Design and simulation of 60kWp solar on-grid system for rural area in Uttar-Pradesh by “PVsyst”

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Abstract. The load demand is increasing rapidly, with limited coal fired plants. In this situation, many researchers are trying to find a way through which, we can make the balance between energy demand and supply for the consumers. The renewable energy sources are gaining popularity as green, clean, and abundant sources of energy. Solar energy is available throughout the year in India and thus provides an alternate source of energy to fulfill the local load demand. The function of solar PV system, depends on the numerous factors i.e. site location, qualities of material to make system components and accessibility of solar radiation etc. In previous research work, many simulation based analysis have been done through PV-syst software package by considering solar photovoltaic system at different sites around the world. In this proposed paper, we are designing and simulating a “60kWp solar power plant” which is basically an on-grid type solar photovoltaic system by PV-syst software version 7.2.2 in rural area of Uttar-Pradesh, India. This analysis has been done for seasonal tilt angles i.e. 10° for summer season and 47° for winter season. Later on, detailed performance study and various losses descriptions are summarized in upcoming segments for the proposed system.

1. INTRODUCTION

From long time we are using conventional power plants for the purpose of Electricity demand fulfilment. Conventional ways to satisfy the power needs of the consumer become expensive in terms of human health and natural balance. In many research studies, solar energy is utilized for the production of electrical power, which is environmental friendly and reduces the effect of global warming. In previous research study, numerous applications of solar PV system for various locations around the world have been analysed. In India, design of solar rooftop on-grid system, of 2 kWp through PV-syst for the location in Odisha have been already studied. In addition to this work, the case study which was based on the grid connected rooftop solar system for the location of Ujjain with different software i.e. SolarGIS, PV-SOL, PVGIS, has been studied. Based on this analysis, we are designing and simulating a system of 60kWp by using the PV-syst software package, of solar On-grid system for the site located in Uttar-Pradesh, India. The coordinates of the working site are 27°59’21.19”N and 77°44’37.08”E. Fatehpur-village is located in Aligarh district of Utter-Pradesh, India. The population of this village is about 1000-1200 peoples and 200 habitations are available for the residents of the village. The availability of electrical energy for the villagers is about 6 to 7 hours per day for their daily needs. Fatehpur village has the great potential of solar irradiance on yearly basis i.e. 5.22 kWh/m²/day according to National Renewable Energy Laboratory by Homer-pro. By using PV panel, solar energy is directly converted into electrical energy. The output of a panel is normally a DC (Direct Current) format which can be easily stored in the batteries for later application. We can
harness the solar energy in three modes i.e. On-grid mode, off-grid mode and hybrid mode. In this study, solar grid-tied method is selected for harnessing the solar energy. In this mode we connect the solar PV system to the grid with the help of some auxiliary equipment’s i.e. Bidirectional meter/ Net meter, connecting cables, clamps and charge controller etc. This system generates power which is dc, and this available dc converted into ac power by using inverter module so that power feeding can be done to the grid in an easy way. After utilization of electric energy by consumers, the excess quantity of power sell back to the grid, which gives advantages in the form of reduction in electricity bill for the consumers. In work of [1], a simulation and performance analysis has been studied for 1kW system by PV-syst in Hamirpur, India. By using PV-syst version 6.84 software design and performance analysis for 2kW capacity system has been done for Bhuvnesbwar, Odisha in [2]. In [3], A case study of an institute i.e. MIT Manipal for its building load, floor and laboratory load is taken to design the solar PV system by PV-syst software is explained. In work of [4], Design and Installation of rooftop solar system which is grid connected type of 10 kW capacity synchronized with 3 phase, 50 Hz, 750 KVA transformer is given. Analysis of performance of a 48kWp solar grid-tied system, rooftop type, located in New Delhi, India has been studied in [5]. Simulation based analysis as well as orientation optimization of a 100kWp on-grid system installed in Poornima University, India has been studied for India by PVsyst programme in [6]. In [7], Design & analysis of standalone solar energy harnessing system for Dina Farm Rest in Egypt, is explained through PV-syst software. For school in village community of Chennai in India, design analysis of solar off-grid system has been studied in [8]. The location of work in this paper is suitable for the power generation by the proposed system due to its good availability of solar irradiance, i.e.5.22 kWh/m²/day according to the Homer-pro database. Here, Homer-pro means “Hybrid Optimization of Multiple Electric Renewables”.

2. METHODOLOGY

In this work, we are designing and simulating the solar power plant which is basically an on grid type system for the site Fatehpur rural area in Utter Pradesh. Design of such a system mainly depends on solar irradiance of the site location and some other factors like quality and type of material for the manufacturing of solar photovoltaic panels, types of converter circuits, connecting wire, and some auxiliary equipments etc. A software package known as “PVsyst” version 7.2.2 is used here. It has huge database of meteorological information, almost all locations of the globe. This package provides many features for the purpose of analysis i.e. On-grid system, Off-grid system, Hybrid system, Solar-energy based pumping system, Floating PV system etc. In this study, the solar irradiance is measured by “Meteonorm 8.0” which is provided by PV-syst software for the site located at 27°59’21.19”N and 77°44’37.08”E. In this work, functional details of 60 kWp solar on grid system for Fatehpur (U.P.) are given. The view of the work site is presented in figure 1.

![Figure 1. Location of the project site.](image_url)
photovoltaic system (SPV) completely, which helps in designing and simulation preparation to the research scholars and engineers. In this project for the purpose of simulation, an on-grid system with a capacity of 60kWp is done by using the latest version 7.2.2 of PVsyst software. It has various useful features of meteo and PV systems components database and general solar energy tools. It has a feature of collecting solar insolation information for any site of interest of all over the world. With this facility, an engineer can design the better system. PV-syst gives results, which consists of various graphs and tables, just only to help research scholars or industry person to analyse the results in the easiest way so that according to the simulation output, he/she can understand the merits and demerits or consequences of that particular project which they want to install and analysis on their site location. Useful variables of PV-syst are given below:

Topographical data, Incident irradiance on collector plane, Incident energy parameters, PV module characteristics, Inverter losses, System operating conditions, Energy uses, Efficiencies, Normalized performance index (NPI) etc. [1]

2.2 System Architecture
A grid-tied solar system consists of various equipments in which solar PV panels, solar inverter, net metering/ bidirectional meter, power grid, cables for connection purpose and electrical load etc are present. This system has the following features:
1. It works only with grid power supply.
2. It has capability of feeding unutilised solar energy to the grid.
3. It cannot be used for charging batteries directly from solar energy.
4. Cheaper than an AC off-grid system but does not provide power backup.
5. It saves on electricity bill etc.

![Figure 2. Layout of solar PV system.](image)

2.3 Load Calculation
Here we are designing and simulating the solar system for electrification purpose of the whole village Fatehpur. To calculate the peak power of load, computation of load of 10 homes at starting is done firstly. Later on obtained the consumption of 3.973 kWh/day/home for summer seasons and 2.453 kWh/day/home for winter seasons, and finally we multiplied the total no. of houses with the 3.973 kWh/day/home to get the total load during summer season i.e. 794.6 kWh/day. Similarly, we obtained the load for winter season i.e 490.6 kWh/day. But, the kWp of the plant is determined through the annual average energy consumption of 642.6 kWh/day. Here we can understand that to supply the whole village, a power plant of 60kWp is a suitable choice. The actual load calculated by local survey at the site, given in table 1.
### Table 1. Load calculation

| S. no. | Light \((Q \times W \times H)\) | Fan \((Q \times W \times H)\) | T.V. \((Q \times W \times H)\) | Freeze \((Q \times W \times H)\) | Water Pump \((Q \times W \times H)\) | Mobile Charger \((Q \times W \times H)\) | Washing Machine \((Q \times W \times H)\) |
|-------|-------------------------------|-------------------------------|--------------------------|-------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 1     | 4x15x8=480                   | 2x90x8=144 0                 | 1x80x4=32 0              | 1x350x12=42 0                | 1x1000x1/2                     | 1x7x2=14                       | 1x255x2=510                    |
| 2     | 2x15x9=270                   | 2x90x8=144 0                 | 1x80x5=40 0              | NA                           | NA                             | 1x7x2=14                       | NA                             |
| 3     | 4x15x10=600                  | 2x90x12=21 60                | 1x80x5=40 0              | NA                           | 1x1000x1/2                     | 1x7x2=14                       | 1x255x2=510                    |
| 4     | 5x15x6=450                   | 1x90x10=90 0                 | 1x80x3=24 0              | NA                           | NA                             | 1x7x2=14                       | NA                             |
| 5     | 6x15x8=720                   | 1x90x10=90 0                 | 1x80x4=32 0              | NA                           | NA                             | 1x7x2=14                       | 1x255x2=510                    |
| 6     | 4x15x8=480                   | 3x90x7=189 0                 | 1x80x6=48 0              | 1x350x12=42 0                | 1x1000x1/2                     | 1x7x2=14                       | NA                             |
| 7     | 2x15x12=360                  | 4x90x5=180 0                 | 1x80x4=32 0              | NA                           | NA                             | 1x7x2=14                       | NA                             |
| 8     | 5x15x6=450                   | 2x90x6=108 0                 | 1x80x5=40 0              | 1x350x12=42 0                | 1x1000x1/2                     | 1x7x2=14                       | NA                             |
| 9     | 4x15x10=600                  | 2x90x8=144 0                 | 1x80x4=32 0              | NA                           | NA                             | 1x7x2=14                       | NA                             |
| 10    | 2x15x8=240                   | 2x90x12=21 60                | 1x80x5=40 0              | NA                           | NA                             | 1x7x2=14                       | NA                             |
| Total | 4650 Wh/day                  | 15210 Wh/day                 | 3600Wh/day               | 12600 Wh/day                 | 2000 Wh/day                    | 140Wh/day                      | 1530 Wh/day                    |

Note:-

- ‘Q’ represents the quantity of the product,
- ‘W’ represents the wattage of the product,
- ‘H’ represents the hours of application.

#### 2.4 Data in PV-syst

To design the system by PVsyst, a set of data is necessary for this purpose. In this collection of data, the “latitude and longitude” of the selected site are required. And according to these coordinates of location, software will get the data of “solar irradiance” for the selected site through Mateonorm 8.0 feature which is available in version 7.2.2 of PV-syst. In next step, the proper value of tilt angle is necessary for orientation of PV panels suitably for different seasons, i.e. summer and winter months.

Based on Indian weather conditions, we select the 10 degree and 47 degree respectively as tilt angles and zero degree azimuth angle for the proposed system. Under summer duration: April May, June, July, August and September months are considered,

While for winter season: Oct, Nov, Dec, Jan, Feb, Mar etc. months are considerable.
2.4.1 Azimuth angle
To define the direction of the sunshine, Azimuth angle is required. Its value is zero if the PV panels are facing south direction in northern hemisphere. The angle between the sun’s rays and true south is called as “Azimuth angle”. Positive azimuth angle points a position East of South, while negative azimuth angle points West of South.

2.4.2 Albedo radiation
To measure the reflectivity or contemplatively of the earth’s surface, the knowledge of Albedo is must. Range of Albedo is varies between “0.9 to 0.1”. The value of “Albedo” is higher in icy areas. The reflected radiation by earth and its object is called as “Albedo radiation”.

2.4.3 Module Description
To design 60kWp system at Utter Pradesh, we are using PV panels of “Innotech Solar” manufacture 2014. Model no. of panel is “Design Black 250” each of 250 watt, silicon polycrystalline type.

2.4.4 Inverter data
In design of 60kWp system, we are considered Inverter capacity of 2kW each with model number AS-IR01-2000 (2kw) by AEG Industrial Solar Gmbh since 2017.

2.4.5 Solar Irradiance
The average solar irradiance at the place of location 27.9° N and 77.7° E is about 5.22kWh/m²/day, which is satisfactorily value for the production of electrical energy. The received solar energy per unit area is called as solar irradiance or irradiance. It is measure in W/m². Maximum value of this insolation is occurs in summer season as compared with the winter duration.

3. SIMULATION RESULTS & DISCUSSION

A comprehensive detail including numerous tables and graphs acquired by PV-syst programme is explained in current segment. 30 units of inverter of capacity 2 kWp each and 240 units of PV panels of capacity 240 watt each are required for this system. After applying all important amendments, output power is obtained. In following figures, various variables and main results, evaluated from the PV-syst are given;

| PV module | Manufacturer | Generic |
|-----------|--------------|---------|
| Model     | DesignBlack 250 |
| Unit nominal power | 250 Wp |
| Number of PV modules | 240 units |
| Nominal (STC) | 60.0 kWp |
| Modules | 30 Strings x 8 In series |
At operating condition (50 °C)

| Parameter  | Value     |
|------------|-----------|
| P_{mpp}    | 54.4 kWp  |
| U_{mpp}    | 218 V     |
| I_{mpp}    | 250 A     |

Total PV power

| Parameter                  | Value     |
|----------------------------|-----------|
| Nominal (STC)              | 60 kWp    |
| Total                      | 240 modules |
| Module area                | 396 m²    |
| Cell area                  | 350 m²    |
| MPP voltage                | 30.4 V    |
| MPP current                | 8.3 A     |

Inverter

| Parameter                  | Value     |
|----------------------------|-----------|
| Manufacturer               | Generic   |
| Model                      | AS-IR01-2000 (2kW) |
| Unit nominal power         | 2.00 KWac |
| Number of inverters        | 30 units  |
| Total power                | 60.0 KWac |
| Operating Voltage          | 120-410 V |
| P_{nom} ratio (DC:AC)      | 1.00      |

Main results

| Parameter                  | Value     |
|----------------------------|-----------|
| System production          | 89.5 MWh/yr |
| Specific production        | 1491/kWh/kWp/yr |
| Performance ratio          | 0.737     |
| Normalized production      | 4.09 kWh/kWp/day |
| Array losses               | 1.22 kWh/kWp/day |
| System losses              | 0.23 kWh/kWp/day |

Sheds system, Sizes & Models used

| Parameter                  | Value     |
|----------------------------|-----------|
| No. of sheds               | 20 units  |
| Sheds spacing              | 5.00 m    |
| Collector width            | 3.35 m    |
| Ground cov. Ratio          | 67.0 %    |
| Top inactive band          | 0.02 m    |
| Bottom inactive band       | 0.02 m    |
| Limit profile angle (winter) | 42.4 °  |
| Transposition              | Perez     |
| Diffuse                    | Perez, Meteonorm |
| Circumsolar                | Separate  |
| Near shadings              | Linear shadings |

Fig. 3 presents the scatter diagram between energy inserted into the grid in kWh/day and global incident collection plane in kWh/m²/day. In this diagram, a small curvature is present, which is the indication of temperature effect. And some points which are equivalent to days are disturbed with respect to the diagram, which is the representation of the state of overloading.
Figure 3. Daily input-output details of the system.

Fig. 4 represents the bar plots between normalized production and loss factor. It is an annually based representation. According to this graph, the energy given to consumer is 73.7 percent, and has the collection loss about 22.1% and system loss is approximately 4.2%.

Figure 4. Normalized production and loss factors.

Fig.5 represents the solar horizon of 60kWp On-grid system for the selected site in Uttar Pradesh. In a simple way to defining shading in PV-syst software, the concept of “Horizon” is used. It depicts the terrain skyline around the choosed site. The relevant shading of the PV modules annually is evaluated from this horizon. It is enough for PV system installed in open landscapes area.

Figure 5. Sunshine horizon.

Fig.6 displays the graph of Incident Irradiation Distribution between Global incident in collection
plane in W/m² and Global incident in collection plane in kWh/m²/Bin.

Fig. 6. Incident Irradiation Distribution.

Fig. 7 represents the incident energy in collector plane annually, which is equal to 5.541 kWh/m²/day. The value of incident energy are maximum during the month of April, while during the month August, it has the minimum value with respect to many months consideration.

Fig. 7. Reference Incident Energy in Collector Plane.

Fig. 8 displays the bar plots for Performance ratio (PR) and loss diagram (LD) details for proposed system. The value of “PR” for the selected system is 0.737. It displays the ratio between output of an inverter and PV array mechanism.

Fig. 8. Performance ratio.

The loss parameters for 60kWp SPV On-grid methodology, obtained through loss diagram (LD). It
includes various losses which occur during operation of the system i.e. \( I^2R \) waste, module quality degradation, converter power waste, lowered efficiency etc.

| Loss-diagram parameters                              | Value                                           |
|-----------------------------------------------------|------------------------------------------------|
| Global horizontal irradiation                        | 1775 kWh/m²                                     |
| Global incident in coll. Plane                       | +13.9 %                                         |
| Near shadings: Irradiance loss                       | -3.39 %                                         |
| IAM factor on global                                 | -2.13 %                                         |
| Soiling loss factor                                  | -2.00 %                                         |
| Effective irradiation on collectors                  | 1874 kWh/m² * 396 m² coll.                     |
| Efficiency at STC                                    | 15.20 %                                         |
| Array nominal energy ( at STC efficiency)            | 112.8 MWh                                       |
| Module degradation loss                              | -3.80 % (for 10 years)                         |
| PV loss due to irradiance level                      | -0.51 %                                         |
| PV loss due to temperature                           | -8.11 %                                         |
| Spectral correction                                  | +0.32 %                                         |
| Module quality loss                                  | +1.25 %                                         |
| Light induced degradation (LID)                      | -2.00 %                                         |
| Mismatch loss, modules and strings (including 0.8 % for degradation dispersion) | -2.91 %                                         |
| Ohmic wiring loss                                    | -1.35 %                                         |
| Array virtual energy at MPP                          | 94.6 MWh                                        |
| Inverter loss during operation (efficiency)          | -3.49 %                                         |
| Inverter loss over nominal inverter power            | 0.00 %                                          |
| Inverter loss due to max. input current              | 0.00 %                                          |
| Inverter loss over nominal inverter voltage          | 0.00 %                                          |
| Inverter loss due to power threshold                 | -0.11 %                                         |
| Inverter loss due to voltage threshold               | 0.00 %                                          |
| Available energy at inverter output                  | 91.2 MWh                                        |
| System unavailability                                | -1.87 %                                         |
| Energy injected into grid                            | 89.5 MWh                                        |

The “LD” gives sharp & intuition look into the quality about the design of Photovoltaic system by...
considering the numerous sources of deprivation. It is accessible in the simulation data, on yearly basis.

\[
\begin{array}{|c|c|}
\hline
\text{Total} & 2512.5 \text{ tCO}_2 \\
\text{System production} & 89.48 \text{ MWh/yr} \\
\text{Grid Lifecycle Emissions} & 936 \text{gCO}_2/\text{kWh} \\
\text{Source} & \text{IEA List} \\
\text{Country} & \text{India} \\
\text{Lifetime} & 30 \text{ years} \\
\text{Annual degradation} & 1.0 \% \\
\hline
\end{array}
\]

Series diode loss

| Voltage drop | 0.7 V |
| Loss fraction | 0.3 % at STC |

Thermal loss factor (Module temperature according to irradiance)

| \(U_C\) (const) | 29.0 W/m\(^2\)K |
| \(U_V\) (wind) | 0.00 W/m\(^2\)K/m/s |

DC wiring loss

| Global array resistance | 15 m\(\Omega\) |
| Loss Fraction | 1.5 % at STC |

Tab-2 displays the main outcomes of the proposed system for the selected site using PV-syst. Table 2 display the results in terms of balances and main results for the 240 units of PV panels for capacity of 240 watt each. The specific production of the proposed system is 1491 kWh/kWp/year. To represent the data, some important terms are used here i.e.

- \text{GlobHor} : Global horizontal irradiation
- \text{DiffHor} : Horizontal Diffuse irradiation
- \text{T_Amb} : Ambient Temperature
- \text{GlobInc} : Global incident in coll. Plane
- \text{GlobEff} : Effective Global, corr. For IAM and Shadings
- \text{EArray} : Effective energy at the output of the array
- \text{E_Grid} : Energy injected into grid
- \text{PR} : Performance ratio

The annual production probability in terms of P50, P90 and P95 are give below;

| Annual Probability | Production | Energy Output |
|--------------------|------------|---------------|
| Variability        | 1.67 MWh   |
| P50                | 89.48 MWh  |
| P90                | 87.33 MWh  |
| P95                | 86.73 MWh  |
4. CONCLUSION & FUTURE SCOPE

The study has been done for a rural area known as “ Fatehpur village” in Aligarh district of Uttar Pradesh. There is still energy crisis present in the village. In this work, solar on-grid system is analysed for energy purposes via PV-syst programme. The system produces 89.5 MWh/year with the “PR” of 73.73%, which are quite satisfactory. Further, this system also helps in reducing the CO$_2$ emission throughout the operation i.e. approximate “2043.730 tons” of CO$_2$ saved during project life cycle. The yearly loads demand i.e. 642.6 kWh/day energy of rural community can be compensated suitably. Application of renewable energy in real situation is the requirement of our society. Conventional power sources have many issues related to their operation, cost and pollution. The proposed system is an alternate way which helps in remote areas for their energy purpose, where availability of grid is limited or completely absent. It is a pollution free method with least capital investment. During study it is found that, it is a feasible solution to overcome the energy crisis in rural region under study.

5. References

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