Energy Yield Estimation, Installation and Monitoring of 3-Phase Grid Connected PV System

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Abstract

This paper describes installation and analysis of photovoltaic system (PV) which has been installed in Soke/Aydin, Turkey. Generally, the PV systems are installed on roof according to inclination of roof as well north facade. Therefore, large losses occur. In order to minimize losses, for the first time in Turkey the PV panels were placed both on North and South facade with 15 and 10 degree angle to the South, contrary to traditional roof installed PV systems. In this way it was determined that efficiency of PV panels especially the ones that are positioned at North facade were increased by 10%. The simulation of the system was done using different sun irradiation sources such as Geomodel, Meteocontrol, Meteonom and PVGIS. The total DC power of the system is 155.3 kWp. Annual electricity production amount and performance ratio was calculated as 243 MWh and 80.9% respectively for the first year. The uncertainty of the models and calculation steps with respect to the average specific yield and average yield is estimated to be ± 7.1% assuming a simple standard deviation. The PV system has produced 50.522 kWh energy from January to April, 2014.

Key Words — Annual Energy Yield, Grid Connected PV, Installation, Performance Ratio, Photovoltaic Systems

1 Introduction

Energy procurement is the most important problem and it is fast becoming a critical element in the world at the present time. Especially in the developed countries, generation and usage of energy is not sustainable. Since, the energy is generally obtained from fossil based sources (80-85%). The main important problems with fossil based sources are that they cause air pollution and climate change, there is a limited amount of them and their prices are not stable. The most convenient alternative against the usage of the fossil based sources in energy procurement is using renewable energy sources. Renewable energy sources don't pollute the air, they reduce the dependence on foreign energy and they don't have input cost due to the energy raw material. Because of all these advantages the renewable energy sources attract more attention day by day [1]. All over the world between 2004 and 2011, new investments in renewable energy field reached 260 billion dollars from 54 billion dollars. This means an increase of approximately 381 percent in 7 years. Although there was an economic crisis on the world between the years 2008-2011, considerable amounts of investments had been made. It is seen from the sectors quality reports that investments in wind and solar energy are higher than other renewable energy sources [2]. Photovoltaic's market had an extraordinary growth around the world in 2011 compared to the previous year and total installed power had reached 70 GW. According to this information, in 2011, approximately 30 GW of new photovoltaic systems had been installed. At the end of 2012, installed PV capacity had reached 136 GW [3]. PV power capacity had reached 35.717 MW, 18.600 MW and 17.928 MW in Germany, China and Italy respectively in 2012. Although Turkey has much more solar energy potential than the mentioned countries Turkey has only 18 MW installed PV power capacities [4].

In this study, grid connected PV system which power is 155.3 kW was installed in accordance with regulation of unlicensed electricity generation in Turkey. The biggest problem for individual investor is the high period of redemption. The period of redemption can reduced either reduces the capital cost or increase of the annual production amount. PV panels were placed both on North and South facade with 15 degree angle to the South, contrary to traditional roof installed PV systems. Furthermore, shading effect of PV panels was minimized using mathematical calculations according to position of the roof, PV panel specifications and sun movement in the region. In this way, it was determined that efficiency of PV panels was increased by 10%. The whole system's model was prepared using different simulation program for determine the energy yield and losses. It was seen that annual electricity production amount, performance ratio and uncertainty of the model was calculated as 243 MWh, 80.9% and ± 7.1%respectively for the first year. Depends on PV technology the electricity production amount and performance ratio will change year by year.

2 Materials and Methods

2.1 Meteorological data, system design and components

2.1.1 Data Sources

The PV system has been installed in Soke/Aydin (37^0 44'N 27^0 26'E). For this location, various data sources were used to determine the meteorological conditions such as Geomodel, Meteocontrol, Meteonorm and PVGIS (photovoltaic geographical information system). Table 1 shows annual global radiation on a horizontal plane, diffuse fraction of radiation and temperature for the location.

Table 1. Annual Global Radiation, Diffuse Fraction of Radiation and Temperature

Data Sources	Global Radiation on a Horizontal Plane (kWh/m²)	Diffuse Fraction of Radiation (%)	Temperature (⁰C)
Geomodel	1829	35	17.9
Meteonorm	1572	45	18.3
PVGIS	1909	-	-
Meteocontrol	1827	-	-

The annual global radiation value, the ratio of direct to diffuse radiation as well as the ambient temperature at the site is used according to Geomodel.

2.1.2 Sytem Design

In this project, a PV system with six subsystems installed at this site. The modules of a PV system were installed with a specific tilt angel and orientation. The title and orientation of the PV system are listed in Table 2.

Table 2. Inclination and Orientation of the PV

Subsystem	Module Tilt Angel (^{0})	Module Orientation (^{0})
Roof	15	137
Porch	10	137
Ground	25	137

A certain number of modules were mounted vertically above each other. The module row height is calculated as the product of this number of modules above each other and the length or the width of the individual module. The unobstructed gap between two adjacent rows is defined as the unobstructed distance between the two rows. The shading angle is calculated from the unobstructed gap between two rows and the ground slope, if applicable. Figure 1. shows the geometrical installation of the PV System.

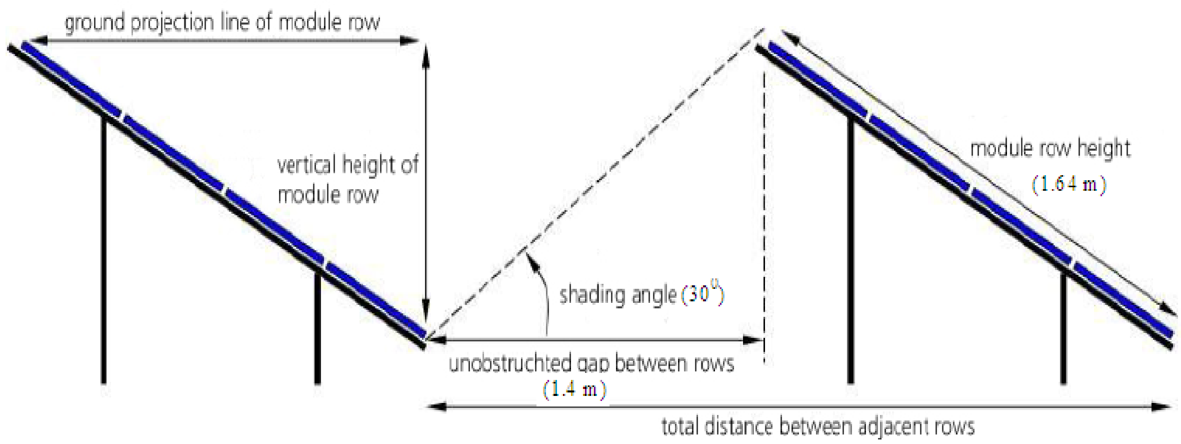

Figure 1. Geometrical Installation of The PV System

This PV system is installed with modules from BYD Company, model 250P6C-30 and inverters from Delta Energy System, model Solivia 30 EU T4 TL. The components distribution, the electric circuit connection type and the DC total power are given Table 3.

Table 3. Subsystem Distrubution and Component Arrangement

Subsystem	Modules per String	String per Inverter/MPPT	Inverters per Subsystem	Modules per Subsystem	Installed Power (kW)
Roof	20	6	2	240	60
Porch_1	21	3	1	63	15.8
Porch_2	22	3		66	16.5
Porch_3	21	6	1	126	31.5
Porch_4	21	5	1	105	26.3
Ground	21	1		21	5.3
Total			5	621	155.3

In this system minimum inverter MPPT voltage is 480 V and maximum inverter MPPT voltage is 800 V. String MPP voltage values are between 503 V – 522 V at maximum module temperature. String MPP voltage values are between 675 V – 742 V at minimum module temperature. String open circuit voltage values are between 827 V – 910 V and inverter current values are between 9 A. – 51 A. at maximum module temperature. With these values and the specified system configuration, the modules and inverters do comply with the specifications.

2.1.3 Components

The most important two component of the PV power system are PV module and inverter. Technical specifications of the modules and the inverters which are used in this PV system are shown in Table 4 and Table 5.

Table 4. Datasheets of the Modules

Cell Type	Polly-Si
Rated Power (Wp)	250
Voltage at MPP (V)	30.1
Current at MPP (A)	8.30
Open Circuit Voltage (V)	37.7
Short Circuit Current (A)	8.81
Temperature Coefficient for Power (%/K)	-0.43
Temperature Coefficient for Voltage (%/K)	-0.32
Tolerance for Rated Power (W)	0/+5

Table 5. Datasheets of the Inverter

AC Rated Power (kVA)	30
Limitation of Effective Power (kW)	30
Maximum DC Power (kWp)	31
Maximum DC Voltage (V)	1000
MPPT Voltage Range (V)	480-800
Maximum DC Current (A)	68
Maximum Efficiency (%)	98.2*
*Reffered to a DC Voltage of 640 V	

2.2 Simulation and Calculation Procedures

The life time of the installed PV modules is at least 20 years. Depending on the type of cell technology, various effects of output power reduction can occur [5]. If crystalline silicon modules are used, the decrease of rated PV capacity was found to be on average 0.25 %/yr [6]. In the literature, the degradation rates of PV system are varied between the 0.23 %/yr – 0.59 %/yr for crystalline silicon modules [7]. In this work, I have considered the degradation rates as 0.25%/yr. There are many factors to calculate and simulate annual energy yield. These factors are radiation on the module plane, losses due to shading, losses due to soling and snow, deviation from standard test conditions, losses due to the inverter, module losses due to mismatch and cable losses for the modules. I considered all of these parameters when I simulated and calculate this PV system. The losses leading to the average specific yields and performance ratios (PR) were determined. As an illustration, Table 6 is indicated this parameters for roof subsystem.

The performance of PV systems depends on several parameters which are mentioned above. The PR is used to determine overall behaviour of the PV systems. The performance ratio is independent from the irradiation and orientation of a PV plant therefore useful to compare systems. It takes into account all pre-conversion losses, inverter losses, thermal losses and conduction losses. PR is defined by the EN 61724 standard [8]. The PR is calculated according to the equation 1.

$$PR = \frac{Y_f}{Y_r} = \frac{\frac{E_{ac}}{P_0}}{\frac{H}{G_{STC}}} \qquad (2.1)$$

Where, Y_f; solar yield, Y_r; reference yield, E_{ac}; electrical energy at AC side (kWh) in actual conditions, P_0; nominal power of the PV plant, H; solar energy or irradiation on PV plane (Wh/m²), G_{STC}; reference irradiance in STC conditions [9]. The PR value is higher in the winter than in the summer and has a value between 0.6 and 0.8 [10]. High PR value means that the system is more efficient. Average specific yield, average yield and the corresponding PR for each of the subsystems are shown in Table 7.

Table 7. Results for the PV System

Subsystem	Installed Power (kWp)	Initial Specific Yield (AC)(kWh/kWp)	Initial Yield (MWh)	Initial PR	PR over 20 Years
Roof	60.0	1502	90	77.1	75.2
Porch_1	15.8	1598	25	83.2	81.1
Porch_2	16.5	1598	26	83.2	81.1
Porch_3	31.5	1599	50	83.2	81.1
Porch_4	26.3	1599	42	83.2	81.1
Ground	5.3	1681	9	85.1	83.0
Total or Average	155.3	1564	243	80.9	78.9

The reason for PR values of the PV panels that were positioned on the porch are greater than the ones that were placed on the roof is, panels on the roof cause shade to each other during sunset especially in the winter. However the simulation results showed that if the panels that were placed on the north facade of the roof not turned towards the south with 15 degree angle the PR value would be 10% lower.

2.3 Mechanical Analysis of PV Modules Construction

Table 6. Annual Values of Energy Generations, Looses and PR

	Uncertainty	Value(kWh/m²)	Gains/Losses (%)	PR (%)
Global Irradiation on Horizontal Plane	5.0	1829		
Irradiation on Module Plane	2.5	1951	6.7	
Horizon Shading	0.5	1950	-0.1	100
Row Shading	2.0	1764	-9.5	90.5
Object Shading	3.0	1764	0.0	90.5
Soiling	2.0	1738	-1.5	89.1
Deviations from STC Reflection Losses	0.5	1691	-2.7	86.7
Spectral Losses	0.5	1674	-1.0	85.9
Irradiation-dependet Losses	0.5	1657	-1.0	85.0
Temperature-dependet Losses	1.0	1557	-6.1	79.8
Interconnection Losses	0.5	1544	-0.8	79.2
DC Cable Losses	0.5	1539	-0.3	78.9
Inverter Looses	1.5	1506	-2.1	77.3
Inverter Power Limitation	0.5	1506	0.0	77.3
AC Cable Losses at Low Voltage	0.5	1502	-0.3	77.1
Total	**7.3**	**1502**		**77.1**

Depending upon to the type of roof, the mounts need to be attached in a manner that will ensure that the roof will not leak at the roof penetrations. PV module layout is important for aesthetics and to assist in cooling the modules. A common structural material used for array mounts is corrosion resistant aluminium. The location of module junction boxes is important due to the lengths of electrical wiring. Modules are normally installed in groups that produce the desired source circuit voltage [11]. The PV systems are often installed according to the aesthetics, performance and minimal wind loading. These are important factors but if we want to build a durable structure we must pay attention to the placement of PV modules. The most important factor in the installation of PV modules is wind load. There are some standards for design of PV modules structure. Installation of the modules must be proper according to Turkish Standards Institute (TSE) in Turkey. The standard of the TSE about this topic is TSE 498, TSE 648 and TSE 500 [12, 13, 14]. Endurance test of anchor bolt is done according to this standard.

The maximum pulling force to the anchor bolts due to the effect of wind;

$$P = A(-0.4)q \tag{2.2}$$

Where, P: Pulling force (kg), A: Critical area, q: Distributed load (kg/m^2).

Cutting resistance for anchor bolts

$$P_{cr} = AF_{v,cr} \tag{2.3}$$

Where, P_{cv}: cross sectional area of bolts (kg).

Crushing strength for bolts

$$P_{cr} = D.L.F_v \tag{2.4}$$

Where D: Diameter of bolt, L: thickness of deck sheet, F_v: usable cross sectional area. Figure 2 shows mounting diagra m of PV modules.

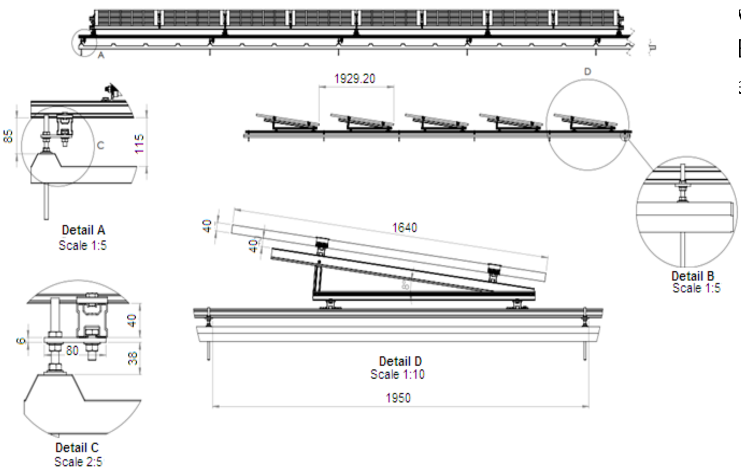

Figure 2. Mounting Diagram of PV Modules

Appearance of installed grid connected PV power system is shown in Figure 3.

Figure 3. Appearance of Grid Connected PV System

3 Experimental Results

The PV system has been producing energy since January 1^{st}, 2014. In this power system, 5 inverters (30 kW each) have been used. The measurement values of the systems can be monitored remotely. Fig. 4 illustrates the value of the AC power in the each inverter output for January 20, 2014.

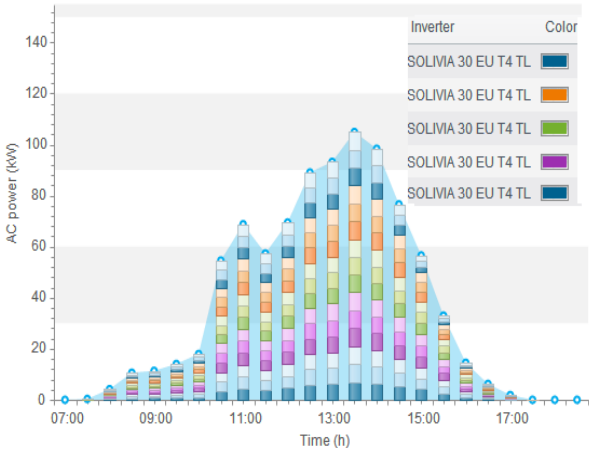

Figure 4. AC Output Power of The Inverter

The system's energy production values can be monitored on a daily, weekly and monthly basis. The energy generating values for January are shown in Fig. 5

The PV system has generated 50522 kWh electrical energy until April 09, 2014. The measured actual values for 3 months are observed to be similar to the simulation results. Also, until now about 32.1 t CO_2 emissions have been avoided under favour of this system.

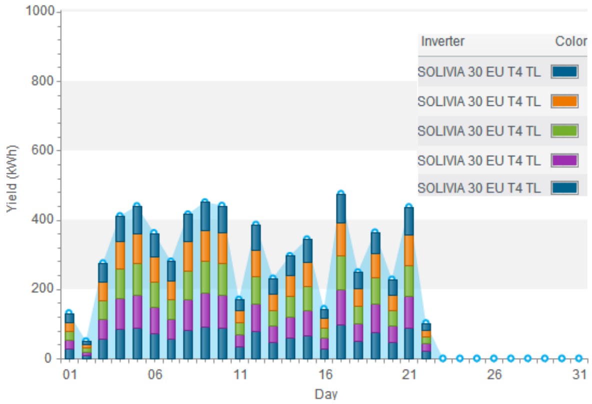

Figure 5. Energy Generating Values

4. Results and Discussion

Technical evaluation and simulation of three phase grid connected PV system have been executed in this study. This study indicates that grid connected PV system applications could grow substantially in Turkey like other advanced countries due to the ease of application and competitiveness ratio.

In this paper, I discussed energy production of a 155.3 kW grid connected PV system. Energy yield, power, voltage and current of PV system were monitored remotely in a daily, weekly and monthly basis. For installation site, with an average annual global irradiation on a horizontal plane of 1829 kWh/m^2, an initial average annual specific yield of 1564 kWh/kWp is predicted. For the given system dimensions, this leads to an average annual yield of 243000 kWh for the first year. The expected performance ratio of the system is 80.9 % for the first year. Taking the degradation effect of crystalline modules into account, the resulting specific annual yield over an operation of 20 years is expected to be 1525 kWh/kWp, and then the average yield is 237 MWh and the performance ratio is 78.9 %. With this background, it was seen that the grid connected PV system is a good profit-generating investment in the long term. In the system the PV panels were positioned with 3 different angles, by this 3 different positioning the suitable positioned for PV panels are determined. Especially, in north facade installing the system at a certain angle to the south increases the efficiency with 10%.

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