Performance Analysis of Single Phase Induction Motor with Solar PV Array for water Pumping System

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***Abstract*—This Paper deals with performance analysis of solar photovoltaic array fed single phase induction motor (IM) drive for water pumping system. It is configured by two different topologies based on the power supplied to the induction motor. In first proposed method, the output of solar PV Array is fed to the DC to DC boost converter to increase the voltage level of DC supply. This DC output is converted in AC supply with the help of an inverter. The output of this inverter is fed to the single phase induction motor. In the second proposed method the output DC power of the solar PV array is directly fed as input to the inverter and output of the inverter is fed to the single phase induction motor for water pumping system. A centrifugal pump connected with the single phase indication motor for water pumping system. The size of PV array and motor rating selected such that the water can also be pumped during the varying in temperature and irradiation level. This study evaluates starting, dynamic and steady state performance under changing atmospheric conditions and examines the effectiveness the single phase induction motor for solar PV based water pumping system. The detailed simulation study of single phase induction motor with PV array has been carried out in MATLAB/Simulink environment.**

Keywords*— Induction motor; maximum power point tracking ;PV Array; DC-DC boost; irradiation; MATLAB/Simulink;

I. INTRODUCTION.

Recently, most of the countries in the world are working to explore renewable resources of energy to meet out the increasing demand of electrical energy because the non-renewable energy resources are depleting with a high rate. The solar and wind energy based power generation system has come up as an important alternative. The solar energy is no exhaustible energy source which can be harnessed using the solar photovoltaic (PV) system and solar thermal systems. Solar PV systems are gaining increased attention of academician, researchers, scientists and industrialist due to decreased cost of the solar PV material and pollution free generation of the energy [1].

The irrigation sector is one of the major sectors where solar PV based power has extensive use for the water pumping with the help of various types of motors. It has been reported in literature that solar PV water pumping has been realized using the DC motor. But the DC motor has the associated disadvantages like low efficiency, and high maintenance cost. However, the induction motor has the advantages such as ruggedness, mechanical simplicity, high efficiency, reliability, low cost and low maintenance cost compared to the DC motors. Hence, the induction motor has the capability to replace the DC motors if explored for application with the solar PV systems [2-4]. The single phase induction motor has wide application in the domestic purpose and small agriculture fields. The application of incremental conductance and perturb and observe maximum power point tracking (MPPT) algorithms are found to be more effective with the solar PV based single phase induction motor. Solar photovoltaic array water pumping has been realized using the DC motor. However, The dc motor has been replace by single phase induction motor due to its advantage such as mechanical simplicity, ruggedness, reliability, high efficiency, low maintenance and low cost. Here, a solar PV array fed single induction motor drive using PWM inverter control is employed [9-10]. The SPV (solar photovoltaic) power depends on solar irradiation level and temperature.

The characteristic of PV module exhibits a single power peak. The tracking of maximum power is very important part of PV system. Hence, various MPPT techniques have been developed and detailed in the literature. These algorithms vary in their speed, range of effectiveness, low cost and complexities [11]. Here, an incremental and conductance (I&C) MPPT algorithm is used to track MPPT which has advantages over perturb and observe method which increases losses in slow varying atmospheric condition as it oscillates around Maximum power point. A DC-DC boost converter is employed in different SPV array based applications for MPPT. Nonetheless, the SPV array based single phase induction motor driven water pumping is still unexplored with the use of a boost converter. In this paper, a boost converter is used as an intermediate DC-DC converter in SPV array based single phase induction motor driven water pump. The study has been carried out in MATLAB/Simulink.

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II. SYSTEM CONFIGURATION

Fig.1 and Fig.2 show configuration of the proposed Photovoltaic array and single phase induction motor drive based water pumping system. Fig.1 show single phase Induction Motor with double stage converter, PV array, boost converter and inverter. The output of solar PV Array is fed to the DC to DC boost converter to increase the voltage level of DC supply. This DC output is converted in AC supply with the help of an inverter. The output of this inverter is fed to the single phase induction motor.

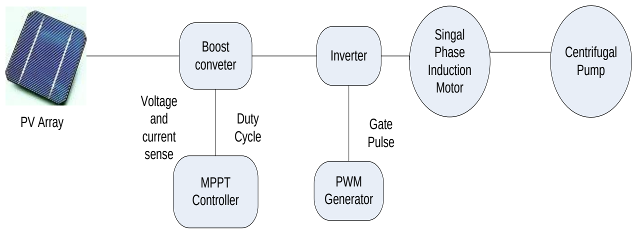

Fig. 1 single phase Induction Motor with double stage converter

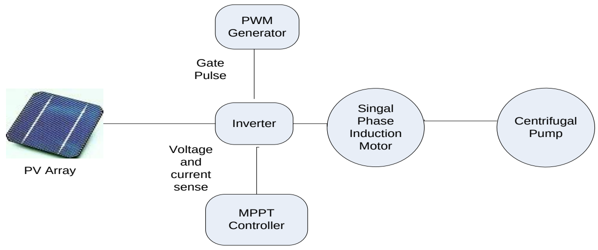

Fig. 2 single phase Induction Motor with Single stage converter

Fig. 2 Show single phase Induction Motor with single stage converter, solar PV array and single phase inverter. The output of solar PV Array is fed to the single phase inverter. This inverter converts DC output of the solar PV array in AC supply. The output of this inverter is fed to the single phase induction motor. The design and working principle of each stage of the configuration are Explain in the following Subsections.

A. PV Array

Photovoltaic cells are solid-state semiconductor devices that change the light energy into electrical energy. These cells are commonly built of silicon with traces of other elements and are deliberate as first cousins to LED's, transistors and other electronic devices. Photovoltaic (PV) generation is appropriate increasingly important as a renewable source because it is offering many advantage as not being polluted, no fuel costs, requiring little maintenance, and emitting no noise compared to others. The awesome thing about solar power is that all the electrical power that is generated from the material of the solar panels is the energy from the sun light. The solar panels are mainly made out of semiconductor material, silicon being the most commonly used semiconductor. The advantage of using semiconductor material is very high due to the ability of it to control its conductivity whereas insulators and conductors materials are not.

The characteristics of PV cell can be modeled through the use of an equivalent electric circuit, Here the electrical equivalent circuit of a single PV cell is as shown in following figure.2

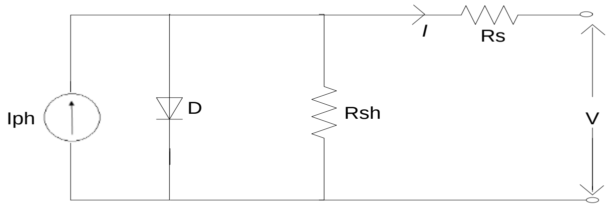

Fig. 2 Photovoltaic cell model

The volt-ampere equation of the photovoltaic system is given by

$$I = I_{ph} - I_0 + I\left(e^{\frac{V+IRs}{aVt}} - 1\right) - \frac{V+IRs}{Rsh} \qquad 1$$

$$Vt = \frac{NsKTc}{q} \qquad 2$$

A. Boost Conveter

In Figure 3 a boost converter is shown. The output voltage is always greater than the input voltage.

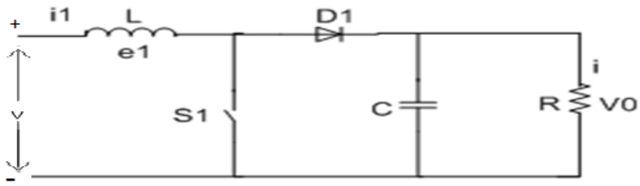

Fig. 3 Design of dc boost converter

When the switch 1 S is turned on, the voltage across the inductor is given by

$$V_L = L\frac{di}{dt} \qquad 3$$

The peak to peak ripple current in the inductor is given by

$$\Delta I = \frac{Vs}{L}T_1 \qquad 4$$

The average output voltage is

$$V_o = Vs + L\frac{\Delta I}{T2} = Vs\left(1 + \frac{T1}{T2}\right) = Vs\frac{1}{1-D} \qquad 5$$

The voltage across the load can be stepped up by changing the duty ratio D. The minimum output voltage is Vs and is achieve when D=0.

The power electronic converter illuminated in Fig. 3 is a DC-DC converter or boost converter, which increase the output voltage of the PV array. The boost converter consists of a MOSFET and a diode in the power circuit. The MOSFET is switched at a particular time period determined by the control strategy so that the required voltage is achieve at the output of the converter. The working principle, analysis and operation of the boost converter are characterize in this section. For the analysis of boost converter, the understanding of circuit using a simple switch is demonstrated in Fig. 3. In this paper.

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B. Design of inverter

An inverter is an electrical device that converts direct current (DC) to variable alternating current (AC). The converted AC can be at any required voltage and frequency with the use of appropriate switching (gate pulse) and control circuits we can adjust as per our requirement[20]. Static inverters have no moving parts and are used in a wide range of applications from small switching power supplies in computers or large electric serviceableness using high-voltage direct current that transport bulk power to the load . Inverters are frequently used to supply AC power from DC sources such as batteries or solar PV panels. Here the inverter studied is of single phase inverter [13] as shown in fig.4.The electrical inverter is a high-power electronic oscillator.

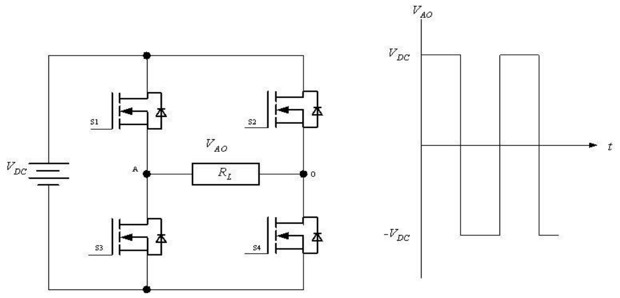

Fig 4 Design of single phase PWM inverter

Fig.4 Single phase IGBT inverter The inverter attain the unlike function of a rectifier. Here in the proposed model we are considering the single phase inverter design based on 2 bridge armed IGBT devices. A inverter convert the dc output of boost change into alternating current (AC) for the use in home appliances and possibly to supply the singe phase induction motor.

C. Design of single phase induction motor

A single phase induction motor is an asynchronous AC (alternating current) motor that consists of a fix part stator and moveable part a rotor. In the single phase induction motor a sinusoidal or non sinusoidal AC voltage is applied to the stator, this results in an induced electromagnetic field. This field induces a current in the rotor that creates another field that tries to align with the stator field causing the rotor rotate.

TABLE 2. PARAMETER OF SINGLE PHASE INDUCTION MOTOR

Sr. No	Parameter	value
1.	Type	Capacitor start capacitor run
2.	Rating	1 hp
3.	Voltage	220
4.	Frequency	60
5.	Main winding resistance, inductance	2.02Ω,5.6*10-3 H
6.	Auxiliary winding resistance, inductance	7.14 Ω, 8.5*10-3H
7.	Disconnection Speed(% synchronous speed)	75%
8.	Initial speed(% synchronous speed)	10%

The induction motor considered is of the ratings as shown in the Table.2.

D. Proposed Algorithm for maximum power point tracking

Incremental Conductance and perturb and observe algorithm is used for the design the systems. Incremental Conductance was designed based on an observation of P-V characteristic curve. This algorithm was developed in 1993. IC tries to become better the tracking time and to produce more energy on a vast irradiation changes environment. The MPP can be compute by using the relation between dI/dV and –I/V. If dP/dV is negative then MPPT is lies on the right side of recent position and if the MPP is positive the MPPT is on left side. Incremental conductance algorithm flowchart is shown in Fig. 5 whereas the Perturb & observe MPPT algorithm flowchart is shown in Fig. 6.

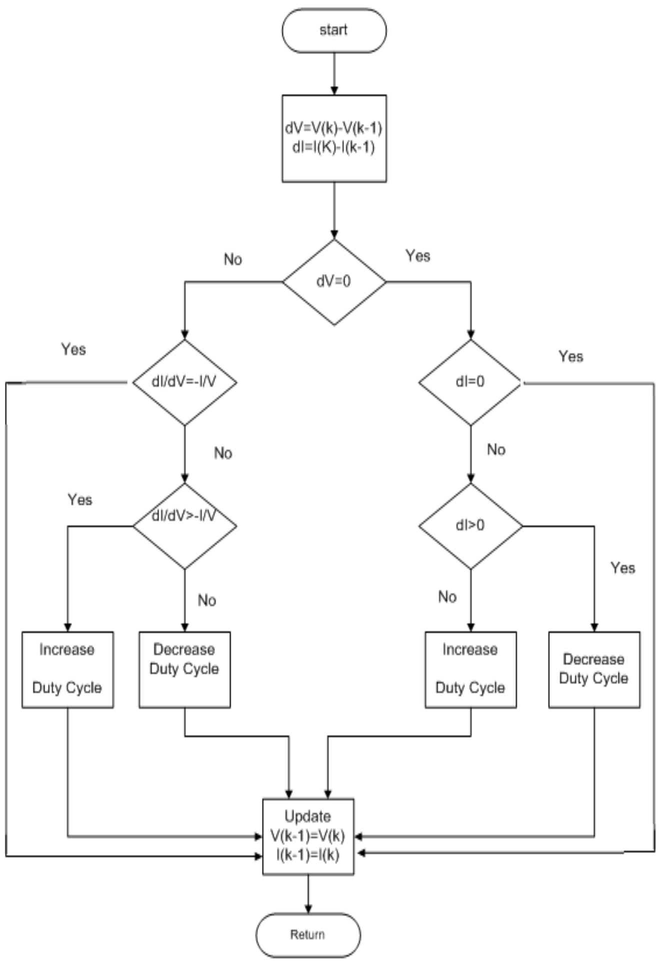

Fig. 5 incremental conductance MPPT algorithm flowchart

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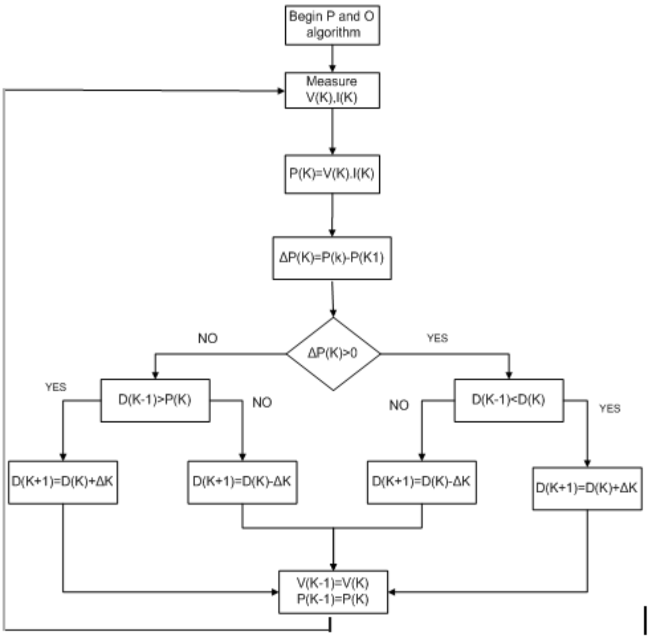

Fig. 6 Perturb and observe MPPT algorithm flowchart

III. SIMULATION RESULTS

A.Simulation Result of PV Array

The simulation results related to the performance of proposed solar PV array obtained with the different test conditions like change in the temperature and irradiations levels. Fig. 6, Fig. 7, Fig. 8 and Fig. 9 show different test conditions and their results.

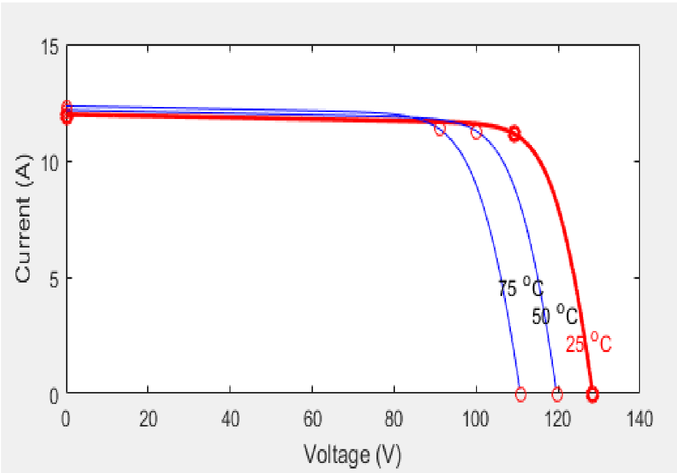

Fig. 6 PV array voltage and current characteristics at different temperature

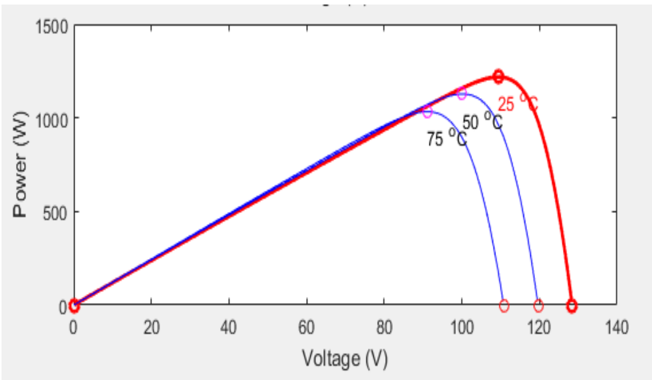

Fig. 7 Solar PV array voltage and power characteristics at different temperature

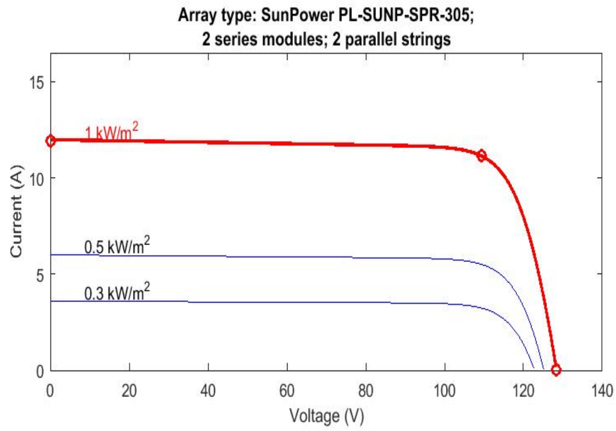

Fig. 8 Solar PV array V-I characteristics at different irradiation level

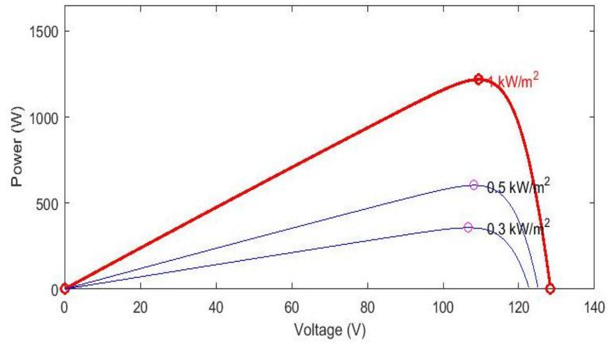

Fig. 9 Solar PV array voltage and Power characteristics at different irradiation level

It is observed from the above four Fig. that if we increase the solar array temperature then the output power of solar array decrease and if increase the irradiation level then output of PV array increase.

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B. Simulated Results of Boost converter with MPPT

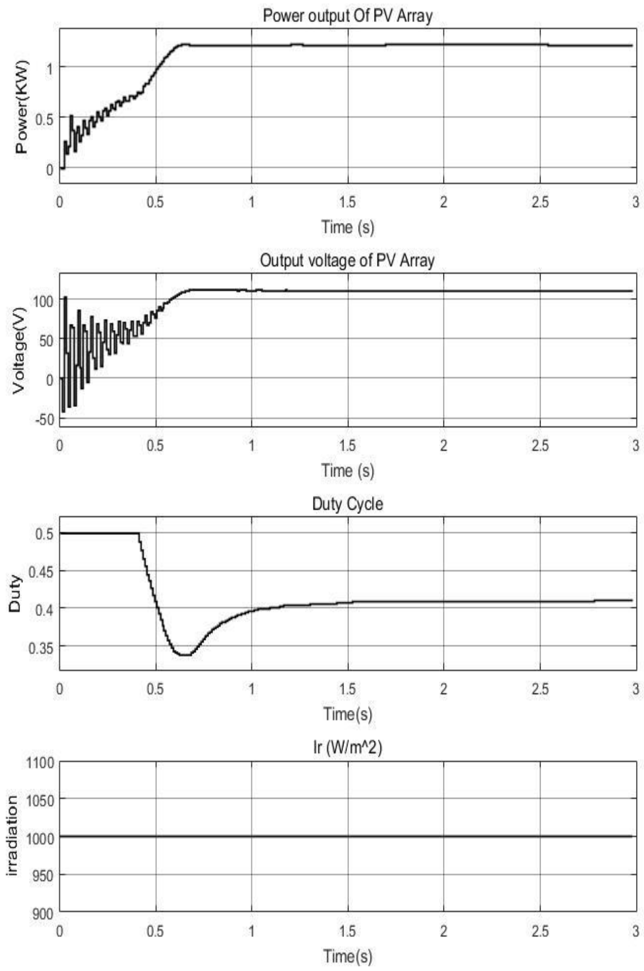

Fig. 10 Simulated result of PV array with boost converter (a) power output of PV array (b) PV array voltage (c) boost converter voltage (d) input irradiation level of array (1000 W/m^2)

Fig. 10 illustrates the output results of solar PV array with boost converter using incremental conductance MPPT technique. It is observed from Fig. 10 (a) that the maximum output power is extracted from the PV array after time duration of 0.6 s. The voltage has been achieved maximum after 0.6 s with the help of duty cycle as shown in Fig. 10 (b). This maximum voltage ultimately maintains the maximum power output of the PV array. The duty cycle is shown in the Fig. 10 (c). It changes according to the variations in the output power of the PV array. Finally, it becomes constant when the constant output power is achieved with the help of MPPT point.

C. Performance Analysis of Single Phase Induction Motor with Double Stage Single phase Inverter Fed by PV Array

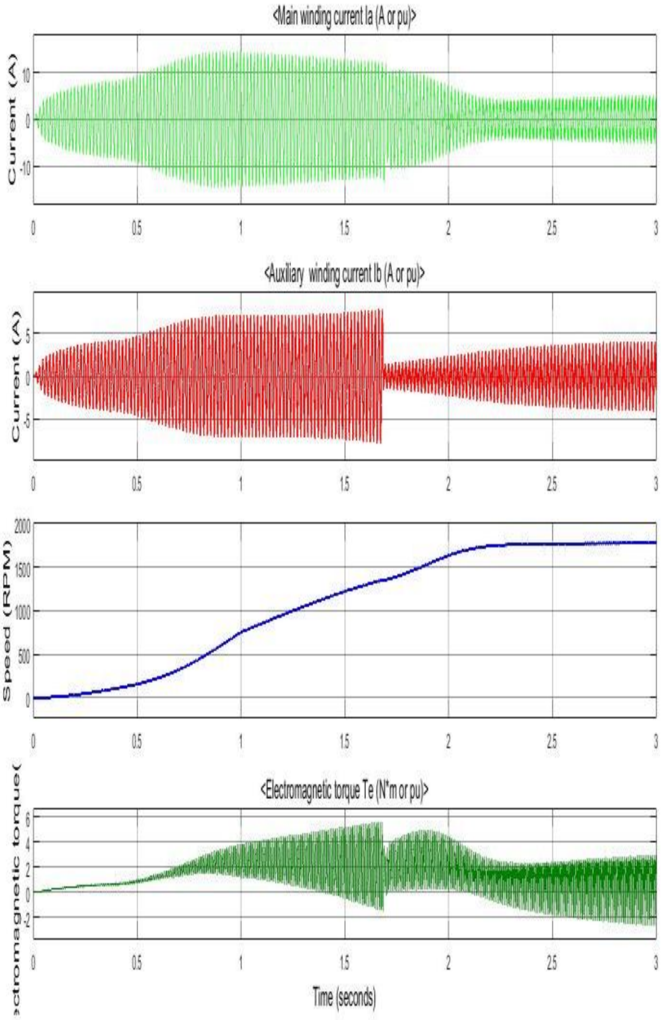

Fig. 11 Simulated result of single phase induction motor With Double Stage converter

The waveform of current drawn by main winding of induction motor, auxiliary winding of induction motor, rotor speed and electromagnetic torque developed are shown in Fig. 11. It is observed from the waveforms that the starting current in the main and auxiliary winding of the induction motor are quiet high and it becomes constant after the capacitor switched off and attains constant current at 2 s. The speed becomes constant at a value of 1875 after the time duration of 1.8 s. It is also observed that the electromagnetic torque of the induction motor is of the positive during the period when there is dynamics due the starting of the motor and it attains a regular waveform with equal positive and negative values when motor run at constant speed.

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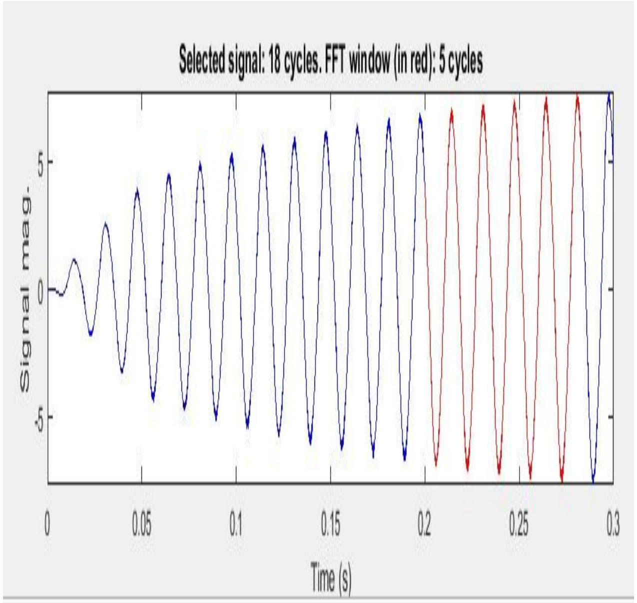

Fig. 12 Current waveform of main winding for THD calculation

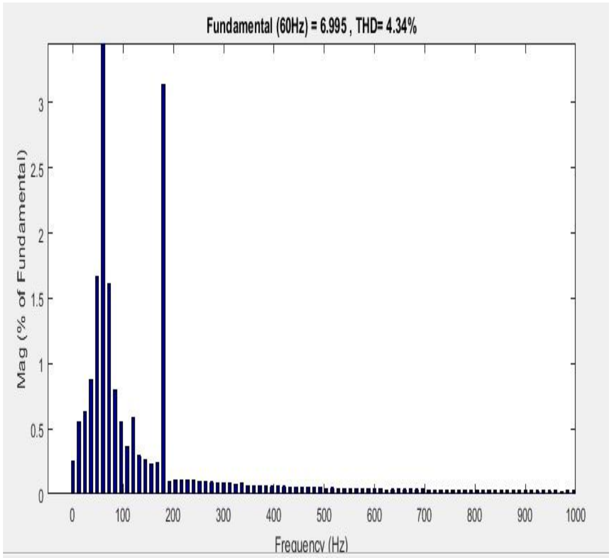

Fig. 13 THD of current waveform of main winding

The waveform of the main winding current used for the calculation of the THD is shown in Fig. 12. It is observed from this figure that the initial current is zero. It increases continuously and becomes maximum corresponding to the maximum power supplied by the solar PV array depending on the method of MPPT used.

D. Performance Analysis of Single Stage Converter Based Induction Motor Fed by Solar PV Array

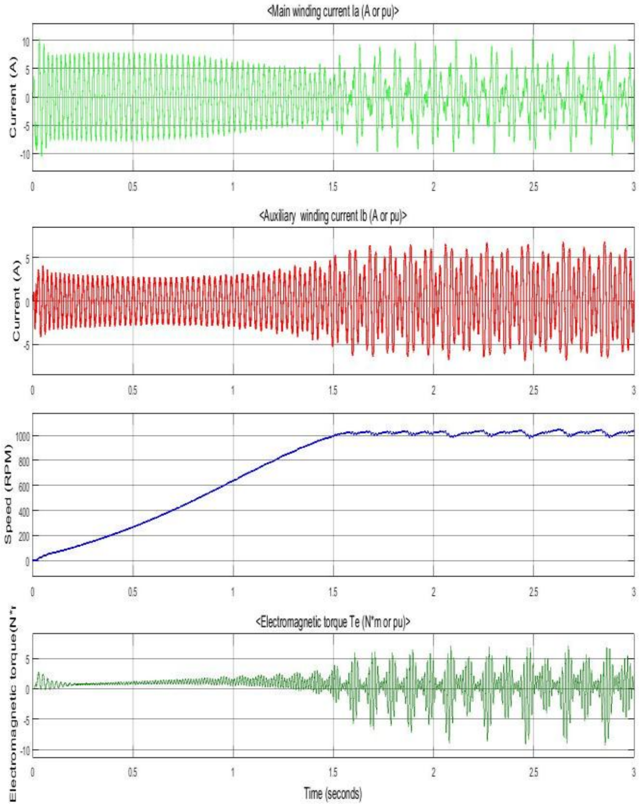

Fig. 14 Simulated result of single phase induction motor

The waveform of current drawn by main winding of induction motor, auxiliary winding of induction motor, rotor speed and electromagnetic torque developed with the single stage converter are shown in Fig. 14. It is observed from the waveforms that the starting current in the main and auxiliary winding follow the pure sinusoidal waveform. The waveforms of these currents are distorted after 1.5s due to the variation of the MPPT point to extract to the maximum power from the solar PV array. The maximum speed of the induction motor is achieved at 1000 rpm but it has the variations. The variations in the torque are also observed. It is concluded that the distortions are introduced by the use single stage converter and steady stage condition is not suitable for water pumping system.

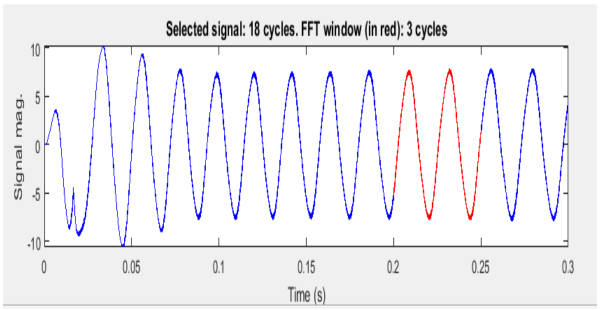

Fig. 15 Waveform of main winding current of single phase induction motor.

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The waveform of main winding current used for the calculation of THD is shown in Fig. 6.6. The THD spectrum of this current is shown in Fig. 6.7. It is observed that the THD value of 94.97% is obtained. This value is very high compared to the two stage converter.

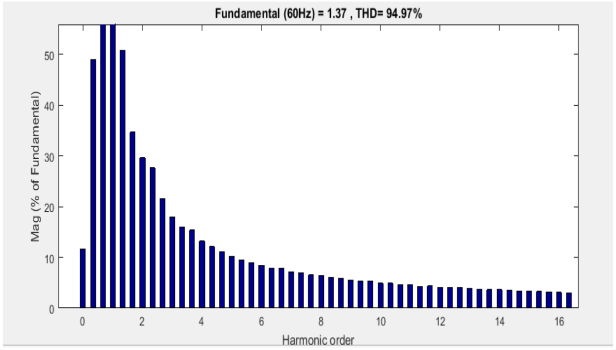

Fig. 16 THD of main winding current waveform.

IV. CONCLUSION

The research work presented in this paper has considered the design and implementation of single stage and two stage converters for the single phase induction motor driven water pumping systems. The proposed designs are simulated in the MATLAB/Simulink environment. The results related to the performance and efficiency of the both the proposed converters has been presented in this work. The performance comparison of the single and two stage converters used for the single phase induction motor based water pumping system is carried out based on the values of THD of main winding current of the induction motor and output speed of rotor (in terms of rpm). It is observed that the value of THD of main winding current of the single phase induction motor is 94.97% for the two stage converter and it is equal to 4.34% for the single stage converter. Hence, for the two stage converter the value of THD 21.88 times is higher compared to the single phase converter. The output rotor speed with use of two stage converter is observed to be 1875 rpm whereas with the use of single stage converter it is equal to 1000 rpm with same input solar PV power. Further, the variations in the speed are also observed by the use of single stage converter.

Therefore, it is concluded that the performance of the two stage converter driven water pumping system is better compared to the single stage converter driven water pumping system. Hence, two stage converter is recommended for the single phase induction motor driven water puming system for domestic and irrigation purpose.

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