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MODELLING AND SIMULATION OF MATLAB/SIMULINK BASED LOOKUP TABLE MODEL OF SOLAR PHOTOVOLTAIC MODULE

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ABSTRACT

This paper proposes lookup table (LUT) based model for solar photovoltaic (PV) module. The performance of a solar PV module is greatly influenced by insolation level and temperature. The experimental data including voltage and current of the PV module are obtained for various insolation conditions. These data are then used to develop a lookup table to mimic the behaviour of the actual PV module. To ensure that the maximum power is transferred from the PV module to the load, maximum power point tracking (MPPT) algorithm is usually employed. The paper also proposes LUT based MPPT to track the optimal operating point whenever the insolation changes. The V-I and V-P characteristics obtained from the look up table based Matlab/Simulink model and the conventional model (five parameter model) are compared. The results are validated with the experimental data.

Keywords: PV module, MPPT, boost converter, lookup table.

INTRODUCTION

As the demand for electricity is on the rise, the renewable or the alternate energy sources like solar and wind are gaining attention these days. Unlike the conventional methods of power generation from fossil or nuclear fuels, these renewable sources produce clean energy and require less maintenance. The power produced by a solar PV module is influenced by many environmental factors like insolation, cell's working temperature, wind speed, shading caused by the passing clouds or nearby structures, etc. Of these, the output current of the PV module is greatly affected by insolation. The internal resistance of the PV module varies with the intensity of the sun's radiation and the module's operating temperature [1]. This causes a mismatch between the source and the load impedances.

To maximize the power transfer, it is necessary to match the load impedance with that of the source (PV module). Whenever there is a change in the atmospheric conditions there will also be a corresponding variation in the PV source impedance. Unless the load impedance is adjusted to match the variation in source impedance, the power transferred from the source to the load will not be optimum. MPPT algorithm is usually employed to track the optimum operating point of the module. DC- DC converter is included and the impedance matching is achieved by adjusting the duty cycle of the gating pulse fed to the converter. Many MPPT algorithms like perturb and observe, incremental conductance and fuzzy based algorithms have been proposed in the literature [2]. This work proposes a simple method using lookup table (LUT) approach. The maximum power point voltage of the PV module is obtained for various insolation conditions by both experimental procedures and simulation using conventional model. A lookup table is then formed with these data and when used, it will give the V_{mpp} for any insolation level.

Mathematical model of a PV module

The standard one diode model [3, 4] is used to model the solar PV source. The equivalent circuit of a single solar cell is shown in Figure-1.

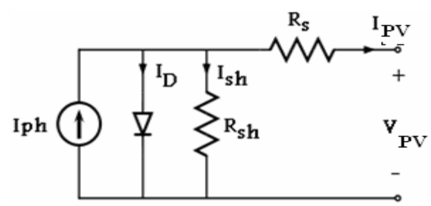

Figure-1. Equivalent circuit of PV cell

The following equations (1)-(4) are used for modelling the PV system.

The output current from PV panel, I_{pv} is given as

$$I_{pv} = I_{ph} - I_D - I_{sh} \tag{1}$$

where, I_{sh} is the current through the shunt resistor and I_D is the diode current. The photon generated current of the PV panel, I_{ph} is given as

$$I_{pv} = \left\{K_i\left(T - T_n\right) + I_{pvn}\right\}\frac{G}{G_n} \tag{2}$$

The current through the diode, I_D is calculated as

$$I_D = I_r\left\{\exp\left[\left(V_{pv} + I_{pv}R_{se}\right)V_{ta}\right] - 1\right\} \tag{3}$$

and

$$I_r = \frac{K_i(T - T_n) + I_{scn}}{\exp\left[\left(K_v(T - T_n) + V_{ocn}\right)V_{ta}\right] - 1} \tag{4}$$

From the mathematical equations describing the behavior of a PV cell, it is clear that the photovoltaic current depends not only on internal parameters R_{se}, R_{sh}, I_{ph}, and I_r, but also on the external factors like insolation G and cell temperature T [5, 6].

SOLKAR solar PV module is used in the work and the specifications of the same at reference conditions (G=1000 W/m^2, T=25^{0}C) are

Maximum power (P_{max})	:	37.08 W
Voltage at maximum power(V_{mpp})	:	16.56 V
Current at maximum power (I_{mpp})	:	2.25 A
Open circuit voltage (V_{oc})	:	21.24 V
Short circuit current (I_{sc})	:	2.55 A
No. of series cells (N_s)	:	36

MATLAB m-file is written incorporating all the above mentioned equations. The diode ideality factor is considered to be 1.5. The insolation level is varied from 100 W/m^2 in steps of 100 and the V-I and V-P characteristics are obtained for a single PV module and are presented in Figure-2 and Figure-3.

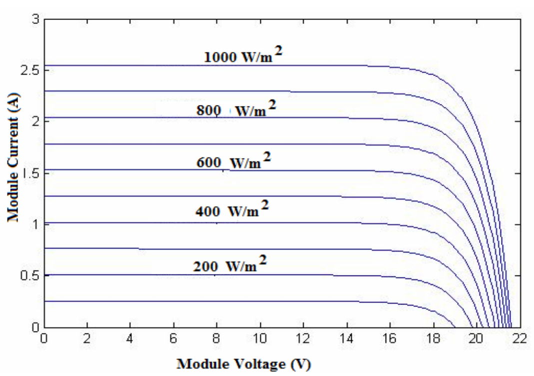

Figure-2. V-I Characteristics of PV module

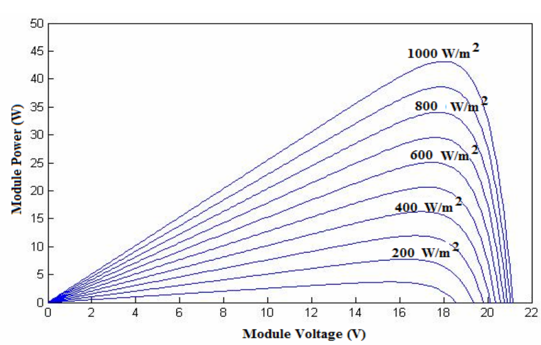

Figure-3. P-V characteristics of PV module.

It is clearly shown in the Figure-2 and Figure-3 that, as the insolation decreases, the V-I and V-P characteristic curves of the PV module shifts down and so does the maximum power point. The efficiency of the PV panel is very less and hence it becomes necessary to extract the maximum power from the panel by shifting the operating point to the maximum power point [7, 8]. The operating point of the PV module is dependent on the load resistance. Perturb and Observe (P & O) MPPT algorithm is adopted in this work due to its simplicity. In this algorithm, a perturbation is made on the PV operating point to force tracking in the direction towards maximum power point. MATLAB code is written to implement P & O algorithm and the maximum power points for various insolation levels are shown in Figure-4.

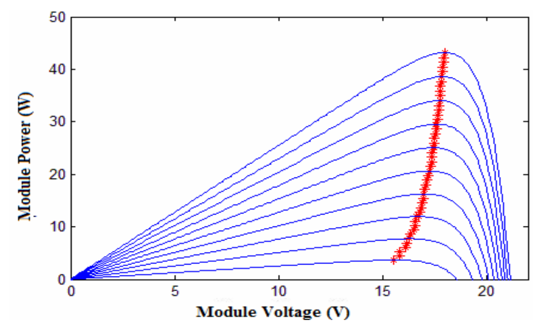

Figure- 4. Maximum power points on PV curves

Modelling using lookup table method

Development of a suitable PV model is the first step in the analysis and development of any PV based system. Often it is not possible to test the system experimentally at a particular insolation level, as insolation is an uncontrollable natural factor. So modelling play a vital role in the design stage of a PV system. In the one diode model, the PV module is characterized by five parameters i.e. I_{pv}, I_{ph}, V_{oc}, R_{se} and R_{sh}. The values of I_{pv}, I_{ph} and V_{oc} can be obtained from the datasheet. But the values of R_{se} and R_{sh} are to found out experimentally. Moreover, the diode ideality factor can take the value in the range of 1 to 1.5. Initially the value is set at 1 and then gradually adjusted so that the V-I characteristics obtained from simulation are on agreement with the experimental data. All these adjustments are to be made so that the model replicates the actual module [9, 10]. Instead, if it is possible to model a PV module just from the V-I characteristics that are obtained from the experimental data, it would save a lot of time. The experimental data are obtained from the following setup shown in Figure-5. The insolation level is measured by measuring the proportional short circuit current I_{sc}. The data observed from the setup using electronic load [11] as shown in Figure-5 are stored in excel format using Agilent DSO.

Figure-5. Experimental setup to observe the PV module characteristics

The voltage and current data for various insolation levels obtained from experimental setup are used to develop the lookup table. The lookup table based Matlab/Simulink model of the PV module is shown in the Figure-6. For any given insolation level, the developed model mimics the behaviour of the actual PV module. Since the computations involved in this model are simple, the model works faster than the conventional model.

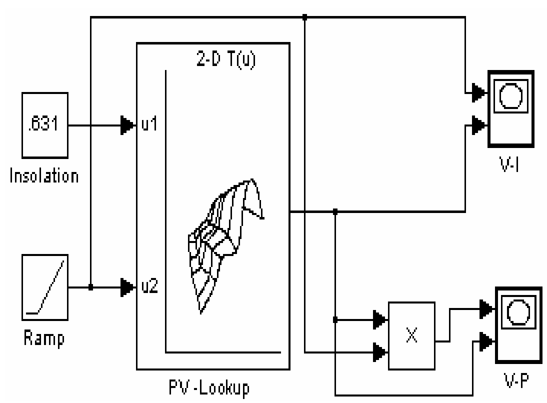

Figure-6. Lookup table model of PV module

To obtain the V-I and V-P characteristic curves by this method, the insolation value is entered through a constant block and the change in voltage is given by a ramp signal. The V-I and V-P characteristics obtained by this method are shown in Figure-7 and Figure-8, respectively. These characteristics are then compared with those obtained from the conventional one diode model where, the mathematical equations describing the PV module are coded in m- file. Both the methods gave almost the same result for any given insolation. An insolation value of 1000 W/m^2 is chosen and the V-I and V-P curves are plotted. The experimental data at few significant points are shown in the same figures.

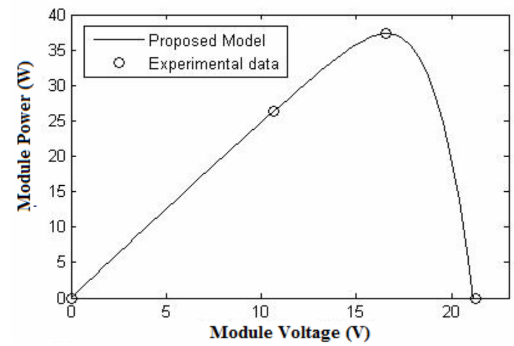

Figure-7. V-P curve obtained by the two methods

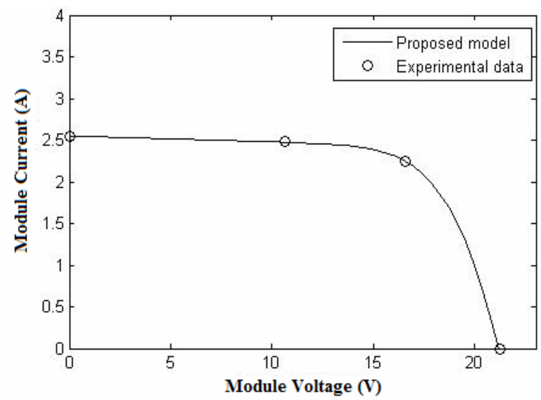

Figure-8. V-I curve obtained by the two methods

The significant parameters including the open circuit voltage, short circuit current and the maximum power obtained from the LUT based PV model are presented along with the datasheet values in Table-1 for an insolation level of $1000W/m^2$.

Table-1. Comparison table at STC (G=1000 W/m^2, T=25^0 C).

Parameter	LUT model	Data Sheet	Conventional model
Open circuit voltage, V_{oc}	21.24	21.24	21.24
Short circuit current, I_{sc}	2.55	2.55	2.55
Max. power point voltage, V_{mpp}	16.56	16.56	16.56
Max. power point current, I_{mpp}	2.5	2.5	2.49
Maximum power, P_m	37.08	37.08	37.08

The lookup table model is validated for few other conditions other than the standard test conditions and the data obtained are also presented in Table-2. From the Table-2, it is evident that the lookup table model mimics the behaviour of actual PV module at various insolation conditions. Hence whenever PV module is interfaced with other power conditioning circuits or systems, LUT based model is preferable over the conventional model due to its simplicity.

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Table-2. Comparison table at different insolation conditions.

V_{pv} (V)	I_{pv} in Amps.								
	G=245 W/m^2			G=498 W/m^2			G=750 W/m^2		
	LUT	Expt. Data	Conv. model	LUT	Expt. data	Conv. model	LUT	Expt. data	Conv. model
V=0	0.63	0.63	0.625	1.27	1.27	1.269	1.91	1.91	1.91
V=V_{mp}	0.56	0.56	0.411	1.12	1.12	1.03	1.69	1.69	1.646
V=V_{oc}	0	0	0	0	0	0	0	0	0

Lookup table based MPPT

Usually to track the maximum power point, tracking algorithms like P & O, incremental conductance or any other intelligent algorithms will be employed. These computationally intensive algorithms will track the maximum power point voltage by adjusting the duty cycle of the boost converter. This work proposes lookup table approach for maximum power point tracking also. The maximum power point voltages for various climatic conditions are obtained and the data is fed to the lookup table. Once modelled, the lookup table will give the maximum power point voltage for any input conditions. The schematic diagram of the overall system incorporating lookup table model for PV module and MPPT is shown in Figure-9.

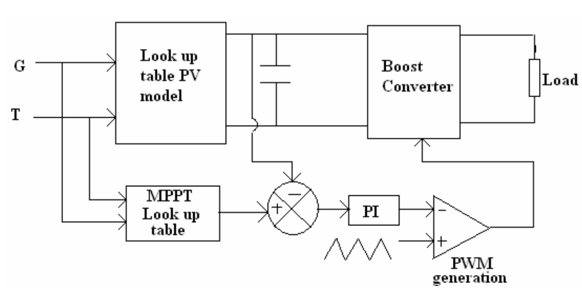

Figure-9. Schematic diagram of the overall system

The boost converter which is included to track the maximum power point has one controlled semiconductor switch. The turn off resistance of the switch is very much higher than the turn on resistance. Thus by varying the duty cycle of the gating pulse, the resistance of the circuit as seen from the PV module is varied. The actual PV module voltage is compared with the MPPT voltage and an error signal is generated. The error signal is fed to a PI controller tuned by Ziegler Nichols tuning algorithm and the duty cycle of the boost converter is altered till the impedance matching is achieved [12]. Thus the lookup table based MPPT tracks the optimal operating voltage and the PV module is operated at the optimal operating point. The MPPT (boost) converter parameters were calculated considering the specifications given below:

Current ripple factor < 30%
Voltage ripple factor <= 5%
V_{in} = 16.55 V
V_{out} = 50 V
I_o = 2.25 A
Switching frequency f_s=10 kHz.
L = 1.64 mH
C = 60.3 μ F

The complete model including LUT model of PV module, boost converter, LUT based MPPT [13, 14] and PI controller is developed in Matlab / Simulink and is shown in Figure-10.

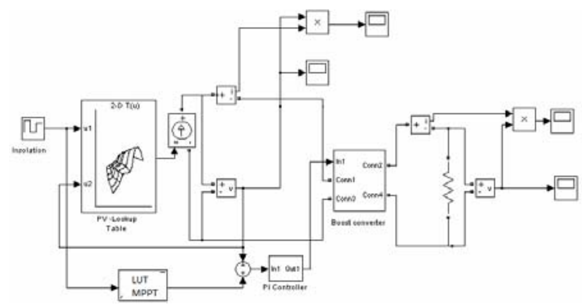

Figure-10. Lookup table based PV module and MPPT with boost converter

RESULTS AND DISCUSSIONS

The proposed model is validated for the changing environmental conditions and the results are discussed in this section. Initially, the complete model is simulated for standard test conditions (G=1000 W/m^2, T=25^{0}C). The data sheet specification of maximum power point voltage is 16.55 V at STC. It is shown in the Figure-11 that the model has tracked this MPPT voltage.

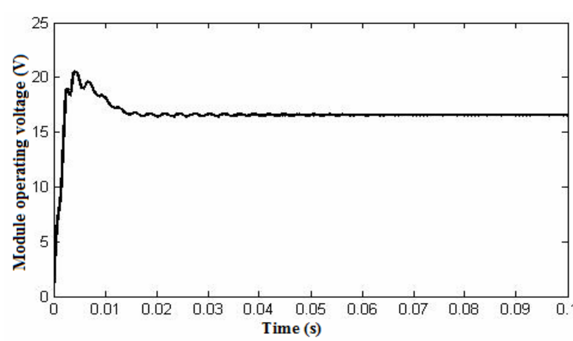

Figure-11. PV module operating voltage

The output voltage of the boost converter for the same STC is shown if Figure-12.

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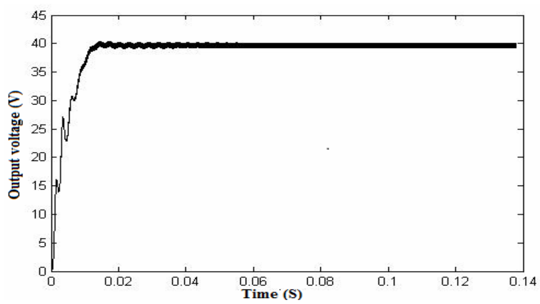

Figure-12. Output voltage of converter

The insolation level and temperature will not remain constant in real time. So the model is to be validated for varying environmental conditions also. A signal builder block added in the model helps to change the input insolation level every 0.2 s. The insolation is initially set at 1000 W/m^2 and it is reduced to 400 W/m^2 for another 0.2 s and it is then increased to 800 W/m^2. The overall model responded well and the LUT based MPPT tracked the maximum power point voltage and the duty cycle got adjusted so as to extract the maximum power from the PV module. The change in the module voltage with respect to the change in insolation level is shown in Figure-13 and the corresponding output voltage of the PV module is shown in Figure-14. To ensure that the maximum power is transferred, the module power and the power available at the output of the converter are shown in Figure-15 and Figure-16, respectively. The LUT based PV module and MPPT are replaced by the conventional PV model and P & O algorithm. The overall system is simulated for the same input conditions and the results are compared with that of the proposed model.

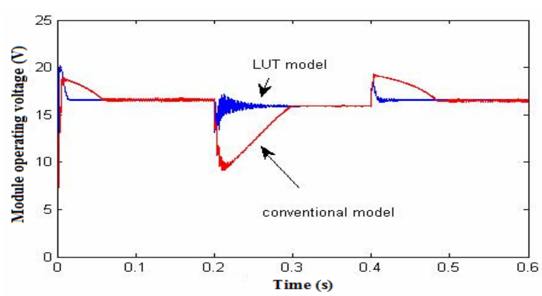

Figure-13. Module voltage under changing insolation

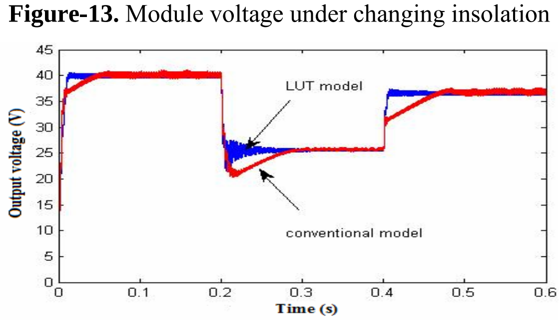

Figure-14. Converter output voltage under changing insolation

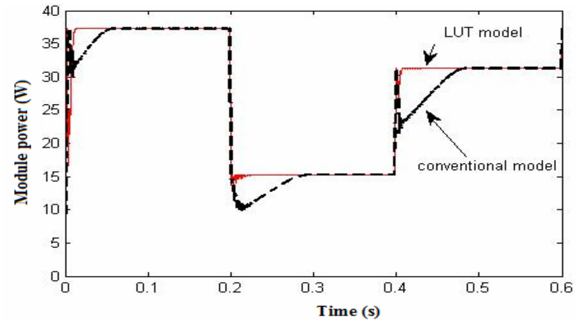

Figure-15. Module power under changing insolation

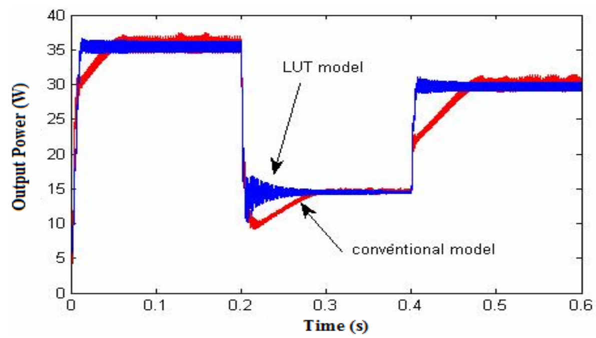

Figure-16. Output power under changing insolation

The comparison has been made for different test conditions and from the results; it is evident that the system based on LUT model responds faster i.e., optimal point tracking time is lesser than the conventional model. For complex interfacing systems like grid connected PV system, the proposed LUT based PV model and MPPT not only reduces the complexity of the overall system but also reduces the time taken for simulation.

CONCLUSIONS

This work has proposed lookup table based model for a solar PV module and MPPT. The V-P and V-I characteristics obtained by this method are validated with the experimental data. It is also shown that the LUT based model responds quicker to the environmental changes than the conventional model due to less computational complexities. The time taken for simulation is lesser than the conventional model especially when interfaced with the power conditioning systems. The work can be extended to study the impact of partial shading in different types of configurations. Moreover the proposed method can be well utilised in simulating complex PV grid connected system.

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Nomenclatures	
I_{ph}	Light-generated or photocurrent
I_r	Reverse saturation current of diode
I_{scn}	Nominal value of short circuit current
q	Charge of an electron (1.6×10^{-19}C)
k	Boltzmann's constant (1.38×10^{-23}J/K)
T	Cell's operating temperature
T_n	Nominal temperature
a	Diode ideality factor
R_{sh}	Shunt resistance of a solar PV Cell
R_{se}	Series resistance of a solar PV cell
V_{ocn}	Nominal value of open circuit voltage of PV cell
V_{ta}	Thermal voltage (=aKT/q)
K_i	Short circuit current temperature coefficient
G_n	Nominal insolation level (1000 W/m^2)

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