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Determination of Temperature Dependent Factor for Selected Regions of Nepal for Sizing Solar Photovoltaic Systems

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Abstract

The temperature of a photovoltaic module is a key parameter for the accurate assessment of its performance. Temperature influences the power produced by a photovoltaic system. Since module temperatures are above 50°C in summer it is evident that module efficiency decreases significantly from the efficiency rating obtained at standard operating conditions based on measurements at 25°C. Nepal's weather pattern over regions show similar pattern with warm southern belt and a cool northern belt. The potential of two different sites Kathmandu and Jumla is calculated. The meteorological data for the two sites are obtained from DHM(Department of Hydrology and Meteorology). Available local solar irradiance, ambient temperature and the local wind speed was used to compare the output of the different locations and evaluate the effect of temperature in the respective regions. The modeling of solar station was carried out through PVsyst with KC85T PV module. MATLAB environment was used to simulate the KC85T under different available meteorological data. The simulation results from the PVsyst model and the MATLAB model were compared. The simulation results showed comparable yearly output results but contradicting monthly output results. The variation of output was consistent with the variation of temperature between the sites. The lower average temperature and slight high irradiance in Jumla provided higher energy output than in Kathmandu.

Keywords

Photovoltaics – Temperature – Efficiency

1. Introduction

The energy demand dominated by fossil fuels can be equalized by replacing the conventional energy sources with renewable energy source as solar energy. For optimum utilization of solar energy and the optimum sizing of photovoltaic systems must start from the initial design phase. The availability of irradiance data as well as the weather factors must be considered in the design phase.

Photovoltaic industry is primarily based on semiconductor materials. It is known that resistivity of semiconductor devices has an inverse relation with temperature. This affects negatively the performance photovoltaic (PV) devices. The increase in temperature reduces the band gap of a semiconductor, thereby effecting most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. Therefore low energy is required to break the bond.

The temperature of operation of a PV module is determined by the law of conservation of energy. The solar energy that is absorbed by a module is converted partly into thermal energy and partly into electrical energy which is removed from the cell through the external circuit.

Nepal is blessed with Renewable Energy Sources (RES) such as hydro energy, solar energy and wind energy. Hydro energy is the most matured for of renewable energy in Nepal. With constant rise of energy demand solar energy has gained intense recognition. Solar energy is available freely and promises to be the technology of the future with its attractive returns and relatively low maintenance aspects. The intent of this paper is to calculate the effective efficiency due to yearly temperature fluctuations on different regions of Nepal.

2. System Modeling

2.1 Inclined Irradiance Model

Meteorological stations usually measure global and diffuse solar irradiance received on horizontal surfaces. The HDKR model[1] calculates the global radiation on the tilted surface using GHI. The model requires different factors for the scaling of beam diffuse and reflected components to calculate the overall radiation.

The diffuse component can be related to the clearness index kt. The hourly clearness index can be calculated from the Knight et al[2].

$$kt = G/(G_o) \tag{1}$$

Where, G = Local horizontal radiation [kW/m^2] Go = extraterrestrial horizontal radiation [kW/m^2] The clearness index can be related to evaluate the diffuse irradiance as suggested by Erbs et al.[3]

$$\frac{G_d}{G} = \begin{cases} (1.0-0.09kt)|(kt \leqq 0.22) \\ (0.9511-0.1604kt+4.388kt^2-16.638kt^3 \\ +12.336kt^4)|(0.22 < kt \leqq 0.8) \\ 0.165|(kt > 0.8) \end{cases} \tag{2}$$

From this equation a diffuse radiation can be estimated for each time step for the respective clearness index. The beam radiation is then calculated by subtracting the diffuse radiation from the GHI.

The HDKR model calculates the global solar radiation incident on the PV array G

$$G_t = (G_b+G_dAi)Rb+G_d(1-Ai)((1+Cos\beta))/2 \\ [1+fSin^3(\beta/2)]+G\rho g(1-Cos\beta/2) \tag{3}$$

Where, Ai = Anisotropy index, f = Horizon brightening, ρg = ground reflectance The irradiance incident on the inclined surface has the three components beam, diffuse, and ground reflected and is dependent on the slope (β) of the surface with respect to the horizontal.

2.2 Temperature Model

King(2004)[4] developed at Sandia National Laboratories an empirical formula for the measurement of module temperature using the ambient temperature and the prevalent irradiance.

$$T_m = G.e^{(a+bWS)} + T_a \tag{4}$$

Where,
Tm = Back surface module temperature
Ta = Ambient air temperature
E = Solar irradiance incident on module surface
WS = Wind speed measured at standard 10m height
a,b = Empirically determined coefficients

The model has been applied successfully for flat-plate modules mounted in an open rack, for flat-plate modules with insulated back surfaces simulating building integrated situations, and for concentrator modules with finned heat sinks.

The temperature of cells inside the module can be related to the module back surface temperature.

$$T_c = T_m + \frac{G}{G_o}\Delta T \tag{5}$$

Where, Tc= Cell temperature inside module

Table 1: Coefficients for different modules and mount types

	Module Type	Mount	a	b	Δ T
1.	Glass/ cell/ glass	Close roof mount	-3.47	-0.0594	3
2.	Glass/ cell/ /glass	Open rack	-2.98	-0.0471	1
3.	Glass/ cell/ polymer sheet	Insulated back	-3.56	0.075	3
4.	Glass/ cell/ polymer sheet	Open rack	-2.81	-0.0455	0
5.	Polymer/ thin-film/ steel	Tracker	-3.58	-0.113	3

2.3 Single Diode Model

The simplest equivalent circuit of a solar cell is a current source in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell (photocurrent I_{ph}).

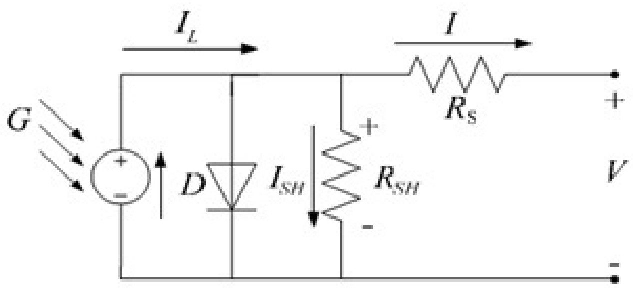

Figure 1: single diode PV model

In this study, a model of moderate complexity was used according to González[5]. A single shunt diode was used with the diode quality factor set to achieve the best curve match. The net current of the cell is the difference of the photocurrent, I_L and the normal diode current I_0. The shunt resistance R_{sh} is neglected.

$$I = I_L - I_0(e^{(q(V+IR_s)/nkT)} - 1) \tag{6}$$

The photocurrent I_L and the saturation current of the diode I_0 depends on the cell temperature.

$$I_{(L,STC)} = I_{(SC,STC)} \frac{G}{G_{STC}} \tag{7}$$

$$I_L = I_{(L,STC)} + K_0(T - T_{STC}) \tag{8}$$

$$I_{(0,STC)} = \frac{I_{(SC,STC)}}{e^{\frac{qV_{(OC,STC)}}{(nkT_{STC})}} - 1} \tag{9}$$

$$I_0 = I_{(0,STC)} \frac{T}{(T_{STC})^{(3/n)}} e^{\frac{qV_{(q,STC)}}{nk(1/T - 1/T_{STC})}} \tag{10}$$

The series resistance R_s represents the resistance inside each cell in the connection between cells.

$$R_S = -\frac{dV}{dI_{(V_{OC})}} - \frac{1}{X_V} \tag{11}$$

$$X_V = I_{(0,STC)} \frac{q}{(nkT_{STC})} e^{\frac{qV_{(OC,STC)}}{nkT_{STC}}} \tag{12}$$

The diode equation has the current I term on both sides of the equation and requires an iterative process to compute the diode current. Newton Raphson method is used on the eqn(6) and the diode current is evaluated.

3. Temperature Dependence

3.1 Operating Parameters

Solar irradiance is the input to any photovoltaic device determining the power output of a PV system. A typical Silicon PV module converts $10-25\%$ [6] of the incident solar radiation into electricity, depending upon the type of solar cells and climatic conditions. The rest of the incident solar radiation is converted into heat, which increases the temperature of the PV module and reduces the PV efficiency of the module.

The effect of temperature on the electrical efficiency of a PV cell can be obtained by applying boundary conditions of the I-V curve on the fundamental diode equation eqn(6) [7].

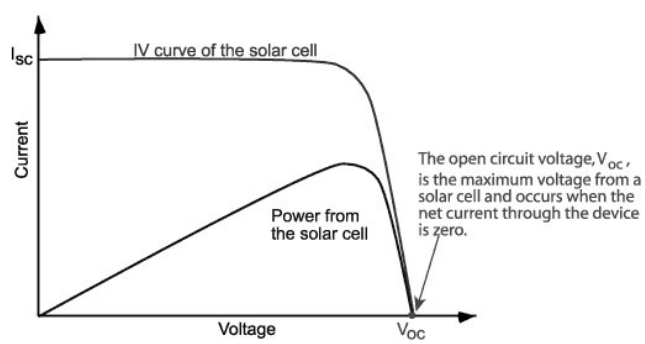

Figure 2: IV curve of a Solar Cell

For Silicon the following are obtained

$$\frac{1}{V_{OC}} \frac{dV_{OC}}{dT} \approx -(0.0022 \text{ to } 0.0025) \text{ per}^\circ\text{C}$$
$$\frac{1}{I_{SC}} \frac{dI_{SC}}{dT} \approx -0.002 \text{ per}^\circ\text{C} \tag{13}$$

3.2 Electrical efficiency

Temperature affects the properties of electronic systems in a number of fundamental ways. Photovoltaic system are basically semiconductor devices are affected with reduction of band gap voltage. The overall effect in efficiency is represented in a linear equation[8].

$$\eta_c = \eta_{T_{ref}}[1 - \beta_{ref}(T_C - T_{ref}) + \gamma log_{10} G_T] \quad (14)$$

in which $\eta_{T_{ref}}$ is the module's electrical efficiency at the reference temperature, $T_{(ref)}$, and at solar radiation flux of 1000 W/m^2 . The parameter γ, however, is usually taken as zero [8], and Eqn(14) reduces to

$$\eta_c = \eta_{T_{ref}}[1 - \beta_{ref}(T_C - T_{ref})] \quad (15)$$

The above equation represents according to Evans and Florschuetz [9] the traditional expression for the PV cell efficiency. The quantities $\eta_{T_{(ref)}}$ and $\beta_{(ref)}$ are usually given by the PV module manufacturers, but they can be also obtained from flash tests.

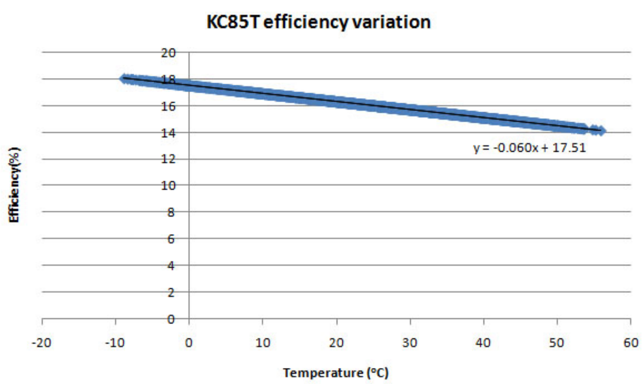

Figure 3: Variation of Efficiency of Solar Module

4. Methodology

The study consist of simulation on two sites one in Kathmandu International Airport located at Latitude 27.6964°N and Longitude 85.3589°E and other in Jumla Airport located at Latitude 29.2744°N and Longitude 82.1933°E. Meteorological data [10] were taken from these sites and simulated using the KC85T[11] solar module. The meteorological data for Jumla was taken from the year 2012 and that of Kathmandu was taken from the year 2013. The same year couldn't be used due to large data inconsistencies. MATLAB2010 was used for the simulation of photovoltaic module.

A system based on Kathmandu was also developed using the KC85T in PVsyst 5.03[12]. PVsyst is a popular tool that gives a good approach of the PV system design and behavior. The database of PVsyst for Nepal was, however, limited to the location in Kathmandu.

Simulation from MATLAB and PVsyst was used to analyze the output energy generation and effect of temperature.

5. Results

The output of the simulation shows high output in summer months while PVsyst shows higher output in winter months. The maximum output in Jumla is in the month May with 33.8kWh and the minimum output is in the month December with 19.6kWh. The yearly output from the simulation is 310.6kWh. These values are still not concise as the data was measured hourly and there were many days with unrecorded data.

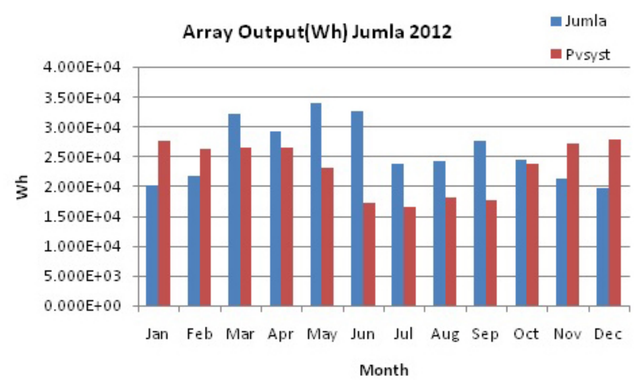

Figure 4: Simulations Output at Jumla

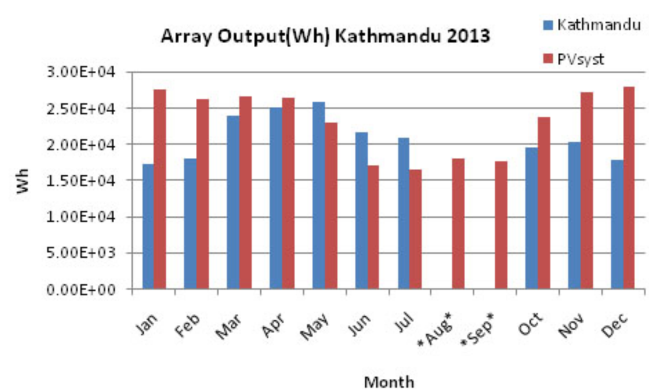

Figure 5: Simulation Output at Kathmandu

The simulations for Kathmandu shows a yearly output of 210kWh excluding the months August and September.

The output from PVsyst simulation showed a yearly output of 277.04kWh and 242.14kWh excluding the months August and September.

The output of simulation on hourly data of Kathmandu shows an output current of 2.94A at an irradiance of $588.9471W/m^2$ and simulation of Jumla shows an output of 5.92A at and irradiance of $581.7972W/m^2$ at MPP. The output voltage at MPP for Kathmandu is 16.92V at 34.4°and for Jumla is 17.64V at 24.4°The output power at MPP are 50W and 51.5W for Kathmandu and Jumla respectively.

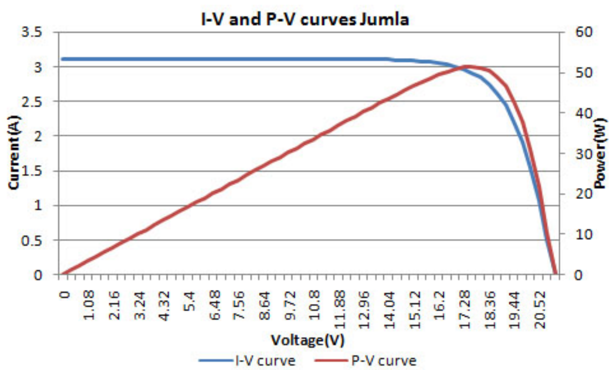

Figure 6: IV curve (Jumla January 4th 2012)

The efficiency of the solar panel with respect to the temperature is shown below. The efficiency for KC85T changes with a slope of -0.06. The temperature range in the respective locations causes the efficiencies to vary from 14.1% to 18% in Jumla and 13.5% to 17.6% in Kathmandu.

6. Discussion

The simulations were performed with KYOCERA KC85T modules. The results indicated that the average voltage for maximum power point for Kathmandu was around 17V while the average voltage for Jumla during the same time period was 18V. The power difference for a particular hour showed a difference of 1.5Watts.

The output of PV syst was also compared with simulation results from the site-Jumla Airport. The irradiance was higher while the temperature was lower. The solar output was significantly higher in Jumla which confirms the relation of temperature with solar output.

The output of the results matches with the results obtained by Ya'acob et al[13] where they tested an experimental setup in Malaysia. An increase in output power was resulted in summer which contradicts the principle of output power being inversely proportional to the temperature. The operating temperature plays a central role as it determines the electrical efficiency which decreases linearly with it. The minimum efficiency was found to be 13.5% as compared to the standard 16%. The increased output should ,however, be credited to the increased irradiance. A relationship between irradiance and output power is shown in the figure(7) for Jumla

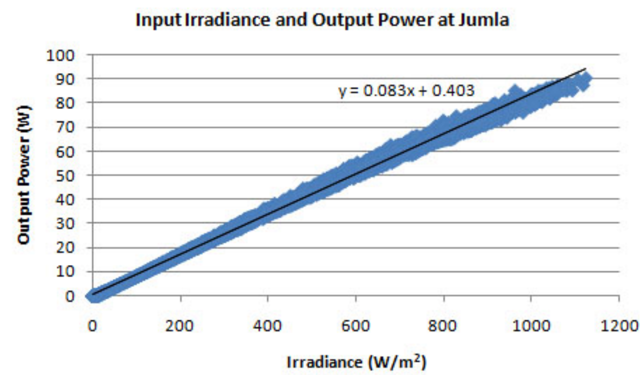

Figure 7: Variation of Output with Irradiance

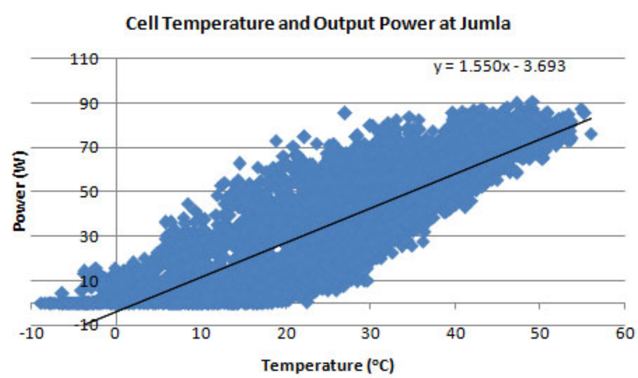

Figure 8: Variation of Output with Temperature

PVsyst has specified a detailed series of loss factor during the conversion from effective irradiance on the surface of PV cell to DC electrical energy.

- PV loss due to low irradiance level
- PV loss due to temperature
- Module quality loss
- Module array mismatch loss

- Ohmic wiring loss

The output of the PVsyst simulation shows a lower because of all the accumulated losses. MATLAB simulation only includes the losses due to the irradiance level and temperature. The conversion efficiency primarily depends on the relevant technology, irradiance performance and temperature. The efficiency including overall loss due to irradiance and temperature are found to be 16.4% for Kathmandu and 16.9% for Jumla.

7. Conclusion and Future Work

This study investigated how seasonal changes in cell temperature induce changes in photovoltaic (PV) module conversion efficiency in different regions. The electrical efficiency and hence the power output of a PV module depend on the varying weather conditions. The overall effect of temperature and irradiance produced the conversion efficiency of 16.9% at Jumla and 16.4% at Kathmandu.

Studies in Malaysia[13] and Greece[14] have shown the effect of temperature, irradiance and wind speed on the output. These studies focus on the comparison of output between different technologies.

The study only shows preliminary output which shows dependence of output voltage and thus output power on the operating temperature. A detailed study must be carried out to establish a firm relation between total output in the selected regions and the yearly meteorological patterns.

A relationship can be established to verify the effect or temperature and irradiance separately using a DOE (Design of Experiment) method. Hannane et al[15] used this method to establish the degree of effect on the output due to irradiance and temperature.

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