A NOVEL MATLAB/SIMELECTRONICS MODEL OF PV ARRAY WITH MPPT CONTROLLER

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Abstract - A photovoltaic array (PVA) simulation model to be used in Matlab-Simelectronic GUI environment will be developed and analyzed in this paper. In Simelectronic environment the simulink signal is converted to physical signal and again physical signal is converted to simulink signal. The model is developed using basic circuit equations of the photovoltaic (PV) solar cells including the effects of solar irradiation and temperature changes. The new model developed will be tested using a directly coupled dc load. A new implemented Photovoltaic Array Simulation model is to be developed by using Matlab/ Simelectronic Simulation Software. Test and validation studies with proper load matching circuits are simulated and results are presented here.

Keywords - *Buck-Boost, Maximum Power Point Tracker, Photo Voltaic Array, Incremental Conductance Algorithm.*

I. INTRODUCTION

The use of new efficient photovoltaic solar cells (PVSCs) has emerged as an alternative measure of renewable green power, energy conservation and demand-side management. Owing to their initial high costs, PVSCs have not yet been a fully attractive alternative for electricity users who are able to buy cheaper electrical energy from the utility grid. However, they have been used extensively for water pumping and air conditioning in remote and isolated areas where utility power is not available or is too expensive to transport. Although PVSC prices have decreased considerably during the last years due to new developments in the film technology and manufacturing process [1], PV arrays are still widely considered as an expensive choice compared with existing utility fossil fuel generated electricity. After building such an expensive renewable energy system, the user naturally wants to operate the PV array at its highest energy conversion output by continuously utilizing the maximum available solar power of the array. The electrical system powered by solar arrays requires special design considerations due to varying nature of the solar power generated resulting from unpredictable and sudden changes in weather conditions which change the solar irradiation level as well as the cell operating temperature.

Salameh and Dagher [2] have proposed a switching system that changes the cell array topology and connections or the structural connections of the arrays to establish the required voltage during different periods of a day. A steady-state analysis of a scheme employing direct coupling between a series/shunt or separately excited dc motors and the photovoltaic solar arrays has been given by Roger [3]. The dynamic performance of a dc shunt motor photovoltaic system has been studied by Fam and Balachander [4]. The starting and steady-state characteristics of dc motors powered by a solar cell array source have been studied by Appelbaum [5] to select the suitable parameters and type of dc motor for a desired utilization scheme. All these studies concerning dc motors or permanent magnet (PM) dc motors powered by PV generators have been done by considering the direct interface between the motor load and the PV source generator. For direct coupling of dc motors to PV solar arrays, the separatelyexcited or PM motors with a ventilator type load are the most suitable [5]. Owing to changes in the solar radiation energy and the cell operating temperature, the output power of a solar array is not constant at all times. Consequently, during the design process of PVA powered systems; a simulation must be performed for system analysis and parameter settings. Therefore an efficient user friendly simulation model of the PVAs is always needed. The PVA model proposed in this paper is a circuitry based model to be used with Simelectronic. The proposed model was simulated with various types of loads for performance checking.

II. BASIC BLOCK DIAGRAM

A general block diagram of a PVA model for GUI environment with MPPT controller using Simelectronics is given in Fig. 1 along with load model.
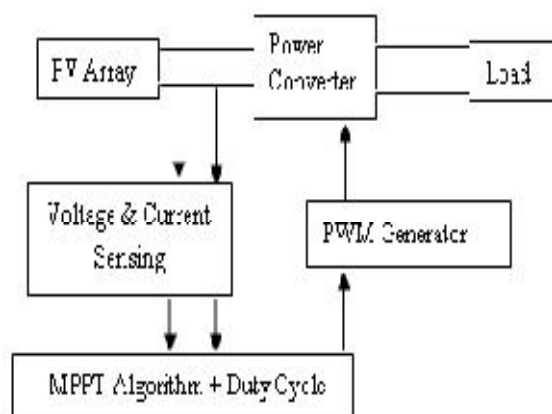

Fig 1: Block Diagram

III. PHOTOVOLTAIC SYSTEM

A. Electrical Equivalent Circuit

PV arrays are built up with combined series/parallel combinations of PV solar cells, which are usually represented by a simplified equivalent circuit model such as the one given in Fig. 2 and/or by an equation as in (1).
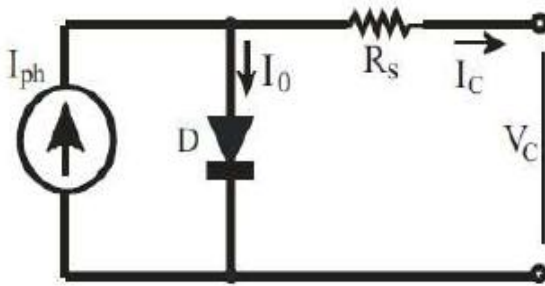

Fig. 2. Simplified-equivalent circuit of photovoltaic cell

B. Voltage – Current Equations

The PV cell output voltage is a function of the photocurrent that mainly determined by load current depending on the solar irradiation level during the operation.

$$V_C = \frac{AKT_C}{e} \ln\left[\frac{Iph + Io - ic}{Io}\right] - RsIc \qquad (1)$$

Where the symbols are defined as follows:

e: electron charge (1.602×10^{-19} C).

k: Boltzmann constant (1.38×10^{-23} J/oK).

Ic: cell output current, A.

Iph: photocurrent, function of irradiation level and junction temperature (5 A).

I0: reverse saturation current of diode (0.0002 A).

Rs: series resistance of cell (0.001 Ω).

Tc: reference cell operating temperature (20 °C).

Vc: cell output voltage, V.

Both k and Tc should have the same temperature unit, either Kelvin or Celsius. The curve fitting factor A is used to adjust the I-V characteristics of the cell obtained from (1) to the actual characteristics obtained by testing. Eq. (1) gives the voltage of a single solar cell which is then multiplied by the number of the cells connected in series to calculate the full array voltage. Since the array current is the sum of the currents flowing through the cells in parallel branches, the cell current IC is obtained by dividing the array current by the number of the cells connected in parallel before being used in (1), which is only valid for a certain cell operating temperature Tc with its corresponding solar irradiation level Sc. If the temperature and solar irradiation levels change, the voltage and current outputs of the PV array will follow this change. Hence, the effects of the changes in temperature and solar irradiation levels should also be included in the final PV array model. A method to include these effects in the PV array modelling is given by Buresch [1].

According to his method, for a known temperature and a known solar irradiation level, a model is obtained and then this model is modified to handle different cases of temperature and irradiation levels. Let (1) be the benchmark model for the known operating temperature Tc and known solar irradiation level Sc as given in the specification. When the ambient temperature and irradiation levels change, the cell operating temperature also changes, resulting in a new output voltage and a new photocurrent value. The solar cell operating temperature varies as a function of solar irradiation level and ambient temperature. The variable ambient temperature Ta affects the cell output voltage and cell photocurrent. These effects are represented in the model by the temperature coefficients CTV and CTI for cell output voltage and cell photocurrent, respectively, as:

$$C_{TV} = 1 + \beta_T (T_a - T_x) \qquad (2)$$

$$C_{TI} = 1 + \frac{\gamma_T}{S_C} (T_x - T_a) \qquad (3)$$

Where, $\beta T = 0.004$ and $gT = 0.06$ for the cell used and Ta=20°C is the ambient temperature during the cell testing. This is used to obtain the modified model of the cell for another ambient temperature Tx. Even if the ambient temperature does not change significantly during the daytime, the solar irradiation level changes depending on the amount of sunlight and clouds. A change in solar irradiation level causes a change in the cell photocurrent and operating temperature, which in turn affects the cell output voltage. If the solar irradiation level increases from Sx1 to Sx2, the cell operating temperature and the photocurrent will also increase from Tx1 to Tx2 and from Iphl to Iph2, respectively. Thus the change in the operating temperature and in the photocurrent due to variation in the solar irradiation level can be expressed via two constants, CSV and CSI, which are the correction factors for changes in cell output voltage VC and photocurrent Iph, respectively:

$$C_{SV} = 1 + \beta_T \propto_S (S_x - S_C) \qquad (4)$$

$$C_{SI} = 1 + \frac{1}{S_C} (S_x - S_C) \qquad (5)$$

where SC is the benchmark reference solar irradiation level during the cell testing to obtain the modified cell model. Sx is the new level of the solar irradiation. The temperature change, ΔTC, occurs due

to the change in the solar irradiation level and is obtained using

$$\Delta T_C = \propto_S (S_x - S_C) \qquad (6)$$

The constant αS represents the slope of the change in the cell operating temperature due to a change in the solar irradiation level [1] and is equal to 0.2 for the solar cells used. Using correction factors CTV, CTI, CSV and CSI, the new values of the cell output voltage VCX and photocurrent Iphx are obtained for the new temperature Tx and solar irradiation Sx as follows:

$$V_{Cx} = C_{TV} \, C_{SV} \, V_C \qquad (7)$$

$$I_{phx} = C_{TI} \, C_{SI} \, I_{ph} \qquad (8)$$

V_C and Iph are the benchmark reference cell output voltage and reference cell photocurrent, respectively. The resulting I-V and P-V curves for various temperature and solar irradiation levels were discussed and shown in [6, 8, 9], therefore they are not going to be given here again.

IV. MAXIMUM POWER POINT TRACKER

MPPT Algorithm Flow Chart

A PV array is usually oversized to compensate for a low power yield during winter months. This mismatching between a PV module and a load requires further over-sizing of the PV array and thus increases the overall system cost. To mitigate this problem, a maximum power point tracker (MPPT) can be used to maintain the PV module's operating point at the MPP. MPPTs can extract more than 97% of the PV power when properly optimized. MPPT is a power electronic device interconnecting a PV power source and a load, maximizes the power output from a PV module or array with varying operating conditions, and therefore maximizes the system efficiency. The location of the MPP in the *I–V* plane is not known beforehand and always changes dynamically depending on irradiance and temperature. There are a number of methods that have been proposed. Among different algorithms, the Perturb & Observe (P&O) and Incremental Conductance (incCond) methods are commonly used.

In 1993 Hussein, Muta, Hoshino, and Osakada of Saga University, Japan, proposed the incremental conductance (incCond) algorithm intending to solve the problem of the P&O algorithm under rapidly changing atmospheric conditions. The flowchart shown in Figure 3 explains the operation of this algorithm.
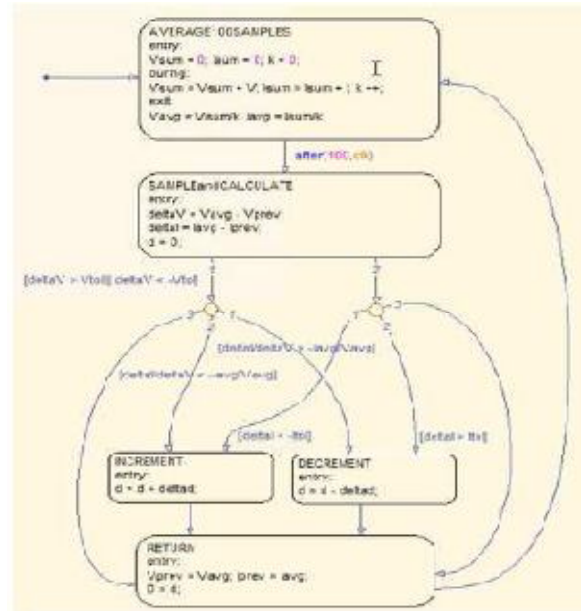

Fig 3: MPPT Algorithm Flow Chart

V. MATLAB MODELLING

Block Diagram

A general block diagram of the PVA model for GUI environment of Simulink is given in Fig. 4 along with load models. The block called *PVA model for GUI* is the last stage of the model. This block contains the sub models that are connected to build the final model. A diode (D1) is connected in series with the load circuit to prevent the reverse current flow. Since the main objective is the development of the PVA functional model for the Simulink environment, the other parts of the operational block diagram given in Fig. 4 are not going to be explained in full detail. However, just to describe the main diagram, as it can readily be seen, the system is modeled to supply power to dc load. The last stage of the PVA model is shown in Fig. 4. The other stages are masked as subsystems under the last stage. The first stage of the PVA modeling is depicted in Fig. 5.
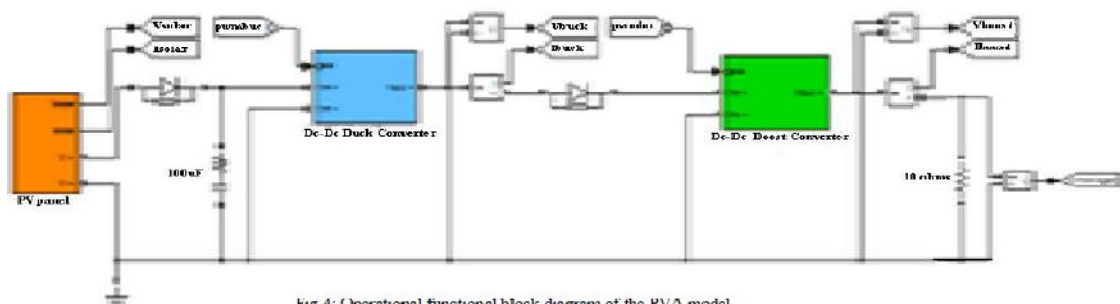

Fig 4: Operational functional block diagram of the PVA model

.PV ARRAY

The PVA consists of 36 PV cells all connected in series to have a desired voltage output. Depending on the load power required, the number of parallel branches can be increased to 2 or more. The effects of the temperature and solar irradiation levels are represented by two variables gains. They can be changed by dragging the slider gain adjustments of these blocks named as *variable temperature* and *variable solar irradiation.*
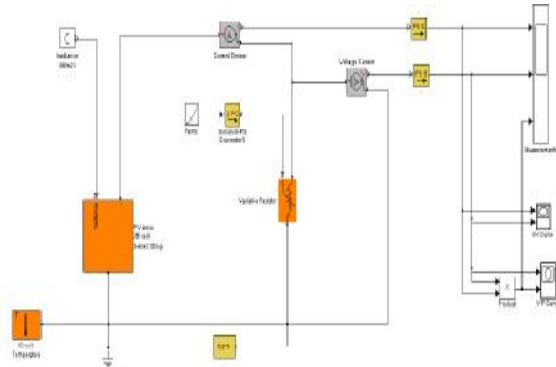

Fig 5: PV Array

BUCK CONVERTER

The simulation diagram of a buck converter using a power MOSFET is shown in fig. By varying the duty ratio of the switch, the average output voltage can be controlled. A Buck Converter produces a lower average output voltage Eo than the d.c input voltage Edc.
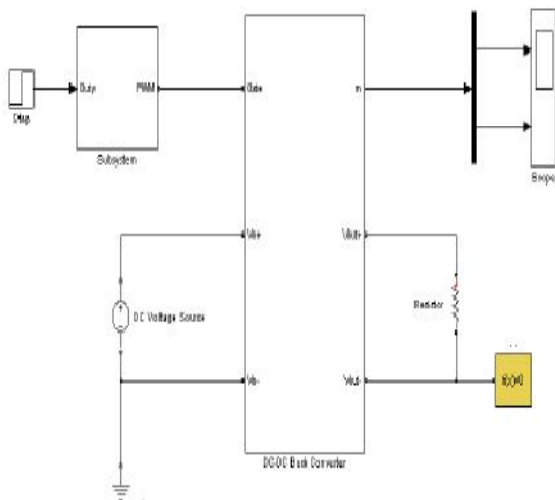

Fig 6: Buck Converter

BOOST CONVERTER

The simulation diagram of a boost converter using a power MOSFET is shown in fig. By varying the duty ratio of the switch, the average output voltage can be controlled. In a Boost Converter the output voltage is always greater than input voltage
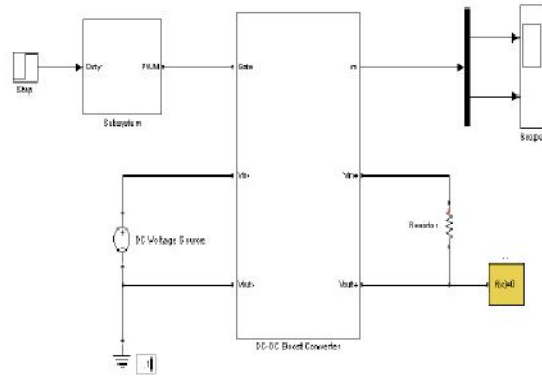

Fig 7: Boost Converter

VI. RESULTS AND DISCUSSION

The current-voltage (I-V) characteristic of the PVA during operation is given in Fig. 5. Since the voltage of the PVA is equal to the open circuit voltage at stand-still, the IV characteristics start at open circuit voltage with current equal to zero. As the simulation starts an the loads begin draw current from the PVA, the voltage and the current start moving toward the operating values, which are shown in Figs. 7 and 8 for voltage and current, respectively. PVA power is given in Figs. 6 and 9. Although the maximum power is above 750 W for the current solar irradiation and temperature levels, the operating power is approximately 750 W.
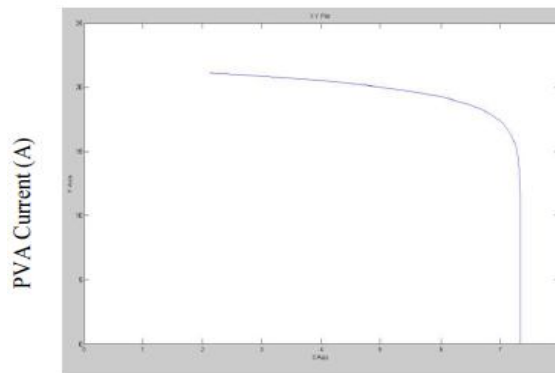

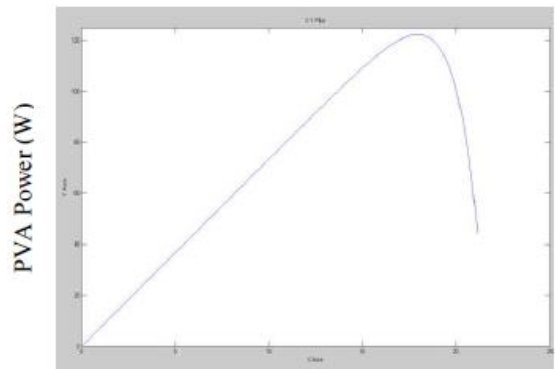**Fig 8: Current-Voltage (I-V) Characteristics of PVA.**

Fig 9: Power-Voltage (P-V) Characteristics of PVA

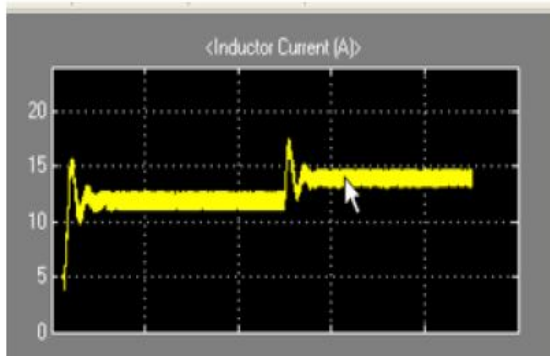The associated voltage and current waveforms of a Buck Converter is shown in fig.
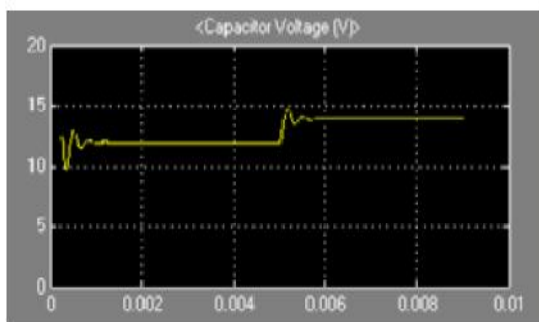

Fig 10: Current Characteristics of a Buck converter

Fig 11: Voltage Characteristics of a Buck converter

VII. CONCLUSION

This paper introduces a simulation model for photovoltaic Arrays (PVS) to be used in Matlabsimelectronics GUI environment. The proposed model has a generalized structure. So that it can be used as a PV power generator along with Wind, fuel cells and small hydro system by establishing proper Interfacing and controllers. The model proposed here is considered as a part of distributed power generation systems.

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