Performance Evaluation of Serhatkoy (1.2 MW) PV Power Plant

Ozgur C. Ozerdem[1], SamuelNii Tackie[2], Samet Biricik[1]

[1]European University of Lefke,Gemikonağı – Lefke,TRNC Mersin 10 / TURKEY
oozerdem@eul.edu.tr, sbiricik@eul.edu.tr
[2]Near East University, TRNC Mersin 10 / TURKEY
samuel.niitackie@neu.edu.tr

Abstract

Solar energy continues to play vital role in the delivery of clean and affordable source of generating electricity. Photovoltaic is the most promising technology amongst the types/methods of producing electricity from solar energy. The aim of this research is to evaluate the performance of Serhatkoy PV power plant (1.2 MW). Being the first grid-connected PV plant in north Cyprus, the results of this research will be useful in expanding the existing solar park or replicate same facility in locations with favorable weather conditions, evaluate the investments made, plan maintenance and estimate the efficiency of production. PVsyst software is used to model Serhatkoy PV power plant and simulation done to determine the performance ratio using meteorological data from NASA. Also the capacity factor (CF) and performance ratio (PR) are calculated. SAM formula proposed NREL is used to calculate the PR. The paypack period of the plant is also determined using exchange rate between Turkish lira and euro.
Keywords: Solar energy, photovoltaic systems, performance ratio, Capacity factor, payback period

1. Introduction

The demand for electricity has surged over the years; this is due to the rise in consumption of power by both developed and developing nations. This demand is expected to grow by 37% by 2040[1]. Renewable energy sources (solar, wind, hydro bio-gas etc) of producing electricity are safe, cheap, clean and environmentally friendly. Solar energy becomes useful when the sun's radiation is converted into other forms of energy such electric power, heat energy, mechanical energy etc. Photovoltaic technology uses solar cells to trap radiations (photons) from the sun, photons liberate electrons in the cell to flow; flow of these electrons is electricity. Photovoltaic system is a success story in most developed countries like Germany, Japan, USA etc; this makes it relatively easy to replicate such facilities in other countries (example north Cyprus) with PV-favorable weather conditions. PV systems can either be stand-alone or grid-connected. The efficiency of commercial PV panels is affected by three parameters; the panel efficiency, inverter efficiency and maximum power point tracking [4].PV panels produce DC voltage; this DC voltage is then converted into AC voltage by inverters [10].

The installed capacity of global grid-connected PV system has increased over the years, by the end of 2013; the total installed capacity amongst IEA PVPS countries was 125GW. 3.6GW power by photovoltaic systems is believed to have been installed over the last 12years according to European Photovoltaic Industry Association [5]. Figure 1 shows the trend of growth of photovoltaic systems from 2000 to 2013.

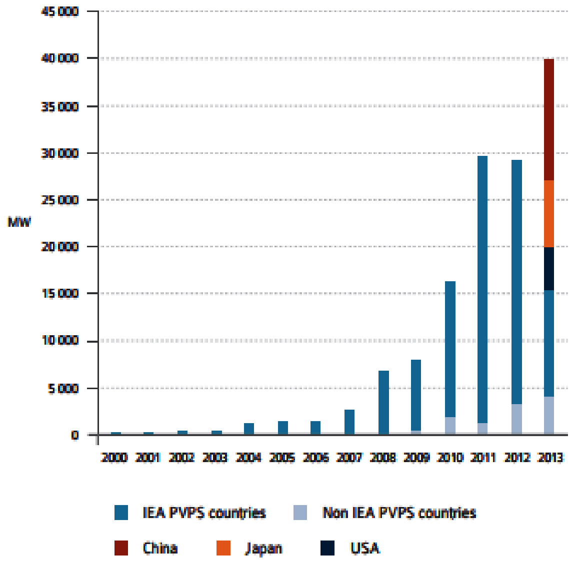

Fig. 1 Evolution of annual PV installations (MW) [5].

Cyprus has one of the best weather conditions for solar energy applications in Europe. The hours of sunshine in winter and summer are 5.5 hours and 12 hours respectively. The solar radiation for Cyprus varies between 1.7kWh/m^2 and 2.3 kWh/m^2[7]. Due to the long hours of sunshine in north Cyprus, the use of solar water heater is a common phenomenon; almost all homes have this facility installed. The solar radiation map of Cyprus is shown in figure 2.

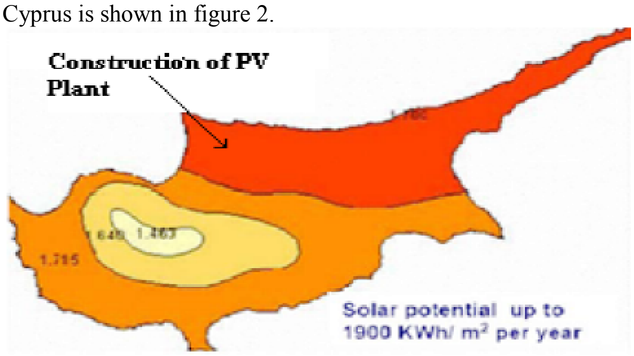

Fig. 2. Solar radiation map of Cyprus [6].

The aim of the this paper is to evaluate the performance of Serhatkoy PV power plant using calculation methods proposed by IEC, SAM and also use PVsyst software for simulation. Serhatkoy PV power plant is the first grid connected PV plant in north Cyprus; the results of the research will be useful in either expanding the existing solar park or building new facility to reduce the reliance on fossil fuel. Also the data obtained from the research will be a useful research tool for engineering students.

2. Serhatkoy PV power plant

Serhatkoy PV power plant is located in small town called Serhatkoy, a suburb in Guzelyurt in the northern part of Cyprus with geographical coordinates; latitude and longitude of 35.2^0N and 33.1^0E respectively, altitude of 110m. Cyprus is an island located south of Turkey and north-eastern part of Mediterranean Sea. Cyprus is a member of EU as *de facto* divided island [2] but the whole of Cyprus is EU territory.

Serhatkoy PV power plant consists of 6192 panels, made up of Polycrystalline solar cells and 86 group inverters. KIOTO photovoltaic is the manufacturer of the panels. KPV 205 PE model type is used. It has the following ratings; Power - 206Wp (Pmpp), Voltage at maximum power $Umpp_{[V]}$ = 25.98V, Current at maximum power $Impp_{[A]}$ = 7.93V, open circuit voltage $Uoc_{[v]}$ = 32.57V, short circuit current $Isc_{[A]}$ = 8.44A. The efficiency of the panel is 13.71% with 5 years guaranty and 90% and 80% efficiency guaranty for 10 and 20 years respectively [3]. The inverter used is manufactured by Powerone with nominal DC power of 13kW and operating MPPT input voltage range of 200 – 850Vdc (580V nominal). The nominal power output of the plant is 1275.5kWp. The cost of installation of the plant is 3.7million Euros and it was financed by the European Union [6].

Fig. 4. Section of Serhatkoy PV power plant [7].

2.1 Field Details

The total area of Serhatkoy PV solar park is 21,600m^2 ie the length and breadth are 120m and 180m respectively. The generating area of the park is 8,412m^2. The solar park is made up of two columns and inbetween the columns is the power house. Each column has two sub columns made up of 21 rows of photovoltaic panels whilst the other column contains 22 rows of photovoltaic panels.

The tilt angle for the plant is 24.84^0 with annual solar radiation of 2000kWh/m^2.

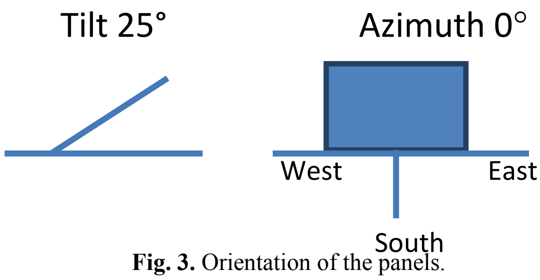

Fig. 3. Orientation of the panels.

3. Capacity factor (CF) calculation

Capacity is the maximum generation output of a power plant, mostly measured in kW, MW or GW ratings. Capacity Factor of any plant shows the efficiency of that plant. It is the relation between of the nominal power of the plant and the yearly power generated i.e. the ratio of energy produced during a period of time (usually a year) to nameplate capacity. CF of PV plants can either calculated from PV array DC output values or inverter AC output values [9]. It is best to use AC voltage values for calculating CF. The capacity factor of solar PV plants falls in the range of 15% to 25%. The formula for calculating capacity factor is:

$$\text{Capacity factor} = \frac{Real\ Power\ generated}{365\ x\ 24\ x\ Nominal\ power}\ x\ 100\% \qquad (1)$$

Table 1. Calculated CF values

Year	Energy produce (kWh)	Capacity factor (%)
2011	909955.72	8.14
2012	1985214.9	17.76
2013	2152368.97	19.26
2014	1012469.44	9.06

Table 1 shows the calculated CF values for four years of operation of Serhatkoy PV plant. From Table 1, 2013 produced the highest capacity factor value. The least CF performance was recorded in 2011.

4. Performance ratio calculation

There are several methods proposed by industry players for the calculation of performance ratio (PR).Using the SAM method proposed by NREL of USA [5], the PR of Serhatkoy power can be calculated by the method:
Period of Analysis = 1 year
Average solar irradiation in a year =2000kWh/m^2
PV Plant area (generating) = 8412m^2
PV module efficiency = 13.71%
Extrapolated value = 2000 x 8412= 16824000kWh
Nominal plant output=16824000kWh x 0.1371= 2306570.4kWh

$$\text{Performance Ratio} = \frac{produced\ power\ kWh}{Nominal\ plant\ output\ kWh}\ x\ 100\% \qquad (2)$$

Table 2. Calculated PR values

Year	Energy produce (kWh)	PR (%)
2011	909955.72	39.45
2012	1985214.9	86.07
2013	2152368.97	93.31
2014	1012469.44	43.89

From the Table 2, the best performance ratio value was recorded in 2013 and in 2011, the least performance ratio value was recorded.

5. Simulation results

PVsyst software is used for simulation; it was designed by university of Geneva in Switzerland and it is used for the study of PV systems. Using meteorological data from NASA, the parameters of Serhatkoy plant is modeled and simulation done to determine expected energy output of the plant.

5.1. Normalized production results

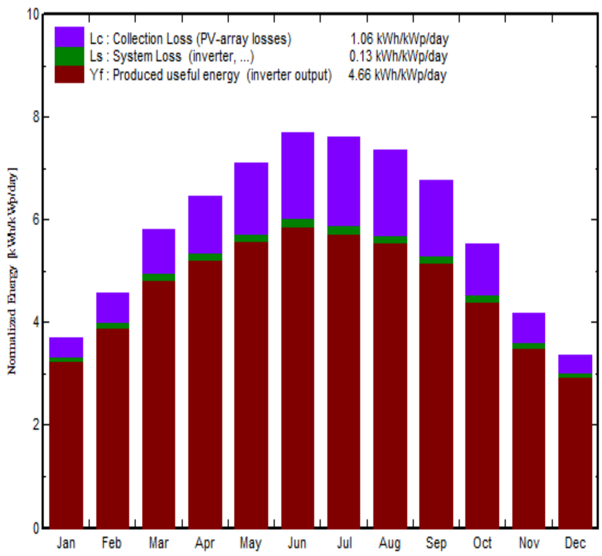

Fig. 5. Normalized production output

Figure 5 shows the normalized production output of the plant. The useful energy produced at the inverter output is 466kWhp/day. System loss is produced by inverter, cable, ohmic losses and Collection loss is produced by PV array, module mismatch, module quality etc. from the results obtained, the collection and system losses are 1.06kWhp/day and 0.13kWhp/day respectively.

5.2. Performance ratio

figure 6 shows the average monthly performance ratio values for a year. The average yearly performance ratio recorded after simulation is 0.796 which is approximately 80%. Performance ratio is the ratio of final yield to reference yield [8]

$$\textit{Performance ratio} = \frac{\textit{final yield} \quad (Y_f)}{\textit{Reference yield} \quad (Y_r)} \qquad (3)$$

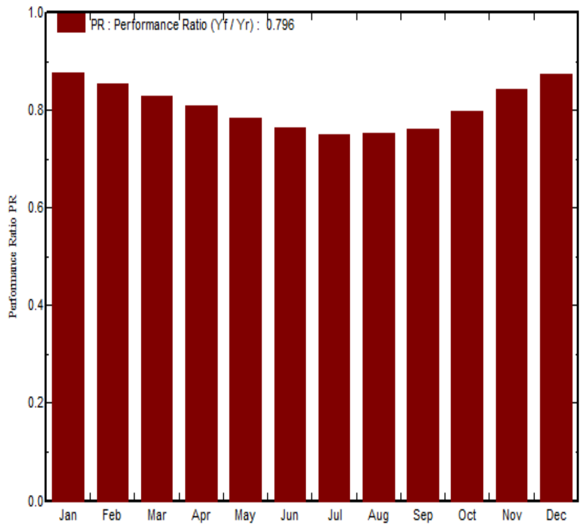

Fig. 6. Performance ratio

5.3 Loss diagram

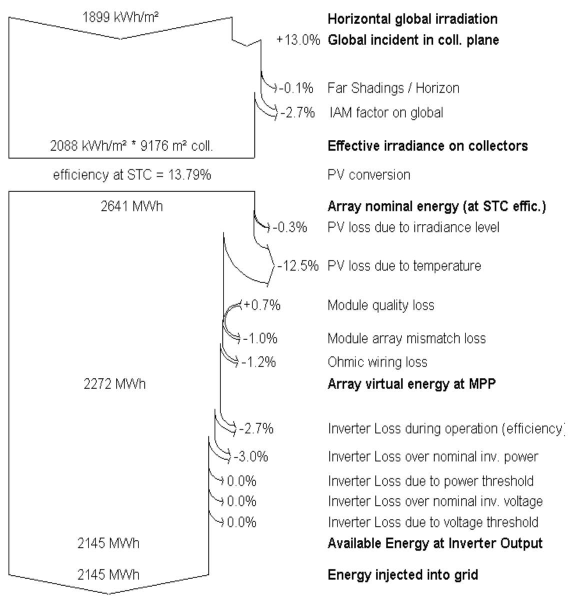

Fig. 7. Loss diagram

The losses incurred by the Serhatkoy PV system after simulation is represented by figure 7. Horizontal global irradiation is 1899kWh/m^2 for Serhatkoy geographical location. The effective irradiance on collectors at an area of 9176m^2 is 2088kWh/m^2. The PV panels have conversion efficiency of 13.79%. PV loss due to temperature is -12.5% and inverter loss during operation is -2.7%. Array nominal energy at standard test conditions is 2641MWh and energy injected into the grid is 2145MWh.

5.4 System losses

Table 3. Detailed Monthly System Losses

Year	ModQu kWh	MisLoss kWh	OhmLoss kWh	EArrMPP kWh	InvLoss kWh
Jan	1006	1351	119	132613	5167
Feb	1113	1495	1457	146533	7563
Mar	1534	2060	2298	201649	12655
April	1596	2144	2498	209795	12851
May	1762	2366	2945	231322	14366
Jun	1786	2400	3164	234397	14461
July	1802	2420	3257	236353	13869
Aug	1746	2345	3161	229031	13232
Sept	1588	2134	2840	208403	12449
Oct	1393	1871	2188	183046	9805
Nov	1056	1418	1342	139045	5976
Dec	911	1223	973	120150	4558
Total	17291	23228	27242	2272339	126950

Table 3 shows the detailed monthly system losses, ModQu is the module quality loss, MisLoss is module mismatch loss, OhmLoss is ohmic loss by wiring, EArrMPP is Array energy at maximum power point and InvLoss is Inverter Loss. From the table, all the losses increase when temperature increases. There is a steady increase of the losses from May through to August and there is a decline afterwards. This period is usually the summer season for Cyprus where temperature tends to go beyond 45^{0}C.

5.5. Comparison between plant results and simulation

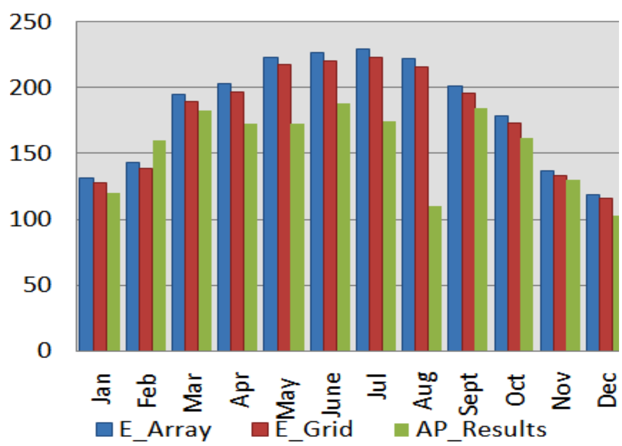

Fig. 8. Actual plant energy output and simulation results Output

Fig. 8 is a comparison between energy injected into the grid by the plant and the energy that is 'supposed' to be injected into the grid after simulation. The difference in results between simulation and plant is about 2% to 5%, except for May, June, July and August where the difference is about 10% to 20%. From the chart, the month of June recorded the highest energy output for all the variants.

6. Payback

The payback period of a plant is the duration for which the plant is able to generate revenue from production to the meet the cost of installation. The cost of installing the plant was/is 3.7million Euros. The cost of 1kWh of power produced by the plant is sold to customers at 0.45TL (Turkish Lira). Table 4 shows the yearly produced power since inception of operation and the revenue generated.

Table 4. Revenue generation for Serhatkoy PV Plant

Year	Energy produced kWh	Generated revenue (0.4/kWh)TL
2011	909955,72	409480.074
2012	1985214,9	893346.705
2013	2152368,97	968566.0365
2014	1012469,44	455611.248
Total	6060009.03	2727004.064

From Table 4, the total revenue generated for Serhatkoy PV Plant for four years of operation is 22727004.064TL. From january 2011 to december 2014, the exchange rate of one turkish lira to one euro has flatuated from a low of 2.00tl to 1euro and a high of 3.11tl to 1euro, using 2.55tl to 1euro as the average exchange rate for this period, the total revenue generated will be 1069413.358euro, the average of this is 267353.34euro (1069413.358euro /4). At this rate of revenue geration, the payback period of the plant will be 11years, this excludes maintenance cost and other cost incured during operation.

7. Discussion

The calculation results for capacity factor and performance ratio shows that the plant is operating close to perfection. The CF and PR values recorded in 2011 and 2014 are low because production started in May in 2011, therefore there was no production from January to May 2011. Also the plant production results from October to December 2014 were not available. Comparing the monthly power output results from the plant and simulation (figure 8), the performance of the plant was most affected by high temperature i.e. summer season. Solar panels are tested at 25^{0}C about 77^{0}F (STC). An increase in the temperature of solar panels reduces the output voltage linearly whilst the current is increased exponentially; this in turn affects the power output of the plant. The efficiency of the plant panels was affected by 18.66% (May, June, July, August figure 8). The temperature coefficient for KIOTO KPV 205 PEis Pmpp= -0.46 %K (Uoc= -116.1 mV/K Isc = +4.40 mA/K) which means that for every 1^0C of temperaure beyound the STC value, the power of the panel is reduced by -0.46%K and for every 1^0C of temperature below STC value, the power is improved by 0.46%K. The number factor mitigating against the perfect productin of the plant is high temperature.

Energy injected into the grid for a year is 2145MWh from simulation results. 2012 and 2013 had full-year productions, 1985214.9kWh of energy was produced in 2012 and 2152368.97kWh of energy was produced in 2013. Comparing simulation and actual plant results, 2013 produced 0.32% more energy than simulation results and in 2012, the actual plant results was 7.47% less than simulation results.

The payback period of the plant is a little high and this is becuase of the increase depreciation of the Turkish lira against most international currencies. As at the start of production of the plant in May 2011, the exchange rate between the turkish lira and Euro was 2.1TL using this rate and revenue generated in 2013, the payback will be 9years.

Table 5 Balances and main results

Year	GlobHor kW/m^2	T.Amb ^oC	GlobInc kW/m^2	GlobEff kW/m^2
January	77.2	12.15	115.7	112.4
February	96.3	11.93	129.4	125.9
March	149.7	13.89	181.9	177.3
April	179.4	17.53	194.2	188.8
May	224.4	21.57	220.4	214.1
June	243.6	25.89	229.8	223.3
July	245.8	29.28	236.3	229.7
august	219.5	29.40	228.8	222.6
September	176.4	26.82	205.1	199.9
October	132.1	22.70	173.5	169.1
November	86.1	17.70	125.9	122.4
December	68.2	13.73	105.3	102.1
Total	1898.7	20.26	2146.2	2087.6
Year	EArray MWh	E_Grid MWh	EffArrA %	EffSysA %
January	131.1	127.4	12.34	12.00
February	142.9	139.0	12.04	11.71
March	194.4	189.0	11.65	11.32
April	202.5	196.9	11.36	11.05
May	223.2	217.0	11.04	10.73
June	226.3	219.9	10.73	10.43
July	228.9	222.5	10.56	10.26
august	221.9	215.8	10.57	10.28
September	201.5	196.0	10.70	10.41
October	178.1	173.2	11.19	10.88
November	136.8	133.1	11.84	11.51
December	118.9	115.6	12.31	11.97
Total	2206.6	2145.4	11.20	10.89

Legends:
GlobHor - Horizontal global irradiation
T Amb- Ambient Temperature
GlobInc - Global incident in collector Plane
EArray - Effective energy at array output
E_Grid - Energy injected into grid
EffArrA-Effic. Eout array/rough area
EffSysA-Effic. Eout system/rough area
GlobEff - Effective global corr. For IAM and shading

Table 5 shows the monthly Balances and main results from simulation. The amount of energy a PV system depends on the available radiation. July recorded the highest global horizontal radiation of 245.8kW/m^2 and this produced the highest energy injected into the grid 222.5MWh.

8. Conclusion

The goal of this research was to evaluate the performance of Serhatkoy PV power plant. The research was divided into two parts; calculations and simulations using meteorological data from NASA. The industry standard of CF for photovoltaic is 15% to 25%, the results obtained from table 1 shows that CF values for 2012 and 2013 are 17.76% and 19.26% respectively; this shows plant is producing efficiently. Analyzing the results from simulation and actual plant production shows little difference in the yearly AC energy injected into the grid. In 2012, the difference in produced energy between simulation and plant was 7.47%. In 2013, the plant produced 0.32% more energy than simulation results. From these results, Serhatkoy PV power plant's production cycle is close to perfection.

It is recommended to either expand the solar park to increase the energy output thereby reducing production from fossil fuel or replicate a bigger facility to a location with similar meteorological data but with lower temperature records for summer season.

7. References

[1] International energy agency, world energy outlook, 2014

[2] http://europa.eu/about-eu/countries/member-countries/cyprus/index_en.htm.

[3] http://www.kiotosolar.com/en/

[4] Trends in photovoltaic applications. Survey report of selected IEA countries between 1992 and 2009, International Energy Agency, Report IEA-PVPPS Task 1 T1-19:2010, 2010

[5] Trends 2014 ın photovoltaıc applıcatıons, SurveyReport of Selected IEA Countries between 1992 and 2013, Report IEA-PVPS T1-25:2014

[6] O.C. Ozerdem S. Biricik, Overview of Energy System and Major PowerQuality Problems in North Cyprus *International Journal onTechnical and Physical Problems of Engineering*, September 2011 Issue 8

[7] Davut Solyali and Miles A. Redfern,Case Study of Cyprus: Wind Energy or Solar Power?, Electrıc powerengıneerıng 2010.

[8] SevnurEyigun, Onder Guler, Turkey solar potential and viability of solar photovoltaic power plant in central Anatolia, *international renewable energy congress,* pp. 94-99, 2010.

[9] http://www.nrel.gov/docs/fy12osti/54704.pdf

[10]Xinjing Zou, Li Bian. Development of a Data acquisition System forGrid-Connected Photovoltaic Systems, IEE 978-1- 4244-8165-1/11/$26.00 ©2011.