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Control of induction machine connected through long cable and Isolation Transformer

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Abstract- It is always a general wondering that which method is better for the controlling of speed of induction motor. This paper deals with the control of induction machine connected through a 2Km long cable and isolation transformer using different control strategies and then comparing the simulation results and various other factors that affect the working of induction motor. This paper deals with V/Hz control and Field oriented control. It uses SVPWM to produce the gating signal and the above controls vary the reference voltage of the SVPWM to produce the desired output voltage. MATLAB/SIMULINK is used to perform the simulation in this paper and the results of that are presented to show the effectiveness of the control strategies.

I. INTRODUCTION

It is often compared amongst the various method of speed control of an induction motor to decide which method is the best. The most conventional method of speed control is Volts/Hz control. In this control the flux in the machine is kept constant by varying voltage and the frequency in equal proportions. But since this method takes only magnitude into considerations there are distortion in the output and also superior control over the speed is not attained. Therefore a better Control technique had to be implemented which takes phase along with the magnitude and frequency into consideration. This led to the study of vector control of induction motor. The vector control is further classified into two categories. If voltage and current measurement along with speed or hall sensors are employed then it is called direct vector control [12]. If only machine parameters are used then it comes under indirect vector control [12]. Field oriented control is one of the methods which are used for control of speed as well as torque. In this method the current is resolved into two components, both in quadrature to each other and independent of each other. The first current is responsible for the production of flux and the other one in the production of torque. Therefore an independent control over flux and thereby speed, and torque is attained. In this paper the control of an induction motor using both of the above methods is shown along with their simulation results. The induction motor is connected to the inverter through a 2Km long []-section line and an isolation

transformer along with the AC filter and series reactor. The gating signals are generated using SVPWM technique and are given to the neutral point clamped inverter (NPC). The NPC inverter used produces a three level output voltage. The Fig.1.1 shows the block diagram and the power flow in the circuitry. A 3- Φ diode rectifier along with an output LC filter to convert the input AC supply to DC is connected so that it can be fed to the Adjustable speed drive (Inverter).

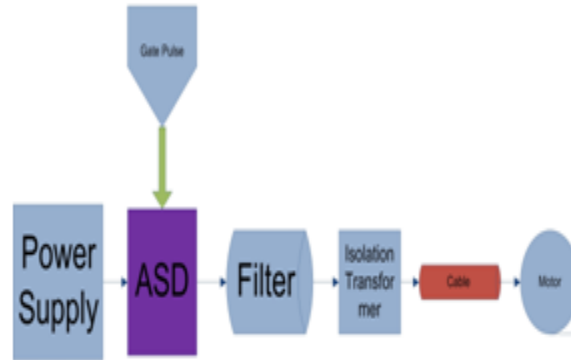


Fig 1.1 Block Diagram representing the power flow

II.NPC INVERTER AND SVPWM

The NPC inverter, as mentioned above, is a 3 level inverter. Fig.2.1 shows the circuit diagram of a three level NPC inverter. For a three level NPC inverter 27 switching states are required. If both of the top switches are ON then the switching state is said to be +1. If both of the bottom switches are ON then it is -1. If the middle two switches are ON then it is 0 [4]. If the switching state of all the three phases is same, like $(-1,-1,-1)$, $(+1,+1,+1)$,

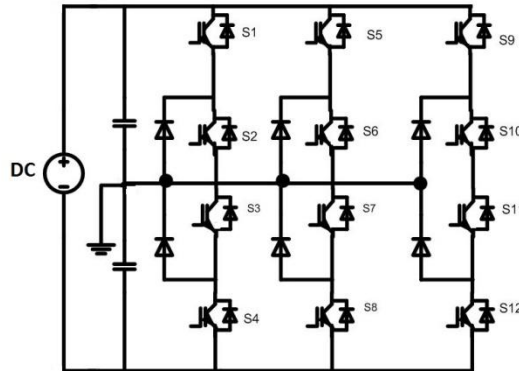


Fig. 2.1 3 level NPC Inverter

$(0,0,0)$, then the vector obtained is called Zero Vector [5]. The Fig.2.2 shows all the 27 states in the form of a hexagon with the three zero vectors at the center. Each triangle in the hexagon is a sector. To determine in which sector the reference rotating vector is the following steps are followed.

- Consider the outermost hexagon as a 2 level hexagon and determine the sector in which the Reference vector is [3].
- Then sub divide each sector into four equal sectors as shown in the Fig. 2.3 and calculate the exact position of the reference vector [3].

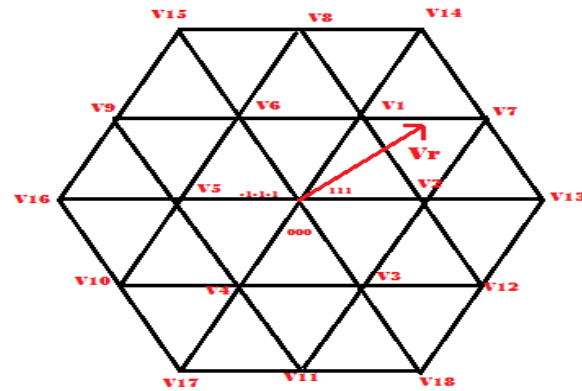


Fig. 2.2 State Diagram

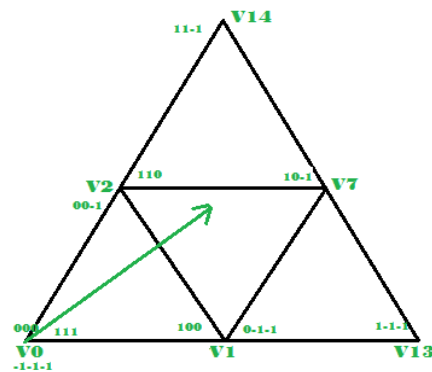


Fig. 2.3 Selected Sector

The selection of the sector is shown in the following flow chart in the Fig. 2.4. The selection of inter sector is also similar to the process employed in the flow chart. After selecting the sector the ting signal are generated [1].

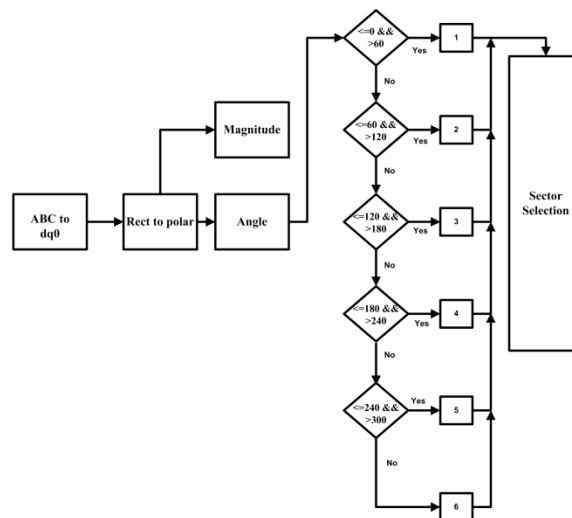


Fig. 2.4 Flow Chart showing sector selection

It is nothing but a scalar control which takes only magnitude into consideration. The speed variation is achieved by varying the input voltage as speed is directly proportional to the square of the voltage [13]. But along with the change in voltage the frequency is also varied so that the ratio of the voltage to frequency is kept constant (hence the name V/Hz control) and thereby keeping the flux constant. The flux is not allowed to vary because with the increase in flux iron losses increases and also the core might get saturated resulting in the increase in magnetizing current [12].

A desired value of speed is given as the reference speed input. Using this speed the value of the frequency is calculated, assuming a 4 pole induction machine, and then the peak value of the phase RMS voltage is calculated in the Voltage and flux calculator block. From this the reference voltages are calculated and converted to $\alpha\beta 0$ plane and then the gating signals are generated using SVPWM technique. These pulses are given to the inverter and the output voltage is provided to the IM through the cable and isolation transformer.



FOC is a closed loop control technique which takes even phase into consideration along with magnitude and frequency. As explained above after resolving the current into two components the magnitude and angle is calculated. This is again, along with the speed is given back as feedback.

The FOC control used in this paper is RFOC. Hence all the calculations are using rotor reference frame and rotor parameters. The Fig. 4.1 shows the block diagram of FOC Control [12]. A speed reference signal (ω_r^*) is given which is compared with the actual speed and the error is given to the speed controller which calculates the reference torque (T_e^*). From this torque reference i_q^* is calculated. The blocks flux converter, magnitude and angle resolver (MAR), torque and current estimator are based on simple mathematical relations between currents, flux linkage, speed and torque [8].



The timing signals generated is then fed to SVPWM block which then will produce the gating signal. The simulation results of FOC are presented in the next segment.

V. SIMULATION RESULTS

This section of the paper shows the final output results. The data assumed for the simulation is shown below in the Table 5.1.

S.No.	Parameters	Value
1	V_{dc}	450V
2	Sampling Frequency	1KHz
3	Reference Speed (ω_r^*)	150rad/s to 110rad/s
4	Cable	$R = 0.0754\Omega/Km$
		$L = 5.04 \times 10^{-4} H/Km$
		$C = 0.84\mu F/Km$
5	Torque	2N-m
6	Induction Motor	4KW, 400V, 50Hz, 4 pole, 1430rpm

Table 5.1 Assumed Data for the simulation

V (A). VOLTS PER HERTZ CONTROL

In this segment the simulation results for V/Hz method with and without cable and isolation transformer are shown. The THD analysis and dv/dt , di/dt stress for the switch are also presented. Fig. 5.1.1 shows the change in speed and torque as the reference speed decreases from 150rad/s to 110rad/s. Fig 5.1.2 shows the change in voltage magnitude and its frequency once the reference speed is changed, thereby keeping the V/Hz ratio constant. The above mentioned figures are for the circuit without cable and isolation transformer. Fig. 5.1.3 and Fig. 5.1.4 show the same for the circuit with cable and isolation transformer.

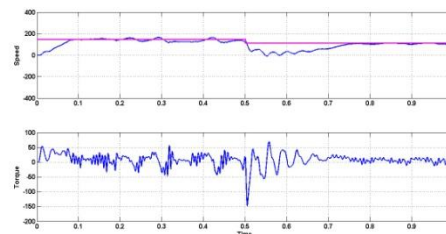


Fig. 5.1.1 Speed and torque of induction motor without cable and isolation transformer

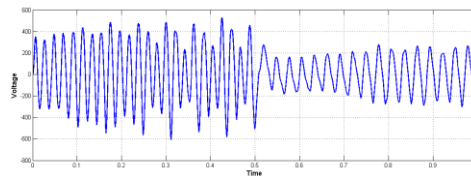
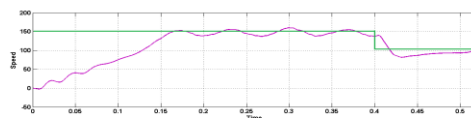


Fig. 5.1.2 Voltage waveform of induction transformer without cable and isolation transformer



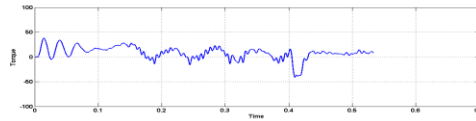


Fig. 5.1.1 Speed and torque of induction motor with cable and isolation transformer

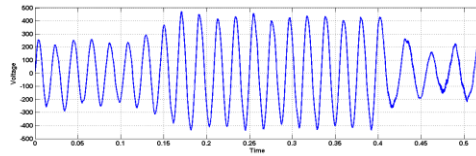


Fig. 5.1.2 Voltage waveform of induction transformer with cable and isolation transformer

The variations in the voltage waveform and speed and torque waveforms are clearly visible in waveforms. The voltage is made more sinusoidal using a LC filter. The ripples in the torque are reduced by using a series reactor. Further important parameters relating the switch and the induction motor are presented below in the Table 5.2 for both the cases including and excluding the isolation transformer and cable.

Parameters	With cable and Isolation Transformer	Without cable and Isolation Transformer
dv/dt stress on switch	140KV/ μ s	75KV/ μ s
di/dt stress on switch	65KA/ μ s	220KA/ μ s
Voltage THD	5.34%	6.18%
Current THD	33.89%	22.45%

Table 5.2 Results for V/Hz control

V (B). FOC CONTROL

The simulation results for FOC control are presented in this segment for both the cases including and excluding the cable and isolation transformer. Fig. 5.2.1 and Fig. 5.2.2 show the speed and torque and voltage waveforms of induction motor without cable and isolation transformer and Fig. 5.2.3 and Fig. 5.2.4 show the same including them.

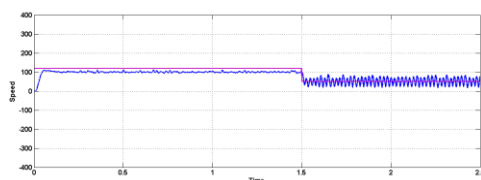
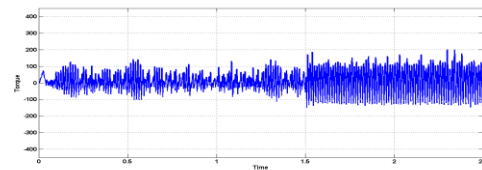


Fig. 5.2.1 Speed and Torque Waveforms without Cable and Isolation Transformer



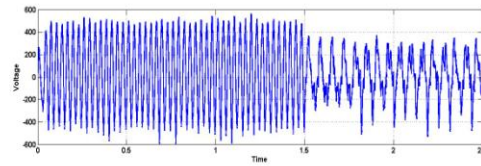


Fig. 5.2.4 Voltage Waveforms without Cable and Isolation Transformer

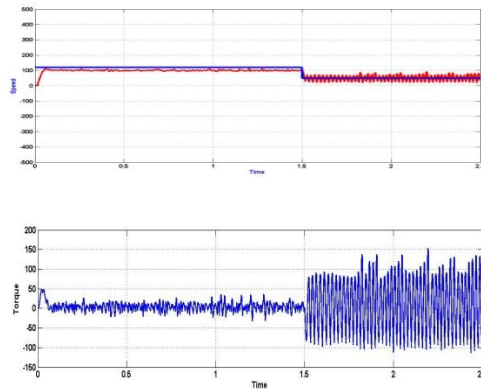


Fig. 5.2.3 Speed and Torque Waveforms with Cable and Isolation Transformer.

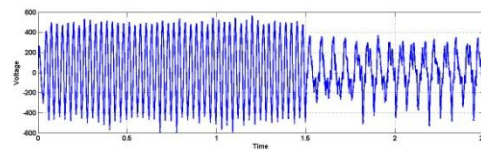


Fig. 5.2.4 Voltage Waveforms with Cable and Isolation Transformer

The ripples in the torque are increasing as the speed is decreasing resulting in the increase of Torque mean value. The error between the reference speed and the actual speed is reduced with the use of a PID controller. The change in frequency and magnitude is clearly visible from the voltage waveforms.

The other important parameters relating the switch and the induction motor are listed below in Table 4.2

Parameters	With cable and Isolation Transformer	Without cable and Isolation Transformer
dv/dt stress on switch	90KV/ns	23.39KV/ μ s
di/dt stress on switch	2.19KA/ps	7.5KA/ μ s
Voltage THD	19%	8.24%
CurrentTHD	30%	32%

Table 5.2 Results for FOC Control

VI. CONCLUSION

V/Hz control is an optimum control technique where cost and space is an important criterion. The efficiency of the system and the stability of the system is less as it is an open loop system. Moreover the proposed control had no controller to reduce the settling time and the steady state error.

In FOC control a proper closed control along with various controllers is implemented reducing both the settling time and steady state error. The decoupling is effectively achieved and a good control over the machine is achieved. Hence with respect to the stability and efficiency this method is better than V/Hz method. However the THD of both voltage and current waveforms is less in V/Hz control when compared to FOC Control.

The Isolation transformer provides a separation between the inverter and cable which reduced the stress on the switches but still the stress on the switches is increased when the cable is connected and which forces to use a switch of higher rating. However that results in the increase in cost of the system. This control along with cable finds its applications in the oil industries.

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Modeling and Simulation of a PV System using DC-DC Converter

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Abstract- In this era of efficient use of energy and cost cutting, solar energy comes into prominence. Conversion of this freely available energy into useable form will reduce the burden on other resources; while at the same time expand our energy reserve. In this paper, an attempt has been made to model and simulate a photovoltaic cell. PV cell works at its efficient best when it is operating at its maximum power point. The energy derived from the cell is used to power the load. A DC-DC converter is used as an interface between the cell and the load. A buck-boost converter is implemented as it serves our purpose over the entire operating range of the PV cell. The duty cycle of the converter is varied to ensure impedance matching between the cell output and the load while the “Perturb and Observe” algorithm tracks the maximum power point of the cell. The set-up is studied under different conditions and for different values of the load. An inverter can be used at this stage for a load that works on ac voltage. The whole circuit is simulated using MATLAB SIMULINK. The idea is to ensure maximum performance of the set-up irrespective of the changes in the physical conditions.

I. Introduction

Solar energy is the primary source of energy. It is renewable and eternal. The need for converting solar energy to usable form arises due to the exhaustion of fossil fuels. A solar cell serves this purpose. This paper aims at the modeling and simulation of a PV system using a DC-DC converter in MATLAB/ SIMULINK. A PV cell is used to convert solar energy into electrical energy by photovoltaic effect. A photovoltaic cell is made up of two layers: n layer and p layer respectively. The p-layer which is thinner than the n-layer is exposed to sunlight. The photons from the sunlight are absorbed by the semiconducting material thereby exciting the free electrons to travel from n-layer to p-layer. Hence there is a flow of current in the circuit. Thus, a PV cell outputs a short circuit current depending on the irradiance and temperature.

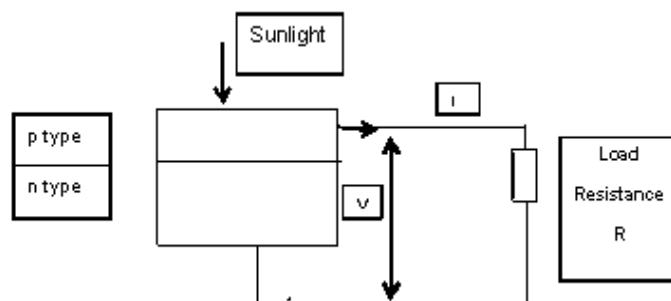


Figure 1: The basic model of a PV cell.

The output of the PV system is not very efficient due to the varying atmospheric conditions such as temperature and irradiance. Hence, to improve the performance of the PV system, a MPPT system and a DC-DC converter are employed. The MPPT system is responsible to track the maximum power point of the PV system and transfer it to the load. The DC-DC converter is used to improve the strength of the source voltage.

II. Materials and Methods

Characteristics of the PV module:

To study the performance of the PV module under various atmospheric conditions, it is required to estimate IV and PV characteristics.

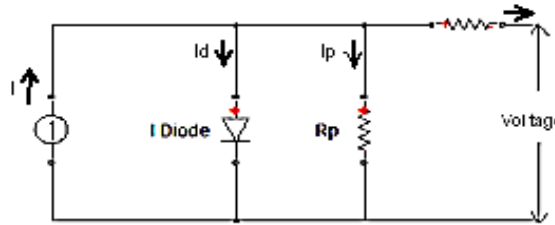


Figure 2: The equivalent one diode model for PV.

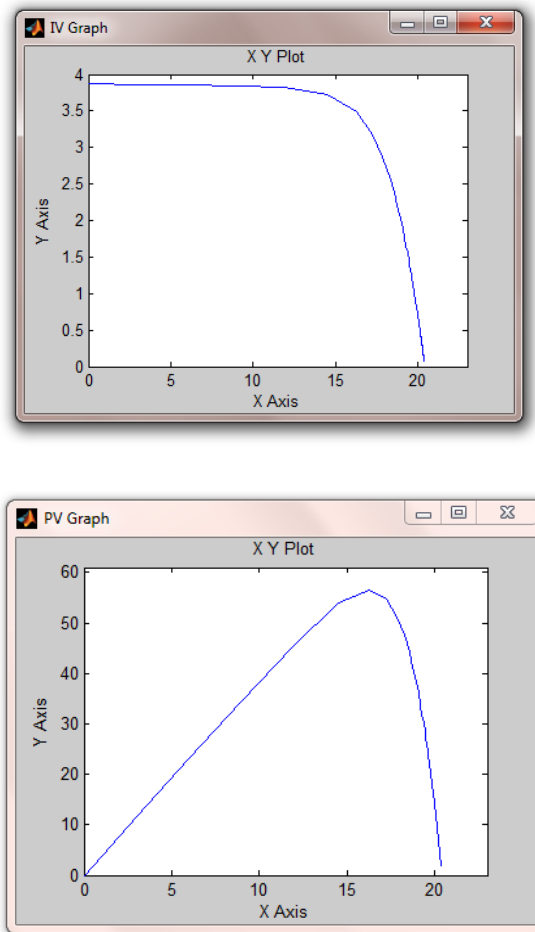


Figure 3: I-V and P-V characteristic curves of a PV module.

When no load is connected to the module, there is no current flow in the circuit. Hence, the voltage across the PV reaches its maximum. This voltage is the Open circuit voltage. When a load is connected there is an increase in the current which results in the decrease in the voltage. This current is called the Short circuit current. This short circuit current is directly proportional to the irradiation. The PV cell operates in two different regions: constant voltage and constant current. The slope of the characteristics in constant current region is decided by R_p and that in constant voltage region is decided by R_s .

On applying Kirchhoff's current law to the node 'A' :

$$I_{ph} = I_d + I_{rp} + I$$

$$I = I_{ph} - I_d - I_{rp}$$

$$I = I_{ph} - I_o [\exp((V + I.R_s)/V_t) - 1] - [(V + I.R_s)/R_p] \text{ ----- equation 1}$$

Where:

I_{ph} : Insolation current

I_o : Reverse saturation current

I : Cell current

V : Cell voltage

R_s : Series resistance

R_p : Parallel resistance

V_t : Thermal voltage = KT/q

K : Boltzmann constant

T : Temperature in Kelvin

q : charge of an electron

Substituting $V = 0$ in equation 1;

$$I_{sc} = I_{ph} - I_o [\exp((I_{sc}.R_s)/V_t) - 1] - [(I_{sc}.R_s)/R_p]$$

I_{sc} : Short circuit current

Substituting $I = 0$ in equation 1;

$$V_{oc} = V_t \cdot \ln ((I_{ph} / I_o) - (V_{oc} / I \cdot R) + 1)$$

V_{oc} : Open circuit voltage.

Modeling of the PV system:

This paper deals with the modeling of a PV system in MATLAB / SIMULINK based on the mathematical equations. The PV module consists of 36 cells which are interconnected, each with a power rating of 1.36W. The module voltage is calculated by multiplying the individual cell voltage by the number of cells.

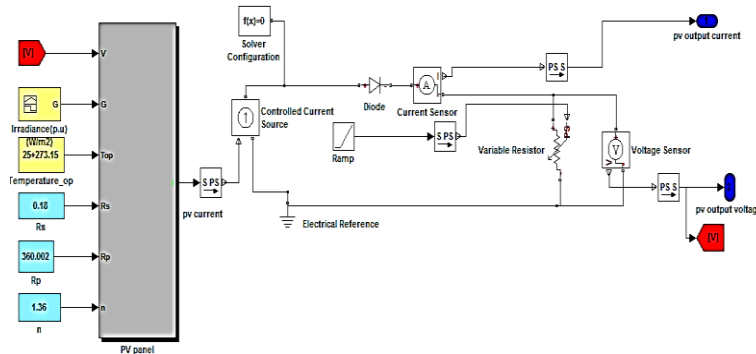


Figure 4: The Simscape model of the PV module.

Buck Boost Converter:

The DC-DC converter acts as an interface between the system and the load. A buck boost converter (step up / step down) is implemented here; it extracts the maximum power point regardless of the temperature difference, irradiance and load conditions. On changing the duty cycle of the converter the source impedance can be matched with the load impedance to maximize the power efficiency. This converter either bucks or boosts the output voltage with respect to the input voltage. The buck boost converter is designed based on the following formulas:

The output voltage of the converter,

$$V_o = V_s(D / (1 - D)) \text{ where } V_s = V_{pv}$$

The inductance L is given by,

$$L = (1 - D)^2 R / (2 \cdot f)$$

Where R is the load resistance and f is the switching frequency.

The voltage ripple of the buck boost converter is computed from,

$$\Delta V / V = D / R \cdot C \cdot f$$

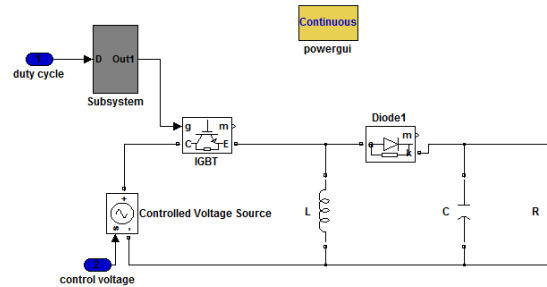


Figure 5: Buck boost converter.

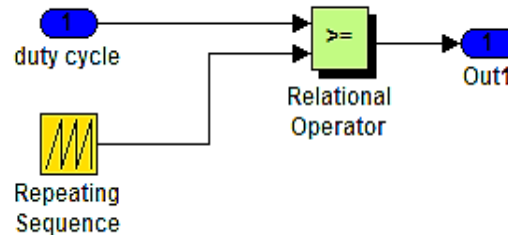


Figure 6: Generation of PWM signal.

The figure shows the buck boost converter. The duty cycle is generated by the MPPT system and it is compared with a repeating sequence to produce a PWM signal as shown in the figure. The PWM signal is used to control the ON and OFF time of the IGBT in the converter. As long as the IGBT is ON, the capacitor charges and the input voltage of the converter i.e. the PV voltage is reproduced at the output. If the duty cycle $D > 0.5$ then the output voltage of the converter is larger than the input voltage and if $D < 0.5$ the output voltage is smaller than the input voltage.

Maximum Power Point Tracking system:

Since the output of the PV is less efficient, a MPPT system is adopted to enhance the PV power. This paper emphasizes on the Perturb and Observe algorithm to optimize the performance. This is achieved by varying the duty cycle of the buck boost converter so that the source impedance can be matched with load impedance. Each time the output power of the buck boost converter is compared with the previous power of the module and the duty cycle of the converter is adjusted accordingly to track maximum power point. This process continues until the power of the PV reaches the maximum value (close to MPP).

Perturb and Observe method:

In this algorithm, the PV voltage $V(k)$ and the current $I(k)$ are the inputs. The power of the PV is calculated accordingly. The power and the voltage of the PV are delayed by $(k-1)$ instant. The present value of P and V are compared with the previous values and their difference is noted.

$$\Delta P = P(k) - P(k-1)$$

$$\Delta V = V(k) - V(k-1)$$

If ΔP and ΔV are positive then the duty cycle is decreased i.e.; $D = D - \Delta D$.

And if ΔP is positive and ΔV is negative duty cycle is increased i.e.; $D = D + \Delta D$.

On doing this repeatedly, the maximum power point is tracked and the output power of the PV system is maximized.

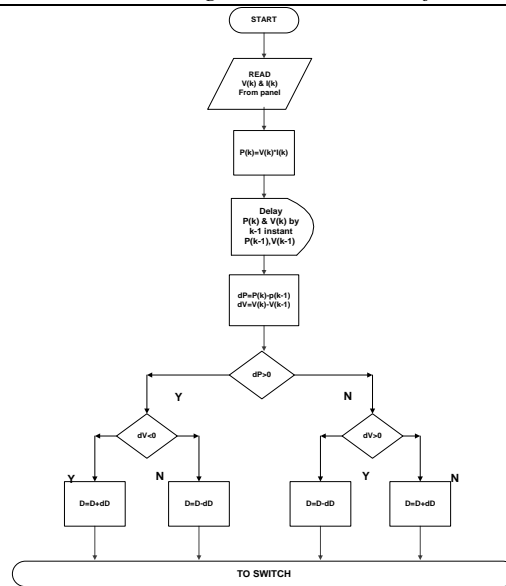


Figure 7: Flowchart for the MPPT.

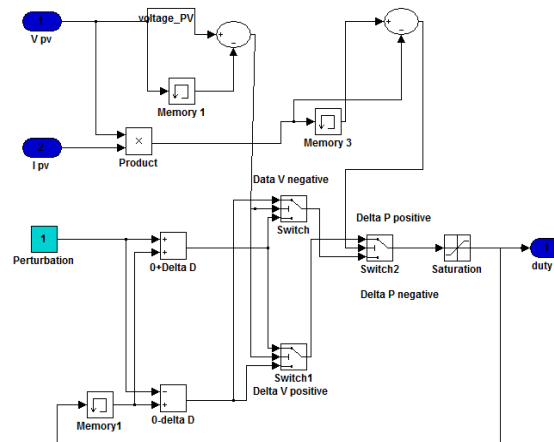


Figure 8: Perturb and Observe MPPT design in Simulink.

The whole system:

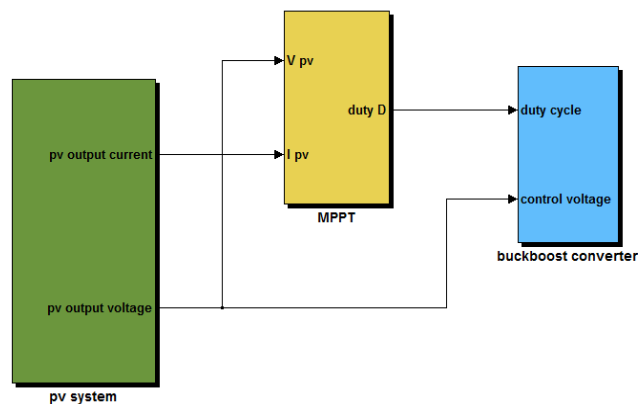


Figure 9: Whole system.

The whole system is an interface between the PV system and a converter with a MPPT block. The PV module is implemented in MATLAB/Simscape, the MPPT is developed in MATLAB/Simulink and the converter in SimpowerSystems. The output current and voltage from the PV is given to the MPPT which is used to generate duty cycle. The MPPT system will change the duty cycle of the converter depending on the atmospheric variations. The other input to the converter is the PV voltage which is coupled using a controlled voltage source (which is an interface between Simscape and Simpower Systems).

III. Results and discussions

The proposed PV module in MATLAB/Simscape is shown in the figure 4. The I-V and P-V plot for different irradiances at constant temperature $T=25^\circ\text{C}$ are shown in figure 10 and 11 respectively.

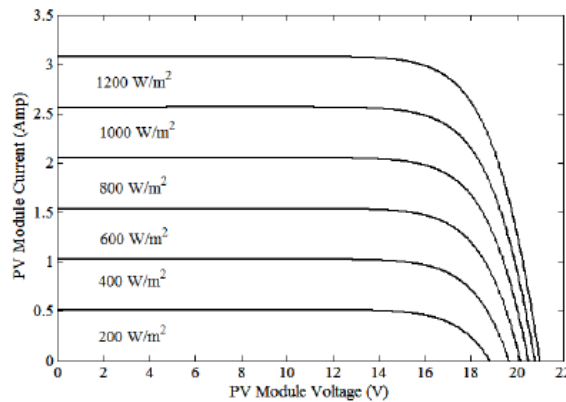


Figure 10: I-V characteristics curves of the PV system for different irradiances.

When the irradiance decreases the output photo current of the PV system also decreases thereby decreasing the load voltage.

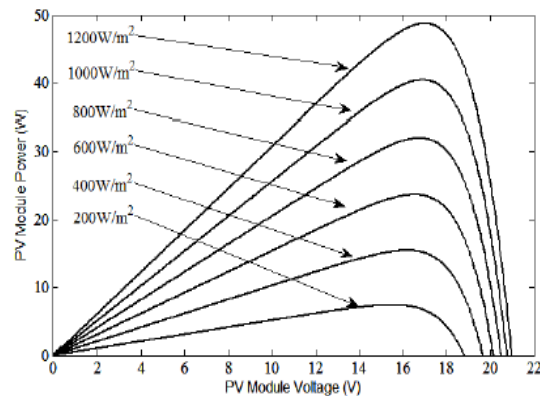


Figure 11: P-V characteristics curves of the PV system for different irradiances.

We see that the power of the system increases with the increase in voltage. Once the power reaches its maximum value, with further increase in voltage the power decreases. The maximum power is transferred when the resistance of the load matches with the source resistance

An irradiance of 200 W/m^2 has obtained a maximum power of almost 10 W and an irradiance of 1200 W/m^2 has a maximum power of 50 W.

The current and voltage outputs of the buck boost converter are shown in the figure 12.

The input voltage to the converter is 20.6V and the output voltage of the converter is 18.4 V. The buck boost converter is controlled by applying duty cycle to the IGBT. This is calculated using the formulae $V_o = V_s \cdot (D/1-D)$. So the duty cycle is 0.533. For a buck boost converter, if $D = 0.5$ the output voltage either decreases or increases with respect to the input voltage. In this system, the output voltage is decreased. Hence it acts as a buck converter.

The system power is 73 W. The figure 13 shows the output power of the system.

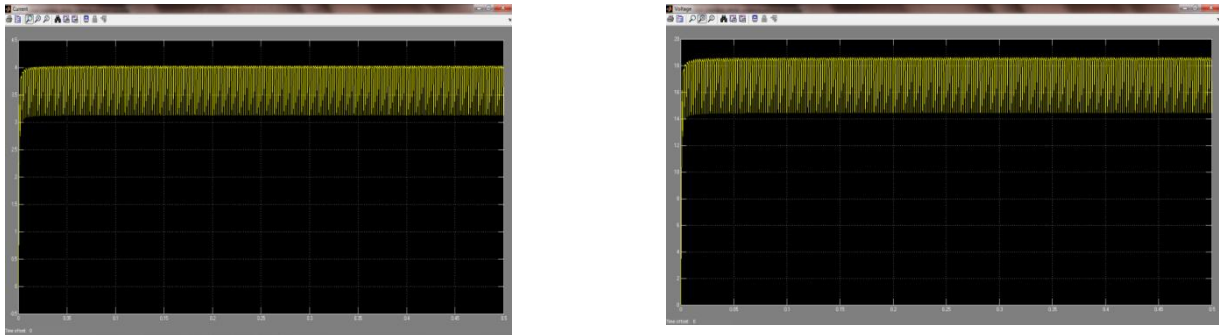


Figure 12: The output Voltage and Current of the converter.

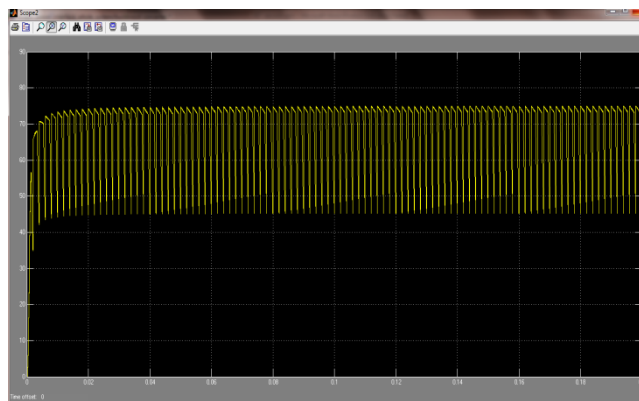


Figure 13: The system power.

The Perturb and Observe method works efficiently and provides duty cycle to the converter.

IV. Applications

The output of the PV system is a DC voltage. Therefore, it can be used to charge a battery. An inverter converts DC voltage into AC, which can power which work on AC like television and other home appliances.

V. Conclusion

This paper analyzes and studies the performance of a PV system implemented using MATLAB/Simulink. The simulation result implies that the Perturb and Observe algorithm tracks the maximum power point. We conclude that the MPPT system adjusts the duty cycle of the buck boost converter in varying irradiances and temperature to extract the maximum power from the system and deliver it to the load. The buck boost converter will either increase or decrease the output voltage with respect to the input voltage based on the duty cycle. The I-V and P-V characteristics of PV module is studied under various irradiances and it is found that the generated photo current has only a very little effect on the short circuit current and also, on increasing the temperature the efficiency of the PV module decreases.

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