Measurements of meteorological parameter effects on photovoltaic energy production

Şafak Sağlam, Bülent Oral, Sertaç Görgülü

***Abstract:* -** Photovoltaic systems (PV) use solar cells convert the sun's rays into electricity by exciting electrons in the cells using the photons of light from the sun. These conversion efficiency mainly related sun's rays and solar cells. The conditions which are effects sun's rays and solar cells firmly related with energy outputs of the PV systems. The energy yield is strongly associated with the weather because the electrical energy is produced directly from the solar energy. Most of the PV energy prediction models based on the meteorological parameters such as solar radiation, ambient temperature, relative humidity, wind speed, clearness index and sunshine duration. These meteorological parameters are associated with the geographical conditions where the PV systems installed. In this study, identical two photovoltaic panel systems are established in Istanbul and Kırklareli at Marmara region. Photovoltaic panel outputs and surface temperatures, solar irradiance values and meteorological parameters are measured and analyzed to find out regional differences.

***Keywords:* -** Photovoltaic System, Energy Production, Regional Differences, Solar Radiation, Surface Temperature, Meteorological Parameters

I. INTRODUCTION

ENERGY is a vital factor for the socio economic development of any country. About 80% of the world's energy demand comes from fossil fuel. However, till date coal is the major source of electricity with sharing of electricity by 42% and continues to be the prime source of electricity in many countries in the coming few decades. The highest levels of electricity will be generated in the non-OECD countries. The generation will be increased by an average of 3.3% per year than the demand of these countries [1].

Renewable energy sources have grown to supply an estimated 19% of the total global energy consumption in 2012. Of this total, modern renewable energy (wind, solar, geothermal, etc.) accounted for an estimated 10%, a share that has increased in recent years according to GSR2014 report.

It is known that solar energy has many advantages compared with renewable energy sources. These advantages include good availability, abundant, low maintenance and increasing efficiency. The total installed capacity of solar electricity, however, is much less than other modern renewables. But the growth rate of solar energy (%39) in the last year was the biggest value among the other renewable sources [2].

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Photovoltaic (PV) is the direct conversion of radiation into electricity. Photovoltaic systems contain cells that convert sunlight into electricity. Inside each cell there are layers of a semiconducting material. Light falling on the cell creates an electric field across the layers, causing electricity to flow. The intensity of the light determines the amount of electrical power each cell generates. Research on semiconductors (III–V and II–VI) based solar cells were studied since 1960 and at that time, new technology for polycrystalline Si (pc-Si) and thin-film solar cell have been establish in order to lower the material cost and energy input but increase the production capacity [3].

The main applications of photovoltaic (PV) systems are in either stand-alone (water pumping, domestic a street lighting, electric vehicles, military and space applications) or grid-connected configurations (hybrid systems, power plants). Unfortunately, PV generation systems have two main problems: the conversion efficiency of electric power generation is low (10-17%) especially under low irradiation conditions (such a seasonal variation in PV module conversion efficiency), and the amount of electric power generated by solar array changes continuously with weather conditions [4].

Efficiency is an important matter in the PV 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 and steady as to render this task easy. After a nearly half of a century of attempting it, cost still does not allow a widely usage of this technology.

A. *Overview of Solar Energy*

The Earth has two global movements that affect the reception of the solar energy to its surface: the rotation that it makes once on itself per day and the yearly revolution that it makes around the sun. The combination of these movements explains the daily changes in the reception of the solar light in particular places. The reason for which the energizing flux received to soil does not pass 1000 W/m2 is that the atmosphere modifies in an important way the direct radiance of the sun due to the following mechanisms [5]:

- absorption of light by the various gases constituent,
- diffusion by their molecules,
- absorption and diffusion by the dusts.

In addition, the solar flux received on a surface depends on [5],[6]:

- The orientation and the slant of the surface,
- The latitude of the place and its degree of pollution,
- The period of the year,

• The time considered in the day,
• The nature of the cloudy layers.

Solar panels can be placed on a roof or on the ground level if the place is cleared well. The orientation of the panel depends on:

• Impact angle: It is the angle formed by the solar panel and the solar rays. The optimal impact angle is an angle of 90°.
• Slant angle: It is the angle formed by the solar panel and the horizontal.
• Zenith angle: It is the angle formed by the solar rays and the horizontal.

The phenomenon named "photovoltaic effect" consists mainly in converting the solar light in electric energy by means of semiconductors devices named photovoltaic cells. The photovoltaic generator is constituted of a series and parallel association of the number of necessary modules to assure the requisite energy to product [5], [6].

The efficiency of PV panels is measured in the Laboratory at standard artificial (simulated) sunlight conditions, according to ASTM Standard E 948 and an associated bundle of standards [7].

These conditions refer to
A panel temperature of 25 °C
A solar insolation of 1000 W/m^2
An air mass AM=1.5 (ASTM G173) [8].

II. PV SYSTEMS EFFICIENCY FACTORS

The PV systems are, by nature, non-linear power sources that need accurate estimation of the maximum power generation and following the efficient operation among various distributed power sources. For the operation planning of power systems including PV systems, the accurate prediction of the maximum power from the PV systems is inevitable. The maximum power generation depends on the environmental factors, mainly the irradiation and the cell temperature. The

Measurement of the temperature is easy compared with that of the cell temperature [9].

In addition, the wind velocity is also easy to get. Therefore, the environmental factors such as the irradiation, the temperature, and the wind velocity are utilized for the prediction of the maximum power in the studies.

Efficiency is an important matter in the photovoltaic (PV) 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. After a quarter of a century of attempting it, cost still does not allow a generalized use of this conversion technology [10].

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 [9][10].

Solar cells have three important output characteristic parameters: the first one is open voltage, that is to say, when there is no current in the circuate, the produced voltage after lighting. The second one is the short-circuit current density (Jsc), that is to say when the extra electric field is zero, the current in the circuate. The third one is the fill factor (FF), it refers to the specific value between maximum output power (UmJm) and the product of open voltage short-circuit current.

When the load resistance of solar cells is zero (RL→0), can detect short-circuit current of solar cells, When the load resistance of solar battery is infinite (RL→∞), can detect the open voltage. Solar battery open voltage is relative to the spectral intensity, have no relation with the cells size. Solar cells open voltage is proportional to the incident spectral irradiance. An ideal solar battery have small series resistance Rs, while the leakage resistance Rsh is large [11].

A. *Meteorological Parameters*

Meteorological parameters such as solar radiation, ambient temperature, relative humidity, wind speed, clearness index and sunshine duration, are accepted as dependable and widely variable solar energy sources. Therefore it is important to be able to formulate forecasting and estimation models of these meteorological data. These data play a very important role conversion to electricity in PV systems. However, in many cases these data are not available owing to the high cost and complexity of the instrumentation needed to measure and record them.

Solar cells convert the sun's rays into electricity by exciting electrons in the cells using the photons of light from the sun. These conversion efficiency mainly related sun’s rays and solar cells. Sun’s rays follows a long distance (approximately 40 km) passing through the atmosphere. (Fig. 1) On the surface of the earth, we perceive a beam or direct solar irradiance that comes directly from the disc of the sun and a diffuse or scattered solar irradiance that appear to come from all directions over the entire sky. Meteorological phenomena performed in the troposphere layer [12].

The conventional methods (empiric, analytic, numeric simulation and statistic approaches) for estimation and modelling of the meteorological data especially solar radiation are reviewed in several studies in this area.

Despite the significance of solar radiation measurements, they are not yet available everywhere in the world. Due to the cost and maintenance and calibration requirements, this information is not readily available in many developing countries. Therefore, it has been of great importance to propose an efficient alternative to be used as a solar radiation estimator based on other more readily available meteorological data.

Several empirical models for calculating solar radiation have been suggested in literature. Some of these models use variables like sun hours, air temperature, relative humidity, and cloudiness. The most widely used parameter to estimate solar radiation is sunshine duration, which can be easily and reliably measured everywhere of the earth’s surface.

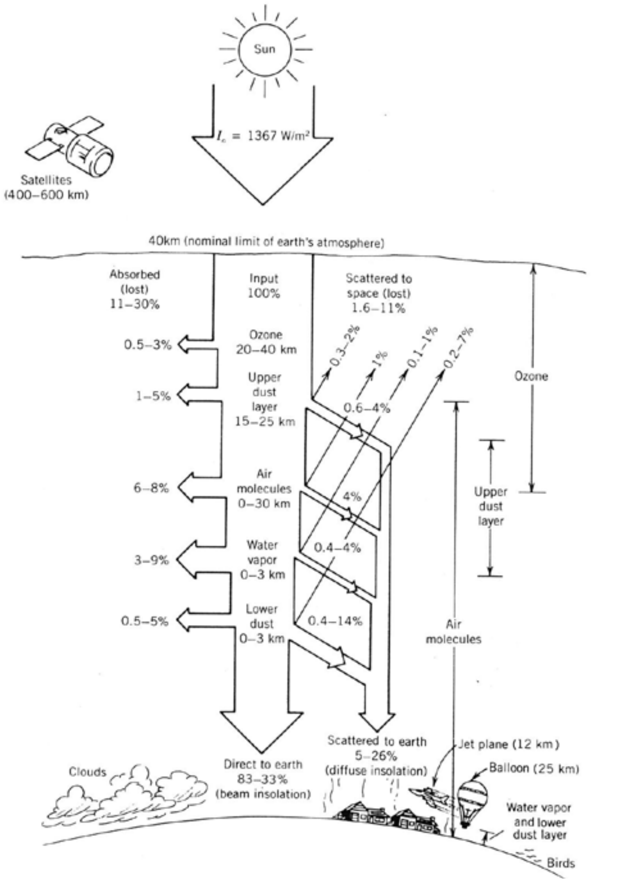

Fig. 1 Nominal range of clear sky absorption and scattering of incident solar energy[12].

Angstrom regression model is the most commonly used method, which is a linear correlation between the average daily global radiation to the corresponding value on a completely clear day and the ratio of average daily sunshine duration to the maximum possible sunshine duration. Prescott suggested replacing the clear sky global radiation with the extra-terrestrial radiation, producing a more convenient form of Angstrom equation called Angstrom – Prescott regression model [13].

III. MEASUREMENT SYSTEM

In this study, identical two photovoltaic panel systems are established in Istanbul and Kırklareli at Marmara region (Fig. 2).

Istanbul is located north east part of the Marmara region. While joining Black Sea and Marmara Sea, Istanbul Straits divides Asian and European Continent as well as Istanbul City. The province is bordered by high summits of Kocaeli Mountain Ranges in the East, by Marmara Sea in the South and waterline of Ergene Basin in the West. Experiment set located 29° 03′10.20″east and 40° 59′07.66″ north latitudes, approximate altitude is 40 meter.

Fig. 2 The Locations of the İstanbul and Kırklareli

Kırklareli is located north west part of the Marmara region. The province is bordered by high hills of İstanbul Çatalca in the East, by Edirne in the South and Bulgaria border in the West. Experiment set located 27° 11′07.27″east and 41° 38′21.53″ north latitudes, approximate altitude is 169 meter.

İstanbul climate is affected by the Marmara Sea and Black Sea against the Kırklareli's terrestrial climate so it has a shorter sunshine hours then the Kırklareli as shown in Table 1.

Table 1 Mean monthly sunshine hours[14]

Month	İstanbul	Kırklareli
Jan	71.3	89.9
Feb	87.6	109.2
Mar	133.3	164.3
Apr	180.0	204.0
May	251.1	272.8
Jun	300.0	282.0
Jul	322.4	322.4
Aug	294.5	319.3
Sep	243.0	240.0
Oct	164.3	167.4
Nov	102.0	114.0
Dec	68.2	68.2
Year	2,217.7	2,353.5

In the experiment sets, resistive loads are directly fed by identical PV panels. PV's 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[15]. Against the power outage PC and power analyzer fed by UPS (Fig. 3).

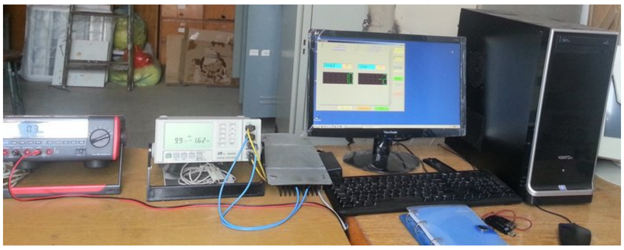

Fig. 3 Experiment set and resistive loads

PV's are polycrystalline panel which characteristics are described in Table 2.

Table 2 Polycrystalline PV Characteristic

V_{oc}	19.48 V
I_{sc}	2.75 A
V_p	15.84 V
I_p	2.53 A
P_p	40 W

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

PV panels are mounted at the roof at both two sets but their angles are different. In İstanbul Göztepe PV's tilt angle is 20° and the other one in Kırklareli Kavaklı 45°.

(a) (b)

Fig. 4 Photovoltaic panels a) İstanbul, Göztepe b)Kırklareli, Kavaklı

Meteorological data's measured with meteorology stations (Davis Vantage Pro Plus 2) during the experiments. Stations where located the same roof with the PV panels and directly connected to PC. Meteorological data's outside temperature, humidity, air pressure, wind speed, wind direction and solar radiation measured and recorded with five minutes intervals.

PV panel's surface temperature measured with digital thermometer (TES 1307) and K type probe placed to surface using thermal band. Solar total radiation on the panel surface measured with solarimeter (Kimo CR 100). These devices recorded data 2 minute intervals on the PC using software (Fig. 5).

Fig. 5 Thermometer and solarimeter with their probes mounted on PV panel.

PV systems measurements synchronization is significant problem. Especially solar radiation values and PV panel outputs can be change in seconds because of the cloud or fog cover. For that reason in the experiment sets whole measurement devices directly connected PC to make synchronization.

IV. EXPERIMENTAL RESULTS

Experiments were done in Istanbul, Göztepe and Kırklareli, Kavaklı from September 2012 to June 2013. During ten months period resistive load voltage (V), load current (A), PV panel surface temperature (T) and solar total radiation (R) measured with 2 minutes intervals. Meteorological parameters (outside temperature, humidity, air pressure, wind speed, wind direction and solar radiation) measured with 5 minutes intervals. PV panel's output powers are summarized with four sample graphics for seasons of the year.

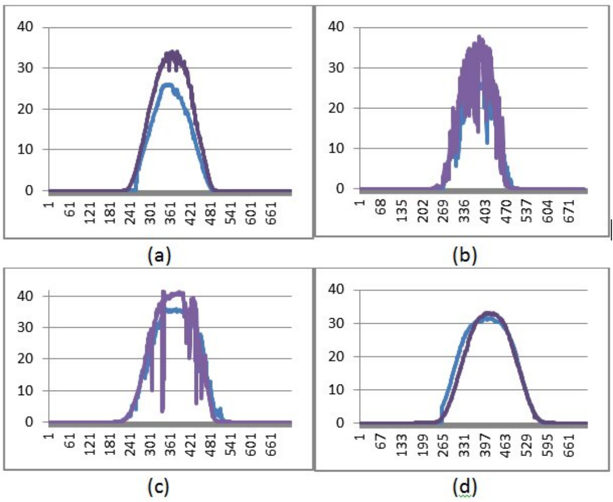

Fig. 6 PV panels output powers for seasons of the year

In graphics blue line shows the power output for İstanbul and purple line for Kırklareli. In Fig. 6-a it can be seen peak power of the PV's in Kırklareli higher than İstanbul nearly 10 watts at autumn (27.11.12)

Due to terrestrial climate in Kırklareli especially at winter months sunshine hours is longer and PV's efficiency is better than İstanbul. Tilt angle of the panel steeper 25° in Kırklareli against the İstanbul. Especially in winter months this is advantage because of the solar orbit. So the output power is higher in Kırklareli than İstanbul in Fig. 6-b at 14.01.13.

In third graphic (Fig. 6-c) it can be seen clearly that weather is cloudy in Kırklareli. But still PV peak power is higher in Kırklareli then İstanbul nearly 5 watts at 18.03.13.

In summer season panel tilt angle is advantage for Istanbul but still in Kırklareli PV's peak power higher than Göztepe İstanbul at 26.06.13 (Fig. 6-d). Clear sky conditions and less humidity are important factors effect the PV's performance positively in Kırklareli.

PV panel output power (Power) is plotted together with panel surface temperature (P.Temp) and air temperature (O.Temp) for İstanbul (I) and Kırklareli (K) in Fig. 7 and Fig. 9. PV panel surface radiation level (P.Solar) and solar total radiation (O.Solar) graphics plotted with the PV panel output power (Power) together in Fig. 8 and Fig. 10.

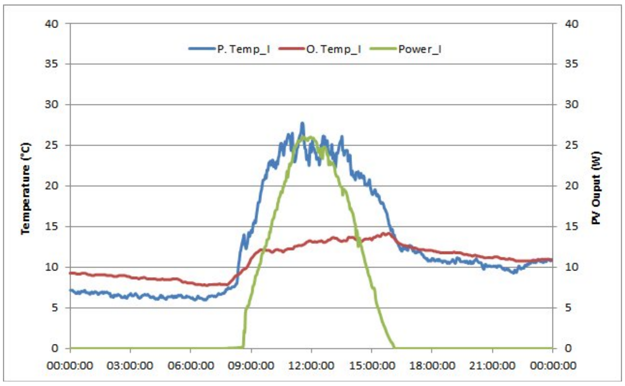

Fig. 7 PV surface temperature, outside temperature and PV output power comparison for İstanbul

Efficiency of the PV panel depends on the temperature. In Fig. 7 PV panel surface temperature, outside temperature and PV output power comparison for İstanbul plotted together in autumn season. Panel surface temperature increased during the day and reached 27 °C against the maximum value of the outside temperature 14 °C. It's decreasing after the solar energy falling with time and under the air temperature till the morning.

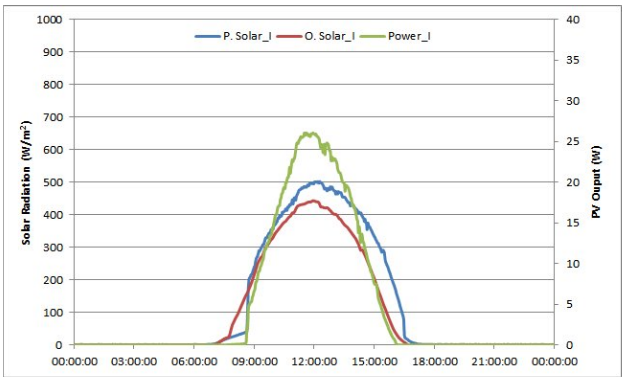

Fig. 8 PV surface solar radiation, outside solar radiation and PV output power comparison for İstanbul

Solarimeter sensor attached the PV panel left side to measure the surface solar total radiation. Sensor position is parallel to panel surface so panel tilt angles same for sensors. Meteorology station solar sensor is parallel to horizon so its tilt angle assumed 0°. For that reason there is a difference between two sensors measurement results. PV panel power output increased accordance with the solar radiation. There is a fluctuation on the power curve because measurement intervals 2 minutes against the solar sensors 5 minutes. After the 14:00 sunlight azimuth angle decreasing, solar radiation and PV power outputs decrease too (Fig. 10).

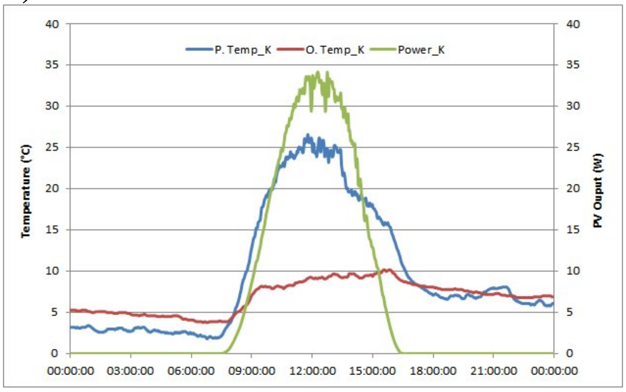

Fig. 9 PV surface temperature, outside temperature and PV output power comparison for Kırklareli

In Kırklareli weather conditions is different from the İstanbul because of the terrestrial climate so air temperature (O. Temp_K) and panel surface temperature lower for the same day (27.11.12). Panel surface temperature is increased with solar radiation till the noon same in İstanbul. But PV power output is higher (34 W) than İstanbul because air humidity is less. Average value of air humidity % 62 in Kırklareli against the % 81 in İstanbul.

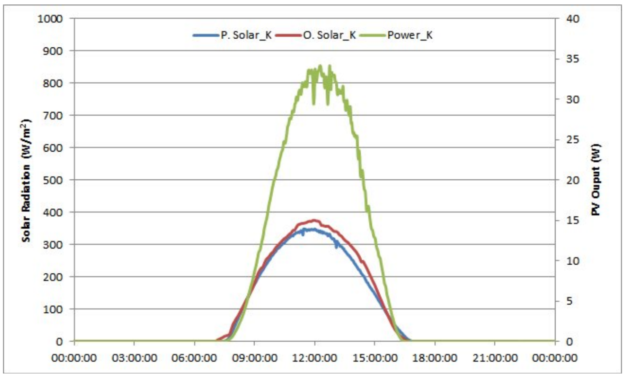

Fig. 10 PV surface solar radiation, outside solar radiation and PV output power comparison for Kırklareli

In Kırklareli solarimeter sensor is attached the PV panel upper right corner, parallel to horizon to measure panel surface solar total radiation. It can be seen clearly weather station solar radiation values and panel surface solar radiation measurement results so close (Fig. 10). Solar radiation values are less than İstanbul results but PV power output power values are higher. In the experiment set panel tilt angle is steeper, surface temperature is lower and air humidity levels are below the İstanbul's values. As a result of these factors PV output power values higher than İstanbul.

V. CONCLUSIONS

In this study electrical energy which is produced from standalone PV systems is measured experimentally for Istanbul and Kırklareli. Standalone PV systems are loaded with resistive characteristic loads and output power is observed continuously.

Based on two-minute interval photovoltaic generation power data of photovoltaic systems in İstanbul-Göztepe and Kırklareli-Kavaklı from September 13, 2012 to June 30, 2013 and the same period with five minute interval meteorological data from meteorology stations, this paper analyses the influence of meteorological factors on solar photovoltaic generation power. The results show that the daily and hourly solar photovoltaic generation power is highly positively correlated with the sunlight and the solar radiation. The longer sunshine time and the stronger solar radiation intensity produced the more output power. The cloud amount and relative humidity play a role of weakening on the efficiency of photovoltaic power generation. The influence of lower cloud amount is larger than the total cloud amount. At the same time the cloud form has the significant influence. The influence of temperature on the efficiency is very complicated; the efficiency would decrease along with the increase of the temperature. The further research is needed to understand this correlation exactly.

Experiment results have recorded during the 10 months periods covers the different seasonal weather and atmospheric conditions. According to experiment results Climate effects on PV system putt forward briefly. PV peak electrical energy production is reached which is highest value in June and lowest value in February. Seasonal climate chancing is effected PV efficiency approximately % 50 percent.

Besides that PV's output power changes monthly according to the seasons there is another reason is geographical conditions are different in İstanbul and Kırklareli. Black Sea, Marmara Sea and Bosphorus changes the climatic effects on PV's in İstanbul. Humidity and fog main problems are effects the PV's efficiency in İstanbul. For advanced studies to determining PV performance changes depending on climatic conditions, system will be followed with measuring surface temperature and efficiency will be compared for same periods in several years.

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