

Analysis of Photovoltaic Cell Performance with Varying Temperature: the Case of South India

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Abstract: Solar energy is one of the important renewable energy available. The efficient usage of solar energy can yield better power output which can be used as an alternate fuel for conventional energy sources. The Photovoltaic cells are used to generate power from solar energy. In this paper we have dealt with the modelling and analysis of photovoltaic cells with varying temperature values of different cities in south India. The photovoltaic cell is modelled and analysed for its performance using MATLAB/Simulink. The mathematical modelling of photovoltaic cell is done by simulating the equivalent circuit design. The generalized photovoltaic model is used for the analysis. The current and voltage curve are generated as a result of simulation. The south Indian cities taken for comparison are Coimbatore, Bangalore, Erode and Vellore. The temperature values of the above mentioned places were used in the form of monthly averaged basis.

Keywords: Solar energy, Photovoltaic cells, Renewable energy, temperature, MATLAB/ Simulink.

I. NOMENCLATURE

I_D	diode current in Amp.
I_L	photogenerated current in Amp
I_{SH}	shunt current in Amp
R_s	series resistance in the double diode model
A	diode parameter
V	cell terminal voltage in Volts
I	cell terminal current in Amp
E	solar irradiance in W/m^2
T	ambient temperature in $^{\circ}K$
k	Boltzmann's constant
e	electronic constant
I_{sc}	short Circuit Current
V_j	voltage across both diode and resistor R_{SH}
V_{oc}	open circuit voltage of each cell
P_m	maximum power of each cell
V_{pm}	maximum power voltage of each cell
I_{pm}	maximum power current of each cell
N_s	number of cells in series
N_p	number of cells in parallel
V_{ocar}	open circuit voltage of the array
P_{mar}	maximum power of the array
I_O	reverse saturation current in Amp.
q	elementary charge
V_{ab}	average load voltage with boost
VSC	voltage-source converters

II. INTRODUCTION

The use of renewable energy in developing countries is of raising importance due to the cons of the non-renewable energy sources such as fossil fuels. These sources have adverse effects on the environment leading

to a total imbalance of the global climatic conditions. All the countries have started concentrating on the use of renewable energy sources such as solar, wind, wave and biomass. There are many ongoing researches which concentrate on the development of the technologies related to the efficient absorption and usage of renewable energy sources [1]. In this paper, we have dealt with the simulation of generalized model of photovoltaic cells in MATLAB/Simulink environment. The paper deals with the prediction of the viable conditions for installation of the Photovoltaic cells in the south Indian region. The places taken for study are Coimbatore, Erode, and Vellore in the state of Tamil Nadu and Bangalore in the state of Karnataka. The dataset for the analysis contains the monthly averaged temperature from the year of 1983 to 2005 collected from NASA surface meteorology and solar energy centre. The data collected can be applied with various data mining technique to learn useful pattern out of it [2]. The simulation environment is MATLAB/Simulink which is a Graphical User Interface environment for modelling and simulation of embedded systems.

III. DATASET DESCRIPTION

The dataset for the paper were collected from the NASA surface meteorology and solar energy centre. The monthly average temperature was collected based on the latitude and longitude of the selected places. The latitude and longitude are represented in table 1.

The places were selected considering the factors of their temperature and their power needs based on the industries located in the cities. This would enable even distribution of power during the demand.

Table 1: Latitudes and Longitudes

Place	Latitude	Longitude
Coimbatore	11.0183° N	76.9725° E
Erode	11.3500° N	77.7333° E
Vellore	12.9202° N	79.1333° E
Bangalore	12.9667° N	77.5667° E

Table 2: Average Temperatures

Place	Average Annual Temperature	Warmest Month
Coimbatore	24.45	March
Erode	25.18	March
Vellore	27.07	April
Bangalore	24.7	March

The average annual temperature of the cities are given in table 2, the data is the annual average temperature of the years 1983 to 2005. The warmest month of the year of each city is also given. The warmest month indicates the chances of obtaining high irradiance during the month. The smart grids are formed in the selected cities which can be later used for distributing the power among the cities based on the demand and supply.

IV. SOLAR CELLS

A solar energy conversion system consist of many devices integrated together to absorb the radiation and convert it into other form of energy for use [3]. The absorption system is of importance which is of prime importance to absorb solar energy incident on the earth surface. The solar energy absorbers are divided into two categories based on their thermal processes and quantum processes. The photovoltaic cells come under quantum processes which convert solar energy directly into electrical energy. The solar cells are used to convert solar energy into direct current (DC) electricity.

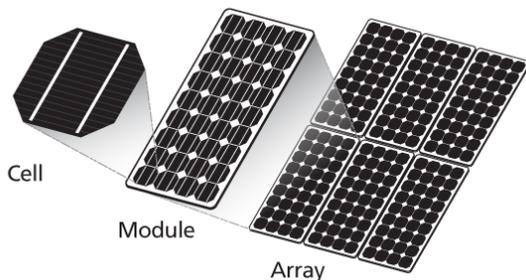


Figure 1: Solar Cells Model

A collection of solar cells forms a solar panel or module and an integration of several modules constitutes a solar array. In a solar panel the photovoltaic cells are arranged in series and parallel. The solar panel is built with silicon

as the raw material which is a semiconductor [4]. The cells placed in a series will yield higher voltage and cells in parallel will produce a higher current.

V. SOLAR CELL MODELLING

The equivalent circuit model of the photovoltaic cell is taken to simulate it in the simulation environment. A solar cell demonstrates a nonlinear I-V and P-V characteristics and it varies with solar irradiance and cell temperature [5].

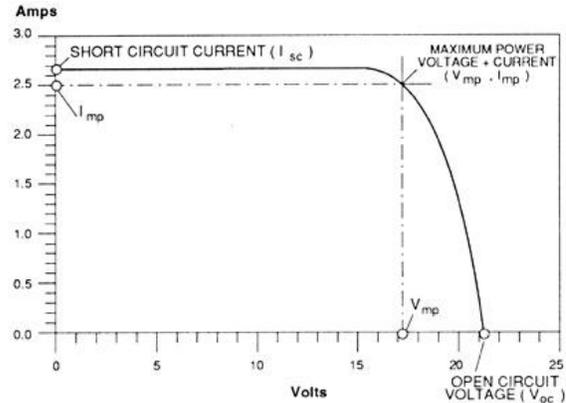


Figure 2: Characteristics of a typical solar cell

The short circuit current is the current when the impedance is low and calculated when the voltage is zero.

$$I \text{ (at } V=0) = I_{sc} \quad (1)$$

The open circuit voltage is the voltage which occurs in open circuit and no current passes through the circuit [6]. Open circuit voltage is calculated when the voltage is zero.

$$I \text{ (at } V=0) = V_{oc} \quad (2)$$

The equivalent circuit of a solar cell [7] is presented in figure 3.

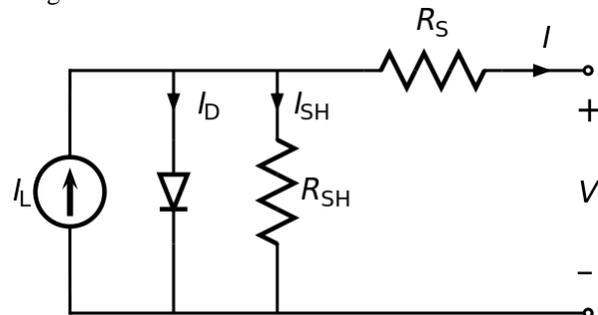


Figure 3: Equivalent Circuit of a solar cell

The equivalent circuit consists of diode, resistance, shunt resistance and diode current.

$$I = I_L - I_D - I_{SH} \quad (3)$$

The current diverted in the diode, by Shockley diode equation,

$$I_D = I_0 \{ \exp [qV_j/nkT] - 1 \} \quad (4)$$

By Ohm's law [8], the current diverted through the R_{SH} is

$$I_{SH} = V_j/R_{SH} \quad (5)$$

Substituting Equation (4) and (5) in Equation (3) we get the equation for the characteristics of a solar cell as,

$$I = I_L - I_0 \{ \exp [q(V + IR_s)/nkT] - 1 \} - (V + IR_s)/R_{SH} \quad (6)$$

Photovoltaic module is formed by connecting the photovoltaic cells in series [9]. The output voltage of the Photovoltaic module is expressed in the Equation (7) and Equation (8),

$$V_m = N_s V \quad (7)$$

$$I_m = N_p I \quad (8)$$

Simulink schema of behavioural photovoltaic model [10] is demonstrated in Figure 4.

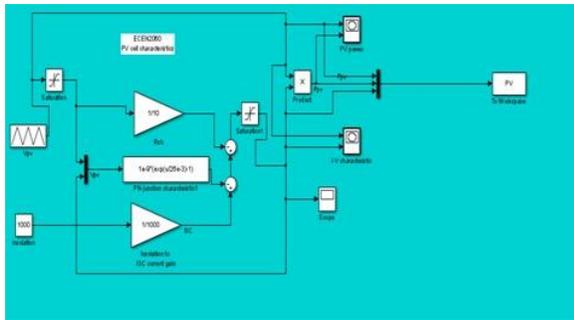


Figure 4: Behavioural schema of Photovoltaic model

VI. SIMULATION AND RESULTS

The Simulation of the Photovoltaic Array was done in MATLAB/Simulink environment. It is a graphical user interface used in simulation of smart grids and other embedded systems.

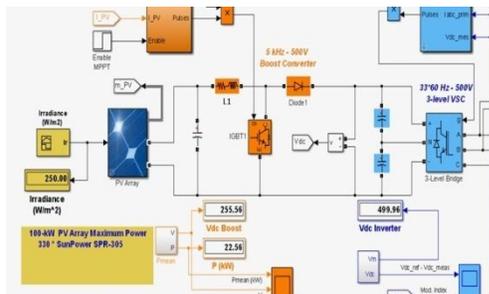


Figure 5: Photovoltaic Array Simulation

Figure 5 illustrates the simulation of photovoltaic array in MATLAB/Simulink environment. The initial irradiance data is set to form the photovoltaic array model [11]. The components available in the model are

- ❖ Photovoltaic array
- ❖ DC-DC boost converter
- ❖ Three- phase coupling transformer
- ❖ 3-level 3-phase VSC
- ❖ Utility grid

The power generated in the module is represented in the graph in Figure 6. The power generated in kilowatt.

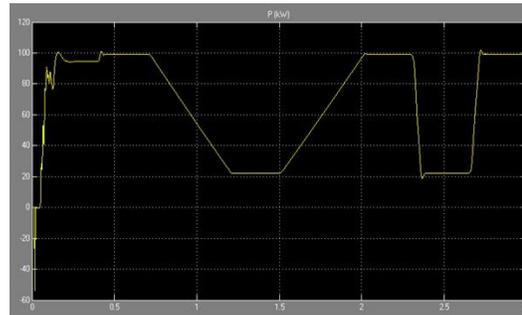


Figure 6: Power Calculation

The continuous movement of electrons in a circuit is termed as current and the force motivating the electron to flow is called as voltage. The MATLAB/Simulink environment helps in the calculation of the voltage and current calculation of the photovoltaic cells. The voltage and current calculations are showed in the graph in figure 7.

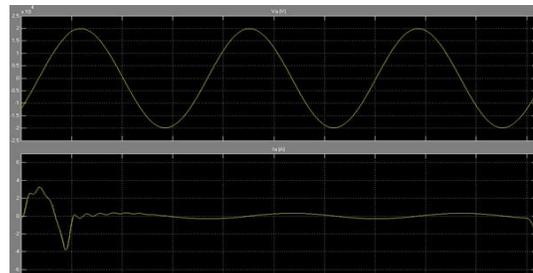


Figure 7: Voltage and current calculation

The maximum power point tracker (MPPT) is an electronic DC to DC converter that converts high level voltage output from solar panels to the lower voltage needed in batteries. There are a wide variety of MPPT techniques available [13]. The MPPT are inserted between the photovoltaic module and its load to achieve optimum matching [14].

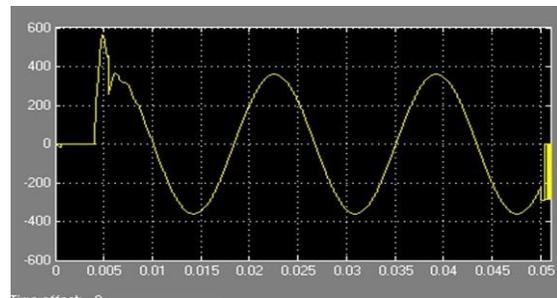


Figure 8: Average load with boost

The VSC calculations are presented in the Figure 9. It shows the variations with temperature.

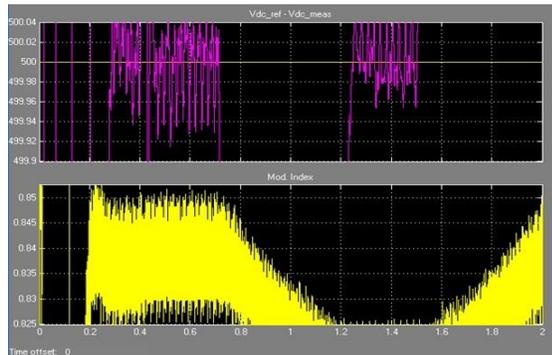


Figure 9: Voltage variance

VII. CONCLUSION

This paper dealt with the modelling of photovoltaic cells and simulating it with varying temperature values of different cities of south India. The photovoltaic cells modelled were typical cells which formed an array and the yearly average temperature of four different cities were analysed for power calculation. The results showed that the power generation increases as the temperature increases.

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