MATLAB/Simulink Model of PV Integrated DC-DC Converter

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***Abstract*— This paper presents a MATLAB/Simulink model of Photo Voltaic (PV) using Maximum Power Point Tracking (MPPT) technique and a converter. This model provide 200 V output from a 24 V input. The development of PV model, the integration of the MPPT with an average model of power electronics and the MATLAB implementation are described. The converter section consists of an isolated coupled inductor DC-DC converter. It has high gain. It consist of a dual-voltage doubler circuit. In addition, the energy in the coupled inductor leakage inductance can be recycled via a nondissipative snubber on the primary side. Thus, the system efficiency is improved. It completes the simulation of a PV energy conversion system.**

***Index Terms*— PV model parameter, insolation, dual-voltage doubler circuits, high voltage gain, nondissipative snubber.**

I. INTRODUCTION

Solar energy is the one of the effective source of natural energy. In research field the use of solar energy and implementation of new technologies using this energy is increasing. In day by day our source of energy is decreasing, so we have to use the never ending energy like wind and solar. For using this type of energy we have to modify the existing circuitry or model suitable for this type of inputs. Such a model of converter system is introduced here. This converter input is provided by using a solar sell. Figure 1 shows the PV energy conversion system consists of PV, DC-DC converter and a DC-AC inverter.

There are three main types of photovoltaic solar panels for both commercial and residential use. They are: Mono-crystalline, Poly-crystalline and Amorphous silicon also called “Thin Filim”. All three types of solar panels have both advantages and disadvantages depending on the end user’s budget, the size and type of environment where they are used and the expected output of the system. In this mono-crystalline and poly-crystalline are called rigid panels. rigid solar panels are often constructed using glass panes and aluminum frames. These types of materials do not degrade over time, making rigid panels the best choice for a “long-term” investment. Rigid panels also usually have the highest efficiencies, making them ideal for applications that require maximum power and a small ‘installation’ footprint. Rigid panel systems are not typically portable. While they produce the most power of any commonly-available solar panel technology, they often do not meet the form-factor requirements to be truly mobile (glass can be broken, and cannot be folded, requiring the maximum amount of space of any other solar panel technology).

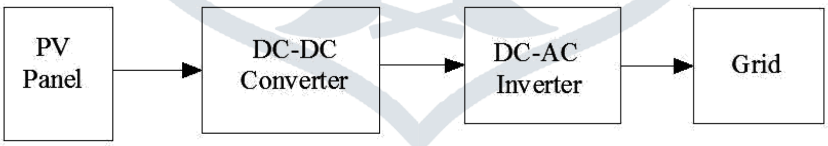


Fig.1. PV Energy Conversion System

II. MATHEMATICAL MODEL OF PV CELL

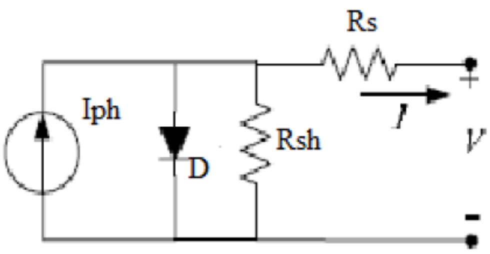


Fig.2. Solar Cell Model

Figure 2 shows the equivalent circuit of the general model which consists of a photo current, a diode, a parallel resistor expressing a leakage current and a series resistor describing an internal resistance to the current flow.

The voltage-current characteristic equation of a solar cell is given as

$$I = I_{ph} - I_s\left[\exp\left(\frac{q(V + IR_s)}{KT_cA}\right) - 1\right] - \frac{V + IR_s}{R_{sh}} \qquad (1)$$

Where
I_{ph} is a light-generated current or photocurrent, I_s is the cell saturation of dark current, q(= 1.6 ×10-19 C) is an electron charge, K (= 1.38 ×10-23J/K) is a Boltzmann's constant, T_c is the cell's working temperature, A is an ideal factor, R_{sh} is a Shunt resistance, and R_s is a series resistance of solar cell.

The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as

$$I_{ph} = \left[I_{sc} + K_i\left(T_c - T_{ref}\right)\right]H \qquad (2)$$

Where
I_s is the cell's short-circuit current at a 25°C and 1kW/m2, K_i is the cell's short-circuit current temperature coefficient, T_{ref} is the cell's reference temperature and H is the solar insolation in kW/m2.

The cell's saturation current varies with the cell temperature, which is described as

$$I_s = I_{RS}\left(\frac{T_C}{T_{ref}}\right)^3 \exp\left[\frac{qE_G\left(T_c - T_{ref}\right)}{T_{ref}T_ckA}\right] \qquad (3)$$

Where
I_{RS} is the cell's reverse saturation current at a reference temperature and standard solar radiation E_G is the bang-gap energy of the semiconductor used in the cell and A is the ideal factor, dependent on PV technology.

A PV array is a group of several PV cells which are electrically connected in series and parallel circuits to generate the required current and voltage. Figure 3 shows the equivalent circuit for the solar module arranged in N_P parallel and N_S series cells.

$$I = N_pI_{ph} - N_pI_s\left[\exp\left(\frac{q(V + IR_{sm})}{N_skT_cA}\right) - 1\right] \qquad (4)$$

Where

$$R_{sm} = \frac{N_sR_s}{N_p}$$

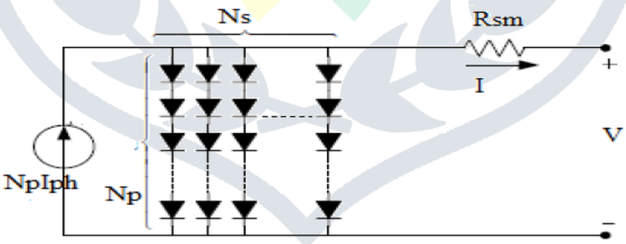


Fig.3. Simplified Model of Solar Array

III. Determination of Model Parameter

The unknown parameters of the models have to be determined for the given type of cell, whose characteristics are to be reproduced by the model. A number of approaches for cells and module parameter determination can be adopted using the datasheet parameters specified by manufacturer or measured.

The general expression of the photovoltaic panel's current as a function of voltage, using the four-parameter (I_{ph}, A, I_s, R_s) model can be expressed as in Eq. 4. It can be simplified to

$$I = N_pI_{ph} - N_pI_s\left[\exp\left(\frac{(V + IR_{sm})}{V_t}\right) - 1\right] \qquad (5)$$

Where

$$V_t = \frac{N_skT_cA}{q}$$

For calculating the panel's parameters, some simplifications to Eq. 5 have been made. As the dark saturation current in silicon devices is very small (compared to the exponential term), the term '−1' can be neglected . For a module N_p =1.
At reference temperature from Eq. 2 and Eq. 3 $I_{ph} \approx I_{sc}$ and $I_s = I_{RS.}$ Hence in open circuit condition (I=0) from Eq.5.

$$0 = I_{sc} - I_{RS}\left[\exp\left(\frac{V_{oc}}{V_t}\right)\right] \tag{6}$$

and the current at MPP

$$I_{MPP} = I_{sc} - I_{RS}\left[\exp\left(\frac{V_{MPP} + I_{MPP}R_{SM}}{V_t}\right)\right] \tag{7}$$

In the third equation, the well-known relation of the derivative of the power with voltage at MPP is used

$$\frac{dP}{dV} = 0 \tag{8}$$

The above equation can be expanded as follows:

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = V\frac{dI}{dV} + I = 0 \tag{9}$$

This leads to the following

$$\frac{dI}{dV} = -\frac{I_{MPP}}{V_{MPP}} \tag{10}$$

Considering the fact that I(V) is a transcendent equation, and I = f(I, V), the derivative of current with voltage can be expressed as:

$$dI = dI\frac{\partial f(I,V)}{\partial I} + dV\frac{\partial f(I,V)}{\partial V} \tag{11}$$

$$\frac{dI}{dV} = \frac{\frac{\partial f(I,V)}{\partial V}}{1 - \frac{\partial f(I,V)}{\partial I}} \tag{12}$$

Therefore, executing the derivative in (12), the equation become

$$\frac{I_{MPP}}{V_{MPP}} = \frac{I_{RS}\left[\exp\left(\frac{V_{MPP}+I_{MPP}R_{SM}}{V_t}\right)\right]}{V_t\left[1+\frac{I_{RS}R_{SM}\{\exp((V_{MPP}+I_{MPP}R_{SM})/V_t)\}}{V_t}\right]} \tag{13}$$

Solving the above system of equations will result in the solution for I_{RS}, R_S and V_t as follows which contains only parameters given in the product datasheet or that are directly measurable.

$$I_{RS}(V_t) = \frac{I_{sc}}{\exp\left(\frac{V_{oc}}{V_t}\right)} \tag{14}$$

$$R_{SM}(V_t) = \frac{V_{oc} - V_{MPP} + V_t \ln\left(\frac{I_{sc} - I_{MPP}}{I_{MPP}}\right)}{I_{MPP}} \tag{15}$$

$$V_t = \frac{(2V_{MPP} - V_{oc})(I_{sc} - I_{MPP})}{I_{MPP} - (I_{sc} - I_{MPP})\ln\left(\frac{I_{sc} - I_{MPP}}{I_{sc}}\right)} \tag{16}$$

One can use these formula's to determine the series resistance of a single cell (R_S), ideality factor (A) and reverse saturation current.

IV. ISOLATED HIGH STEP-UP DC-DC CONVERTER

Isolation means existence of an electrical barrier between the input and output of the DC-DC converter. Figure 4 shows the isolated step-up DC-DC converter. This converter consists of the voltage of the solar panel V_{PV}, an input capacitor C_{in}, snubber diodes D_1 and D_2, a snubber inductor L_1, a snubber capacitor C_1, a coupled inductor T_1, a main switch Q_1, two step-up capacitors C_2 and C_3, two step-up diodes D_3 and D_4, an output diode D_o, an output capacitor C_o and an output load R. The energy stored in the nondissipative snubber capacitor is recycled to the voltage of the solar panel V_{PV} and the input capacitor C_{in}, thereby improving the system efficiency. Moreover, maximum power point tracking (MPPT) is important for solar energy applications. Here the perturb and observe (P&O) algorithm is utilized to achieve an MPPT function for solar energy conversion applications.

To simplify the analysis of the operating principles, the following assumptions are made during one switching cycle.

1) The main switch Q_1 and all the diodes are regarded as ideal components; only the parasitic capacitor C_{DS1} of the main switch Q_1 is considered.

2) Capacitors C_{in}, C_2, C_3 and C_o are sufficiently large that V_{PV}, v_{C2}, v_{C3}, and V_o are regarded as constant values.

3) The turns ratio of the coupled inductor T_1 is $n = N_2/N_1$ and the magnetizing inductance L_m and leakage inductance L_{k1} of the coupled inductor T_1 are considered in the analysis.

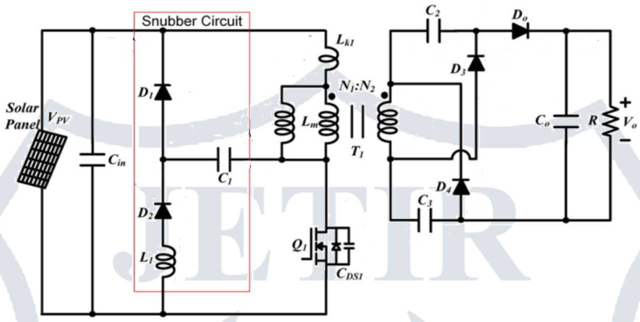


Fig.4. Isolated High Step-Up DC–DC Converter

V. MATLAB/SIMULINK SIMULATION MODEL OF PV INTEGRATED DC-DC CONVERTER

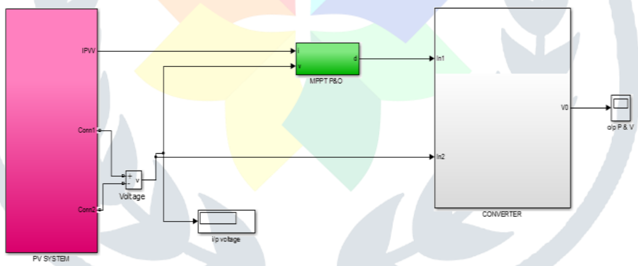


Fig.5. Full Simulation Model of Isolated High Step-Up DC–DC Converter

A generalized PV model is built using Matlab/Simulink according to the Eq. 1, 2 and 5. The unknown parameters (A, R_s, I_{RS}) of the model can be obtained using above Eq. 14, 15, 16 and the parameters specified by the manufacturer. Figure 5 shows the implementation of full model. Figure 6 shows the subsystem PV system contain the simulation design. There is another subsystem inside the Figure 6 shown as subsystem1. Its input is cell temperature, Reference temperature and the PV equivalent circuit output voltage. Its output is PV current and its power. Figure 7 shows the subsystem1. The output of subsystem1 is given to the input of MPPT P&O subsystem. The output of MPPT P&O subsystem is duty ratio. This pulse is given to the gate pulse of switch Q_1 of the DC-DC converter. Figure 8 shows the gate pulse. Figure 9 shows the input and output waveforms of integrated DC-DC converter.

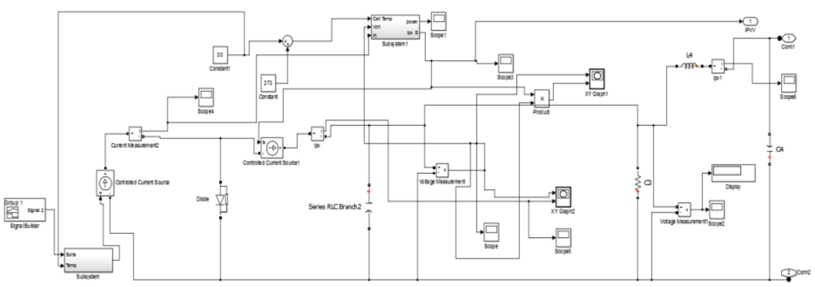


Fig.6. Simulation Model of Subsystem (PV System)

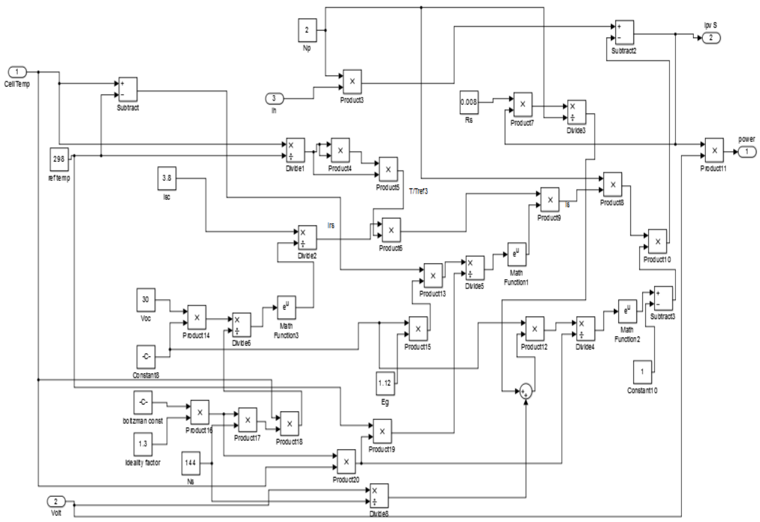
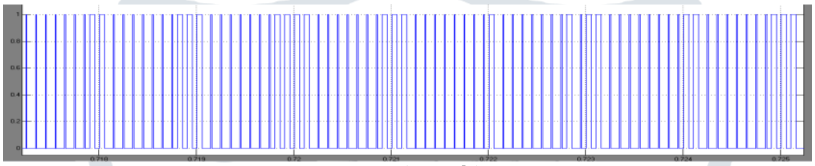


Fig.7. Simulation Model of Subsystem 1



Time in (seconds)

Fig.8. Pulse Generated by MPPT P&O Subsystem

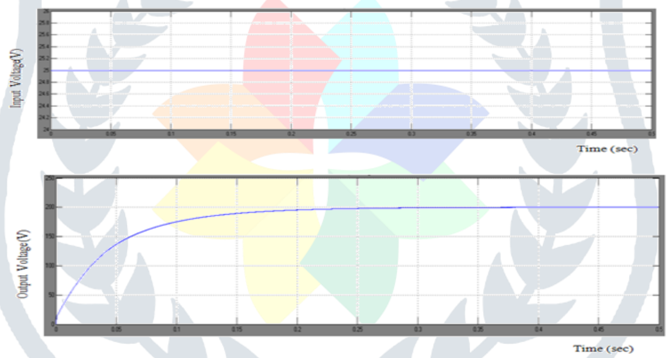


Fig.9. Input and output waveforms of Isolated high step-up dc–dc converter

VI. Conclusion

PV module has been developed and verified using MATLAB/Simulink. Using the mathematical equations and basic math functions a simulation model is developed. It also presented an isolated coupled-inductor integrated DC-DC converter with a nondissipative snubber. The detailed simulation diagrams and the corresponding waveforms have been provided. The result shows that high stepup voltage gain and high efficiency are achieved.

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