Estimating Future Site of Grid PV System with Optimal Shade Analysis

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Abstract- Grid Tie Inverter (GTI) system are allowed to sell their energy to the utility grid. Different analysis has made great efficiency with the economic feasibility of Solar Photovoltaic (SPV) projects. Tax rebates, government subsidy and utility payback policies have made the land owner to design in optimal construction. While considering endurance of the SPV is 25 years, an optimal solution is mandatory for the large investment. This paper proposes a novel algorithm for the selection of a PV generator site with the optimal shade. The shade profile model of gabled roof has been analyzed with the result of optimal arrangement of pv array to yield more power for rural electrification. And for erecting a PV system, shade analysis of adjacent building with different direction placement of PV generator is comparatively analyzed. It also focuses on optimal retrofitted PV array into existing roof and buildings for the development of electrification. Performance of various sites with different arrangement of PV array with shade time calculation is accurately analyzed using solar pro simulation software and tested with a different shade profile of PV array with the feasible energy production.

Keywords—Optimal Shade analysis, PV arrangement,PV generator ,Shade calculation, solar pro.

Nomenclature

Ψs Solar azimuth, rad

β Tilt angle of PV cell, rad

ρ Albedo

θ_{zs} angle of incidence on between sun ray & normal to tilted surface, rad

θ_s angle of incidence on PV cell, rad

γ_s Sun altitude, rad

Γ_{ob} obstacle outline, rad

γ_m PV cell azimuth, rad

α_m PV cell altitude, rad

T_{BS} Building shade time, (hh:mm)

T_{sf} Shade factor time, (hh:mm)

T_{sh} Shade time, (hh:mm)

SN Solar Noon, (hh:mm)

G_t Total irradiance on tilted plane, W/m^2

E_t Total solar irradiance,W/m^2

E_{dni} Direct normal irradiance, W/m^2

E_{diff} Diffused irradiance, W/m^2

E_{ref} Reflected irradiance, W/m^2

E_{cs} circumsolar component, W/m^2

E_{hz} horizon brightening diffuse component, W/m^2

E_{iso} Isotropic diffuse component, W/m^2

D_h Diffuse radiation on horizontal plane, W/m^2

D1&D2 circumsolar & horizon brightness

$C_{sh,dir}$ direct shading factor

$C_{sh,diff}$ diffuse shading factor

$F_{sh,ref}$ Reflected shading factor

E_h Direct irradiance on horizontal plane,W/m^2

$\Delta E_{t,sh}$ Total irradiance loss received on shaded PV cell,Wh/m^2

$E_{t,sh}$ Total irradiance on shaded PV cell,Wh/m^2

$\Delta D_{t,sh}$ periodic irradiation loss due to shading,Wh/m^2

$C_{sh,ref}$ Reflected shading component

D_t Irradiance on PV cell, W/m^2

C^p_{sh} Periodic shading component,W/m2

1. Introduction

Increasing of Energy demand and the depletion of fossil fuel has made mandatory to look back into renewable energy based generation of electricity. Particularly solar energy based photo voltaic (SPV) has gained more importance based on availability and feasibility. The surplus amount of power produced, apart from giving to the consumer load can be fed to the grid utility with IEEE standards and policy [1]. In the interest of expanding the number of PV based GTI installations and providing maximum benefit, it is necessary to consider in more detail of the power loss from a partially shaded PV system discussed in [2]. In most of the analysis [3-5], Shading factors and shade time of PV generators envisages the production of output power. Due to immobile in nature and firm operation PV systems are operated in populated area and commercial buildings [6,7]. Considering to that, PV generator site is estimated with optimal shade for the conservative energy yield of sustainability. In this paper, different PV generator site like gabled roof,hip roof, top of building, roof line and wall surface have been analyzed with the diagrams in 3D CAD for perfect panorama. This paper presents the calculation of shading factor and a novel algorithm for the selection of preferred dimension of the PV site area with optimal shade. The arrangement and placement of the PV array are made for gabled roof with practical of 3.2 kW of PV generator set and compared with other residential sites.

2. Indian Residential PV Market

According to 2011 Census [10], In India an average house can accommodate 1-3kW of solar PV system. Ministry of New & Renewable Energy(MNRE) launched a pilot scheme in 2013 for grid integrated rooftop PV power projects-being executed by Solar Energy Corporation of India (SECI). The scheme allows system size from 100kW to 500kW for a subsidy of 30% would be provided and 70% met by the customer. Due to the effect installation of grid connected solar photovoltaic (SPV) has augmented between 2008-2013 as shown in Fig. 1.The mission and vision of the MNRE in India are to promote and establish solar powered projects as per the first phase (2012-13) of Jawaharlal Nehru National Solar Mission (JNNSM) is to promote GTI with the production of 1GW [8].

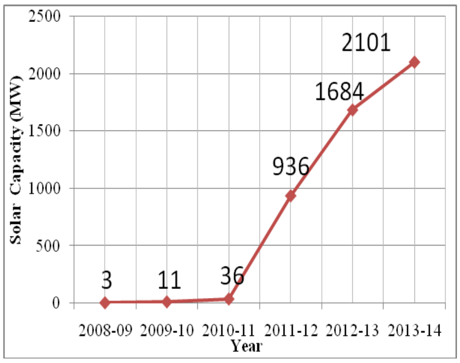

Figure 1. Expansion of solar capacity in year wise

The grid-connected solar power as of december 2010 was hardly 10 MW [9]. In order to promote and encourage the Vision policy MNRE has given subsidy based on the production of power by the consumer [10]. Parallel to the stand alone solar PV system, GTI is accessed by net metering by exporting the excess power from the SPV and importing the needed power from the utility grid. Aforementioned forced the land owners to predict the site with shade analysis and arrangement of SPVA.

3. Geographical Location with Meteorological Data

A PV system's geographical location were considered for Vellore, Tamilnadu, India with the longitude of 79^0 9′ 32″ E & Latitude of 12^0 58′ 26″ N & with solar insolation of 930 W/m^2 as collected from [11].Positional changes of sun path determine the volume of feasible sunshine that falls on the modules. The location decides the possible sunshine that is blocked before reaching the array and it shows capability of the system in displaying the modules to the sunlight. Vast land with solar insolation has made the landowner to design a solar park to generate huge amount of peak power.

4. Factors Affecting Shading in Photovoltaic Cell

SPV array is assembled by series/parallel connection of SPV modules to obtain desired voltage and current. In a larger SPVA occurrence of partial shade is common due impact of trees, falling of leaves, nearby buildings or other solar obstructions. The shading of solar panel makes the internal cell to get heated, and hotspot problem [12] is created and makes the entire system to get damaged. The shading and partial shading affects SPV in their energy yield. To harness received solar radiation into thermal or electrical energy it should be installed in a proper orientation as examined in [13, 14].

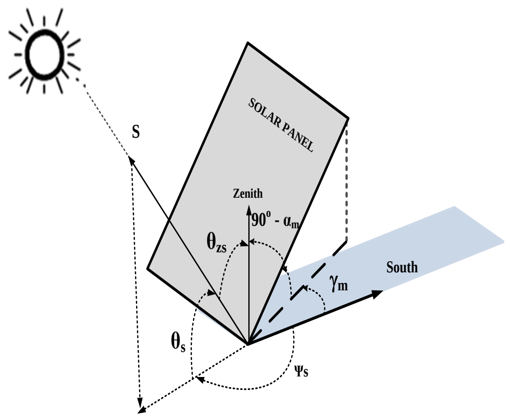

Figure 2. Relationship between the angles at a tilted photovoltaic generator plane

In [15, 16] several Maximum Power Point Tracking (MPPT) techniques are discussed for extracting power. The SPV has the nonlinear relationship between four variables: current, voltage, irradiance and temperature. For the huge requirement of power it is desired to connect a higher number of solar panels together in an array, the shade on one module affects the entire array dealing with its many configurations like series-parallel (SP),Total Cross-Tied (TCT), Bridge-linked (BL) and Honeycomb (HC) performances are evaluated in [17] by connecting the bypass diodes. It has been noted that shading factors play a major role in consideration. The method used for manipulating the irradiance on shaded planes is described in [18]. The relationship between all angles is shown in Fig. 2

4.1. Calculation of unshaded PV cell Irradiance

Direct Normal Irradiance (DNI) varies worldwide, according to its location and tracking of the sun path which falls on the PV cell, also called as direct irradiance E_{dni}. Scattered part of the sun rays gives the diffused irradiance E_{diff} proposed by Perez et al [19]. Different models have been created for finding global irradiance on tilt PV cell. This is due to the fact that irradiance falling on a horizontal plane is different from tilting PV plane [20, 21]. On the tilted plane there is irradiance component reflected from the ground E_{ref}. The global irradiance (E_t) is defined as,

$$E_t = E_{dni} + E_{diff} + E_{ref} \tag{1}$$

Total solar radiance Et of above inclined plane can smoothly defined as E_h,Using

$$E_{dni} = E_h \left[\frac{\max\,(0^0, cos\theta s)}{\cos\theta zs}\right] \tag{2}$$

The designed equation on inclined plane is with the inclusion of three components described as,

$$E_{diff} = E_{cs} + E_{hz} + E_{iso} \tag{3}$$

Where,E_{cs} is the circumsolar diffuse component, E_{hz} the horizon brightening diffuse component and E_{iso} the isotropic diffuse component. The diffuse component from scattered light of the horizontal plane E_h is given as,

$$E_{diff} = D_h \left(D_1 \frac{\max\,(0^0, cos\theta s)}{\cos\theta zs}\right) + D_h(D_2 \sin\beta) + D_h \left((1 - D_1)\frac{1+cos\beta)}{2}\right) \tag{4}$$

Where angle of inclination is defined as β.Diffuse radiance on horizontal plane with D_1 & D_2 as circumsolar & horizon brightness is acheived.Albedo (ρ) is most significant in reflected surfaces therefore ground reflected irradiance is affected by albedo with a very small value. The reflected irradiance is dealt with albedo as follows

$$E_{ref} = (1- \cos\beta)\frac{\rho}{2} \tag{5}$$

If the value of ρ is unidentified, it is taken as 0.2

4.2. Calculation of Shaded PV Cell İrradiance

The shading component build upon shaded PV cell irradiance is implemented. The general term for calculating shaded plane irradiance is $E_{t,sh} = E_t - \Delta E_{t,sh}$,if C_{sh}=0,the plane is away from shadows ($\Delta E_{t,sh}$=0) & if C_{sh}=1,this states that plane is totally shaded (E_t=0).The inclined plane radiation relies on direct, diffuse & reflected components to forecast the irradiance loss $\Delta E_{t,sh}$.As quoted earlier, the position of sun with respect to obstacle outline ($\gamma_s(\Psi) \le \Gamma_{ob,}(\Psi)$) and sun altitude angle as,(γ_s) = arc sin(cos Ψ_s) decides the three shading factor. The direct shading component is exhibited with the above mentioned approaches

$$C_{sh,dir} = \begin{Bmatrix} 0 & if & \gamma s(\Psi) \le \Gamma ob, \\ 1 & & otherwise. \end{Bmatrix}$$

the above equation is valid for opaque objects, if obstacles are zero. Otherwise it is one. By removing the circumsolar component from diffuse irradiance the diffused shading component is given as

$$C_{sh,diff} = \begin{Bmatrix} 1 - \dfrac{E_{cs}}{E_t} & if & \gamma s(\Psi) \le \Gamma ob, \\ 1 & & otherwise. \end{Bmatrix}$$

Consideration of the shading reflected diffuse component, it is not affected by the shading. Accordingly it is constantly balanced as 1

$$C_{sh,diff} = 1;\ \forall\, \gamma_s(\Psi) \tag{6}$$

The shading component can be defined as overall irradiance collected on shaded PV cell to the irradiance collected on shaded PV cell.

$$C_{sh} = \frac{\Delta E_{t,sh}}{E_t} \tag{7}$$

From the above equation, we can calculate periodic shading component using following equation

$$C_{sh}^{P} = \frac{\Delta E_{t,sh}}{E_t} \tag{8}$$

It is the average periodic shading component on PV cell & $\Delta D_{t,sh}$ the day to-day irradiation loss due to shading.With the above discussion, the flowchart for calculating shading factor with total irradiance on PV cell with shade is depicted in Fig. 3

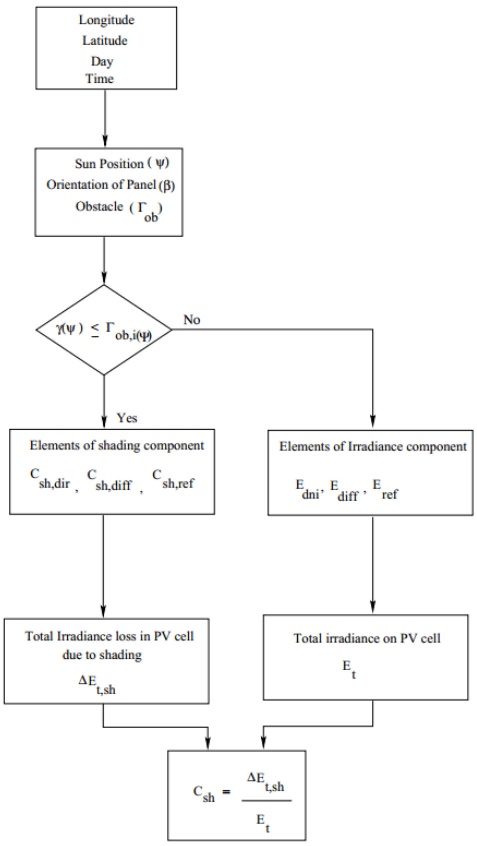

Figure 3. Flowchart for estimating shading factor

5. Consideration of SITE Construction

To maximize the PV potential of a building, solar PV system design should be ideally considered and coordinated with the architectural design of a project [22]by knowing the zoning laws [23].However, grid-connected systems are usually found in urban and suburban areas and the modules are usually installed on roofs, where some shading is sometimes inevitable. Factors influencing the relative impact of shadow effects are site-specific and include differences in terrain elevation between involved properties, the height and bulk of structures, the time of year, the duration of shading in a day, and the sensitivity of adjacent land causes loss of sunlight.

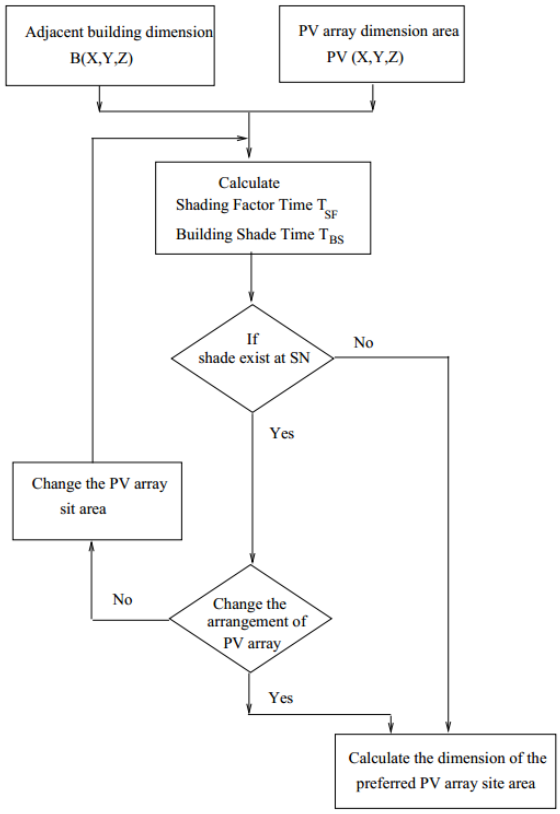

Figure 4. Estimation of PV site area

Shadows cast by structures vary in length and direction throughout the day and from season to season. Of the total amount of the sun's energy available during a daylight period, approximately 85 % of it reaches the earth between 9:00 a.m. and 3:00 p.m.Therefore energy harvest is necessary to obtain maximum energy from the sun. Voltage and current based MPPT techniques, and enhanced PV output using optical sensors is seen in [24-26] and load voltage of the illuminated portion of the array is derived in [27]. Due to different shading effects, V-I characteristics are also mismatched as examined in [28]. By knowing the dimensions of the adjacent building and SPVA, shade time can be predicted and the preferred site can be selected. If shade exist at peak hours the arrangement of SPVA can be changed with steps as shown in the flowchart in Fig. 4.

5.1. 3D CAD Modelling of Different Site

By [29] perspective view of different site is modeled in 3D CAD as shown in Fig. 5, 6, 7, 8, 9 . The specifications of solar panels in rows and columns, direction, angle, placement of directions are entered in to it. From 5 it is noted that due to the adjacent building shading affects the gabled roof SPVA.In 6 telephone poll shade affects hip roof SPVA.In Fig. 7, 8 two adjacent building disturbs the

SPVA.In Fig. 9 line roof SPVA is affected by self-shading. Fig. 10 shows time in x-axis and x- co ordinate position of solar panel in y-axis and accurate shade time is calculated for different site and conclude that accurate placing of SPVA is necessary to avoid shade effects during peak hours of sun.

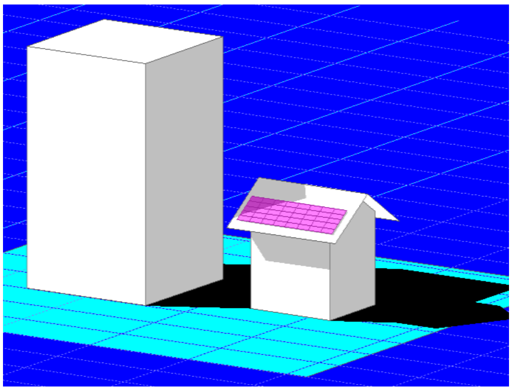

Figure 5. Gabled roof

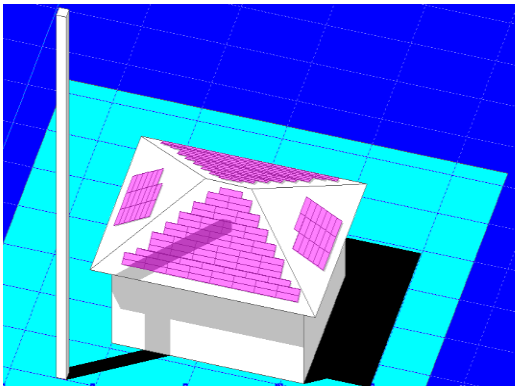

Figure 6. Hip roof

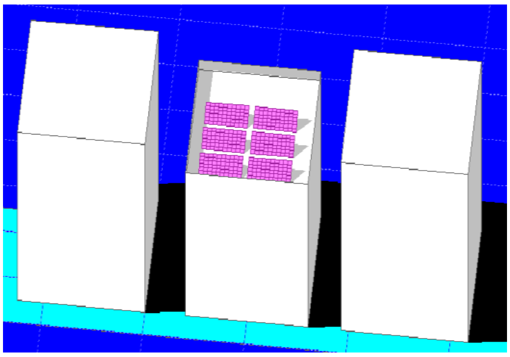

Figure 7. Top of Building

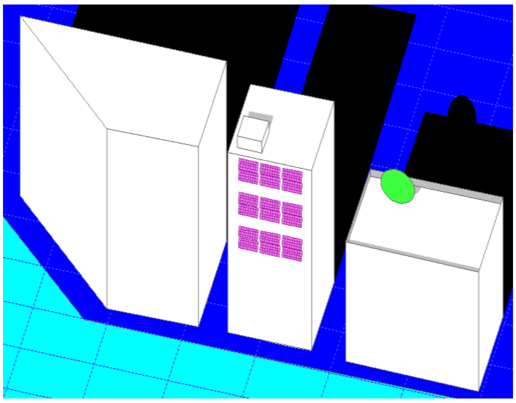

Figure 8. Wall surface

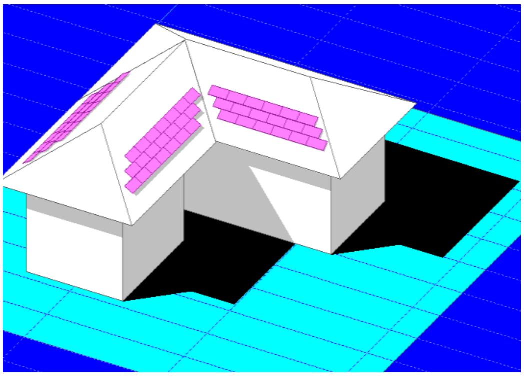

Figure 9. Line Roof

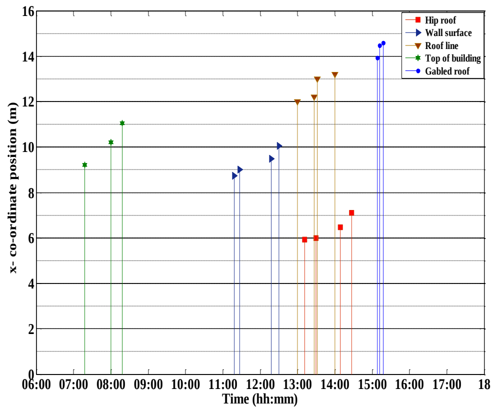

Figure 10. x- co-ordinate position of SPVA with the time

5.2. Shade Analysis of Gabled Roof

The proposed method implies in placing 3.2 kW of SPVA in gabled roof pointing towards south direction as shown in Fig. 11 and the parameters are depicted in the Table 1.The PV panels are linked in series and parallel to form SPVA as shown in Fig. 12 The parameters of solar panel are specified in Table 2.The global insolation with maximum average of 930W/m^2 and with

Table 1. Parameters of site area.

Kotak Manufacturer	P_{max} (W)	V_{pm} (V)	I_{pm} (A)	V_{oc} (V)	I_{sc} (A)
Experimental	80.00	17.10	4.67	21.30	5.30
Simulation	3193.39	135.97	23.49	170.38	26.50

Table 2. Official Parameters of solar PV array.

Specification of Gabled roof site	
X-Position	14.11m
Y-Position	10.90m
Width	8m
Height	6.20m
Oblique	27.22m
Depth	7m
Eaves 1	1.50m
Eaves 2	1.50m

the help of Eq.(8) shading factor is calculated as 0.152 on 27.07.14 as shown in Fig.13 With the help of [28] shade analysis result is obtained.The real time simulation of shade locus is captured as shown in Fig.14.The accurate PV curve

Figure 11. Shade profile model of SPVA in Gabled roof

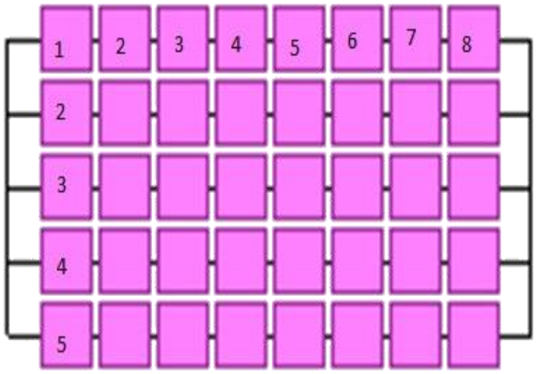

Figure 12. Arrangement of solar panel array

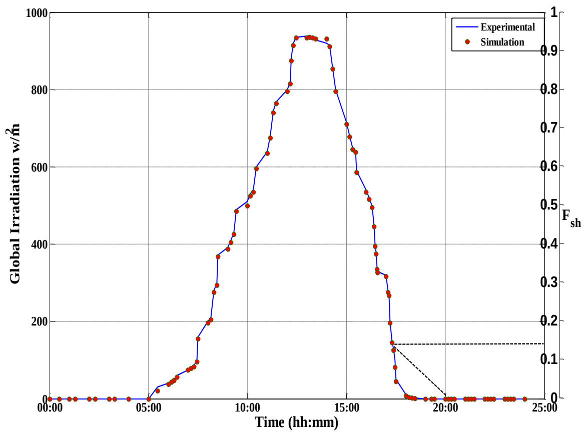

Figure 13. Simulation and measured values of insolation received on SPVA on 27/07/14

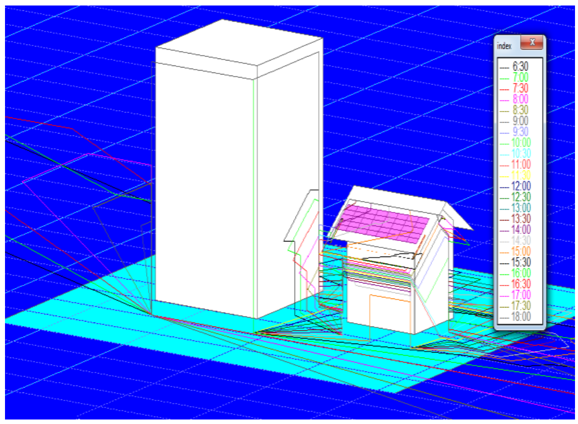

Figure 14. Shade locus of gabled roof at an interval of half an hour (6.00 -18.00)

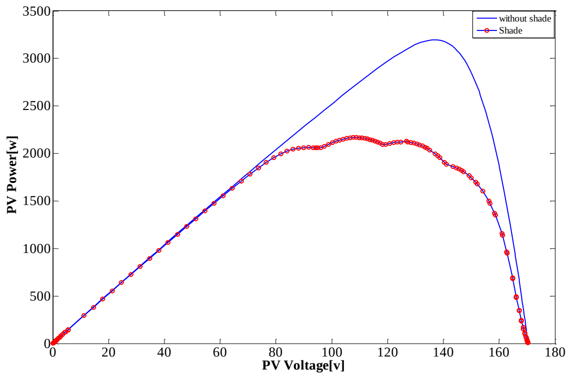

Figure 15. Output characteristics PV curve of SPVA with shade and unshaded condition

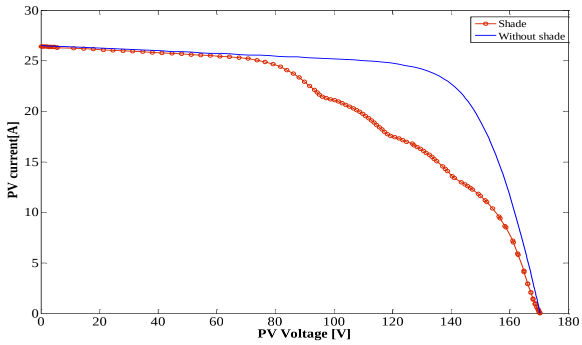

Figure 16. Output characteristics IV curve of SPVA with shade and unshaded condition

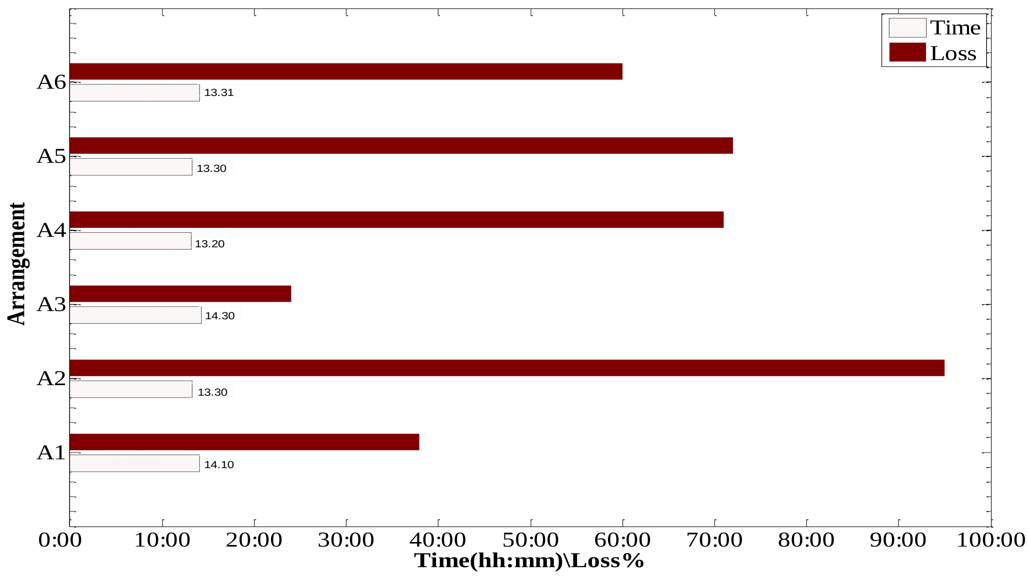

Figure 17. Different PV array arrangements and its losses

and IV curve is compared with the actual result as shown in Fig.15,16. By the valid results the graph is plotted between arrangements and shade time loss as shown in Fig.17. In arrangement A1 and A3 shade time start at 14.10 and 14.30 with the loss of PV power 38% and 25%. Whereas in A2,A4, A5, A6 it start early in 13.30,13.20,13.30,13.31 with the loss of of 95%,68%, 70% and 58%.

6. Simulated and Experimental Results

The result of shade analysis is exhibited in Table.3 with six arrangements. The arrangements A1 to A6 with number of rows and columns demonstrates different placement of direction, covered within the area, starting from the shady time & Pmax with shade and without shade. And it is clear that the arrangement and placement of SPVA create different shade time obtaining maximum power (Pmax). Arrangement, A1 (8x5) solar panel is placed left to right and it is within the 300 square foot area with starting of shade time 14.10 with maximum power 3193.99W with shade and 2167.62W without shade. Correlating with other arrangements,A1 (8x5) and A3 (20x2) is feasible by giving an optimal solution of 2506.26W and 2167.62W. Since, the shade time starts at 14.10 and 14.30 while other arrangement starts early in 13.20 with the shade profile for a day. Further, some of the arrangement is not within the 300 square foot area.With starting of shade time 14.10 with maximum power 3193.99W with shade and 2167.62W without shade. Correlating with other arrangements, A1 (8x5) and A3 (20x2) is feasible by giving an optimal solution of 2506.26W and 2167.62W. Since, the shade time starts at 14.10 and 14.30 while other arrangement starts early in 13.20 with the shade profile for a day. Further, some of the arrangement is not within the 300 square foot area.

Table 3. Summary of the performance of SPVA in gabled roof

Arrangement of panel array panel in south direction	Placement of direction	Area within 300 square feet	Starting of Shade time, (T_{sh})[HH:MM]	P_{max}(W)	
				Without shade	Shade
A1 (8x5)	Left-Right	Applicable	14.10	3193.39	2167.62
	Top-Bottom	Applicable	13.26		
A2 (5x8)	Left-Right	Applicable	13.30	3193.48	1127.6
	Top-Bottom	Not Applicable	13.32		
A3 (20x2)	Left-Right	Not Applicable	14.30	3194.23	2506.26
	Top-Bottom	Applicable	14.00		
A4 (2x20)	Left-Right	Not Applicable	13.20	3194.23	1508.94
	Top-Bottom	Not Applicable	13.28		
A5 (4x10)	Left-Right	Applicable	13.28	3194.28	1509.12
	Top-Bottom	Applicable	13.32		
A6 (10x4)	Left-Right	Applicable	14.07	3193.62	1716.14
	Top-Bottom	Applicable	13.31		

7. Conclusion

A suitable method for finding shading factor and novel prediction of the site consideration is proposed. This evaluates the optimal arrangement of PV array dimension in the roof by avoiding the peak shade timings. The dimension of the site area and SPVA is considered, and the arrangement decides the output power with respect to shade timings. The output characteristic under various arrangements shows different peak powers with the shade timings. The x- coordinate position with the timing graph predicts shade time of various sites. By predicting the PV site area with the shade analysis, feasible solution of energy yield of maximum power can be made reliable.

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