

Production Techniques of PV's and Polycrystalline PV Performance Analyses for Permanent Resistive Load

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Abstract: - Photovoltaic (PV) panels which are used to convert solar energy to electrical energy one of the fastest growing source on energy sector. Their efficiencies are increasing day by day with new technologies. Photovoltaic's average efficiencies are still 15-20% in daily usage. In this study general photovoltaic production techniques are explained briefly. New technological developments affect these production techniques so the new methods on photovoltaic production are examined. During one year period polycrystalline PV performance which feeds the permanent resistive load is tested experimentally for Istanbul-Goztepe.

Key-Words: - Photovoltaic, D.C. Loads, Energy Consumption, Production Techniques.

1 Introduction

The photovoltaic (PV) systems are generally designed for operating hybrid, grid connected or stand alone. Their most importing advantages against the conventional energy production systems are their modular structures, silence operation property, having no moving parts, less maintenance needs and having no harmful gas emissions. For that reasons PV systems are good alternatives to diesel generator systems that have been widely used in rural areas in recent years.

The most important disadvantage of these systems is high initial investment costs. Although, the investment costs of PV cells have decreased 10 times in the last twenty years, they are still not an alternative to conventional energy production systems in grid connected networks. PV cells had the biggest share in initial investment costs for PV systems [1].

Unfortunately, PV generation systems have two major problems: the conversion efficiency of electric power generation is very low (15-20%) especially under low irradiation conditions, and the amount of electric power generated by solar array changes continuously with weather conditions [2].

Efficiency is an important matter in the photovoltaic conversion of solar energy because the sun is a source of power whose density is not very low, so it gives some expectations on the feasibility of its generalized cost-effective use in electric power production. However, this density is not so high as to render this task easy. After a quarter of a century of attempting it, cost still does not allow a generalized use of this conversion technology [3].

Efficiency forecasts have been carried out from the very beginning of PV conversion to guide the research activity. In solar cells the efficiency is strongly related to the generation of electron-hole pairs caused by the light, and their recombination

before being delivered to the external circuit at a certain voltage. This recombination is due to a large variety of mechanisms and cannot be easily linked to the material used to make the cell [4].

Basic structure of photovoltaic cell is shown in Fig. 1.

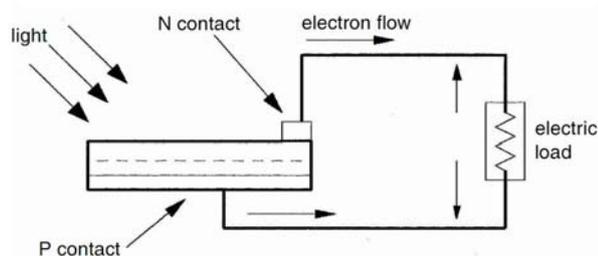


Fig. 1 Basic structure of photovoltaic cell

PV power technology uses semiconductor cells (wafers), generally several square centimeters in size. From the solid-state physics point of view, the cell is basically a large-area p-n diode with the junction positioned close to the top surface. Numerous cells are assembled in a module to generate the required power [1].

2 Traditional PV Cells

Very comprehensive studies are being made to decrease the material size and costs and increase the output of crystal, nano-crystal, multi-crystal, thin film poly-crystal and amorphous PV cells.

In general, it is accepted that reducing the thickness of thin film PV cells below 50mm will considerably decrease the material need when compared to silicon layers and have the potential to reach higher productivities. Reduction in thickness of PV cell cause increasing in open circuit voltage. However, crystal cell technology gives better response to cell performance and demands depending on costs when compared to other cell production systems [5] - [7].

2.1 Mono or Multi-Crystalline Silicon Solar Cells

Crystalline silicon solar cells and modules have dominated photovoltaic technology from the beginning. They constitute more than 85% of the PV market today, and although their decline in favor of other technologies has been announced a number of times, they presumably will retain their leading role for a time, at least for the next decade.

One of the reasons for crystalline silicon to be dominant in photovoltaic's is the fact that microelectronics has developed silicon technology

greatly. On the one hand, not only has the PV community benefited from the accumulated knowledge but also silicon feedstock and second-hand equipment have been acquired at reasonable prices. Fig. 2 shows cross-section of a standard silicon module.

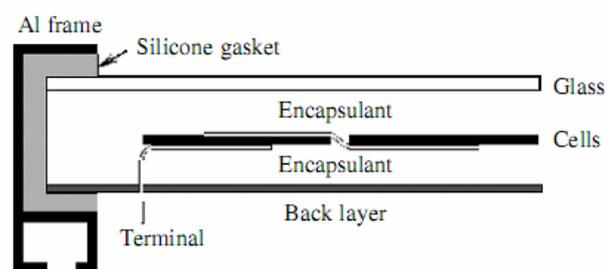


Fig. 2 Cross-section of a standard module [4].

SunPower has reported a silicon panel solar cell with at least 20% output having better life, thickness and compatible price. The wide tolerance provided by silicon panel in respect of thickness and resistance facilities production of the silicon from ingot and rapidly decreases the cost of silicon panel so the production cost of cell. Production of crystal solar cells moves to Multi-Silicon from Mono-Silicon to decrease the defects in crystal structure and the metal contamination [5],[6].

2.2 Thin-Film PV Cells

The thin film technology the indium and gallium elements are used provides significant advantages in PV cells in respect of high output and economical price. Following the initial success, texture etching became a standard process step for fabricating Si solar cells, both in the laboratory and commercially. Fig. 3 shows calculated short-circuit current density values as a function of thickness for different texture structures including planar, standard chemical texture, pyramids, inverted pyramids, and perpendicular slats. The surface structures are illustrated in Fig. 4. However, only the laboratory cells, fabricated on high-quality wafers and with high-reflectance back contacts, realized the advantage of light-trapping. Although commercial cells also use texturing, its usefulness was perhaps largely limited to lowering the surface reflectance, rather than enhancing light-trapping. This is because the typical commercial solar cells use an Al-alloyed back contact that develops a rough interface, which has very low reflectance and allows most of the light to be transmitted into the metal where it is absorbed. The light absorbed in the metal constitutes an optical loss [4].

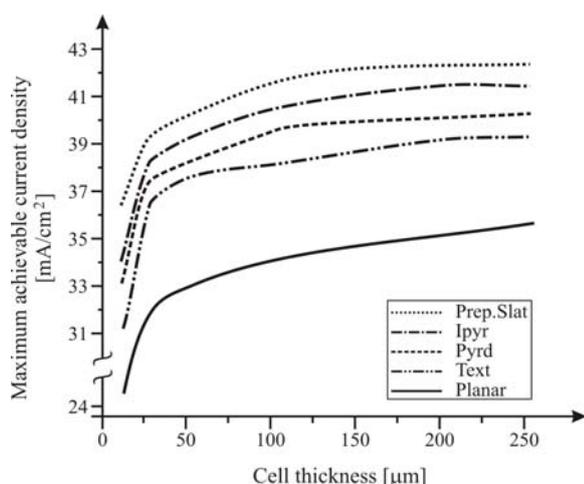


Fig. 3 Calculated maximum achievable current density for Si solar cells with different texture shapes

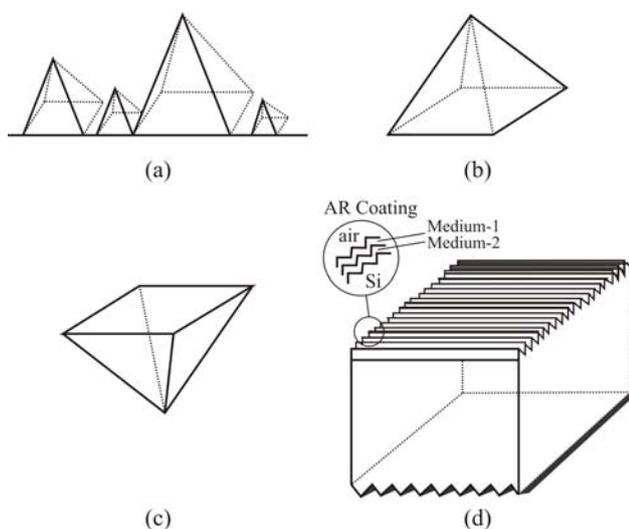


Fig. 4 Sketches of various surface structures used in calculations shown in Fig. 3. (a) chemically textured random pyramids, (b) uniformly textured pyramids, (c) inverted pyramids and (d) perpendicular slats

In production of such cells, to obtain hard and bendable flexible structure, ink-base non-vacuumed production techniques are used. In this system, copper, indium and gallium oxides in nano particle state are coated with molybdenum or nonconductive layer. While polyimide coating increases the cell output in rate of 8.9%, molybdenum coatings ensure 13% and glass coatings 13.6% output increase [5].

2.3 Multi-Junction Concentrator PV Cells

Photovoltaic (PV) concentrators use lenses or mirrors to concentrate sunlight onto PV cells. This allows for a reduction in the cell area required for producing a given amount of power. The goal is to significantly reduce the cost of electricity generated by replacing expensive PV converter area with less

expensive optical material. This approach also provides the opportunity to use higher performance PV cells that would be prohibitively expensive without concentration. As a result, concentrator modules can easily exceed 20% energy conversion efficiency [8].

Development of silicon collector cells began at the end of 1980's. Recently, Amonix has undertaken commercial development attempts of collector cells. The highest cell output reported by Amonix is 27.5%. Recently, multi-junction cell producers have obtained cell output exceeding 40% with local collector applications [5], [6], [10].

The main market barriers have been due to the fact that concentrating systems, which in most cases must track the sun, are not well suited to the existing PV market that serves small remote loads and, more recently, are building integrated applications. Concentrators were conceived of as a vehicle to generate large amounts of nonpolluting renewable energy. As yet, costs are still too high to compete with fossil fuel-fired generation, or even the most direct renewable competitor – wind power. The cost gap is narrowing, however, and there appears a strong likelihood that in the future concentrator systems will find cost-effective niche applications that will continue to expand as natural gas prices rise and concern over power-plant emissions increases.

2.4 Amorphous Silicon / Silicon Hetero-Junction Cells

High output PV cell production with silicon hetero-junction (SHJ) for temperatures under 150°C contains an attractive structure. By using the thin amorphous silicon plates combined with hydrogen as emitters or rear contacts of such cells, the output is increased to 17.5%. By combining the rear contacts of silicon material combined with hydrogen with -p- and -n- type silicon plates, the structure of double hetero-junction cells is developed and the output is increased to 18.2%. These contacts operate reliable at temperatures above 250°C [5], [11].

2.5 Dye-Sensitized PV Cells

Dye-sensitized PV cells (DSPVCs) are a relatively new alternative energy source. Since first reported in 1991, there has been much research interest due to the lower material and processing costs relative to the traditional PV cells. The DSPVC works on a different basis from the silicon PV cells, in which the semiconductor layer is simultaneously the light absorber and the site of the

charge separation, which gives rise to the electric current under illumination. In the DSPVC these functions are separated [12].

A DSPVC comprises a nanocrystalline TiO_2 modified with a dye fabricated on transparent conducting oxide, a platinum counter electrode, and an electrolyte solution with a dissolved iodide ion/triiodide ion redox couple between the electrodes (Fig. 5).

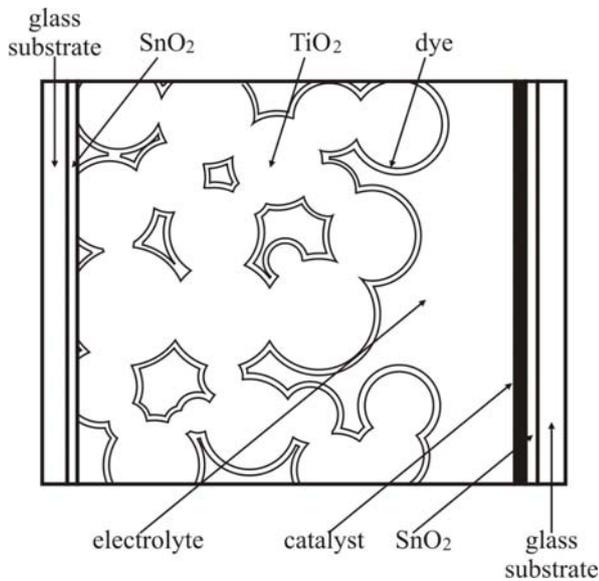


Fig. 5 Structure of dye-sensitized PV cell

In DSPVCs transport of photo generated electrons in a polycrystalline film of randomly connected oxide nanoparticles occurs by trap-limited diffusion. The dye monolayer in the cell is the light sensitive component that photo catalyzes incident light via a process that mimics the role of chlorophyll in photosynthesis. The charge separation is facilitated by other components in the cell, the semiconductor and the electrolyte. The semiconductor facilitates the negative charge path, while the positive charge travels through the electrolyte. The open circuit voltage is defined as the difference in potentials of the red ox electrolyte and the Fermi level of the semiconductor. But this is slow and limits carrier collection efficiency, especially red wavelengths. However, for practical application, a DSPVC module with size 50x50mm for aperture area 26.5cm^2 has achieved cell efficiency of 6.32% [5], [6], [12].

3 PV Cell Model

During darkness, the solar cell is not an active device; it works as a diode, i.e. a p-n junction. It produces neither a current nor a voltage. However, if it is connected to an external supply (large

voltage) it generates a current, called diode current or dark current. Fig. 6 shows the I-V characteristic of the solar cell for a certain ambient irradiation (G_a) and a certain fixed cell temperature (T_c).

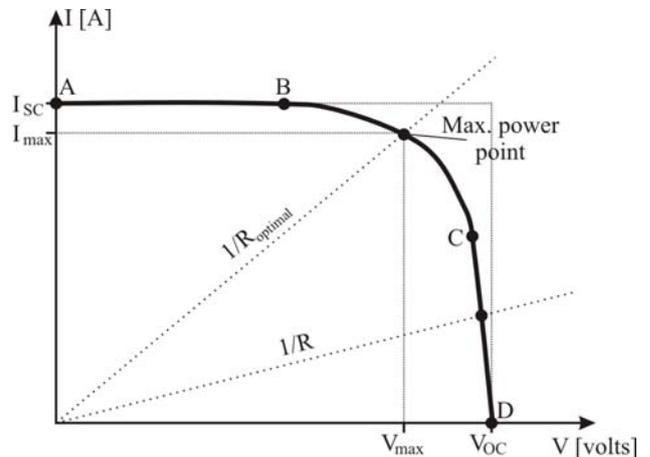


Fig. 6 Typical I-V characteristic of PV cell

In the representation of I-V characteristic, a sign convention is used, which takes as positive the current generated by the cell when the sun is shining and a positive voltage is applied on the cell's terminals. If the cell's terminals are connected to a variable resistance R , the operating point is determined by the intersection of the I-V characteristic of the solar cell with the load I-V characteristic. For a resistive load, the load characteristic is a straight line with a slope $I/V=1/R$. It should be pointed out that the power delivered to the load depends on the value of the resistance only. However, if the load R is small, the cell operates in the region A-B of the curve, where the cell behaves as a constant current source, almost equal to the short circuit current. On the other hand, if the load R is large, the cell operates on the region C-D of the curve, where the cell behaves more as a constant voltage source, almost equal to the open circuit voltage.

A real PV cell can be characterized by the following fundamental parameters,

- a- *Short circuit current* (I_{sc}) It is the greatest value of the current generated by a cell. It is produced under short circuit conditions ($V = 0$).
- b- *Open circuit voltage* (V_{oc}) corresponds to the voltage drop across the diode (p-n junction), when it is traversed by the photocurrent I_{ph} namely when the generated current is $I = 0$.
- c- *Maximum power point (MPP)* is the operating point ($V_{max} - I_{max}$) in Fig. 6, at which the power dissipated in the resistive load is maximum

$$P_{\max} = V_{\max} \cdot I_{\max} \quad (1)$$

d- *Maximum efficiency* (η_{\max}) is the ratio between the maximum power and the incident light power

$$\eta_{\max} = \frac{P_{\max}}{P_{\text{input}}} = \frac{V_{\max} \cdot I_{\max}}{A \cdot G_a} \quad (2)$$

where A is the cell area.

e- *Fill factor* (FF) is the ratio of the maximum power that can be delivered to the load and the product of I_{sc} and V_{oc} .

$$FF = \frac{P_{\max}}{V_{oc} \cdot I_{sc}} = \frac{V_{\max} \cdot I_{\max}}{V_{oc} \cdot I_{sc}} \quad (3)$$

The fill factor is a measure of the real I-V characteristic. Its value is higher than 0.7 for good cells. The fill factor diminishes as the cell temperature is increased.

In Fig. 6, an I-V characteristic of a PV cell for only a certain ambient irradiation G_a and only a certain cell temperature T_c is illustrated. The influence of the ambient irradiation and the cell temperature on the cell characteristics is presented in Fig. 7. Fig. 7(a) shows that the open circuit voltage increase logarithmically with the ambient irradiation, while the short circuit current is a linear function of the ambient irradiation. The arrow shows in which sense the irradiation and the cell temperature, respectively, increase. The influence of the cell temperature on the I-V characteristics is illustrated in Fig. 7(b). The dominant effect with increasing cell's temperature is the linear decrease of the open circuit voltage, the cell being thus less efficient. The short circuit current slightly increases with cell temperature [13-15].

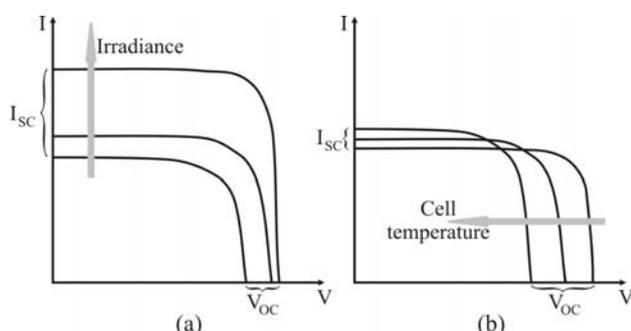


Fig. 7 Influence of the (a) ambient irradiation and (b) the cell temperature on the cell characteristics.

4 Performance Factors of PV Cells

When designing a PV system, some factors discussed are considered at different points in the design process. Solar intensity depends upon the site location – its prevalent weather, pollution, latitude, and percent shade. Operating temperature depends on the site location as well, but a cooling system using chill water piping will mitigate the effects of heat on cell efficiency. Finally, the mechanical and electrical controllers affect the sites operating performance. The mechanical controller tracks sun position and cants the PV cells to minimize the sun's incident angle, and the electrical controller loads the cell appropriately to maximize its efficiency [1], [16], [17].

4.1 Modules are rated in DC Watts at STC

All solar module manufacturers test the power of their solar modules under specific Standard Test Conditions (STC) in the factory. The test results are used to rate the modules according to the tested power output.

For example, a module tested in the factory, which produces 100 W of DC power, is rated and labeled as a 100 W STC DC solar module.

The Standard Test Conditions include, but are not limited to, a specific light intensity, light angle, and module temperature. Any differences from these specific test conditions affect the power output of the solar module [18].

4.2 Increasing Module Temperature Decreases Power (Temperature Factor)

Module operating temperature increases when placed in the sun. As the operating temperature increases, the power output decreases (due to the properties of the conversion material - this is true for all solar modules). The PV USA Test Condition (PTC) ratings take this into consideration by calculating the PTC ratings based primarily on the specific module temperature characteristics. The PTC ratings are different for each module, and can vary from approximately 87%-92% of the STC rating. A typical decrease in power output is approximately 12% for crystalline based solar modules.

This decrease results in a STC rated 100 W DC solar module being PTC rated at approximately 88 W DC [18].

4.3 Particulate build up ("Soiling")

When a module is placed outdoors, airborne particulates (e.g. dust, debris) settle on the glass surface of the module, similar to dust settling on

glass automobile windshields. These particulates block the amount of light reaching the module and therefore reduce the power produced by the module. Modules produce more power when exposed to more light! The reduction in power from particulate build up can range from 5%-15%. A typical value for this can be estimated at 7%. A module installed in a wet weather climate would have less "soiling" than a module installed in a drier climate, due to the rain water rinsing off the module's glass surface.

The effect of particulate build-up results in the power decreasing from 88 W to approximately 82 W [18].

4.4 System wiring and module output difference decrease (System Wiring/Module Output Differences Factor)

Typical solar electric systems require more than one module to be connected to one another. The wires used to connect the modules create a slight resistance in the electrical flow, decreasing the total power output of the system, similar to low pressure water flowing through a long water hose. In addition, slight differences in power output from module-to-module reduce the maximum power output available from each module. The system AC and DC wiring losses and individual module power output differences could reduce the total system rated energy output from 3%-7%. A typical value for these losses is 5%.

This result in the estimated power output is decreasing from 82 W DC to 78 W DC [18].

4.5 Inverter conversion losses

In order for the DC power from the solar modules to be converted to standard utility AC power (used by homes and businesses), a power inverter needs to be used.

The conversion from DC power to AC power results in an energy decrease from approximately 6%-10%, and varies for each inverter (primarily due to energy lost in the form of heat). A typical value for this loss is 6%.

This result in the estimated power output is decreasing from 78 W DC to 73 W AC [18].

4.6 Solar Module Tilt Angle

The module installation angle in relation to the sun affects the module energy output. The module produces more power (Watts), and resulting energy (Watt-hours), when the light source is located perpendicular to the surface of the module. For this reason, solar module installations are often tilted towards the sun to maximize the amount and intensity of light exposure.

As the sun angle changes throughout the year (higher in the sky during summer and lower in the sky during winter), the amount of light falling directly on the module changes, as does the energy output.

In Southern California, a typical optimum tilt angle for average module power production over the course of a year in a fixed tilt system is approximately 30 degrees. The typical Southern California residential roof is tilted approximately 15 degrees. The reduction in the average annual energy output for a module, which is mounted at a South facing, 15-degree tilt, is approximately 3% when compared to the optimal tilt angle of approximately 30 degrees. This results in the energy (from one sun hour exposure-1000 W/m² over one hour) decreasing from 73 W to approximately 71 Wh AC.

For flat mounted systems, the reduction in average annual energy output for a module is approximately 11% when compared to the optimal tilt of approximately 30 degrees [18].

4.7 Solar Module Compass Direction

As the sun moves across the sky throughout the day, from the East in the morning to the West in the afternoon, the compass direction, "orientation", (South, Southwest, East, etc.) of the module affect the cumulative energy output.

For this reason, it is optimal to install a South-facing module in order to obtain the maximum amount of direct light exposure throughout the day. If the module is facing East or West, it will be exposed to less direct sunlight as the sun moves across the sky. There is no loss factor for south facing modules, so the estimated energy (from one sun hour exposure-1000 W/m² over one hour) for this particular example will remain at 71Wh AC.

If the module was not facing south, the estimated module energy output would have been reduced. For example, a southwest-facing module estimated energy output would be reduced by approximately 3% [18].

4.8 Sun Hours

Every location on earth has a different amount of sunlight exposure throughout the year, which is measured in kWh/m² or Sun Hours. For example, a coastal California city like Long Beach will have a lower average amount of yearly Sun Hours than a desert California City like Dagget because of coastal fog and moisture in the air. Since solar modules produce power, and resulting energy, when exposed to sunlight, the more Sun Hours a location receives, the more energy will be produced from a module installed at that location.

"One Sun" is approximated as the peak noon sunlight power intensity in the middle of summer. "One Sun Hour" is energy produced by the peak noon sunlight intensity in the middle of summer, over one hour.

Recorded sun hour data for particular locations is used to help approximate the energy produced by a module, as it is the energy from the sun that is converted to energy from the solar module.

The amount of Sun Hours for one particular location differs from day to day. There are multiple Sun Hour data sources which slightly differ from one another. The U.S. Department of Energy and NASA have recorded this data for over 20 years and have calculated average daily sun hour data for most locations, which helps predict yearly energy output.

This recorded data shows an approximate daily Sun Hour average of 5.5 hours throughout the year for many Southern California locations.

The Sun Hours during the summer season average approximately 7.1 hours per day and the Sun Hours during the winter season average approximately 3.9 hours per day. These seasonal averages result in an average of approximately 5.5 Sun Hours per day ($7.1 + 3.9 / 2 = 5.5$).

In order to estimate the yearly energy production of a solar module, one simply multiplies the estimated module energy output (from one sun hour exposure- 1000 W/m^2 over one hour), 71 Wh AC, by the amount of Sun Hours for the particular location, 5.511. This results in approximately 391 Wh AC per day or 0.391 kWh AC per day.

When estimating yearly energy production, the estimated daily energy production, 0.391 kWh AC, is multiplied by the total number of days in the year, 365. This results in approximately 142 kWh AC energy production. One 100 Watt DC module will produce approximately 142 kWh AC of energy under the specified conditions in this example [18]. Researches show that, there are several major factors influencing the electrical design of the solar array for the photovoltaic energy systems.

5 System Description

In this study, resistive load is directly fed by PV panel. PV is polycrystalline panel which characteristic's is described in Table 1.

In experiment system current and voltage values measured with power analyzer. Power analyzer is connected PC via RS232 serial port. All measurements are recorded at PC with software. Against the power outage PC and power analyzer

fed by UPS. For this purpose experiment set was setup as shown in Fig. 8.

Table 1 Polycrystalline PV Characteristic

Quantity	Value
Open Circuit Voltage (V_{OC})	20.8V
Short Circuit Current (I_{SC})	3.3A
Voltage at Maximum Power Point (V_{MPP})	17.0V
Current at Maximum Power Point (I_{MPP})	3.0A
Maksimum Power (P_{MPP})	50W

Rating at 1000 W/m^2 irradiance, temperature 25°C
(Direct Current Values)

Solar irradiance measurements recorded with electronic weather station which is installed at the roof of the building. Solar irradiance values and PV output current, voltage and power values are merged in database file. These database files examined and several graphics plotted to understand correlation between these values for different weather conditions. Solar irradiance is depending meteorological conditions so PV output current and voltage is strictly related with it.

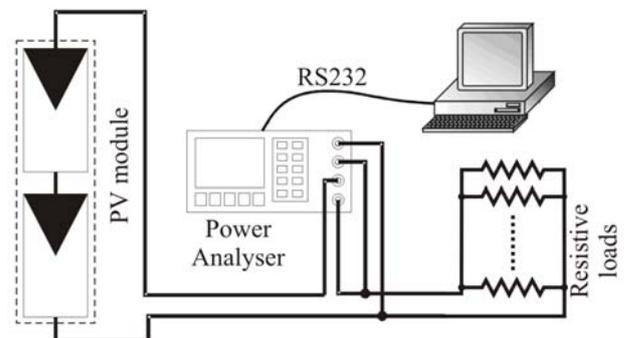


Fig. 8 Experimental setup for measurements

Resistive load is set of 18 parallel connected resistors. Each resistor 100Ω and 5W wire wound resistor. Ohmmeter measurements show that set resistance value is 5.5Ω including with contact resistance. Wire wound resistor used at load because long period load current exist in circuit which fed from PV. Fig. 9 shows the picture of experiment system.



Fig. 9 Experiment system with resistive load

fourth column PV output power which is calculated with $PV_{out} (W) / PV_{area} (m^2)$ are shown. Photovoltaic efficiency is found with $PV_{out} (W/m^2) / Radiance (W/m^2)$ formula.

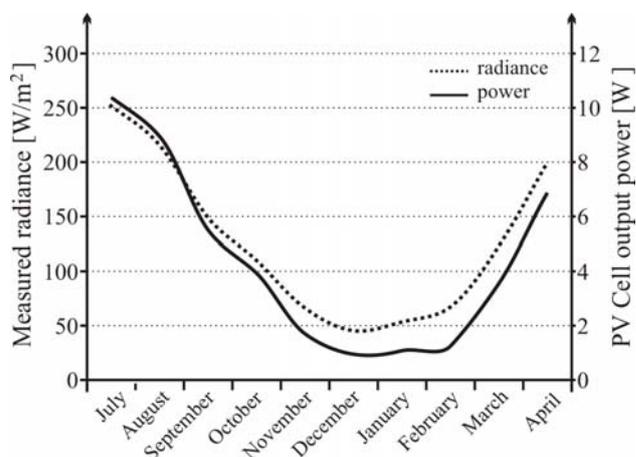


Fig. 10 Comparison of measured radiance and PV output power

6 Experimental Results

Experiments were done in Istanbul, Goztepe from 4 July 2008 to 30 April 2009. During ten months period load voltage (V) and load current (A) measured with 2 minutes intervals. Weather station recorded solar radiance (W/m^2) with 5 minutes intervals and these measurements were recorded during the day (24 hour).

Table 2 Measured and calculated values for PV

Months	Measured Radiance [W/m ²]	PV Out [Watt]	PV Area [m ²]	PV Out [W/m ²]	Efficiency
July	253.03	10.34	0.373	27.72	0.1095
August	218.28	9.025	0.373	24.19	0.1108
September	150.61	5.496	0.373	14.73	0.0978
October	110.98	4.016	0.373	10.76	0.0970
November	67.803	1.690	0.373	4.530	0.0668
December	45.680	1.010	0.373	2.709	0.0593
January	52.929	1.135	0.373	3.043	0.0575
February	68.303	1.295	0.373	3.472	0.0508
March	123.92	3.652	0.373	9.789	0.0790
April	200.07	6.898	0.373	18.49	0.0924

Experiment results are summarized at Table 2. In first two columns monthly average solar radiance (W/m^2) and PV out power (W) are given. Third Column PV surface area (m^2) (0.41×0.91) and

In Fig. 10 comparison between PV out power and measured solar radiance is shown. Solar radiance directly effects PV system output power. But this direct effect is slightly changed especially in December, January, February and March. PV efficiency curve is declined (Fig. 11) these months which is drowned data's from Table 2.

Table 3 Solar radiance and sun hours' comparison

Months	Measured Radiance (W/m ²)	Min. Peak Sun Hours (h/day)
July	253.03	10.4
August	218.28	9.4
September	150.61	8.0
October	110.98	5.2
November	67.80	3.3
December	45.68	2.2
January	52.92	2.4
February	68.30	3.1
March	123.92	4.6
April	200.07	6.0

Minimum solar peak hour's data are taken from Turkish State Meteorological Service for Istanbul-Goztepe and measured radiance values are shown in Table 3 [19]. PV efficiency is affected negative from decreasing of Minimum solar peak hour's and solar radiance.

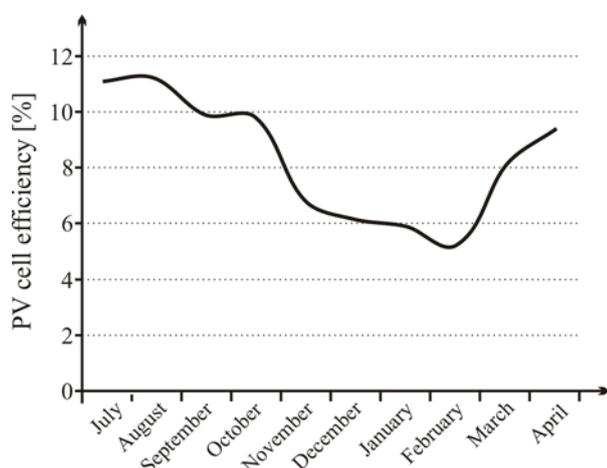


Fig. 11 Monthly change of efficiency graphic

7 Conclusions

In this study, production techniques of traditional photovoltaic cells are examined and polycrystalline stand-alone PV module performance is tested experimentally for Goztepe-Istanbul. Thus, the impact on efficiency of seasonal changes is intended to obtain. For this purpose, stand alone PV system is loaded with resistive load and output power is observed continuously. Experiment results have recorded during the 10 months period from July 2008 to May 2009.

As it is known, photovoltaic cell losses can be classified as optic losses resulting from reflection, energy carrying losses caused by bad combination or material quality, heat losses resulting from heating of electrons and optic power losses that occur because of wasting of infrared light in big size.

Experiments show that obtained power from PV cell varies linearly with solar radiation. However, the linearity is distorted a bit, especially in the month December, January and February (Fig. 10). According to experiment results Climate effects on PV system putt forward briefly. PV efficiency is reached %11 which is highest value in August and lowest value is %5.08 in February. Seasonal climate chancing is effected PV efficiency approximately % 50 percent.

Besides that PV efficiency is decreasing because of humidity, corrosion and equipment breakdown with time. For advanced studies to determining PV performance change depending on time, system will be followed and efficiency will be compared for same periods in several years.

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