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INVESTIGATION OF PERFORMANCE ANALYSIS OF PV FED MULTILEVEL INVERTER FOR WATER PUMPING APPLICATIONS

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ABSTRACT:

Inthis paper, the proposed work is to extract maximum power from the PV powered water pumping system driven induction motor. The PV powered water pumping is commonly used for agriculture and households applications. To seek out the peak power from the PV array, the inverter is operated at variable frequency, to vary the output of the water pump. The proposed system utilizes the multilevel inverter to generate a sinusoidal waveform instead of quasi square wave inverter. The anticipated system has the benefits of less Total Harmonic Distortion in the output voltage, low switching losses, less in filter requirements, low heating of motor under rating condition, less in ripple torque production and so on. The fuzzy logic based peak power point tracking technique is employed. The extraction of peak power is achieved by varying the frequency of multilevel inverter in order to operate theinduction motor at maximum torque condition. The additional features of the PV fed system is that, the motor current is limited to an upper limit of PV array current, so that motor winding and power semi conducting switches can be protected against excessive current flow. The system is tested using MATLAB/ simulinkforenvironmentunder different condition like, change in insolation and change in temperature for the validation of the proposed work.

I. INTRODUCTION

The Application of PV system has become popular especially in remote areas, where power is not available or too costly. The PV powered water pumping system is frequently used for agriculture and in households. There are different methods proposed for extracting maximum power from the PV array. Maximum Power Point(MPP) may vary time to time due to different levels of insolation. For water pumping system induction motor optimization is obtained by v-f relation of motor [1]. Different pumps are available for water pumping, among those centrifugal pumps are mostly used. The optimum utilization achieved by proper load matching is the simple technique [2]. The output of PV array is dc which have to be converted to ac source to drive the motor pump. For that a six step quasi square wave inverter is proposed to run the motor by tracking the maximum power using variation in inverter frequency to reduce the switching losses [3]. MPP can alsotrack by using the duty ratio of converter in case of using a battery forcharging the PV output power, which is generally placed between PV& battery. Optimization of PV pumping system can also done based on new reference voltage criterion which is the addition of open circuit voltage of PV and a segment of solar radiation so as to ensure the optimum chopping ratio of a back boost converter [4]. Three MPPT are used for this operating conditions (i) with variable voltage and current (ii)

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with fixed voltage and varying current (iii) with variable reference voltage based on fixed percentage of open circuit voltage. Efficient usage of PV array is done by spraying water over PV panels which reduces the degradation of PV [5]. Sensor less BLDC motor can also be used instead of IM where MPP tracked by controlling Z-source inverter [6]. Perturb and observe algorithm for MPPT is used for good efficiency without a battery[7].

The system proposed and analysed in this paper is PV fed water pumping system without a battery, utilizing the diode clamped five level inverter instead of six step quasi square wave inverter in order to reduce the Total Harmonic Distortion (THD). Here the MPP is tracked by varying operating frequency of the Induction motor utilizing the multilevel dc-ac inverter, with that maximum power of the PV array the motor pumps the water. The inverter is modulated to adjust the frequency of the induction motor to search for the optimum power of PV array.

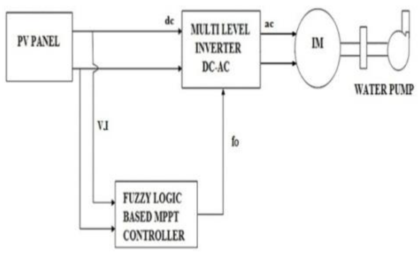

Fig.1 block diagram of proposed system

The block diagram of the system is shown in Fig. 1. The PV array receives energy from the sunlight. The PV array generates electric power, which is fed to the induction motor via an inverter. The induction motor is mechanically coupled to the water pump. As the insolation level varies during the day, the output of the PV array follows the change. The water pump is a centrifugal pump, with the output torque varying as the square of its rotor speed. To increase the output of the water pump, the speed of the water pump is increased by adjusting the frequency of the inverter.

II. PV ARRAY MODEL

The optimum power of the PV is useful for any purposes. But the power output of the PV varies instantly due to the various level of insolation. The overall output of PV depends on the number of cells presented in the array, the total power has the contribution of each cell. So, by calculating the output of one cell, we may calculate the total output easily. The Fig .2 shows the equivalent circuit of a PV cell.

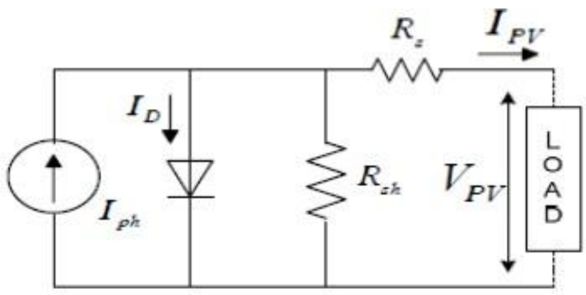

Fig .2, equivalent circuit of a PV cell

The nonlinear Ipv - Vpv and Ppv - Vpv characteristics of solar cells are well known. Using equivalent circuit of Fig.2, the nonlinear Vpv - Ipv characteristics of PV module is:

$$V_{pv} = \frac{1}{\lambda}\ln\left(\frac{I_{sc} - I_{pv} + I_0}{I_0}\right) - R_s I_{pv} \quad (1)$$

Where *Isc*is the cell short-circuit current, *Io* is the reverse saturation current, *Rs*is the series cell resistance, and λ is a constant coefficient and depends upon the cell material. Equation (1) expresses a nonlinear relation between voltage current characteristic of a PV module.

The PV array is formed by the combination of many PV cells connected in series and parallel fashion to provide the desired value of output voltage and current. This PV array exhibits a nonlinear insolation- dependent V-I characteristic, mathematically expressed consisting of Ns cells in series and Np cells in parallel as

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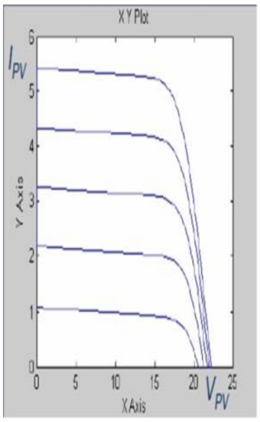
$$V_A = -I_A\left(\frac{N_s}{N_p}\right) + \left(\frac{N_s}{\wedge}\right)\ln\left\{1 + \frac{N_p I_{ph} - I_A}{N_p I_0}\right\} (2)$$

$\wedge$ = (q/AKT),q is the electric charge; A is the completion factor; K is the boltzmann's constant; T is the absolute temperature; Rs is the cell series resistance; Iph is the photo current; Io is the cell reverse saturation current; I_A and V_A are solar cell array current and voltage. The characteristic curves of PV is shown in following fig



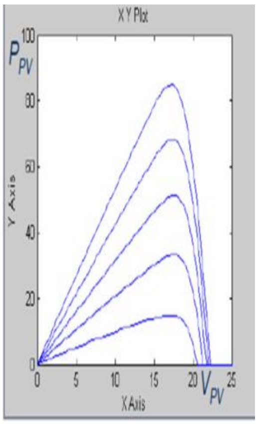


Fig .3.1 I-V characteristic of PV array

Fig .3.2 P-V characteristic of PV array

III. MULTI LEVEL INVERTER

The Multilevel Voltage Source Inverter is recently applied in many industrial applications as AC power supplies, static VAR compensators, drive systems, etc… The significant advantage of multilevel configuration is the harmonic reduction in the output waveform without increasing switching frequency or decreasing the inverter power output. As the number of levels reach infinity, the output THD approaches zero.

There are three types of multilevel inverter in usage, they are (1) Diode Clamped Inverters

(2) Flying capacitors Inverters (3) cascaded Inverters

Among these types Diode clamped inverters are used for this investigation.

Diode clamped inverters

An m-level diode clamped inverter typically consists of (m-1) capacitors on the dc bus and produces m levels of phase voltages. An m-level inverters leg requires (m-1) capacitors, 2(m-1) switching devices and (m-1)(m-2) clamping diodes.

SWITCHING STATES :

Va0	Sa1	Sa2	Sa3	Sa4	Sa5	Sa6	Sa7	Sa8
Vdc	ON	ON	ON	ON	OFF	OFF	OFF	OFF
3Vdc/4	OFF	ON	ON	ON	ON	OFF	OFF	OFF
Vdc/2	OFF	OFF	ON	ON	ON	ON	OFF	OFF
Vdc/4	OFF	OFF	OFF	ON	ON	ON	ON	OFF
0	OFF	OFF	OFF	OFF	ON	ON	ON	ON

These switching states is for the five level diode clamped inverter. Based on these switching states the switches should be operate to generate a stepped sinusoidal voltage waveform of desired output. The circuit diagram and thewaveform for this inverter is shown Fig.4.1 &4.2

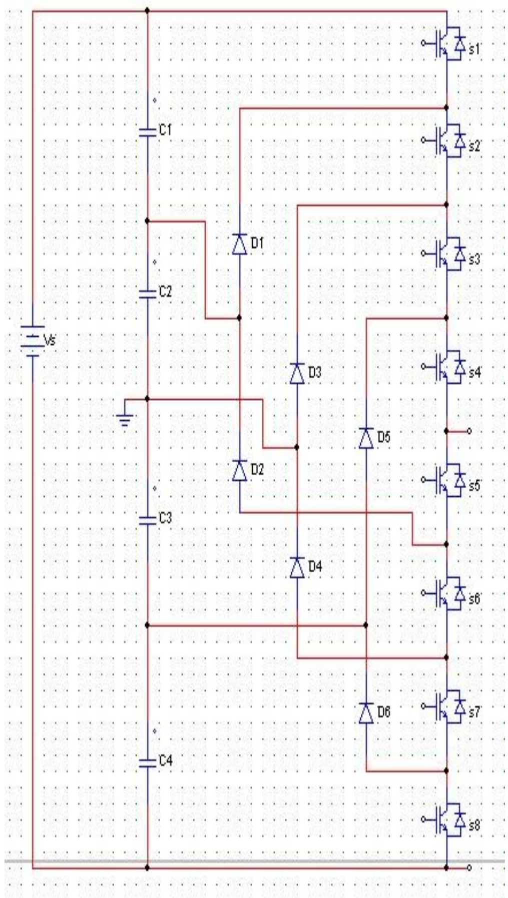


Fig .4.1 five level diode clamped inverter

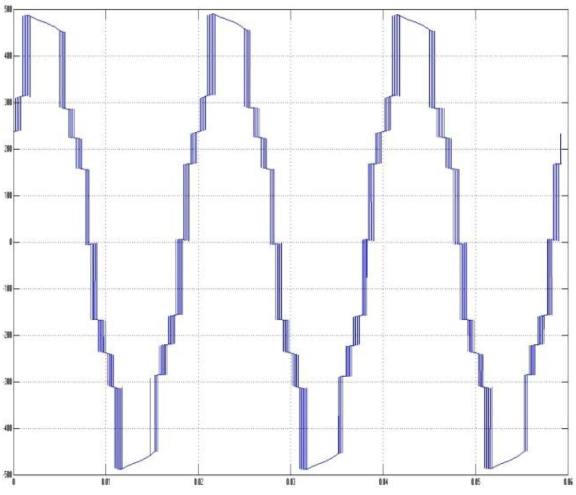


Fig.4.2 load voltage waveform of five level diode clamped inverter

IV. MOTOR AND PUMP CHARACTERISTICS

To optimize the energy captured, the PV array should always operate at its maximum output power as the insolation changes. The output power of the motor can be varied by changing the speed of the water pump. The speed of the water pump is regulated by controlling the inverter frequency. Thus inverter is the interface between the PV array and the electric motor. For the electric motor, a water pump is needed for this application. Mostly water pump chosen is the centrifugal pump where the output is propotional to the cube of the rotor speed. The output power and torque can be written as

$$\mathbf{P} = K_w W_m^3 \ (3)$$

$$T = K_w W_m^2 \ (4)$$

where, $K_{w,}$ is the consant of water pump in watts/(mech rad/s)^3 andW_m is the rotor speed in mech rad/s

Thus, to vary the output of the water pump, the frequency supply of the electric motor driving the pump must be varied. The operation of the inverter and electric motor is related to the characteristics of the PV array. The PV array, as can be seen from Fig. 3.1&3.2, behaves approximately as a current source when the voltage output of the PV array is lower than the optimum voltage, and it behaves as a voltage source when the output voltage of the PV array is higher than the optimum voltage. As the slip of the motor is varied, the resistance of the variable resistor follows the change accordingly. The slip is adjusted indirectly, by controlling the frequency of the inverter. Thus, at any speed slip can be changed from unity to zero, or even to a negative value, by changing the frequency applied to the induction motor.

TheFuzzy Knowledge Base rule associates the fuzzy output to the fuzzy inputs is derived by understanding the system behavior. In this paper, the fuzzy rules are designed to incorporate

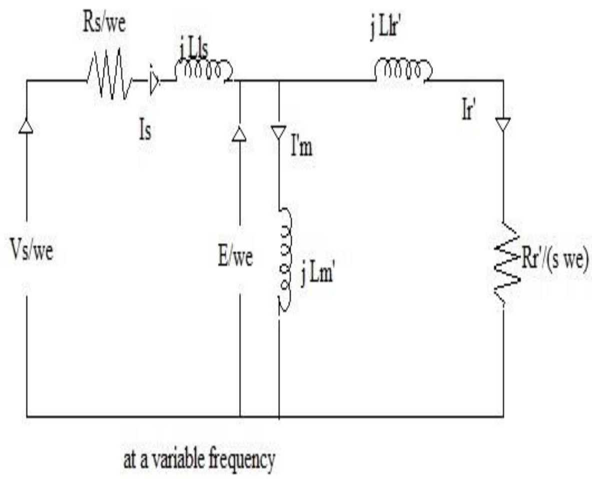


Fig.5, Equivalent circuit of induction motor

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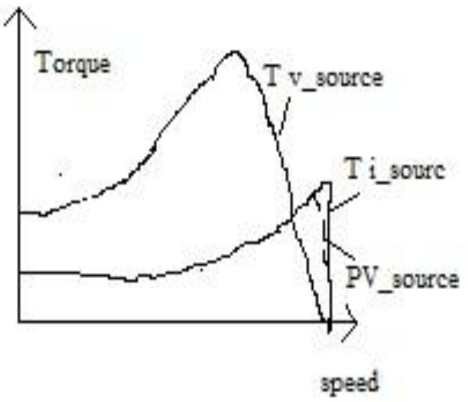

Fig .6.1, speed-torque characteristics of IM voltage source and current source

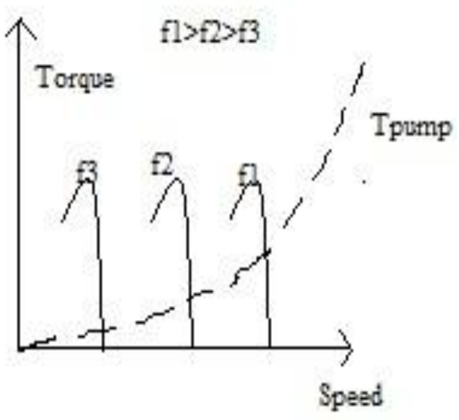

Fig.6.2, Connected to PV inverter for different frequencies

The torque-speed characteristics of the induction motor connected to the voltage source differ from the characteristics of the induction motor connected to a current source. The slip frequency where the peak torque occurs can be computed. For a voltage source& a current source, the slip frequency is,

$$s\omega_{e\text{-}peak} \approx \frac{R'_r}{\sqrt{\left(\frac{R_s}{\omega_e}\right)^2 + (L_{1s} + L'_{1r})^2}} \quad (5)$$

$$s\omega_{e-peak} \approx \frac{R'_r}{L'_m + L'_{1r}} \quad (6)$$

The behavior of the system depends on the operating voltage of the PV array. In the low slip region, the impedance of the system is high. For the same amount of current, the terminal voltage is higher in the low-slip region than in a high-slip region; thus, the PV inverter operates as a voltage source. As the slip increases, the terminal voltage of the induction motor is lower, so it tends to behave as if in a more current-source mode. Near the optimum voltage, the torque-speed condition of the induction motor connected to a PV inverter is between the current-source and voltage source modes, as illustrated by the torque-speed (dashed) line shown in Fig. 6.1. The operation of the system is related to the range of slip between peak slip and zero slip. To compute the approximate optimum frequency, the following assumptions should be made.

1) The optimum voltage of the PV array is constant.

2) The mechanical output power of the water pump is approximately proportional to the cube of the frequency.

3) There are no mechanical and electrical losses in the conversion process.

The mechanical output power of the water pump and the output power of the PV array are equal if the losses in the motor and the power converter are neglected. They can be written as

$$P = Kf^3 = V_{dc-opt} I_{sc-cell} \quad (7)$$

$V_{dc\text{-}opt}$ is the average optimum voltage of PV array (known)

$I_{sc\text{-}cell}$ is the current of the PV array at low voltage or short circuit for normal conditions(measured)

V. MPPT ALGORITHMUSING FUZZY CONTROLLER

To extract the maximum power from the PV array MPPT algorithm is used. Here fuzzy logic is proposed for tracking the maximum power from the PV array. By using the incremental conductance method of MPPT we are seeking out the MPP with the conductance value at every instant of varying insolation. Based on the pre conductance and present conductance value the change in conductance value is observed. From that value, we track the MPP. This job is done by varying the inverter frequency. The flow chart for the incremental conductance algorithm is shown below. Based on this flow chart, the algorithm is proposed to find the MPP to drve the Induction motor for water pumping applications. For this algorithm we use fuzzy logic control for the objective.

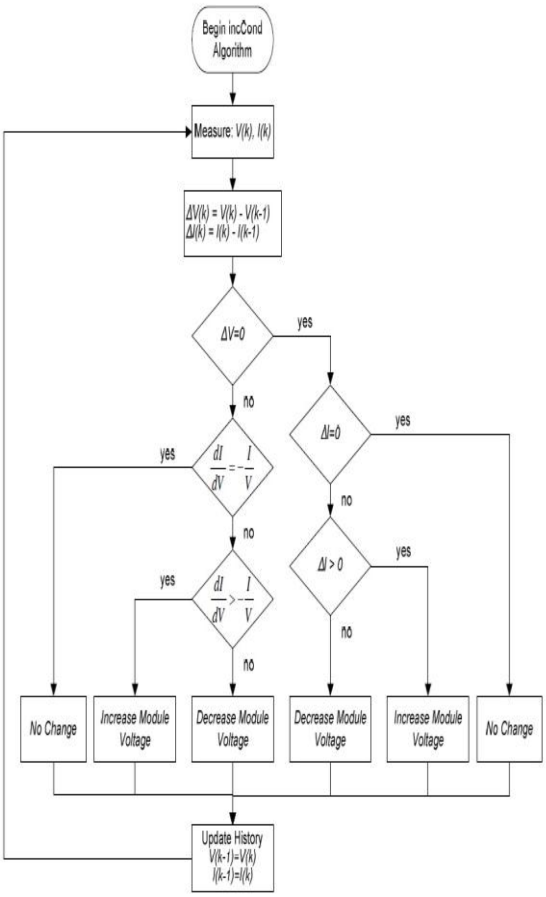

Fig .7, MPPT flow chart

In recent years, FLCs have been widely used for industrial processes owing to their heuristic nature associated with simplicity and effectiveness for both linear and nonlinear systems. Advantages of fuzzy logic controllers over the conventional controllers are: 1) they do not need accurate mathematical model; 2) they can work with imprecise inputs; 3) they can handle nonlinearity; 4) they are more robust than conventional nonlinear controllers. This section will briefly describe the techniques used in fuzzy logic controller, viz., fuzzification, fuzzy knowledge base and defuzzification.

In the fuzzification process the numerical variable is converted into a linguistic variable. The following five fuzzy levels are chosen for the controlling inputs of the fuzzy controller:NBNegative big, NS Negative small, ZE zero, PS positive small**,** PB positive big.

Membership functions for controller inputs, i.e. $E, \Delta E$ and incremental change in the controller output (ΔU) are defined on the common normalized range of[-1,1].

RULE BASE TABLE FOR FUZZY CONTROLLER

E \ ΔE	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	NB	NS	NS	NS	ZE
NS	NS	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	PS	ZE	PS	PS	PS
PB	ZE	PS	PS	PS	PB

TheFuzzy Knowledge Base rule associates the fuzzy output to the fuzzy inputs is derived by understanding the system behavior. In this paper, the fuzzy rules are designed to incorporate the following considerations keeping in view the overall tracking performance. 1) When the SCA terminal voltage is much greater than the MP point voltage (Vm), then change the frequency of the inverter so as to bring the terminal voltage to Vm. 2) When the SCA terminal voltage is less than the MP point voltage, then the change of frequency is negative and it must be large so as to bring the terminal voltage to Vm. 3) When the array voltage is close to the Vm, then the incremental frequency is small. 4) When the array voltage is near to MP point voltage and is approaching it rapidly, then the change of frequency should be zero so as to prevent operating point deviation away from the MP point. 5) When the array voltage is equal to the MP point voltage, then the change of frequency should be maintained at zero.

Taking the above points into consideration the fuzzy rules are derived and the corresponding rule base is given in Table. These rules can be employed in any PV system for MP point tracking irrespective of size and type of converter used.

In the defuzzification process the crisp value of the change of duty cycle is obtained. This paper uses the well-known center of gravity method for defuzzification.

VI. INVESTIGATION OF SIMULATION RESULTS

This paper mainly investigate about the usage of multilevel inverter for operating the induction motor for water pumping application. The source for the inverter is the solar insolation which is converted into a dc source by means of the PV panel. Due to the range of insolation and the number of cells present in the PV array the output differs time to time which we seen in the fig .2. For this condition MPPTalgorithm is used to operate the PV at optimum condition where the optimum power for each insolation level is obtained. The Simulink model of PV reveals the actual condition of this source.

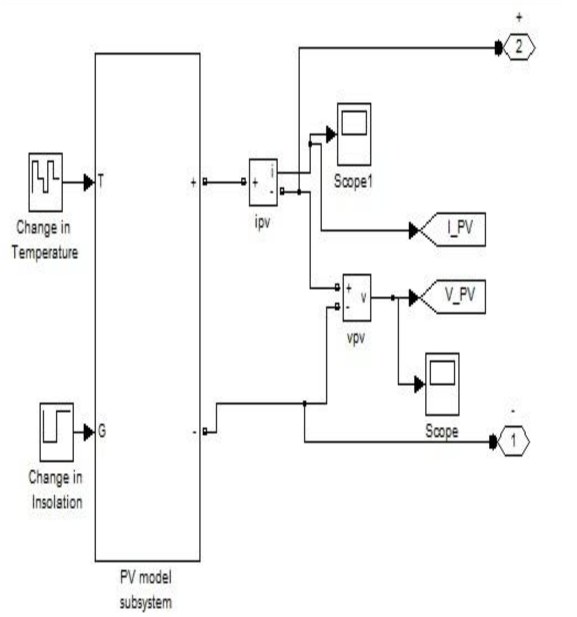

Fig .8 PV model for various insolation

Here the various insolation level is represented by the repeating sequence stair1 which gives both high and low values of insolation. For that the PV has to operate, and V_PV & I_PV are the outputs of this model. Where, I_PV decreases from the short circuit value and the V_PV increases to open circuit voltage. The sub system of this model and the output of this model are shown below in Fig .8.1 & 8.2

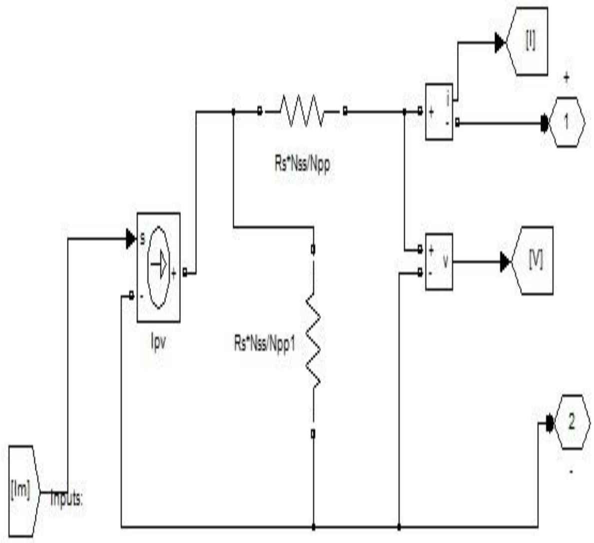

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Fig .8.1 subsystem block of PV model

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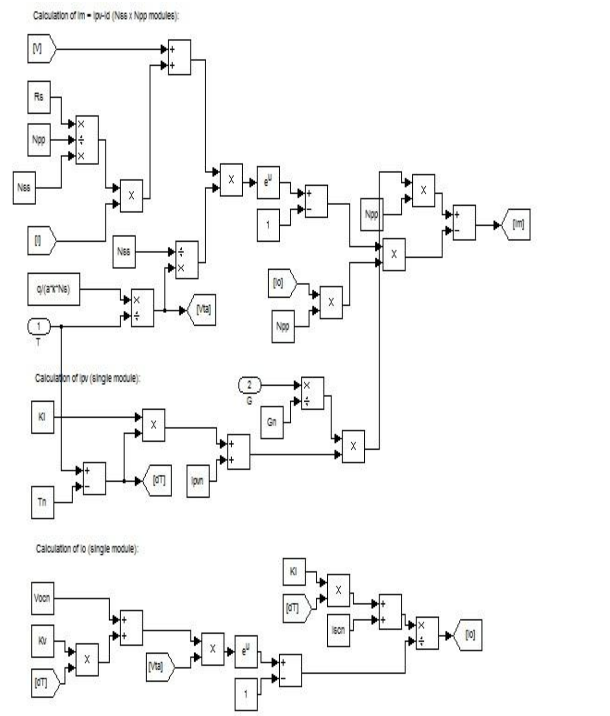

Fig.8.2 mathematical model of the subsystem

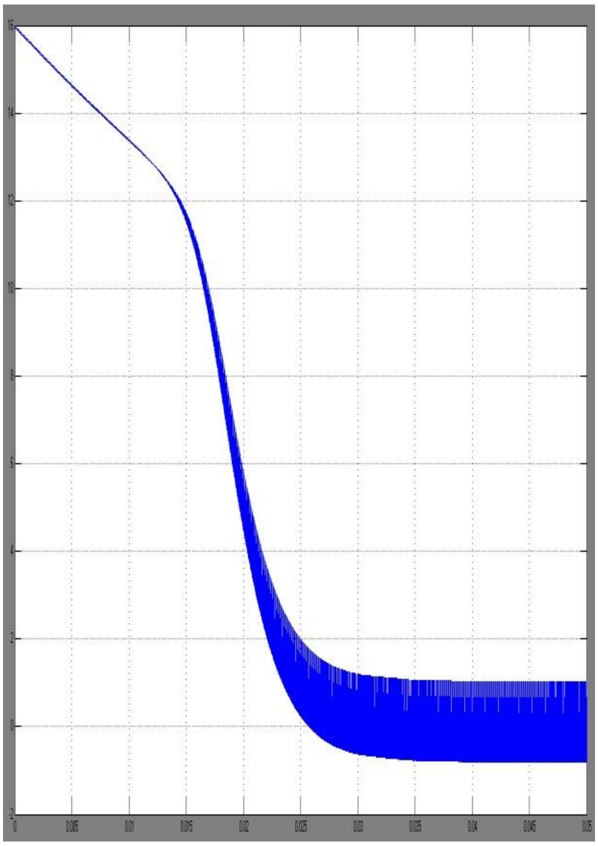

Fig .8.3 I_PV curve of the PV model

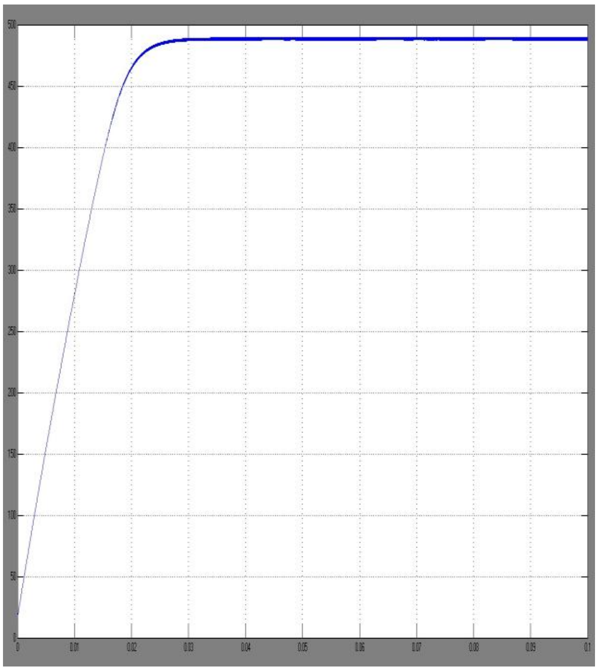

Fig .8.4 V_PV curve of the PV model

The output obtained from the above PV array is connected to the Five level diode clamped inverter for converting the dc-ac. The Five level inverter consist of four capacitors for dividing the voltage range into five levels 0, Vdc/4, Vdc/2, 3Vdc/4, Vdc. Diodes provided necessary bias to the switches connected to generate a stepped wave output for driving the induction motor efficiently by reducing the THD. The pulses given to the switches are using the firing circuit consists of a sine wave generator and a repeating sequence of triangular wave. The two waves are combined to produce the pulses necessary for triggering the switches. The switches are triggered by the means of the switching state table given above. The multilevel inverter is here compared to a normal H-bridge inverter for verifying that this paper proposed a better choice for running an Induction motor. Here comparisons done by changing the Modulation index of the both inverters to find the better choice.

While comparing this two, our multilevel inverter is better in torque, efficiency, mechanical power, power factor etc…

The comparison table and the graphs plotted for that comparison reveals the better performance of the multilevel inverters.

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Fig .9 Comparison Tabulation between H-bridge and multilevel inverter

PWM BASED MLI FED CAPACITOR START RUN IM						IGBT BASED PWM INVERTER FED CAPACITOR START RUN IM				
MI	Pmec	P.F	Eff	Speed	Torque	Pmec	P.F	Eff	Speed	Torque
0.4	783	0.82	69.63	148.9	5.259	257.6	0.58	53.4	150.3	1.714
0.5	835.5	0.697	57.17	152.3	5.485	111.7	0.163	17	156.6	0.713
0.7	790.2	0.684	46.78	152.5	5.187	190.1	0.139	15.14	157.2	1.209
0.8	764.4	0.67	51.33	152.7	5	244.9	0.136	14.92	157.5	1.555
0.9	865.3	0.633	54.3	153.6	4.96	307.7	0.135	14.8	157.8	1.95

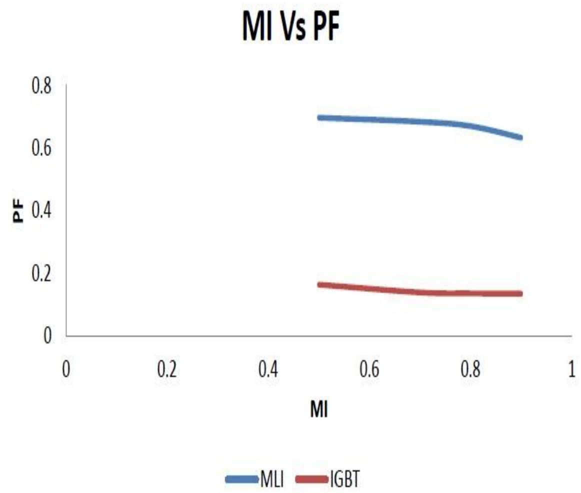

Fig .9.1 graph between modulation index Vs power factor

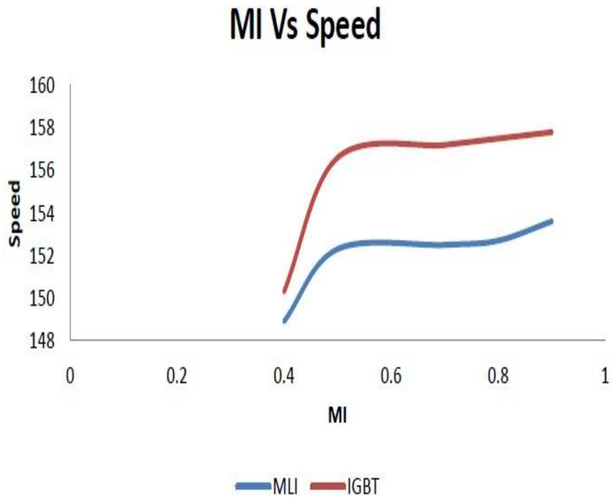

Fig 9.3 graph between modulation index Vs speed

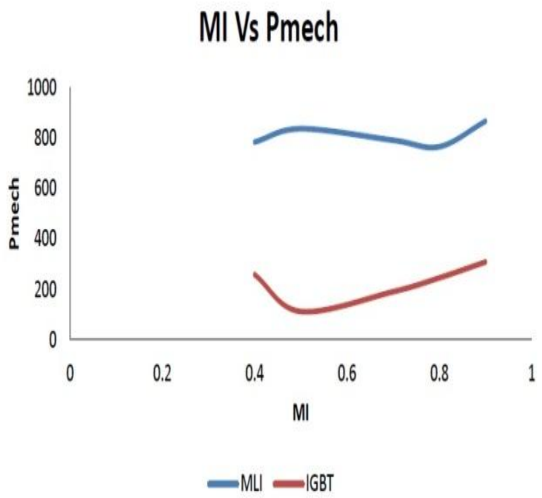

Fig 9.2 graph between modulation index Vs mechanical power

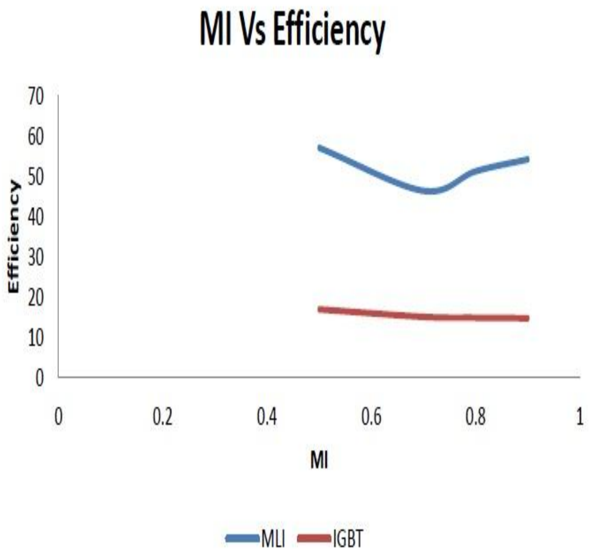

Fig 9.4 graph between modulation index Vs efficiency

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The simulation diagram and the corresponding output obtained are given below. The PV input is given to the multilevel inverter, the output of which is given to the capacitor start run motor for settling the motor quickly. The characteristic curves of the motor is shown in Fig .10.3, the main and auxillary winding current of the motor goes on decreasing after the settling time, the ripple torque is also less providing maximum efficiency by lowering the hormonics and reduces the filter components. The same procedure when used for H-bridge inverter all the effects are considerably less than the multilevel inverter. We can observe this difference in the Fig .9-9.4.

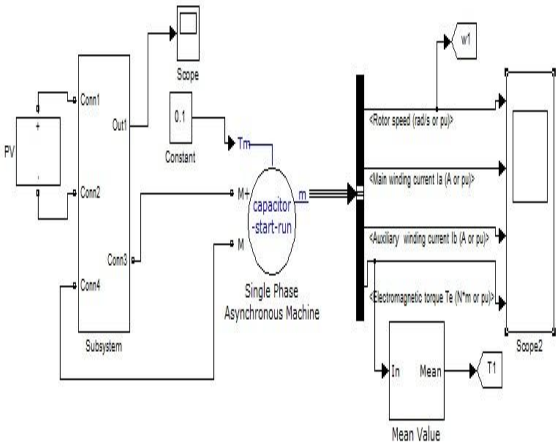


Fig .10.1 simulation diagram of H-bridge inverter

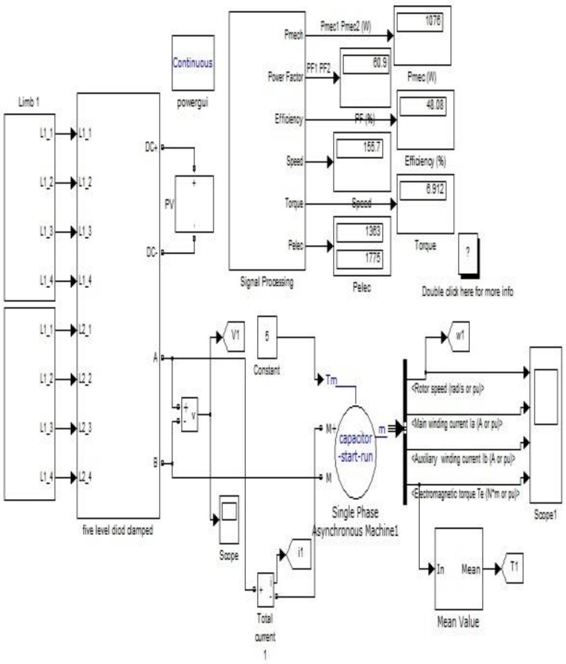
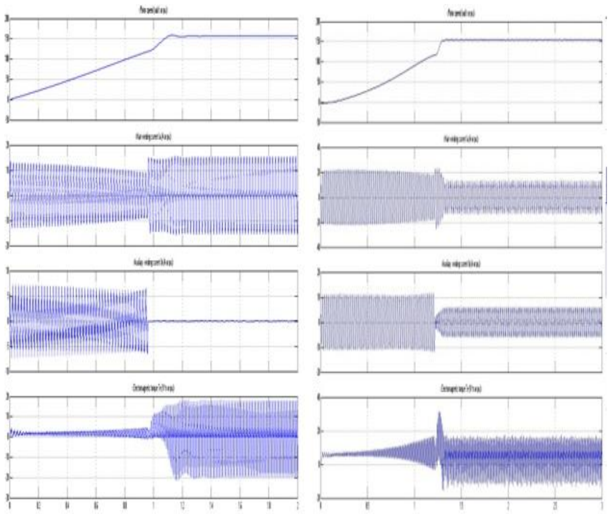


Fig .10.2 simulation diagram of multilevel inverter



(a) (b)

Fig .10.3 simulated output characteristics of (a) H-bridge (b) multilevel inverters

The MPPT block is the final and closed path of this paper. It is obtained by the fuzzy logic controller which deals with the incremental conductance algorithm shown in Fig .7. based on this algorithm controller stores the present and the previous conductance value at each instant. If the conductance value increases means the controller shifts its position to the new value in order to track the peak power. In this paper, the V_PV and I_PV are obtained and its previous value is stored in the controller, the dI/dV ratio gives the change in conductance at the present instant. Based on the dI/dV value the operating frequency of the IM varies in order to track the optimum power from the PV array. The MPPT simulation block & controller block are shown in Fig .11.1-11.3.

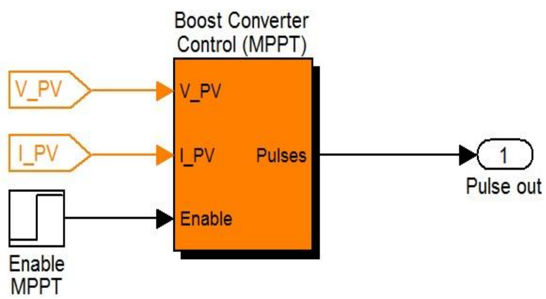


Fig .11.1 simulation block of MPPT

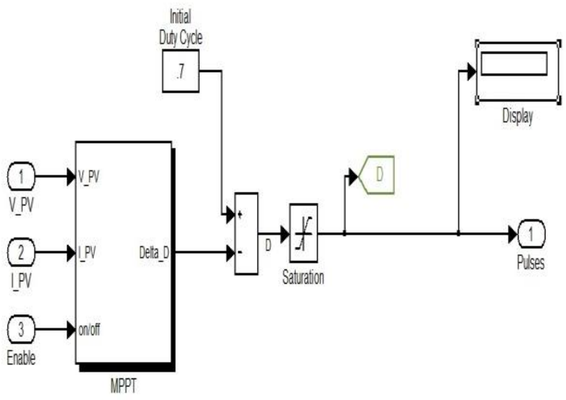


Fig .11.2 Subsystem block of MPPT

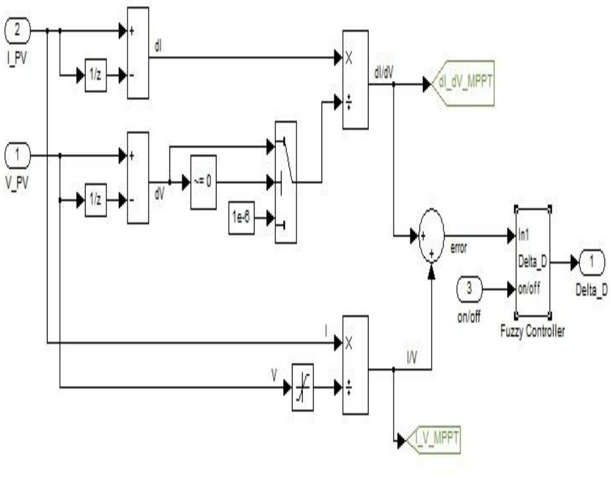


Fig .11.3 Controller block of MPPT

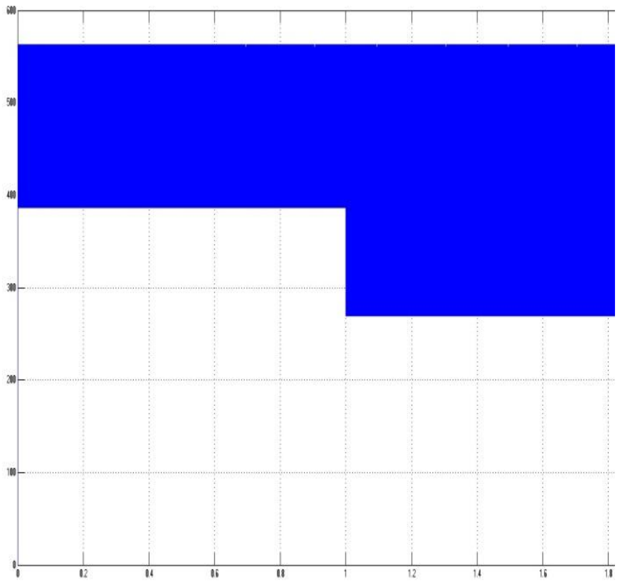


Fig 11.4 PV Voltage waveform of change in insolation

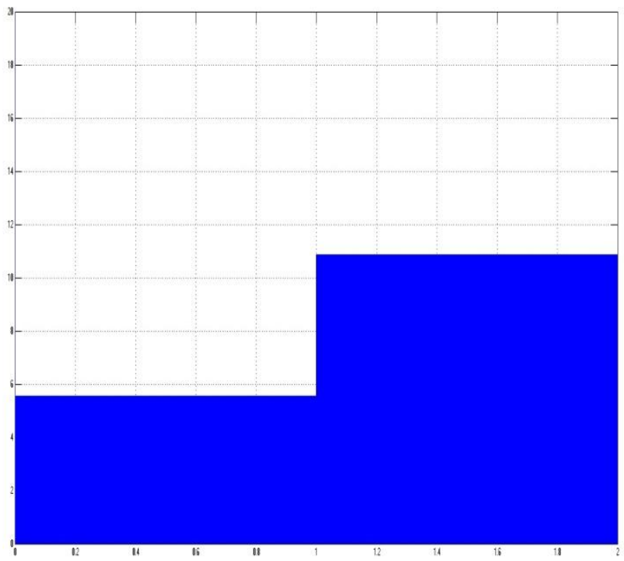


Fig 11.5 PV current waveform of change in insolation

VII. CONCLUSION

From the investigation of H-bridge and multilevel inverter we conclude that the multilevel inverter is the better choice for PV fed water pumping application. By using the multilevel inverter as the variable frequency source and the peak power tracker, the total hormonics distortion, swithing losses, filter requirements, ripple torque are minimized, therefore heating of the motor at rated condition is also reduced. The system is coupled with a centrifugal water pump, and the controller is set to adapt to changing insolation and temperature due to the atmospheric conditions. Using the PV array has an advantage that, the motor current is limited to an upper limit of PV array current, so that no chance of degradation of motor windings due to short circuit current of PV array.

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