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SET-UP OF A LABORATORY FOR RESEARCH AND EDUCATION IN SOLAR ENERGY IN RIO DE JANEIRO

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Abstract – Brazil has a large potential for the use of solar energy: High irradiance levels with relatively small seasonal variations, a large rural population with no access to the public electricity grid (16 million) and a good match of power consumption to the course of solar irradiance. To make use of this potential, courses for graduated and post-graduated students to teach photovoltaic systems have been set up, following several workshops and activities in the solar thermal area. Each course lasts for three months, begins with the assessment of the potential of solar energy, discusses the natural and technical means to convert it, then goes into photovoltaic energy conversion and the related topics such as hybrid systems, energy storage and power distribution. The areas included are multi-disciplinary: Astronomy, Optics, Semiconductor physics, electronics, energy management, economics and politics. In the next semester the course will be part of the Interdisciplinary Initiative of COPPE for post-graduate studies. The course is available on the Internet (http://www.solar.coppe.ufrj.br) and also features a live-web-cam to allow students remote participation.

1. INTRODUCTION

Brazil has a large potential for the use of solar energy: High irradiance levels with relatively small seasonal variations, a large rural population with no access to the public electricity grid (16 million people) and a good match of power consumption to the course of solar irradiance. Recently the existing power generation (mostly hydro) came close to its limits, so new power plants are needed. Compared to this potential the number of research and education facilities in the field of renewable energies is poor.

Therefore, initiatives to improve the situation have been started. Next to a course on the thermal use of solar energy at the Department of Mechanical Engineering, a PV-course was set up at the Electrical Engineering department to initiate education in PV-Systems at university level.

The duration of the PV-course is three months consisting of a theoretical and practical part which take four hours a week each.

Most of the contents was made available for students on the Internet (http://www.solar.coppe.ufrj.br): This allows the students to follow a course at home without wasting time and money for long drives to the campus, and thus serves as a contribution to energy saving and lowering of emissions. While the courses for graduated and post-graduated level had been presented in English language in the beginning, they were shifted to Portuguese after a year. The course is the result of a collaboration between UFRJ-COPPE and TUB, which received financial support from GTZ/DAAD and CAPES.

1.2 Education about solar energy

The energy being radiated from the sun to the surface of the Earth is more than 14,000 times the amount of the world's energy consumption. Saying it another way: The energy consumption of the entire human population within one year is delivered from the sun to the earth within half a hour. The energy being radiated within one year by the sun is equivalent to 10 to 30 times of all known resources of coal, oil, gas and uranium put together. The actual part of solar energy being used by technical solar energy converters is diminutive.

Despite the consequence of the present and future obligation of solar energy use, the possibilities to attend a course about solar systems are marginal, especially in Third World countries. Despite the enormous market potential given by high solar radiance on the one hand and a marginal energy infrastructure on the other, the density of training sites is the lowest in these countries.

Education about solar energy consists of a very broad spectrum of different disciplines which makes an ubiquitous approach indispensable. The different disciplines and their meaning for the field are explained subsequently.

Astronomy

The knowledge of the Earth's course around the sun is important for the determination of the sun's position seen from earth, because this fixes the sun's incidence angle and its actual spectrum which are influencing the performance of the solar cell by reflective losses and spectral mismatch as well as the time of sunrise and sunset.

Meteorology

Determining the average hours of sunlight and the variance of the solar yield to be expected requires knowledge about the atmospheric composition, occurrence of clouds and their influence on the incidencing spectrum. Relation of the amount of direct versus diffuse radiation and the resulting yield variation is also a part of it.

Optics

The properties of the optical surface of a solar converter and the incidence angle of the radiance onto it determine the amount of the reflection losses. Due to the enormous variation of incidence angles during a day - respectively a year - the reflective losses accumulate to give an inaccuracy of 10-15 % to the yield - if neglected. This is particularly important for solar facades which will be a major application of PV in the forthcoming years.

Thermodynamics

The thermodynamic and thermal properties of a solar system in a specific surrounding determine the operating cell temperature and the efficiency.

Solid state physics

This subject is used to determine the absorption properties and efficiencies of different types of solar cells, a certain knowledge of semiconductor physics is essential.

Electronics and Power Electronics

Because the electrical power is used directly by some loads, it has to be adapted by electronic converters. So called ”Maximum Power Point Trackers” allow an electronic match of the load, to assure that all the power available from the generator is being used.

Electrochemistry

Often generation and consumption of the energy is out of phase, thus it has to be stored in accumulators. To design a system properly some knowledge of the specific properties and parameters of the chemical transitions are helpful. For example, to calculate a correct assumption of the size of the system required considers self discharge, charging losses and ageing.

Environmental science

The impact of set-up, closedown and emissions during operation of an energy system have to be calculated. The increase of the carbon dioxide contents of the atmosphere and global warming have had a negative effect. E.g. increased atmospheric activities with more storms and more destructive power increased the public economy damage of natural disasters from 50 billion $ US in 1980 to 150 billion $ US nowadays. Solar energy may contribute to the reduction of carbon dioxide emissions, therefore its substitutive value has to be considered.

Architecture

To gain acceptance from civil engineers and architects in order to integrate solar systems into buildings, solar energy professionals need to familiarize themselves with building materials and equipment used to deliver energy. The substitutive effects of this integration also allows to reduce PV-system costs.

Statistics

Probability rate plays a major role in determining the reliability of the autonomous energy systems, therefore knowledge about the statistical probabilities of certain weather conditions are substantial (e.g. days without sun).
In autonomous systems the control of the generating system is to be designed in accordance with energy management. This includes a classification of the energy consuming units, so the least important could be switched off automatically in case of energy shortage (or a diesel generating set could be started).

Sociology

For the accurate design of PV-Systems the habits of the users have to be known, registered and - if incompatible with the use of PV systems - be changed carefully. In marketing solar energy to the public, many sociological parameters as social position, prestige, paragon functions etc. need to be considered.

Politics

An immense influence on the solar energy market is the actual costs of fossil energy such as coal, oil and gas. These fuels are widely used largely because of world politics. Also, the subsidy situation used by governments on different kinds of energy consumption is a significant drawback on the marketability of solar power (e.g. government pays for social costs of energy consumption). Last, but not least the availability of certain products or components, like silicon wafers, play a role.

2. THEORETICAL COURSE

The theoretical course consists of 12 lessons at 2 hours each. After each 4 lessons is a practical which sums up the contents of the lessons. The subjects of the course are structured in the manner shown below.

2.1 Energy

The subjects discussed at this part are the following: Energy consumption, energy generation, fossil fuels, emissions, atmospheric carbon dioxide accumulation, greenhouse effect, external costs of energy use, energy saving.

2.2 Solar Energy

Here the Sun as an energy generator is presented: Fusion reactor Sun, Astronomical parameters, Spectral energy distribution, extraterrestrial use, available energy from the sun, measurement of solar radiance, conversion methods of solar energy.

2.3 Influence of atmosphere

Following the path of the energy flow form the Sun to the surface of the Earth the properties and effect of the Earth`s atmosphere are discussed: Composition of atmosphere, effects on solar irradiance, distribution of irradicance on Earth (seasonal change, diffuse/direct), Solar irradiance at solar module (slope, tracking).

2.4 Photovoltaic Effect

In order to be able to entirely understand point 2.5. the principle of photovoltaic energy conversion has to be known before: How does a solar cell work , Cell technologies, equivalent electrical circuits, I-V-curves, Maximum Power Point, dependence of I-V-curves on irradiance and temperature, current and future production technologies.

2.5 Solar Module

By continuing to follow the path of solar energy flow form its source to the solar cells, the optical, electrical and thermal properties of the PV-module are to be examined: spectral efficiency of the cell, I-V characteristics (MPP), irradiance and temperature dependencies, optical and thermal modeling of the PV-module encapsulation.

2.6 Ambient Parameters

While the power output of a PV-generator is very much dependent on the operation conditions, these are discussed separately: Reflection losses, shading losses (hot spots, bypass diodes), temperature effects.

2.7 Photovoltaic system technology

To adapt the generated electricity to the need of the loads, power conditioning units are used: shunt and series regulators, DC/DC converters (MPPT), DC/AC converters.

2.8 Battery storage

To make use of the photovoltaic electricity during an other period time than it is generated, electrical storage becomes necessary: Electrochemical operation of a battery, electrical properties of a battery, charge controllers, sizing of battery system

2.9 PV-Systems

To design a PV-system properly, the components and their interactions to each other have to be known and have to be considered in the layout: Basic configurations, sizing of PV-Systems, cost of PV-systems.

2.10 Hybrid systems

Often it is useful to combine different types of generators to achieve a more continuous power output or to feed peak loads: Wind energy converters, Diesel-electric-generators, hydropower stations, biomass converters, and their control systems.

2.11 Regulations

Regulations about the power rating of PV-modules and of sizing of PV-systems, as well safety regulations on the DC and AC side have to be taken into account for a good system design.

2.12 Architectural integration

Opportunities of roof mounting and facade integration of PV-systems, possible variations in form and appearance of PV-modules, substitutability of conventional parts of the roof and facade by PV-related systems are presented in this last chapter.

3. LABORATORY EXPERIMENTS

Some of the experiments have been adopted and improved from the PV-Systems Lab at the Technical University of Berlin..

3.1 PV-modules

As an introduction into photovoltaic systems the solar electric generator, the PV-module, is explained first. The student learns that the module is neither a constant voltage source nor a constant current source, its characteristic by the I-V curve and the meaning of terms as ”maximum power point” (MPP) or ”fill factor” (FF). The influence of parameters as irradiance and operating temperature on the output current, voltage and power output (at MPP) is taught by recording a set of data varying one of the parameters and calculate the according coefficient. The problem of shadowing of the module - in reality by dust, dirt or shadows of trees or buildings - is discussed by totally shadowing one cell, half of it and a quarter and observing and discussing the effects on the I-V curve.

Fig.1. PV-Facade with cooling and cloud-filter for investigations on thermal and optical performance and parameters.

3.2 Electrical energy storage

The students are introduced to the design of remote photovoltaic home systems: The size of the PV-generator and storage capacity given by the energy consumption (sum of loads as a function of time). The different charge methods, the charging and discharging losses are discussed. The parameters which define the lifetime of the a battery are described. The experiment demonstrates the function of a typical charge controller.

3.3 Electrical power conditioning

Often loads require an AC input power, so the DC offered by the PV generator or by the batteries have to be transformed by a converter. The different kinds of inverters are described and discussed. The efficiency as a function of load is measured, also the harmonic distortion.

The experiment shows the behavior of a typical PWM sine wave inverter with an own oscillator for autonomous PV-systems

Fig.2. Charging device with PV-module and solar simulator at Laboratorio Fotovoltaico at UFRJ-COPPE/EE.

Fig. 3. 800 W_p PV-generator at Laboratorio Fotovoltaico, UFRJ-COPPE.

4. LEARNING AND TEACHING BY INTERNET AND MULTIMEDIA SYSTEMS

4.1 Preclusion

All different disciplines concerning solar energy as shown in chapter ”introduction” the are related to each other and can not be treated independently. A general comprehension in teaching and learning is indispensable. The speed of student’s comprehension at the different areas covered by the matter solar energy use depends strongly on its preliminary knowledge and its specialization. So the progress at the different subjects shows a broader range at the students as in other more specialized courses, which makes additional pre- and post preparation necessary. This fact features the use of information systems which are able to repeat different chapters and also provide the actual data about the upper developments, therefore no faculty could keep up with the different subjects on its own. Beside the thematic diversity the vast distances between the research centers (which mostly are located in the First World) and the application sites (which are particularly promising in the Third World) could be handled. So an information pool called ”solar server” linked to all databases, institutes and appliances by Internet was established. By using the ”Word Wide Web” user interface students have an easy accessibility by hypertext links to the according institutes and self-actualizing references .

4.2 Characteristics

The theoretical part of the course as shown in chapter ”theoretical course” was offered to the World-Wide-Web by transforming all the written material and the transparencies to HTML-code. A multimedia program called ”solar teacher” is under construction, it covers the mentioned course plus some extra aspects as solar thermal systems, marketing of solar systems, environmental issues in general, search of information on different kind databases (e.g. technical information on patent data bases) and a final test.

5. RESEARCH

Research topics in which students are involved with their bachelors and masters thesis cover the following topics: Simulation, performance evaluation and optimization, field-monitoring, yield analysis, optical and thermal enhancement of systems, combined PV-thermal systems, energy storage, PV-pumping systems, hybrid PV-Diesel-systems, solar-home-systems, integration of solar systems into architecture and climatic comfort. Research and education will be extended to other fields of renewable energies.

Fig.4. Example of recent research at PV-Labs UFRJ-COPPE: Increasing the yield of a PV-generator: Lower operating cell temperature and less reflection losses by a frontside water film .

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7. LITERATURE

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