International Journal of Electrical Engineering & Technology (IJEET)
Volume 9, Issue 3, May- June 2018, pp. 100–105, Article ID: IJEET_09_03_012
Available online at http://www.iaeme.com/IJEET/issues.asp?JType=IJEET&VType=9&IType=3
ISSN Print: 0976-6545 and ISSN Online: 0976-6553
Journal Impact Factor (2016): 8.1891 (Calculated by GISI) www.jifactor.com

DISTRIBUTED GENERATION BY GREEN AND SUSTAINABLE TECHNOLOGY USING SOLAR PV ROOF-TOP INSTALLATION

Sunil T. Gaikwad, Prasad Paraskar, Vedant Wankhede and Dr. Y. P. Nerkar
Department of Electrical Engineering, PVG's College of Engineering & Technology, SPPU, Pune, Maharashtra, India

ABSTRACT

In the proposed work, solar rooftop PV generation analysis of existing distribution network in Pune (18.5204303°N,73.8567°S) consists of 3 residential buildings supplied by 100 kVA distribution transformer (DT) has been performed. Distribution side generation provides opportunity to increase system reliability and make the system sustainable. The Google earth, PVsyst and AutoCAD softwares are used to study the feasibility of solar rooftop installation on buildings. A methodology for estimating rooftop solar PV potential for buildings has performed. Global solar radiation on horizontal surface is converted into tilted surface radiation using mathematical formula derived from Liu Jorden model considering fixed tilt i.e., latitude. The energy output for hourly, daily and monthly is estimated for solar rooftop with elevated structure installation capacity of 31.78kW and 25.67 kW with non-elevated installation for both on-grid and off-grid system. In this proposed work PV generation is estimated using multi-crystalline and mono-crystalline PV module. The numbers of electrical vehicle batteries charged are 6000 if 4-wheeler and 30000 if 2-wheeler. Payback period is 14.8 years for non-elevated and 16.9 years for elevated installation.

Keywords: Solar rooftop, radiation on tilted surface, PV generation, Payback period and Carbon footprint.

Cite this Article: Sunil T, Gaikwad, Prasad Paraskar, Vedant Wankhede and Dr. Y. P. Nerkar, Distributed Generation by Green and Sustainable Technology Using Solar PV Roof-Top Installation: *International Journal of Electrical Engineering & Technology*, 9(3), 2018, pp. 100–105.
http://www.iaeme.com/IJEET/issues.asp?JType=IJEET&VType=9&IType=3

1. INTRODUCTION

The use of energy has become an integral part of our life hence its supply should be secure and sustainable. The demand of energy is increasing day by day in such a way that it puts a lot of pressure on the conventional energy sources. Therefore, there is a need for alternative energy sources which can provide us energy in a sustainable manner [1]. Distribution system is an ultimate and revenue related part in power system which provides supply to the

consumers from high voltage transmission system to lower voltage. Integration of roof-top solar PV for three main reasons; to reduce dependency on imported fossil fuels, to protect the environment, and contribution to sustainable development [2]. The electricity generation at distribution load side itself using green and sustainable technologies can reduce the unbalance in the system. The 62.5% of the total area of India, i.e. around 2.0 million sq.km has an annual average direct normal insulation of more than 5.0 kWh/m^2/day [3]. The global solar radiation (GSR) is an input for PV system may or may not be the same so in order to know the behaviour of solar radiation at the site of interest, long-term data of direct, diffused and global solar radiation and other weather parameter from a nearby location are collected and analysed [4]. The calculation of estimation of solar radiation on tilted surface from solar radiation on horizontal surface is proposed by some literature [5][6].Some case study are made for estimation of expected output of PV generation from proposed rooftop system and then concluded with the calculation of capacity utilization factor and payback period [7].In some research the effect variation in of weather parameters like wind velocity, air temperature and relative humidity on global and diffused solar radiation is studied[8][9].This paper proposes a methodology for estimation of solar output generation (kWh) of rooftop on three buildings in the area under study of Pune city. The objectives of study are to estimate solar energy potential from rooftops of selected sites of residential area. The output generated energy would be consumed by these houses. The second objective is to find out possibility of penetration of extra energy into grid after consumer's usage. In this proposed work distribution side generation analysis is performed considering both with and without elevated structure tilted with an angle equal to latitude of Pune city. The calculated tilted surface radiation plays vital role in calculation of energy output of solar PV rooftop (E_{PV}) installation of 3 buildings for hourly, daily and monthly for a year. The elevated and non elevated installations are considered for on-grid and off-grid system. The solar output potential for two types of PV modules as multi and mono crystalline is estimated. This study also contributes for finding out how much carbon emission would be reduced by using this sustainable green technology.

2. METHODOLOGY

In this proposed work the methodology for estimation of solar output generation of three buildings consist of four steps as, calculation of solar PV rooftop installation capacity, estimation of solar radiation on tilted surface, electrical and dimensional data of PV module and estimation of energy output of solar rooftop. All these steps are explained as follows.

2.1. Solar PV Rooftop Installation Capacity (IC)

The initial step of Solar Rooftop PV Generation is to find out installation capacity of rooftop installation. Select the size of single panel (in Wp) which is the necessary for calculating the installation capacity. The next step is to find the number of panel to be installed in available rooftop area for calculating the panel area. In this analysis two cases are considered for IC calculation as without elevation i.e., solar panel ground mounted, and with elevation i.e., solar panel are mounted on elevated structure which increases no. of PV module as shadow effect and roof-top hurdles are less.

Figure1 PV system design using 1(a) Google earth, and 1(b) AutoCAD software

Fig.1 represents the PV system design of one the three building of area under study. First locate the building using Google earth software and noting its X-Y coordinates. The Fig. 1(a) is of a rooftop area mapped in Google earth software, and the next step is plot this mapped area in AutoCAD as shown in Figure 1(b). The 45 panels of 315 Wp can be installed on this building considering elevated installation of total capacity of about14.17 kW i.e., 14x315 = 14175W and for non-elevated installation 36 panels can be installed of 315 Wp so its installed capacity is 11.340 kW i.e., 11x315 =11340W. The total installed capacity of on all three buildings is 31.78 kW and 25.67 kW with and without considering elevation respectively which is less than 40% of the rating of 100 kVA distribution transformer supplying these 3 buildings.

2.2. Estimation of solar radiation on tilted surface

The mathematical formula derived from standard Liu Jorden model is used to convert global solar radiations to tilted surface radiations considering panel tilted at an angle equal to latitude (18.5204303°) i.e., fixed tilt orientation [2][4]. For calculating the tilted surface radiation it is required to perform a brief solar geometry analysis i.e., declination angle (δ), Hour angle (ω) and Local Apparent Time (LAT) [3]. The declination angle is due to the inclination of earth's polar axis and its revolution around the sun. The Declination angle varies between -23.45°(December Solstice) and 23.45(June solstice).In the calculation of hour angle, Local Apparent Time or Local Solar Time is taken as a reference. With the help of tilted surface radiation the expected output from roof top PV system is calculated and output Generation profile is obtained.

The mathematical expression for solar radiation on tilted surface is expressed as [2]

$$I_T = \left[\text{Rsb} + \left(\frac{1+\cos\beta}{2} - \text{Rsb}\right) * K_S + \rho\left(\frac{1-\cos\beta}{2}\right)\right] * I_G \quad 1$$

Where, 'R_{sb}' is the ration of direct radiation flux falling on tilted surface to that falling on horizontal surface is called the *tilt factor* for direct radiation; K_S is the diffuse fraction, the ratio of diffuse radiation (I_D) to global radiation (I_G) [9]; ρ is the reflectivity of surface (for concrete and grass ρ = 0.2) [5][10].

2.3. Electrical data of PV module

In this study electrical and dimensional data of multi crystalline and mono crystalline solar PV module is shared by from manufacturer. The electrical data of PV module consists of electrical rating, module efficiency, open circuit voltage, short circuit current of PV module. The mono-crystalline module has higher efficiency and cost than that of multi-crystalline PV module. The size of PV module is 1.98m x 0.99m and weight of PV module.

2.4. Estimation of Energy Output of Solar Rooftop

The energy output of rooftop installation on all the three building is calculated considering the solar energy available on the panel (E_{SOL}), module efficiency, efficiency of power conditioning unit (PCU) and effect of temperature on reduction of module efficiency. In this work the generation analysis is done for on-grid and off-grid system. In case of on-grid system the entire generation is penetrated on the utility grid its PCU consists of inverter only hence it efficiency of 95%. In case of off-grid system generation analysis has been performed on two cases, for calculating total electrical vehicles as two wheeler and four wheeler charged by PV generation. The second case is to provide the solution for possible number of four wheeler and two wheeler electrical vehicle batteries that can be charged after satisfying the common load of building.

The electrical energy output from solar photovoltaic panel is given by [1][4],

$$E_{PV} = E_{SOL} * \mathrm{A} * \eta_{PV} * \eta_{PCU} * \left[1 + \frac{PTC*(T_{Panel}-25)}{100}\right] \quad 2$$

Where, η_{PV} is efficiency of PV panel i.e.16.25%; η_{PCU} is efficiency of Power conditioning unit i.e., 95% or 75% (for on-grid or off-grid system respectively), E_{SOL} Incident solar energy, T_{Panel} is Panel temperature during h^{th} hour which is calculated using ambient air temperature during h^{th} hour and nominal operating cell temperature (NOCT) is the temperature reached by open circuited cell in a module under standard test conditions. PTC is Power Temperature coefficient, the percentage change in output of PV panel for every degree Celsius of temperature variation from standard 25°C temperature of PV panel [1].

3. RESULTS AND DISCUSSION

The total monthly consumption and generation profile for all 3 buildings in case of on-grid system is shown in Fig. 2. It can clearly identify that solar generation in case of elevated system is more than that of non-elevated system. Monthly consumption is more in month of June around 8000 kWh whereas PV generation is 5000 kWh and 4000 kWh with and without elevated installation. The result shows that in month of June percentage share of PV generation in demand in case of with and without elevation is 60% and 45% respectively.

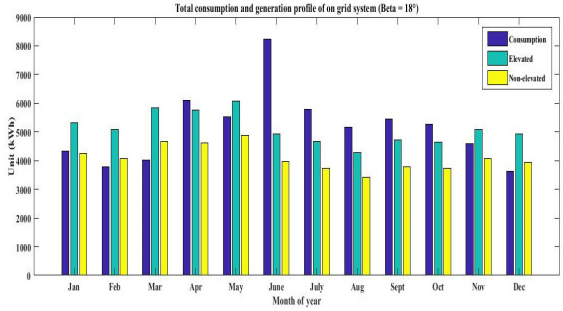

Figure 2 Total consumption and generation profile(on-grid system)

Figure 3 shows the total monthly consumption and generation profile for all 3 buildings in case of off-grid system. Monthly generation for the month of June around is around 3500 kWh with considering elevation and 3000 kWh without considering elevation. i.e., percentage share of PV generation in demand is 45% and 35% for with and without elevation case respectively.

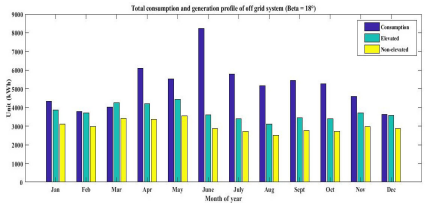

Figure 3 Total consumption and generation profile(off-grid system)

Figure 4 shows the PV generation in mono-crystalline and multi-crystalline PV module with considering elevation and tilt angle of the panel equal to latitude of city. It also shows the difference in the units generated by mono-crystalline and multi-crystalline PV module.The annual consumption of consumers of 3 buildings in the area under study is 61849kWh. The annual generation of 3 buildings in case of on-grid system for elevated and non-elevated system is 61334 kWh and 49190 kWh respectively. The annual generation of 3 buildings in case of off-grid system for elevated and non-elevated system is 44696 kWh and 35847 kWh respectively. The number of 4-wheeler and 2-wheeler electrical vehicle batteries that can be charged are 6000 and 30000 from elevated or non-elevated respectively. Approximately 6.9 × 10−4 metric tons of CO2 are emitted for the generation of 1 kWh of electricity. 1 kWh of solar energy = 6.9 × 10−4 metric tons of CO2 reduction [6]. Therefore in case of on-grid solar rooftop system 42.32 metric tons and 33.94 metric tons of CO_2 reduction can be possible from PV generation with elevation and without elevation respectively. In case of off-grid solar rooftop system 30.84 metric tons and 24.73 metric tons of CO_2 reduction can be possible from PV generation with elevation and without elevation respectively. Capacity utilization factor (CUF) is defined as the ratio of the energy output, in a given time period, from an installation having a rated capacity, to the theoretically maximum energy output possible from that rated capacity in the same time period. In case of on-grid system and off-grid system CUF is 19% and 16% respectively.

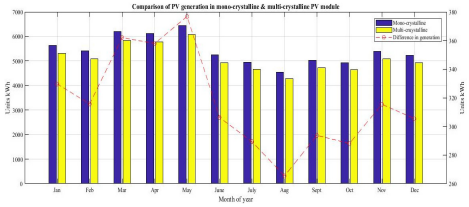

Figure 4 Comparison of PV generation in mono-crystalline & multi-crystalline PV module

4. CONCLUSION

The generation analysis part include the calculation of radiation incident on tilted surface considering fixed i.e., tilt angle equal to latitude of Pune city i.e.18.5204303°. The analysis suggests two kinds of solutions first is the penetration of entire energy generated supplied to grid (On-grid) and second is number of 4-wheeler and 2-wheeler electrical vehicle batteries that can be charged by the rooftop PV generation. Total annual consumption of the entire consumer in area under study is 61849 kWh and estimated total annual generation for on-grid system in case of elevated and non elevated structure are 61344 kWh and 49190 kWh respectively i.e. 99% and 80% of consumption is shared by PV generation. The total annual generation estimation for off-grid system in case of elevated and non elevated structure is 44696 kWh and 35847 kWh respectively. The numbers of 4-wheeler and 2-wheeler electrical vehicle batteries that can be charged are 6000 and 30000. In case of on-grid solar and off-grid rooftop system minimum 33.94 metric tons and 24.73 metric tons of CO2 reduction can be possible from PV generation respectively.

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