into the 1800s. The name derives from gamba, a Latin word meaning the leg or hoof of an animal.

Flat roofs usually have at least a slight slope to assist in the shedding of water thus they are also referred to as "low slope roofs". Flat roofs are typically a more economical roof to build given that it requires less material. While being cheaper to initially build a flat roof will require re-roofing more often with many materials lasting 10–20 years versus 25–50 years for many pitched roof materials.

Flat roofs are susceptible to failure if pooled water is left for long periods of time. Most recent flat roofs are covered by a continuous membrane to help prevent such water pooling. Still, flat roofs are not an ideal choice for areas that get a lot of rain and/or snow.

The most common flat roof materials are:
Roll Roofing
Built-up roof/ Tar and Gravel
Modified Bitumen
Rubber Membrane
Metal Sheets
Green Roofs

Flat roofs have traditionally been very popular in dry climates including the Southwestern portion of the United States.

Bonnet, one of the least common roofs, could be considered a modified hip roof style. Usually found in French Vernacular architecture bonnet roofs have two slopes on all four sides of a structure. It is essentially the opposite a mansard roof in that its upper slope is steeper than the bottom slope. The bottom slope often hangs over the house to cover an open sided porch and provide shelter from the sun or rain.

Bonnet roofs are sometimes referred to as “kicked eaves” roof. Kicked eaves are considered a “roof enhancement” creating a visor effect to the house.

A shed roof (often called a lean-to) is typically a single roof face that slopes down the entirety of the structure or structure addition. It is a generally the cheapest and easiest roof to build. This roof type is associated with home additions, sheds, and porches. Porches may have open sides, whereas home additions and sheds will usually be fully enclosed.

When used as an addition to a structure, the roof will typically be attached to the building wall on the high side as a lean to. Sheds may also be attached to the house, or may stand alone, and are normally used as a workshop, or for storage.

A shed roof addition coupled with a Cape Cod styled house was used to create the saltbox roof during Colonial America.

Glossary

A

Absorption Coefficient The factor by which photons are absorbed as they travel a unit distance through a material.

Activated Shelf Life The period of time, at a specified temperature, that a charged battery can be stored before its capacity falls to an unusable level.

AIC Amperage interrupts capability. DC fuses should be rated with a sufficient AIC to interrupt the highest possible current.

Alternating Current Electric current in which the direction of flow is reversed at frequent intervals.

AM Air mass; The ratio of the mass of atmosphere in the actual observer-sun path to the mass that would exist if the observer was at sea level, at standard barometric pressure, and the sun was directly overhead. AM0 corresponds to the solar spectrum in outer space, and the reference spectrum for STC was defined to be AM1.5.

Air Mass Approximately equal to the secant of the zenith angle—that angle from directly overhead to a line intersecting the sun. The air mass is an indication of the length of the path solar radiation travels through the atmosphere. An air mass of 1.0 means the sun is directly overhead and the radiation travels through one atmosphere (thickness).

Alternating Current (AC) An electric current that reverses direction periodically.

Ambient Temperature The temperature of the surrounding area.

Amorphous Semiconductor A non-crystalline semiconductor material that has no long-range order.

Amorphous Silicon A thin-film PV silicon cell having no crystalline structure. Manufactured by depositing layers of doped silicon on a substrate.

Ampere (Å) Unit of electric current. The rate of flow of electrons in a conductor equal to 1 C/s.

Ampere-Hour (Ah) The quantity of electrical energy equal to the flow of current of 1 Å for 1 h. The term is used to quantify the energy stored in a battery.

Angle of Incidence The angle that a light ray striking a surface makes with a line perpendicular to the surface.

Anode The positive electrode in an electrochemical cell (battery). Also, the earth ground in a cathodic protection system. Also, the positive terminal of a diode.

Antireflection Coating A thin coating of a material, which reduces the light reflection and increases light transmission, applied to a photovoltaic cell surface.

Array A collection of electrically connected photovoltaic (PV) modules.

Array Current The electrical current produced by a PV array when it is exposed to sunlight.

Array Operating Voltage The voltage produced by a PV array when exposed to sunlight and connected to a load.

Availability The quality or condition of a PV system being available to provide power to a load. Usually measured in hours per year. One minus availability equals downtime.

Azimuth Horizontal angle measured clockwise from true north; 180° is true south.

B

Base Load The average amount of electric power that a utility must supply in any period.

Battery A device that converts the chemical energy contained in its active materials directly into electrical energy by means of an electrochemical oxidation–reduction (redox) reaction.

Battery Capacity The total number of ampere-hours that can be withdrawn from a fully charged battery.

Battery Cell The smallest unit or section of a battery that can store electrical energy and is capable of furnishing a current to an external load. For lead-acid batteries the voltage of a cell (fully charged) is about 2.2 V DC.

Battery Cycle Life The number of times a battery can be discharged and recharged before failing. Battery manufacturers specify Cycle Life as a function of discharge rate and temperature.

Battery Self-Discharge Loss of energy by a battery that is not under load.

Battery State of Charge (SOC) Percentage of full charge or 100 percent minus the depth of discharge. See Depth of Discharge.

Battery Terminology

Captive Electrolyte Battery A battery having an immobilized electrolyte (gelled or absorbed in a material).

Deep-Cycle Battery A battery with large plates that can withstand many discharges to a low SOC.

Lead-Acid Battery A general category that includes batteries with plates made of pure lead, lead–antimony, or lead–calcium immersed in an acid electrolyte.

Liquid Electrolyte Battery A battery containing a liquid solution of acid and water. Distilled water may be added to these batteries to replenish the electrolyte as necessary. Also called a flooded battery because the plates are covered with the electrolyte.

Nickel Cadmium Battery A battery containing nickel and cadmium plates and an alkaline electrolyte.

Sealed Battery A battery with a captive electrolyte and a resealing vent cap, also called a valve-regulated battery. Electrolyte cannot be added.

Shallow-Cycle Battery A battery with small plates that cannot withstand many discharges to a low SOC.

BIPV Building Integrated Photovoltaic A term for the design and integration of PV into the building envelope, typically replacing conventional building materials. This integration may be in vertical facades, replacing view glass, spandrel glass, or other facade material; into semitransparent skylight systems; into roofing systems, into shading "eyebrows" over windows; or other building envelope systems.

Blocking Diode A diode used to restrict or block reverse current from flowing backward through a module. Alternatively, diode connected in series to a PV string; it protects its modules from a reverse power flow and, thus, against the risk of thermal destruction of solar cells. A diode used to prevent undesired current flow. In a PV array the diode is used to prevent current flow towards a failed module or from the battery to the PV array during periods of darkness or low current production.

Bypass Diode A diode connected across one or more solar cells in a photovoltaic module such that the diode will conduct if the cell(s) become reverse biased. Alternatively, diode connected anti-parallel across a part of the solar cells of a PV module. It protects these solar cells from thermal destruction in case of total or partial shading of individual solar cells while other cells are exposed to full light.

British Thermal Unit (Btu) The quantity of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit. 1 kw/m^2 Ê 317 BTU/ft^2 hour.

C

Cadmium Telluride (CdTe) A polycrystalline thin-film photovoltaic material.

Capacity The total number of ampere-hours that can be withdrawn from a fully charged battery at a specified discharge rate and temperature.

Cathode The negative electrode in an electrochemical cell. Also, the negative terminal of a diode.

Cathodic Protection A method of preventing oxidation (rusting) of exposed metal structures, such as bridges and pipelines, by imposing between the structure and the ground a small electrical voltage that opposes the flow of electrons and that is greater than the voltage present during oxidation.

Charge The process of adding electrical energy to a battery.

Charge Controller A device that controls the charging rate and/or state of charge for batteries.

Charge Controller Terminology

Activation Voltage(s) The voltage(s) at which the controller will take action to protect the batteries.

Adjustable Set Point A feature allowing the user to adjust the voltage levels at which the controller will become active.

High Voltage Disconnect The voltage at which the charge controller will disconnect the array from the batteries to prevent overcharging.

High Voltage Disconnect Hysteresis The voltage difference between the high voltage disconnect setpoint and the voltage at which the full PV array current will be reapplied.

Low Voltage Disconnect The voltage at which the charge controller will disconnect the load from the batteries to prevent over-discharging.

Low Voltage Disconnect Hysteresis The voltage difference between the low voltage disconnect setpoint and the voltage at which the load will be reconnected.

Low Voltage Warning A warning buzzer or light that indicates the low battery voltage setpoint has been reached.

Maximum Power Tracking or Peak Power Tracking Operating the array at the peak power point of the array's I-V curve where maximum power is obtained.

Multi-stage Controller Unit that allows different charging currents as the battery nears full SOC.

Reverse Current Protection Any method of preventing unwanted current flow from the battery to the PV array (usually at night). See Blocking Diode.

Series Controller A controller that interrupts the charging current by open-circuiting the PV array. The control element is in series with the PV array and battery.

Shunt Controller A controller that redirects or shunts the charging current away from the battery. The controller requires a large heat sink to dissipate the current from the short-circuited PV array. Most shunt controllers are for smaller systems producing 30 Å or less.

Single-Stage Controller A unit that redirects all charging current as the battery nears full SOC.

Tare Loss Loss caused by the controller. One minus tare loss, expressed as a percentage, is equal to the controller efficiency.

Temperature Compensation A circuit that adjusts the charge controller activation points depending on battery temperature. This feature is recommended if the battery temperature is expected to vary more than ±5°C from ambient temperature. The temperature coefficient for lead acid batteries is typically −3 to −5 mV/°C per cell.

Charge Factor A number representing the time in hours during which a battery can be charged at a constant current without damage to the battery. Usually expressed in relation to the total battery capacity, i.e., C/5 indicates a charge factor of 5 h. Related to Charge Rate.

Charge Rate The current used to recharge a battery. Normally expressed as a percentage of total battery capacity. For instance, C/5 indicates a charging current equal to one-fifth of the battery's capacity.

Chemical Vapour Deposition A method of depositing thin semiconductor films. With this method, a substrate is exposed to one or more vaporized compounds, one or more of which contain desirable constituents. A chemical reaction is initiated, at or near the substrate surface, to produce the desired material that will condense on the substrate.

CIS Copper-Indium-Diselelide.

Cloud Enhancement The increase in solar intensity caused by reflected irradiance from nearby clouds.

Concentrator A photovoltaic module that uses optical elements to increase the amount of sunlight incident on a PV cell.

Conversion Efficiency The ratio of the electrical energy produced by a photovoltaic cell to the solar energy impinging on the cell.

Converter A unit that converts a DC voltage to another DC voltage.

Crystalline Silicon A type of PV cell made from a single crystal or polycrystalline slice of silicon.

Current (Amperes, Amps, Å) The flow of electric charge in a conductor between two points having a difference in potential (voltage).

Cutoff Voltage The voltage levels (activation) at which the charge controller disconnects the array from the battery or the load from the battery.

Cycle The discharge and subsequent charge of a battery.

Czochralski Process A method of growing large size, high quality semiconductor crystal by slowly lifting a seed crystal from a molten bath of the material under careful cooling conditions.

D

Days of Storage The number of consecutive days the stand-alone system will meet a defined load without solar energy input. This term is related to system availability.

DC to DC Converter Electronic circuit to convert DC voltages (e.g., PV module voltage) into other levels (e.g., load voltage). Can be part of a maximum power point tracker (MPPT).

Deep Cycle Type of battery that can be discharged to a large fraction of capacity many times without damaging the battery.

Design Month The month having the combination of insolation and load that requires the maximum energy from the array.

Depth of Discharge (DOD) The percent of the rated battery capacity that has been withdrawn.

Diffuse Radiation Radiation received from the sun after reflection and scattering by the atmosphere and ground.

Diode Electronic component that allows current flow in one direction only.

Direct Beam Radiation Radiation received by direct solar rays. Measured by a pyrheliometer with a solar aperture of 5.7° to transcribe the solar disc.

Direct Current Electric current flowing in only one direction.

Discharge The withdrawal of electrical energy from a battery.

Discharge Factor A number equivalent to the time in hours during which a battery is discharged at constant current usually expressed as a percentage of the total battery capacity, i.e., C/5 indicates a discharge factor of 5 h. Related to Discharge Rate.

Discharge Rate The current that is withdrawn from a battery over time. Expressed as a percentage of battery capacity. For instance, a C/5 discharge rate indicates a current equal to one-fifth of the rated capacity of the battery.

Disconnect Switch gear used to connect or disconnect components in a PV system.

Downtime Time when the PV system cannot provide power for the load. Usually expressed in hours per year or that percentage.

Dry Cell A cell (battery) with a captive electrolyte. A primary battery that cannot be recharged.

Duty Cycle The ratio of active time to total time. Used to describe the operating regime of appliances or loads in PV systems.

Duty Rating The amount of time an inverter (power conditioning unit) can produce at full rated power.

DVM digital Volt-meter.

E

Efficiency The ratio of output power (or energy) to input power (or energy). Expressed in percent.

EFG Edge definde Film Growth, A method for making sheets of polycrystalline silicon in which molten silicon is drawn upward by capillary action through a mold.

Electrolyte The medium that provides the ion transport mechanism between the positive and negative electrodes of a battery.

Electric Current A flow of electrons; electricity.

Electrical Grid An integrated system of electricity distribution, usually covering a large area.

Electron Volt An energy unit equal to the energy an electron acquires when it passes through a potential difference of one volt; it is equal to 1.602×10^{-19} V.

Energy Density The ratio of the energy available from a battery to its volume (wh/m^3) or weight (wh/kg).

Equalisation Charge The process of mixing the electrolyte in batteries by periodically overcharging the batteries for a short time.

EVA Ethylene-Vinile-Acetate Foil, it will be used by module production for covering the cells.

F

Fill Factor (FF) For an I–V curve, the ratio of the maximum power to the product of the open–circuit voltage and the short–circuit current. Fill factor is a measure of the "squareness" of the I–V curve.

Fixed Tild Array A PV array set in at a fixed angle with respect to horizontal.

Flat-Plate Array A PV array that consists of non-concentrating PV modules.

Float Charge A charge current to a battery that is equal to or slightly greater than the self discharge rate.

Frequency The number of repetitions per unit time of a complete waveform, expressed in Hertz (Hz).

G

Gassing Gas by-products, primarily hydrogen, produced when charging a battery. Also, termed out-gassing.

Gallium Arsenide (GaAs) A crystalline, high-efficiency semiconductor/photovoltaic material.

Gel Type Battery Lead-acid battery in which the electrolyte is composed of a silica gel matrix.

Grid Term used to describe an electrical utility distribution network.

Grid Connected PV System A PV system in which the PV array acts like a central generating plant, supplying power to the grid.

H

Hybrid System A PV system that includes other sources of electricity generation, such as wind or diesel generators.

I

I-U Characteristics The plot of the current versus voltage characteristics of a photovoltaic cell, module, or array. Three important points on the I-V curve are the open-circuit voltage, short-circuit current, and peak power operating point.

Incident Light Light that shines onto the face of a solar cell or module.

Irradiation The solar radiation incident on an area over time. Equivalent to energy and usually expressed in kilowatt-hours per square meter.

Insolation The solar radiation incident on an area over time. Equivalent to energy and usually expressed in kilowatt-hours per square meter.

Inverter Power Conditioning Unit, PCU, or Power Conditioning System, (PCS) In a PV system, an inverter converts DC power from the PV array/battery to AC power compatible with the utility and AC loads.

Inverter Terminology

Duty Rating This rating is the amount of time the inverter can supply its rated power. Some inverters can operate at their rated power for only a short time without overheating.

Frequency Most loads in the United States require 60 Hz. High-quality equipment requires precise frequency regulation—variations can cause poor performance of clocks and electronic timers.

Frequency Regulation This indicates the variability in the output frequency. Some loads will switch off or not operate properly if frequency variations exceed 1 percent.

Harmonic Content The number of frequencies in the output waveform in addition to the primary frequency (50 or 60 Hz). Energy in these harmonic frequencies is lost and may cause excessive heating of the load.

Input Voltage This is determined by the total power required by the AC loads and the voltage of any DC loads. Generally, the larger the load, the higher the inverter input voltage. This keeps the current at levels where switches and other components are readily available.

Modified Sine Wave A waveform that has at least three states (i.e. positive, off, and negative). Has less harmonic content than a square wave.

Modularity The use of multiple inverters connected in parallel to service different loads.

Power Factor The cosine of the angle between the current and voltage waveforms produced by the inverter. For resistive loads, the power factor will be 1.0.

Power Conversion Efficiency The ratio of output power to input power of the inverter.

Rated Power Rated power of the inverter. However, some units can not produce rated power continuously. See duty rating.

Root Mean Square (RMS) The square root of the average square of the instantaneous values of an AC output. For a sine wave the RMS value is 0.707 times the peak value. The equivalent value of ac current, I, that will produce the same heating in a conductor with resistance, R, as a DC current of value I.

Sine Wave A waveform corresponding to a single-frequency periodic oscillation that can be mathematically represented as a function of amplitude versus angle in which the value of the curve at any point is equal to the sine of that angle.

Square Wave A wave form that has only two states, (i.e. positive or negative). A square wave contains a large number of harmonics.

Surge Capacity The maximum power, usually 3–5 times the rated power, that can be provided over a short time.

Standby Current This is the amount of current (power) used by the inverter when no load is active (lost power). The efficiency of the inverter is lowest when the load demand is low.

Voltage Regulation This indicates the variability in the output voltage. Some loads will not tolerate voltage variations greater than a few percent.

Voltage Protection Many inverters have sensing circuits that will disconnect the unit from the battery if input voltage limits are exceeded.

Irradiance The solar power incident on a surface. Usually expressed in kilowatts per square meter. Irradiance multiplied by time equals Insolation.

I-V Curve The plot of the current versus voltage characteristics of a photovoltaic cell, module, or array. Three important points on the I–V curve are the open–circuit voltage, short–circuit current, and peak power operating point.

J

Joule (J) Unit of energy equal to 1/3600 KW-h.

Junction Box A PV generator junction box is an enclosure on the module where PV strings are electrically connected and where protection devices can be located, if necessary.

K

Kilowatt (kW) One thousand watts. A unit of power.

Kilowatt Hour (kWh) One thousand watt-hours. A unit of energy. Power multiplied by time equals energy.

L

Load The amount of electric power used by any electrical unit or appliance at any given time.

Life The period during which a system is capable of operating above a specified performance level.

Life-Cycle Cost The estimated cost of owning and operating a system for the period of its useful life. See Economics section for definition of terms.

Load Circuit The wire, switches, fuses, etc. that connect the load to the power source.

Load Current (A) The current required by the electrical device.

Load Resistance The resistance presented by the load. See Resistance.

Langley (L) Unit of solar irradiance. One gram calorie per square centimeter. 1 L = 85.93 kWh/m^2.

Low Voltage Cutoff (LVC) The voltage level at which a controller will disconnect the load from the battery.

M

Maintanace Free Battery A sealed battery to which water cannot be added to maintain electrolyte level.

Maximum Power Point or Peak Power Point That point on an I-V curve that represents the largest area rectangle that can be drawn under the curve. Operating a PV array at that voltage will produce maximum power.

Modularity The concept of using identical complete units to produce a large system.

Module The smallest replaceable unit in a PV array. An integral, encapsulated unit containing a number of PV cells.

Module Derate Factor A factor that lowers the module current to account for field operating conditions such as dirt accumulation on the module.

MOS-FET Metal–Oxide–Silicon Field effect transistor; used as semiconductor power switch in charge regulators, inverters etc.

Movistor Metal Oxide Varistor. Used to protect electronic circuits from surge currents such as produced by lightning.

MPP Maximum Power Point; the point on the current–voltage (I-V) curve of a module under illumination, where the product of current and voltage is maximum. For a typical silicon cell, this is at about 0.45 V.

MPPT Maximum Power point Tracker; Means of a power conditioning unit that automatically operates the PV-generator at its MPP under all conditions.

N

NEC An abbreviation for the National Electrical Code which contains guidelines for all types of electrical installations. The 1984 and later editions of the NEC contain Article 690, “Solar Photovoltaic Systems” which should be followed when installing a PV system.

NEMA National Electrical Manufacturers Association. This organization sets standards for some non-electronic products like junction boxes.

NOCT Nominal Operating Cell temperature; The estimated temperature of a PV module when operating under 800 W/m^2 irradiance, 20°C ambient temperature and wind speed of 1 m/s. NOCT is used to estimate the nominal operating temperature of a module in its working environment.

Nominal Voltage A reference voltage used to describe batteries, modules, or systems.

Nominal Voltage A reference voltage used to describe batteries, modules, or systems (i.e. a 12-volt or 24-volt battery, module, or system).

Normal Operating Cell Temperature (NOCT) The estimated temperature of a PV module when operating under 800 w/m^2 irradiance, 20°C ambient temperature and wind speed of 1 m/s. NOCT is used to estimate the nominal operating temperature of a module in its working environment.

N-Type Silicon Silicon material that has been doped with a material that has more electrons in its atomic structure than does silicon.

O

Ohm (Ω) The unit of electrical resistance in which an electromotive force of one volt maintains a current of one ampere.

One Axis Tracking A system capable of rotating about one axis.

Open Circuit Voltage The maximum voltage produced by an illuminated photovoltaic cell, module, or array with no load connected. This value will increase as the temperature of the PV material decreases.

Operating Point The current and voltage that a module or array produces when connected to a load. The operating point is dependent on the load or the batteries connected to the output terminals of the array.

Orientation Placement with respect to the cardinal directions, N, S, E, W; azimuth is the measure of orientation from north.

Outgas See Gassing.

Overcharge Forcing current into a fully charged battery. The battery will be damaged if overcharged for a long period.

P

Panel A designation for a number of PV modules assembled in a single mechanical frame.

Parallel Connection Term used to describe the interconnecting of PV modules or batteries in which like terminals are connected together. Increases the current at the same voltage.

Peak Load The maximum load demand on a system.

Peak Power Current Amperes produced by a module or array operating at the voltage of the I-V curve that will produce maximum power from the module. See I-V Curve.

Peak Sun Hours The equivalent number of hours per day when solar irradiance averages 1,000 w/m^2. For example, six peak sun hours means that the energy received during total daylight hours equals the energy that would have been received had the irradiance for six hours been 1,000 w/m^2.

Peak Watt The amount of power a photovoltaic module will produce at standard test conditions (normally 1,000 w/m^2 and 25° cell temperature).

Photon A particle of light that acts as an individual unit of energy. Its energy depends on wavelength.

Photo voltaic Cell The treated semiconductor material that converts solar irradiance to electricity.

Photovoltaic System An installation of PV modules and other components designed to produce power from sunlight and meet the power demand for a designated load.

Plates A metal plate, usually lead or lead compound, immersed in the electrolyte in a battery.

Pocket Plate A plate for a battery in which active materials are held in a perforated metal pocket.

Polycrystalline Silicon A material used to make PV cells which consist of many crystals as contrasted with single crystal silicon.

Power (Watts) A basic unit of electricity equal (in DC circuits) to the product of current and voltage.

Power Conditioning System (PCS) See Inverter.

Power Density The ratio of the rated power available from a battery to its volume (watts per liter) or weight (watts per kilogram).

Power Factor The cosine of the phase angle between the voltage and the current waveforms in an AC circuit. Used as a designator for inverter performance. A power factor of 1 indicates current and voltage are in phase and power is equal to the product of volt-amperes. (no reactive power).

Primary Battery A battery whose initial capacity cannot be restored by charging.

Pulse Width Modulated (PWM) PWM inverters are the most expensive, but produce a high quality of output signal at minimum current harmonics. The output voltage is very close to sinusoidal.

Pyranometer An instrument used for measuring global solar irradiance.

Pyrheliometer An instrument used for measuring direct beam solar irradiance. Uses an aperture of 5.7° to transcribe the solar disc.

R

Rated Module Current The current output of a PV module measured at standard test conditions of 1,000 w/m^2 and 25°C cell temperature.

Reactive Power The sine of the phase angle between the current and voltage waveforms in an AC system.

Remote Site A site not serviced by an electrical utility grid.

Resistance (R) The property of a conductor which opposes the flow of an electric current resulting in the generation of heat in the conducting material. The measure of the resistance of a given conductor is the electromotive force needed for a unit current flow. The unit of resistance is ohms.

Rated Battery Capacity The term used by battery manufacturers to indicate the maximum amount of energy that can be withdrawn from a battery under specified discharge rate and temperature. See Battery Capacity.

Rated Module Current (A) The current output of a PV module measured at standard test conditions of 1,000 w/m^2 and 25°C cell temperature.

S

Sacrificial Anode A piece of metal buried near a structure that is to be protected from corrosion. The metal of the sacrificial anode is intended to corrode and reduce the corrosion of the protected structure.

Seasonal Depth of Discharge An adjustment factor used in some system sizing procedures which "allows" the battery to be gradually discharged over a 30–90 day period of poor solar insolation. This factor results in a slightly smaller PV array.

Secondary Battery A battery that can be recharged.

Self-Discharge The loss of useful capacity of a battery due to internal chemical action.

Self Distance The rate at which a battery, without a load, will lose its charge.

Semiconductor A material that has a limited capacity for conducting electricity. The silicon used to make PV cells is a semiconductor.

Series Connection Connecting the positive of one module to the negative of the next module. This connection of PV modules or batteries increases the voltage while the current remains the same.

Series Regulator Type of battery charge regulator where the charging current is controlled by a switch connected in series with the PV module or array.

Shallow Cycle Battery A type of battery that should not be discharged more than 25 percent.

Shelf Life The period of time that a device can be stored and still retain a specified performance.

Short Circuit Current (Isc) The current produced by an illuminated PV cell, module, or array when its output terminals are shorted.

Silicon (Si) A chemical element, atomic number 14, semimetallic in nature, dark gray, an excellent semiconductor material. A common constituent of sand and quartz (as the oxide). Crystallizes in face-centered cubic lattice like a diamond. The most common semiconductor material used in making photovoltaic devices.

Single-Crystal Silicon Material with a single crystalline formation. Many PV cells are made from single crystal silicon.

Solar Cell See Photovoltaic Cell.

Solar Constant The strength of sunlight; 1353 W/m^2 in space and about 1000 W/m^2 at sea level at the equator at solar noon.

Solar Insolation See Insolation.

Solar Irradiance See Irradiance.

Solar Noon The midpoint of time between sunup and sunset. The point when the sun reaches its highest point in its daily traversal of the sky.

Solar Resource The amount of solar insolation a site receives, usually measured in kWh/m^2/day which is equivalent to the number of peak sun hours. See Insolation and Peak Sun Hours.

Specific Gravity The ratio of the weight of the solution to the weight of an equal volume of water at a specified temperature. Used as an indicator of battery state of charge.

Stand-Alone PV System A photovoltaic system that operates independent of the utility grid.

Standard Test Conditions Conditions under which a module is typically tested in a laboratory: Irradiance intensity of 1000 W/m^2, AM1.5 solar reference spectrum, a cell (module) temperature of 25°C, plus or minus 2°C.

Starved Electrolyte Cell A battery containing little or no free fluid electrolyte.

State of Charge (SOC) The instantaneous capacity of a battery expressed at a percentage of rated capacity.

Stratification A condition that occurs when the acid concentration varies from top to bottom in the battery electrolyte. Periodic, controlled charging at voltages that produce gassing will mix the electrolyte. See Equalization.

String A number of modules or panels interconnected electrically in series to produce the operating voltage required by the load.

Subsystem Any one of several components in a PV system (i.e., array, controller, batteries, inverter, load).

Sulfating The normal result of battery discharge when lead–sulfate forms on the surface and in the pores of the active plate material. Sulfation becomes a problem when large crystals of lead sulfate form on the active material as a result of inadequate charging and battery neglect or misuse. The large sulfate crystals are difficult to decompose under charge and return sulfates back to the electrolyte. This effectively reduces battery capacity and life. Large sulfate crystals may be detectable by a hard rough surface on the active plate material or a low specific gravity after an equalization charge. This is called excessive sulfation or “hard” sulfation.

Sun Path Diagram Graphical representation of the Sun’s height and azimuth.

Surge Capacity The ability of an inverter or generator to deliver high currents momentarily required when starting motors.

System Availability The percentage of time (usually expressed in hours per year) when a PV system will be able to fully meet the load demand.

System Operating Voltage The array output voltage under load. The system operating voltage is dependent on the load or batteries connected to the output terminals.

System Storage See Battery Capacity.

T

Temperature Compensation An allowance made in charge controllers set points for battery temperatures. Feature recommended when battery temperatures are expected to exceed ±5°C from ambient.

Temperature Factors It is common for three elements in PV system sizing to have distinct temperature corrections. A factor used to decrease battery capacity at cold temperatures. A factor used to decrease PV module voltage at high temperatures. A factor used to decrease the current carrying capability of wire at high temperatures.

Thin Film PV Module A PV module constructed with sequential layers of thin film semiconductor materials. See Amorphous Silicon.

Tilt Angle The angle of inclination of a solar collector measured from the horizontal.

Total AC Load Demand The sum of the AC loads. This value is important when selecting an inverter.

Tracking Array A PV array that follows the path of the sun. This can mean one-axis, east to west daily tracking, or two-axis tracking where the array follows the sun in azimuth and elevation.

Transformer Converts the generator's low-voltage electricity to higher voltage levels for transmission to the load center, such as a city or factory.

Tray Cable (TC) may be used for interconnecting balance-of-systems (BOS).

Trickle Charge A small charge current intended to maintain a battery in a fully charged condition.

TW/THHN may be used for interconnecting BOS but must be installed in conduit—either buried or above ground. It is resistant to moisture.

Two Axis Tracking A system capable of rotating independently about two axes (e.g., vertical and horizontal).

U

Underground Feeder (UF) may be used for array wiring if sunlight resistant coating is specified; can be used for interconnecting BOS components but not recommended for us e within battery enclosures.

Underground Service Entrance (USE) may be used within battery enclosures and for interconnecting BOS.

Uninterruptible Power Supply (UPS) The designation of a power supply providing continuous uninterruptible service. The UPS will contain batteries.

Utility Interactive Inverter An inverter that can function only when tied to the utility grid, and uses the prevailing line-voltage frequency on the utility line as a control parameter to ensure that the PV system's output is fully synchronized with the utility power.

V

Varistor A voltage-dependent variable resistor. Normally used to protect sensitive equipment from power spikes or lightning strikes by shunting the energy to ground.

Vented Cell A battery designed with a vent mechanism to expel gases generated during charging.

Volt The unit of electromotive force that will force a current of one ampere through a resistance of one ohm.

Voltage at Maximum Power The voltage at which maximum power is available from a module.

W

Wafer A thin sheet of semiconductor material made by mechanically sawing it from a single-crystal or multicrystal ingot or casting.

Water Pumping Terminology

Centrifugal Pump See rotating pump.

Displacement or Volumetric Pump A type of water pump that utilizes a piston, cylinder and stop valves to move packets of water.

Dynamic Head The vertical distance from the center of the pump to the point of free discharge of the water. Pipe friction is included. See Friction Head.

Friction Head The energy that must be overcome by the pump to offset the friction losses of the water moving through a pipe.

Rotating Pump A water pump using a rotating element or screw to move water. The faster the rotation, the greater the flow.

Static Head The vertical distance from the water level to the point of free discharge of the water. It is measured when the pump is not operating.

Storage This term has dual meaning for water pumping systems. Storage can be achieved by pumping water to a storage tank, or storing energy in a battery subsystem.

Suction Head The vertical distance from the surface of the water source to the center of the pump (when the pump is located above the water level).

Wet Shelf Life The period of time that a charged battery, when filled with electrolyte, can remain unused before dropping below a specified level of performance.

Wire Types See Article 300 of National Electric Code for more information.

Watt The unit of electrical power. The power developed when a current of one ampere flows through a potential difference of 1 V.

Watt Hour (Wh) A unit of energy equal to 1 W of power connected for 1 h.

Waveform The characteristic shape of an AC current or voltage output.

Z

Zenith Angle The angle between directly overhead and the line intersecting the sun. (90°-zenith) is the elevation angle of the sun above the horizon.

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