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Theoretical Assessment of PV Energy Potential At Assam Engineering College using PV Indices

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***Abstract*: This paper makes a photovoltaic (PV) energy potential assessment of a technological institution, namely Assam Engineering College (AEC) in Assam, India (26.13 °N, 91.66 °E) using PV indices. A 5kWp PV system is designed in MATLAB/SIMULINK simulation platform and PV indices are implemented to evaluate the feasibility and future applicability of the location as a possible site for renewable energy generation using PV technology. Results reflect that the possible yield of renewable power from the site lie within the range of average values of minimum of 1.82 kWh/kWp/day and a maximum of 2.651 kWh/kWp/day with an average value of 2.238 kWh/kWp/day for the year, thus indicating that the site can in fact be used successfully to harness solar energy.**

Keywords:* *Renewable energy, PV, PV indices, Matlab/simulink

I. INTRODUCTION

Power generation through photovoltaic (PV) generation system is one of the most sought after forms of renewable energy sources, popularityof which has been in the rise due to its non-polluting, renewable and inexhaustible nature [1]. Immense demand for finding feasible and environmental friendly renewable energy sources to meet the future energy requirements as fossil fuel reserves deplete. Solar energy is a viable substitute to fossil fuels among other available renewable energy sources such as wind, hydroelectric and geothermal power [2]. Solar PV generators have been used in small scale, stand-alone systems at low voltage levels as well as the high power installations, connected in grid mode and operating at medium or high voltage levels [2].

Government of India, in an effort to meet up with the challenge of growing demand of power, has started several special initiatives to disseminate renewable energy systems in North Eastern states of India[3]. India as a country due to its location near the equatorial Sunbelt enjoys sufficient solar radiation, with about 300 clear sunny days and at an average of 4-7 kWh/day. Assam Engineering College(AEC), the first engineering college in the north-east India, was established in the year 1955. It is situated at Jalukbari in the south-west part of Guwahati, which is a landmark in the colourful and chequered history of Assam [4]. The institution faces a serious deterrent in meeting the adequate power requirement in the summer season due to inadequate supply of power from the utility. This paper studies the feasibility of using PV

systems as a possible viable solution to compensate part of the inadequate supply. The paper is organised as follows. The introduction in section I is followed by the methodology implemented for the analysis in section II. This section comprises of the three subsections that discuss the data used for the site, PV module modelling and the PV performance evaluation for analysis. Section III summarises the results and discussion and section IV concludes with the findings of the study.

II. METHODOLOGY IMPLEMENTED

1. *DATA USED*

The Indian Meteorological department has nationwide network of stations that records solar radiation and sunshine duration on a daily basis. However, North east India is not covered in a full extent by the radiation stations. This paper takes into account indirect measured data [5] (22 year averaged data for the site has been considered) due to inadequate measured data. Also the accuracy of data source is in the range of 11-17% [6].

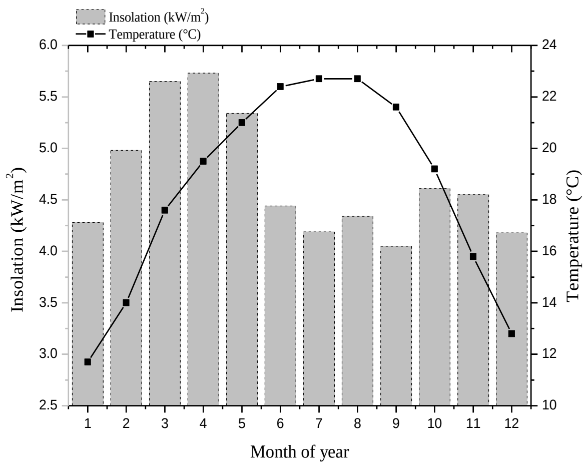

Figure 1: The average monthly solar total in-plane insolation and mean ambient temperature variation over a year

TABLE 1: Solar insolation, temperature, and daylight hours at Assam Engineering College for a year

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Solar Insolation (kW/m^2)	0.4	0.44	0.47	0.45	0.39	0.324	0.308	0.333	0.329	0.400	0.417	0.398
Temperature (°C)	11.7	14	17.6	19.5	21	22.4	22.7	22.7	21.6	19.2	15.8	12.8
Hours (h)	10.7	11.3	12.0	12.7	13.4	13.7	13.6	13.0	12.3	11.5	10.9	10.5

The average monthly solar total in-plane insolation and mean ambient temperature variation over a year is shown in figure 1. Table 1 depicts the compiled data sets used in the analysis, showing the monthly averaged global horizontal incident radiation in kW/m^2, temperature at 10 m above mean sea level above the surface of the earth in (°C) and daylight hours.

2. PV module modelling in software:

A solar cell is basically a p-n junction fabricated in a thin wafer of semiconductor. The electromagnetic radiation of solar energy can be directly converted into electricity through the PV effect. When exposed to sunlight, photon with energy greater than the band-gap of the semiconductor creates the electron-hole pairs proportional to the incident radiation which is responsible for the generation of photocurrent.

Figure 2 shows the equivalent circuit of a PV cell. The current source I_{ph} represents the photocurrent. R_{sh} and R_s are the intrinsic shunt and series resistances of the cell respectively. Usually the value of R_{sh} is very large and hence they may be neglected to simplify the analysis.

Each PV cell, when grouped together in a combination of parallel and series cells constitute a PV module and PV arrays. Equations (1) – (4) are used for the modelling of the reference PV module KYOCERA KC120-1[7].

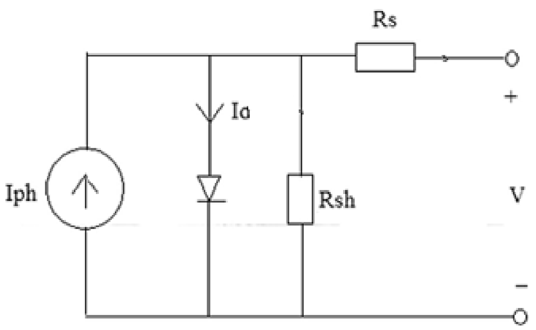

FIG.2. PV cell as a diode circuit

Module Photocurrent (I_{ph}) is expressed by:

$$I_{ph} = [I_{scr} + K_i(T - 298)]\lambda / 1000 \quad (1)$$

Module reverse saturation current (I_{rs}) is given by:

$$I_{rs} = I_{scr} / [\exp(qV_{oc} / N_s KAT) - 1] \quad (2)$$

The module saturation current (I_o) varies with the cell temperature, which is expressed as:

$$I_o = I_{rs}[T / T_r]^3 e\,\mathrm{xp}(qE_{go} / AK)[\frac{1}{T_r} - \frac{1}{T}] \quad (3)$$

The current output of the PV module (I_{pv}) is represented by:

$$I_{pv} = N_p I_{ph} - N_p I_o [e\,\mathrm{xp}\{\frac{q(V_{pv} + I_{pv}R_s)}{N_s AKT}\} - 1] \quad (4)$$

Where I_{scr} is the PV module short-circuit current(A) at 1kW/m^2 and 25ºC, $K_i$is the short-circuit current temperature co-efficient at I_{scr} (0.0017A/°C), T is the module operating temperature in Kelvin (K), λ is the PV module illumination (kW/m^2), I_{rs} is the reverse saturation current of the module (A), q is Electron charge (1.6×10^{-19} C),$V_{oc}$is the open circuit voltage of the PV panel (V), N_s is the number of cells connected in series in the PV module, k is Boltzmann's constant having the value of 1.3805×10^{-23} J/K , A is an ideality factor having value of 1.2, I_o is the PV module saturation current (A), T_r is the reference temperature in Kelvin (298 K), E_{go} is the band gap for silicon having value of 1.1 eV, $I_{pv}$is output current of a PV module (A) , V_{pv} is the output voltage of the PV module (V), N_p is the number of cells connected in parallel for the PV module. In the mathematical model the cells in series and the cells in parallel have values of N_s=36 and N_p=1.

Table II lists the electrical specifications of the Kyocera KC120-1 PV module [7] specified at standard testing conditions (i.e. at a irradiation of 1000 W/m^2, 25° C temperature and AM 1.5)which has been considered as the reference module in this paper for investigation. Figures 2 depicts the current voltage (I-V) and power voltage(P-V) characteristics of the simulated PV module at STC indicating that the model is able to predict accurately the PV module characteristics. To develop a 5kWp PV system, the number of strings required to be connected in series and parallel were found to be 6 and 7 respectively based on the reference module current and voltage ratings.

Table II. Electrical Characteristics of Kyocera KC120-1 PV model[7]

Parameter	**Rating**
Maximum Power	120 W
Voltage at maximum power	16.9 V
Current at maximum power	7.10 A
Short circuit current	7.45 A
Open circuit voltage	21.5 V
Total number of cells in series	36
Total no of cells in parallel	1
Band Energy	1.12 eV
Ideality factor	1.2

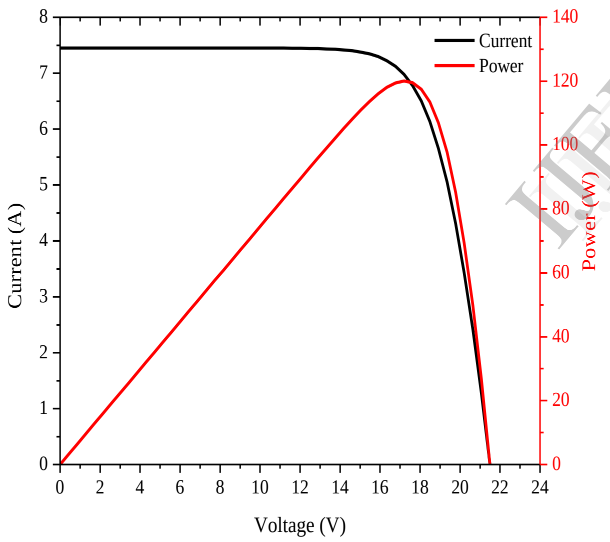

Fig 3: I-V and P-V curve of the PV module at 1kW/m^2 and 25 ºC

3. PV performance evaluation:

In order to ascertain the ideal solar performance for a PV plant, the battery and loads are excluded from the system under investigation. Assumption is made that the system consists of only the PV generator and the inverter. For simplification, the inverter efficiency is assumed to be 95% (to account for the losses in the switching, etc). The system block diagram is shown in figure 3. The monthly averaged data for solar insolation and temperature for a year are given as inputs to the PV model developed in Matlab/Simulink software. The PV energy is computed as the product of the PV output power and the average daylight hour. The available AC power at the output of the inverter is the product of the PV generator power and the converter efficiency. Evaluation of the PV generator performance, the PV system performance monitoring – guidelines for measurement, data exchange and analysis (IEC standard 61724) [8] and the international energy agency task II database on photovoltaic power system [9] have been used.

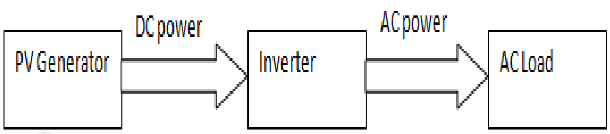

Figure 4: Block diagram of the simple PV generator system

III. RESULTS AND DISCUSSION

The PV system indices considered in this study are the array yield(Y_a), final yield (Y_f), reference yield(Y_r), system losses (L_s) and the performance ratio (PR). These parameters are independent of the array size and are normalised by the array nominal installed power at STC, obtained from the data given in the manufacturer's data sheet for the considered reference PV module. The array yield is defined as the daily array energy output (E_{dc}) per kW of the installed PV array ($P_{pv\ rated}$), and is expressed as

$$Y_a = \frac{E_{dc}}{P_{pvrated}}$$

(5)

The final yield (Y_f) of the PV system is the energy output of the PV generator per kW of the installed capacity of the PV array ($P_{pv\ rated}$). The final yield is represented as:

$$Y_f = \frac{E_{ac}}{P_{pvrated}}$$

(6)

The system losses are the result of the inverter and is given as :

$$L_s = Y_a - Y_f$$

(7)

Table 3: Monthly average array yield, final yield and system losses in kWh/kWp/day

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Array yield (Ya)	2.25	2.47	2.65	2.578	2.303	1.90	1.82	1.96	1.933	2.29	2.37	2.25
Final yield (Yf)	2.14	2.35	2.52	2.449	2.188	1.81	1.86	1.73	1.836	2.18	2.26	2.145
System loss(Ls)	0.112	0.123	0.132	0.128	0.115	0.095	0.091	0.098	0.096	0.114	0.118	0.112

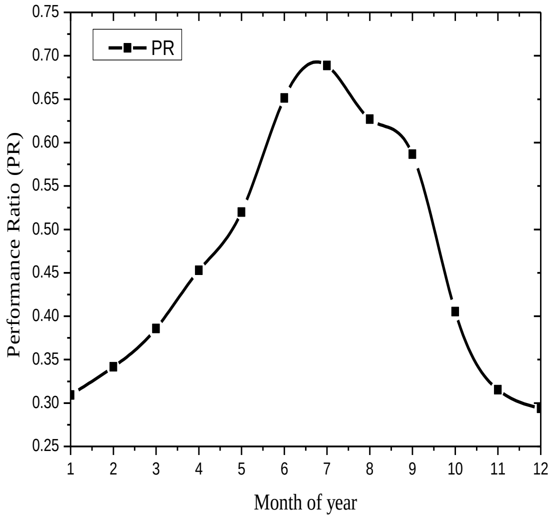

Figure 5 : Performance ratio (PR) variation for the year at AEC

The reference yield (Y_r) is defined as the total daily in-plane solar irradiation H_t ($kWh/m^2/day$) divided by the array reference in-plane irradiance at STC (G_{ref} =1 kW/m^2). The equation representing Y_r is given as:

$$Y_r = \frac{H_t}{G_{ref}} \quad (8)$$

In order to evaluate the system performance the average value of monthly solar radiation and temperature are taken as input to the PV model developed in MATLAB/SIMULINK. The model output is the average PV power output from the system. The available power at the output of the converter is the product of the PV power and converter efficiency. And the difference in these two quantities gives the system loss. The results for the year are recorded in the table 3. The recorded data shows a variation in the available PV power potential

throughout the year. The array yield increases from a value of 2.25 kW/kWp/day in January to 2.65 kW/kWp/day in March, which then decreases in generation capacity from May to September (2.303 kW/kWp/day -1.933 kW/kWp/day) and then shows increased trends towards the end of the year. This is due to the fact that during the months of May to late August and early September the site sees the influence of Monsoon and experiences precipitation. The figure 5 shows the variation of performance ratio throughout the year. From the figure it is evident that the performance of the PV panel increases for the months of April to September, while for the rest of the year it is low despite having sufficient yield in PV power.

IV. CONCLUSIONS

The analysis of the selected site of Assam Engineering College shows that there is potential for harnessing solar energy through PV installation. The results of the PV potential assessment using PV indices shows that the highest array yield is 2.65 kWh/kWp/day for the month of March with a lowest value of 1.82 kW/kWp/day for July, with an average value of 2.232 kW/kWp/day throughout the year. The performance ratio (PR) indicates that the system will have highest performance for the month of July (68.8% utilization) with an annual average of 46.47 %. Taking into consideration the fact that no tracking algorithm exist, the results of the assessment show that the site can be utilized to set up a PV generation system. More significant is the knowledge that the site will perform better during the months of June, July and August as during this period the institution sees shortage of power supply to keep up with the load demand.

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