Journal of Solar Energy Research 24 (2017) 287-293

JSER

Journal of Solar Energy Research (JSER)

Journal homepage: www.jser.ut.ac.ir

The Design and Evaluation of a 100 kW Grid Connected Solar Photovoltaic Power Plant in Semnan City

Iman Gharibshahian [a], Samaneh Sharbati [a*], Ali. A. Orouji [a]

[a] Department of Electrical and Computer Engineering, Semnan University, Semnan,, Iran [*] Email:Samaneh.Sharbati@semnan.ac.ir

ARTICLE INFO

Received: 21 Sept 2017
Received in revised form: 16 Oct 2017
Accepted: 20 Oct 2017
Available online: 25 Oct 2017

Keywords:
solar photovoltaic plant; PV syst software; grid connected solar PV; performance ratio

A B S T R A C T

In this paper, a grid connected solar photovoltaic plant has been proposed, and its performance has been evaluated. The performance analysis has been done on a designed 100kW grid connected solar photovoltaic plant in the Semnan city. The simulated system comprises 625 CIS PV modules. Each PV module has a rating of 160Wp. All the PV modules are arranged in 25 strings, with each string made up of 25 modules in series. Two solar inverters, each having a rating of 50 kW are used for interconnecting with grid. The 100 kW PV system generates 178.99 MWh/year, wich 170.3 MWh/year is injected into the grid. The performance ratio and its total impressed losses have been calculated. The performance ratio of 100KW solar plant in Semnan city obtained 83%. Finally, the simulation results indicate that the designed solar power plant will prevent 171 tons of gas CO_2 from being produced during 30 years.

1. Introduction

Thin film photovoltaic (PV) modules (amorphous asi:H, CIS, CdTe or μC-a:Si technologies) present the most promising opportunity to significantly decrease the prices of PV in the future, as thin films used limited pure materials. The PV systems are as grid connected and standalone. Grid connected photovoltaic systems feed electricity directly to the electrical network, operating parallel to the conventional energy source. Grid-connected systems generate clean electricity near the point of use, without the transmission and distribution losses or the need for the batteries. Its performance depends on the local climate, orientation and inclination of the PV array, and inverter performance. Whereas, a stand -alone system involves no interaction with a utility grid, the generated power is directly connected to the load. In case the PV array does not directly supply a load, a storage device is needed such as a battery [1]. The battery bank stores energy when the power supplied by the PV modules exceeds load demand and releases it backs when the PV supply is insufficient. This stand alone PV power generation will be used in the home for the electrification purpose [2]. A wide variety of tools exist for the analysis of both Grid connected and stand-alone photovoltaic systems.

The photovoltaic modules can provide a safe, reliable, maintenance-free and environmentally friendly source of power for a very long time. A successful implementation of solar PV system involves the knowledge on their operational performance under varying climatic condition [3-7].

Financial analysis can also be performed. Economic feasibility and viability of implementing PV solar energy in the State of Kuwait was found that the energy resources used in producing traditional electricity was saved and the cost of CO_2 emissions was also saved [8]. System designers use simpler tools for sizing the PV system. Most scientists use the simulation tools to designe and optimize a PV system before installation of real one. Software tools related to photovoltaic systems can be classified into pre-feasibility analysis, sizing, and simulation. PVsyst is a dedicated PC software package for PV systems. The software was developed by the University of Geneva [9]. It integrates pre-feasibility designe, sizing and simulation support for PV systems. First, the location and loads of PV systems are determined, then the product database are selectd and the software automatically calculates the size of the system [10].

Reference presented a performance analysis of 3.6 kW Rooftop grid connected solar photovoltaic system in Egypt [11].The system was monitored for one year and all the electricity generated was fed into the 220 V, 50 Hz low voltage grid to the consumer. Some studies were conducted in Serbia to find out possibilities of generating electrical energy through 1 MW PV power plants by taking different types of available solar PV modules and it was concluded that higher electricity is generated using CdTe solar modules [12]. A 5 MW solar PV power plant was designed for 50 cities of Iran [13], using RET screen software. The highest capacity factor was found at Bushier (26.1%) and lower (16.5%) at Anzali, whereas a mean capacity factor is 22.27%.

In this work, a 100kW grid connected solar PV power plant in the Semnan city has been designed the energy production, performance ratio, efficiency and all affected losses has been investigated. The simulations in this research are performed by using PVsyst 6.43[9].

Nomenclature

PR	performance ratio (%)
G_o	global irradiance at STC (W/m^2)
STC	standard test conditions
η_{inv}	inverter efficiency (%)
Y_F	final yield (h/d)
L_C	array capture loss
E_A	array energy output per day
L_{CT}	thermal capture losses
I_{dc}	DC current (A)
L_{CM}	miscellaneous capture losses
V_{dc}	DC voltage (V)
GlobHor	horizontal global irradiation
P_0	Nominal Power at STC
T Amb	ambient temperature
Y_A	array yield (h/d)
GlobInc	global incident in coll. Plane
Y_R	reference yield (h/d)
E_{Array}	effective energy at the output of the array
GlobEff	effective global irradiance
H_t	total Horizontal irradiance on array plane
EffsysR	efficient E_{out} system/rough area
EffArrR	efficient E_{out} array/rough area

2. Designing of the solar PV-GRID system

A grid-connected PV system consists of solar panels, inverters, a power conditioning unit and grid connection equipment. The system has effective utilization of power generated from solar energy, while no energy storage losses. The grid-connected PV system supplies the excess power, beyond consumption by the connected load to the utility grid.

The 100KW solar PV power plant in Semnan city would use the approximate 768 m² of land area. The arrangement of battery storage is not anticipated the storage of electricity.

2.1. Geographical location of the site

A great geography location is where solar power plant can ingest more sun based radiation for the whole year since power generated by solar power plant totally depends up on sun’s insolation. The designed 100 kW solar power plant will be situated at a longitude of 53.4″E, latitude 35.6″N and at a height of 1167 meters.

2.2. Layout of Plant

The aggregate rating of the designed plant is 100kW and it will cover over 768 m^2 of land. The plant will comprise of a total of 625 modules in which 25 modules will be in series and 25 strings will be in parallel. The modules of the designed system is HPC-050HT-E with Hyundai Manufacturer. Inverters are utilized for DC-AC conversion which will be directly supplied to the grid.

For PV array installation, the inclination angle is kept equivalent to the latitude of the specified site so that we can get the most sun powered irradiation [14, 15]. Acording to the geoghraphic latitude of Semnan (35.6°), the inclination angle or tilt for this system is considered 35°, confronting south having an azimuth of 0 degree which is the default value.

2.3. Power conditioning units

In this work, we used two inverters for DC-AC conversion. The inverters power rating 50 kW, PV voltage 450 V and supply DC current 175 A is fed as input to inverter. The output AC voltage and current from inverter are 400 V and 72 A respectively. The output of the inverter is automatically synchronized with same voltage and frequency as that of grid.

2.4. Characterizations of solar panels

The designed solar PV plant is made from CIS thin film modules as SF160-S with Solar Frontier manufacturer. These modules have an open circuit voltage (V_{OC}) of 110 V, short circuit current (I_{SC}) of 2.2 A, nominal power of 160 watts and efficiency of 13.07%. The maximum operating temperature of modules is 45° centigrade. The top glass cover has a clear tempered glass. The current-voltage curve of the module for various radiation is shown in Fig. 1. The distance between the panels in the strings is 4 meters.

3. Results & Discussion

The performance parameters are developed as a reference by International Energy Agency (IEA) for analyzing the performance of solar PV grid interconnected system [16]. The overall performance of system will be determined by the energy production, solar resource and losses parameters. The system parameters are including the performance ratio, the final PV system yield and the reference yield.

3.1. Array yield

The array yield (Y_A) is calculated as the net daily energy from the PV array (E_A) divided by the installed array's rated output power P_0.This yield indicates the daily energy output per kW of the installed PV array.

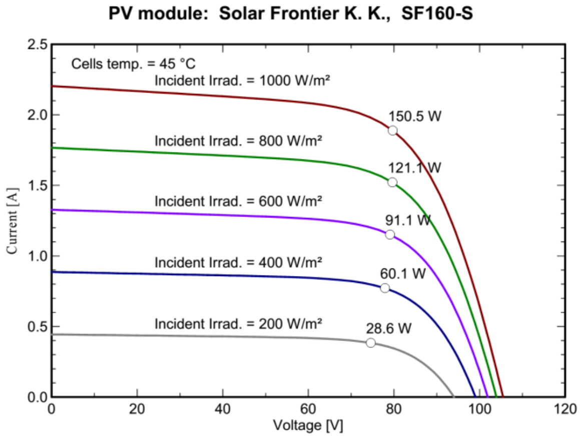

Figure 1. current-voltage curve of the module for various radiations.

Y_A indicates the amount of time during which the array would be required to operate at P_0 to provide the monitored daily energy.
For the designed power plant the annual average array yield has been obtained 4.9 kWh/kWp/day.

3.2. Reference yield

The reference yield (Y_R) can be calculated by dividing the total daily in-plane irradiation H_t (the monthly or yearly average value) by the module's in-plane reference irradiance G_0 (kW/m^2).
This yield represents the number of hours per day during which the solar radiation would need to be at reference irradiance levels in order to produce the same incident daily energy as it was monitored. It is a function of the location, orientation of the PV array, and month-to month and year-to-year whether variability. Thus Y_R would be the number of

peak sun-hours per day. For the designed power plant, the annual average array yield has been obtained 5.62 kWh/m².day.

3.3. Final yield

Final yield (Y_F) is calculated dividing the total system output energy ($E_{PV,AC}$) by the installed array's rated output power P_0. The final PV system yield YF is the portion of the daily net energy output of the entire PV plant which was supplied by the array per kW of the installed PV array. This yield indicates the number of hours per day that the array would need to operate at its rated output power P_0 to equal its monitored contribution to the total system output energy $E_{PV,\ AC.}$ For the designed power plant the annual average array yield has been obtained has been obtained 4.66 kWh/kWp/day.

3.4. Performance ratio

The performance ratio is an internationally introduced measure for the degree of utilization of an entire PV system. It is the ratio of utilizable AC electricity to the amount of energy which could be generated in case modules were operated under STC (standard test conditions) continuously and without any further losses in the system.

The performance ratio is a measure of the quality of a PV plant that is independent of location and it therefore often described as a quality factor. The performance ratio is stated as percent and describes the relationship between the actual and theoretical energy outputs of the PV plant. It thus shows the proportion of the energy that is actually available for export to the grid after deduction of energy loss (e.g. due to thermal losses and conduction losses) and of energy consumption for operation.

The performance ratio is the final yield divided by the reference yield. In this paper the purpose is to evaluate the performance ratio of the designed solar PV power plant which is located in Semnan. Figure 2 shows the performance rate for different months of the year.

The yearly average performance ratio of this designed PV system is minimum (0.791) in July and maximum (0.879) in January. Table 1 shows the average of performance ratio annually is 0.83. A PV system with 0.83 of performance ratio means the designed plant is operating with 83% productivity.

3.5. Inverter efficiency

The Efficiency of an inverter indicates how much DC power is converted to AC power. Some of the power can be lost as heat, and also some stand-by power is consumed for keeping the inverter in powered mode. Inverters with 95.8% efficiency are used in this work.

3.6. CO_2 Balance

Replacing fossil fuels with energy from solar power plants reduces carbon dioxide emissions. The simulation results show that for a period of 30 years, 171 tons of carbon dioxide gas is reduced.

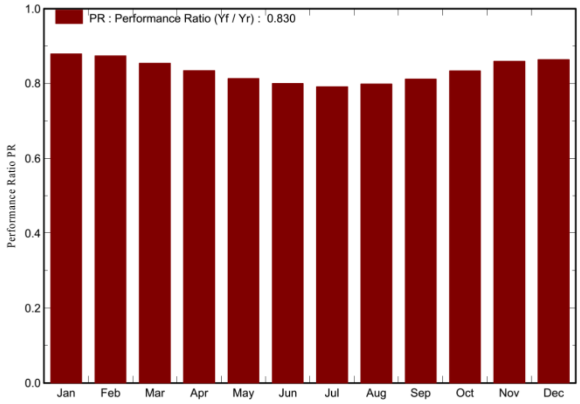

Figure 2. Performance ratio

3.7. losses Characteristics

Energy losses occur in various components in a grid connected solar photovoltaic power plant under real operating conditions. These losses are evaluated using the monitored data.

3.7.1 Array capture losses (L_C):

There are two types of this losses:

- Thermal capture loss (L_{CT}): In practical the modules often operates at higher temperature than STC conditions which will decrease their performance and further the power output. This kind of loss is called thermal loss.

Table 1. Normalized Performance Coefficients						
	Y_R (kWh/m².day)	L_C	Y_A (kWh/kWp/day)	L_S	Y_F (kWh/kWp/day)	PR
January	4.25	0.322	3.92	0.191	3.73	0.879
February	4.92	0.406	4.51	0.215	4.30	0.874
March	5.45	0.555	4.89	0.239	4.65	0.854
April	5.97	0.736	5.24	0.250	4.99	0.835
May	6.22	0.891	5.33	0.269	5.06	0.814
June	6.52	1.021	5.50	0.283	5.22	0.800
July	6.40	1.058	5.34	0.277	5.06	0.791
August	6.72	1.087	5.64	0.267	5.37	0.799
September	6.62	0.977	5.64	0.266	5.37	0.812
October	5.60	0.698	4.90	0.234	4.67	0.834
November	4.78	0.470	4.31	0.202	4.11	0.859
December	3.99	0.367	3.62	0.175	3.44	0.864
Year	5.62	0.717	4.90	0.239	4.66	0.830

- Miscellaneous capture loss (L_{CM}): Losses that are caused by wiring, string diodes, low irradiance, partial shadowing, mismatching, maximum power tracking errors, limitation through dust, losses generated by energy conduction in the photovoltaic modules.

3.7.2 System losses (L_S)

These losses are caused by inverters, conduction and losses of passive elements of circuit. Other factors that contribute to system losses are: dust or dirt on the array, smog or fog, mismatched PV array modules with slight inconsistence in performance from one module to another, wire losses, utility grid voltage. The amount of system losses will be obtained from the difference between array yield and final yield. In this paper value of system loss (Ls) is recorded as 0.24 kWh/kWp/day. The array capture loss value is recorded as 0.72 kWh/kWp/day. Figure 3 represents the simulated value of L_C is 12.8% and the L_S is 4.3% .

Table 2 shows the balances and main results of Grid connected PV system.

Total energy which is obtained from the output of the PV array is 178.99 MWh. Annual efficiency of every array is 11.37% for per area. In the same way, annual efficiency of system is 10.81% per area.

3.8. Loss diagram

loss diagram is obtained from the simulated studies, which help in analysing the various losses that are to be encountered while installing PV plant or constraints to be considered. loss diagram is seen in Fig. 4. Which represents the various losses in the system. Global irradiance on horizontal plane is 1813 kWh/m^2. Total incident energy which is incident on the collector plate is yearly 2051.7 kWh/m^2. But the effective irradiance on collector is 1936 kWh/m^2. This result in the loss of energy. When this effective irradiance falls on the surface of a photovoltaic module or array, electricity or electrical energy is produced. After the PV conversion, array nominal energy at standard testing conditions (STC) is 194.2 MWh. Annual array virtual energy at MPP is 179 MWh.

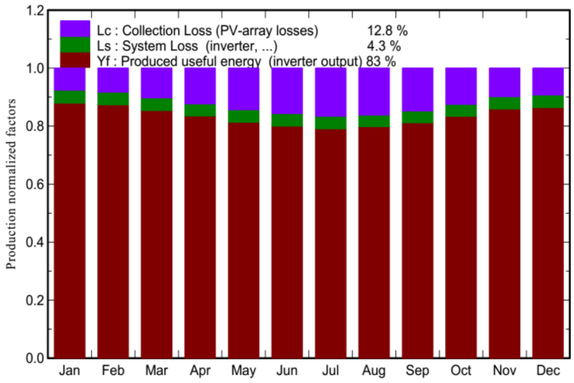

Figure 3 . Loss factors using PVsyst software

Table 2. Balances and main results								
	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	82.8	3.30	131.6	124.4	12.17	11.58	12.04	11.46
February	98.0	6.90	137.6	130.1	12.63	12.03	11.95	11.38
March	140.1	12.80	168.8	159.8	15.16	14.42	11.70	11.13
April	171.5	18.20	179.2	168.6	15.71	14.97	11.42	10.88
May	206.1	24.40	192.9	181.1	16.52	15.69	11.16	10.60
June	220.7	29.30	195.7	183.6	16.50	15.66	10.99	10.42
July	219.3	32.10	198.4	186.3	16.55	15.69	10.87	10.31
August	206.5	31.10	208.4	196.8	17.47	16.65	10.92	10.40
September	171.6	26.30	198.5	188.2	16.91	16.11	11.10	10.58
October	129.4	20.00	173.7	164.7	15.20	14.48	11.41	10.86
November	92.2	11.10	143.4	135.8	12.93	12.32	11.75	11.20
December	74.9	5.00	123.6	116.6	11.22	10.68	11.83	11.25
year	1813.1	18.44	2051.7	1936.1	178.99	170.27	11.37	10.81

The various losses occur in this stage are 8.1 % losses due to temperature, 0.8 % loss due to module array mismatch and 1.1 % is the Ohmic writing losses. Available energy on annual basis at the inverter output facility is 170.3 MWh and the same is injected to grid. Here two losses were possible, one is inverter loss during inverter operation i.e. 4.7 % and inverter loss due to power threshold is 0.2%.

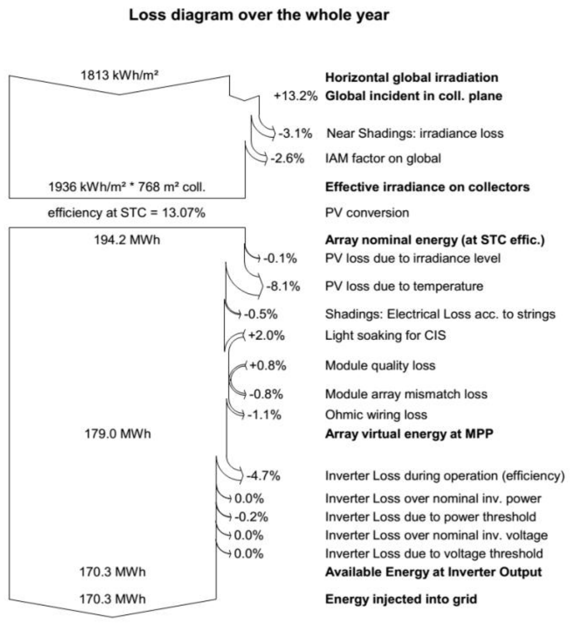

Figure 4. Loss diagram over the entire year in Semnan city.

4. Conclusions

The simulated performance of 100 kW grid connected CIS photovoltaic system is carried out in this study using PVsyst simulation tool. From the results, it can be concluded that the planned PV system will provide the operational benefits to the installer or owner. From this study , on the annual basis, 170.3 MWh/year is the energy that is injected into the grid. Maximum energy injected into the grid is in August i.e. 16.65 MWh, and the least energy is in December i.e. 10.68 MWh. The average performance ratio (PR) of the CIS PV system is operated at 83% in the simulated study for the planned location. The simulation results indicate that the designed solar power plant will prevent 171 tons of gas CO_2 from being produced during 30 years. Further, the study can be carried out using different PV module technologies with appropriate installation methodes for improving the performance.

References

[1] Mermoud, André, Lejeune, Thibault. (2010) Performance assessment of a simulation model for PV modules of any available technology. (Paper presented at the 25th European Photovoltaic Solar Energy Conference , Valencia).

[2] Husnain-Al-Bustam, Md.Zakaria Mahbub, M. M. Shuvro Shahriar,T.M. Iftakhar Uddin& Md.Abrar Saad. (2012).

Analysis of a Standalone Photovoltaic Power Generation System Using PVSYST Software, *Global Journals Inc. (USA)*,12.

[3] G. Makrides, B. Zinsser, M. Norton, G. E. Georghiou, M. Schubert, and J. H. Werner. (2010). Potential of photovoltaic systems in countries with high solar irradiation, *Renewable and Sustainable Energy Reviews*,14(2), 754-762.

[4] P. Bolduc, D. Lehmicke, J. Smith. (1993). Performance of a grid connected PV system with energy storage, (Paper presented at the Photovoltaic Specialists Conference).

[5] A. Kumar, N.S.Thakur, R. Makade, M. Kumar Shivhare.(2011). Optimization of Tilt angle for Photovoltaic Array, *International Journal of Engineering Science and Technology (IJEST)*, 3, 3153-3161.

[6] S. Labed, E. Lorenzo.(2004). The impact of solar radiation variability and data Discrepancies on the design of PV systems, *Renewable Energy*, 29,1007–1022.

[7] D. Picault, B. Raison, and S. Bacha. (2009). Guidelines for evaluating grid connected PV system topologies. (Paper presented at the IEEE International Conference on Industrial Technology).

[8] M. Ramadhan and A. Naseeb. (2011). The cost benefit analysis of implementing photovoltaic solar system in the state of Kuwait, *Renewable Energy*, 36(4), 1272-1276.

[9] PVsyst software. CUEPE, University of Geneva. www.pvsyst.com

[10] D. Turcotte, M. Ross, and F. Sheriff. (2001). *Photovoltaic hybrid system sizing and simulation tools: Status and Needs*.

[11] Elhodeiby, A.S., Metwally, H.M.B., Farahat, M.A. (2011). Performance analysis of 3.6 kW Rooftop grid connected photovoltaic system Egypt. (Paper presented at the International Conference on Energy Systems and Technologies).

[12] T. Pavlović, D. Milosavljević, I. Radonjić, L. Pantić, A. Radivojević, and M. Pavlović. (2013). Possibility of electricity generation using PV solar plants in Serbia, *Renewable and Sustainable Energy Reviews*,20, 201-218.

[13] S. M. Besarati, R. V. Padilla, D. Y. Goswami, and E. Stefanakos. (2013).The potential of harnessing solar radiation in Iran: Generating solar maps and viability study of PV power plants, *Renewable Energy*, 53, 193-199

[14] Ashok Kumar, N.S.Thakur, Rahul Makade, Maneesh Kumar Shivhare. (2011). Optimization of Tilt angle for Photovoltaic Array, International Journal of Engineering Science and Technology (IJEST), 3, 3153-3161.

[15] S. Labed, E. Lorenzo. (2004). The impact of solar radiation variability and data Discrepancies on the design of PV systems, *Renewable Energy*, 29, 1007–1022.

[16] Ayompe, L.M., Duffy, A., McCormack, S.J., Conlon, M. (2011). Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland. *Energy Convers*, 52, 816–825.