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Solar/DC Based Water Pumping System

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***Abstract—* This paper presents a stand-alone solar/DC based water pumping system, mostly suited in isolated or rural areas. This paper comprises of economical, low price water pumping system with a combination of boost converter and a diode clamped multilevel inverter which drives the single phase Induction Motor by using SPWM strategy. Simulation of the two most important MPPT algorithms are compared and analyzed. The proposed system is developed and tested successfully in the laboratory. Experimental result shows the possibility and better functionality of system.**

***Index Terms*— boost converter, diode clamped multilevel inverter, SPWM, Induction Motor, MPPT, Incremental Conductance.**

I. INTRODUCTION

Nowadays energy is important and one of the basic infrastructures necessary for the development of a country economically. An excellent opportunity for generating electricity is provided by the solar energy among all renewable energy sources as it also reduces greenhouse emissions, because of which solar systems draw more attention and has become a major challenge for engineers and scientists [1].

In commercial systems, greater number of motors were DC motors. As these DC motors are having less efficiency and high maintenance cost in comparison with Induction Motors, they are not preferred for applications in isolated areas. The other disadvantage of DC motor is its inaccessibility. Thus single phase Induction Motor has been preferred for the system due to greater robustness, availability in local market lower cost compared to other types of motors. Since the photovoltaic panel powers the motor drive system directly, system is in need of low cost, highly efficient interface i.e. converter between panel and motor to maximize the energy generated from PV. The PV modules are the most expensive element of the system but the average life span of it is 25 years which is the most attractive aspect of Solar Powered Water Pumping System. This paper proposes such a system [2].

Maximum Power Point Tracking (MPPT) is used as a part of photovoltaic to acquire the peak power from the module and provide it to load. By changing the load impedance from the source and match it at the peak power by varying the duty cycle, maximum power is carried. Different MPPT techniques are used for maintaining the PV's operating on its MPP. Various MPPT methods are described in the literature such as, the Fuzzy Logic Method, Perturb and Observe (P&O) method and Incremental Conductance (InC Cond) method etc. Out of these two most popular MPPT techniques (Perturb and Observe (P&O) and Incremental Conductance methods) are compared [3].

A typical layout of photovoltaic water pumping system is shown in Fig. 1. It consists of solar array, DC-DC converter, multilevel inverter and load. A PV array is modeled and simulated in MATLAB/Simulink. Since the output of the solar array is very less, a Boost converter is used to increase the output voltage level. Diode clamped multilevel inverter is used in the system by using SPWM strategy.

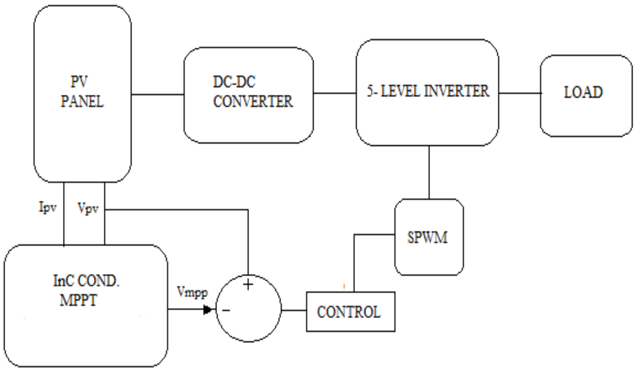

Fig. 1. Block diagram of the proposed system

II. PV CELL

A solar cell is an electrical device which converts the light energy directly into electricity by using photovoltaic effect. It is having the form of photoelectric cell, which is a device whose current, voltage or resistance characteristics changes when exposed to light. Solar cells are nothing but the building blocks of photovoltaic modules which are also known as solar panels. Equivalent circuit diagram of PV cell is shown in fig. 2.

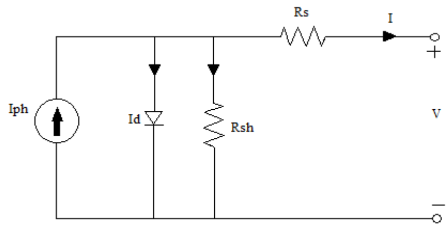

Fig. 2 Equivalent circuit of PV cell

III. COMPARISON OF MPPT ALGORITHMS

A. Perturb and Observe (P&O) Algorithm

In the below algorithm a small perturbation is introduced. Solar array power changes continuously because of the perturbation. The perturbation is carried on in same direction if power increases due to perturbation. When the maximum power is achieved, the power at the later instant decreases and then perturbation is reversed. When the steady state is reached the operating point of this algorithm oscillates around the maximum point [2].

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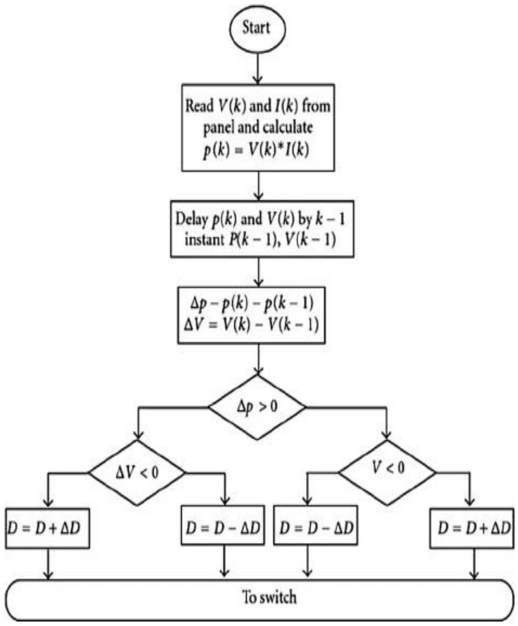

Fig. 3 Perturb and Observe Algorithm

B. *Incremental Conductance Algorithm*

The drawback of P&O method to track the peak power under fast varying atmospheric condition is defeated by Incremental Conductance method. This method finds when the tracking method reaches the MPP and stops perturbing the operating point. This method finds whether the MPPT has reached the MPP and also stops perturbing the operating point. If dP/dV <0 the system moves to the right of MPP, if it is greater than zero, system is to the left of MPP else it is at the MPP [2].

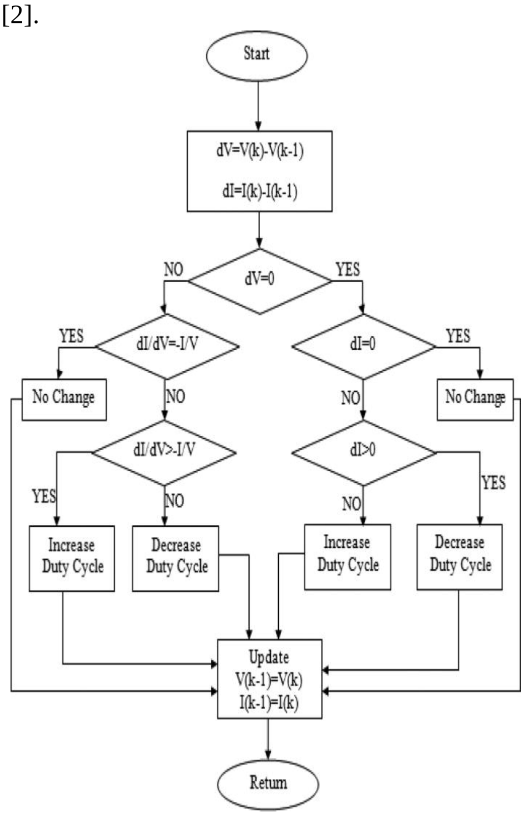

Fig. 4 Incremental Conductance Algorithm

IV. SIMULATIONS RESULTS

A. *PV Array*

The mathematical modeling of PV array is developed using MATLAB Simulink tool. Various parameters of the PV array are chosen.

TABLE I. Parameters specifications of 40W PV module

Maximum Power (Pmax)	40W
Open Circuit Voltage (Voc)	21.50 V
Short Circuit Current (Isc)	02.45 A
Vmp	17.60 V
Imp	02.27 A

B. *Simulink Diagram*

The proposed system software is done in MATLAB/Simulink version R2016a. Simulation of converter and multilevel inverter is done and the waveforms are analyzed. PV cell and MPPT controller is simulated. An input 40V from the PV cell is boosted to a constant 53V. It is then fed to a diode clamped multilevel inverter. The inverter is controlled using SPWM strategy. Simulation of complete proposed system is shown in fig. 5 and the output waveforms of converter, inverter and induction motor are shown in fig. 6, fig. 7, fig. 8, fig. 9, fig. 10.

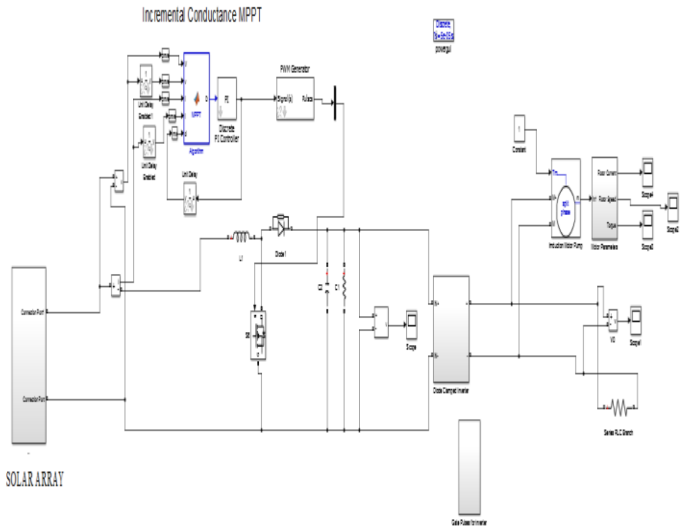

Fig. 5 Simulink Diagram

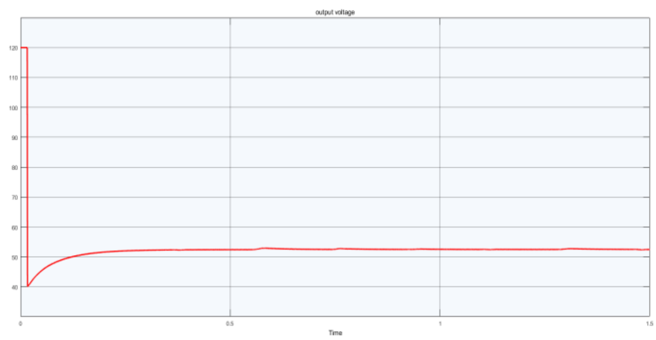

Fig. 6 Boost Converter output voltage waveform (Output voltage vs Time axis)

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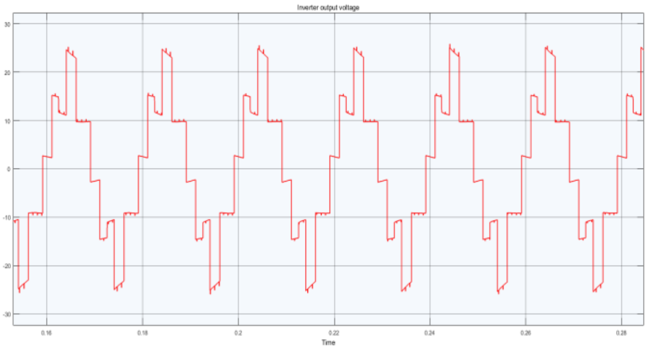

Fig. 7 Output Voltage waveform of multilevel inverter (Voltage vs Time axis)

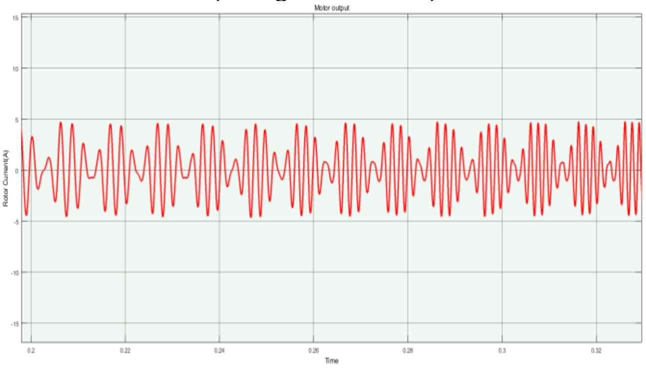

Fig. 8 Simulation result for motor current (Rotor current vs Time axis)

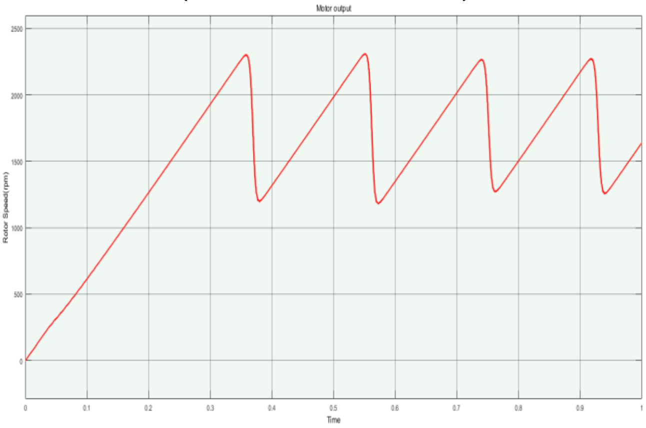

Fig. 9 Simulation result for motor speed output (Rotor speed vs Time axis)

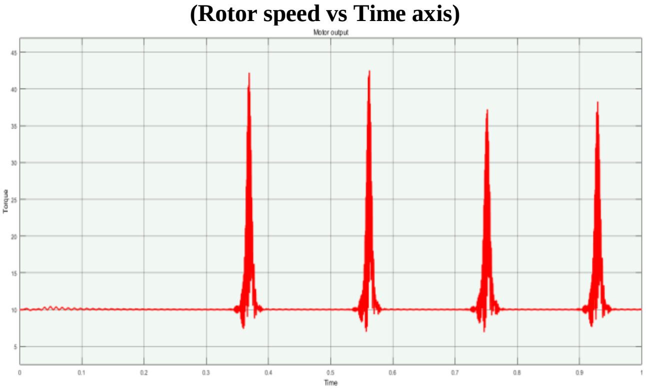

Fig. 10 Simulation result for motor torque (Torque vs Time axis)

Simulation results for motor shows that motor speed increases when torque is constant. As torque increases motor speed decreases and vice- versa.

C. Simulation results for P&O MPPT algorithm

The simulation results for P&O algorithm for voltage, current and power waveforms are shown below.

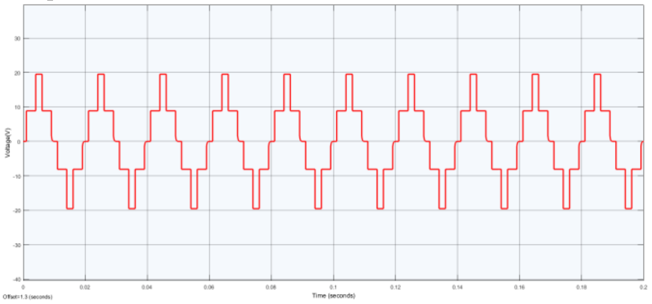

Fig. 11 Voltage output waveform (Voltage vs Time axis)

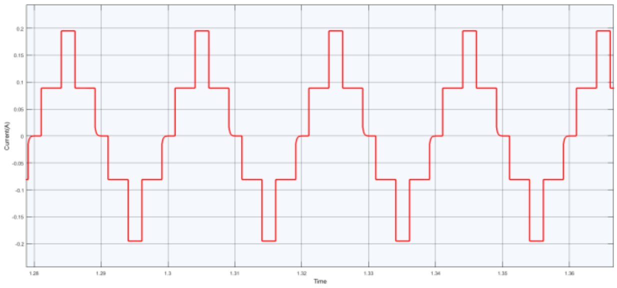

Fig. 12 Current output waveform (Current vs Time axis)

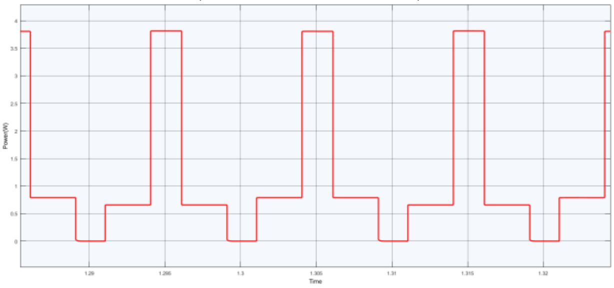

Fig. 13 Power output waveform (Power vs Time axis)

The results show that the voltage output is of 19.6 volts and the current output is of 0.195 ampere and an output power is of 3.8 watts.

D. Simulation results for Incremental Conductance MPPT algorithm

The simulation results for Incremental Conductance algorithm for voltage, current and power waveforms are shown below.

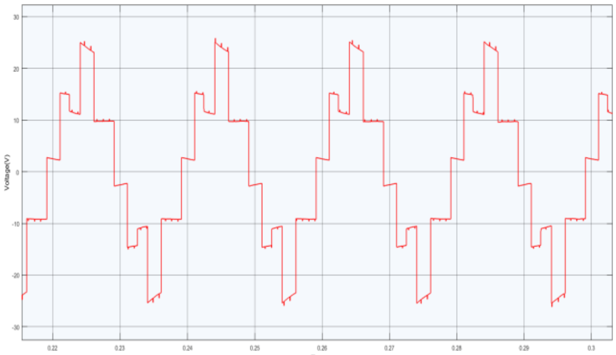

Fig. 14 Voltage output waveform (Voltage vs Time axis)

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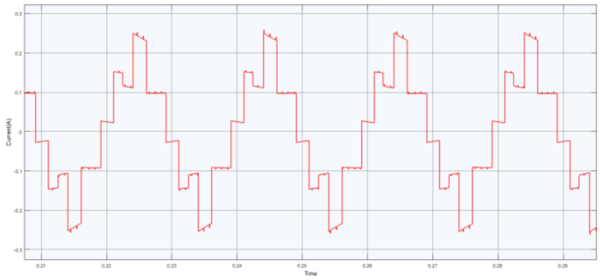

Fig. 15 Current output waveform
(Current vs Time axis)

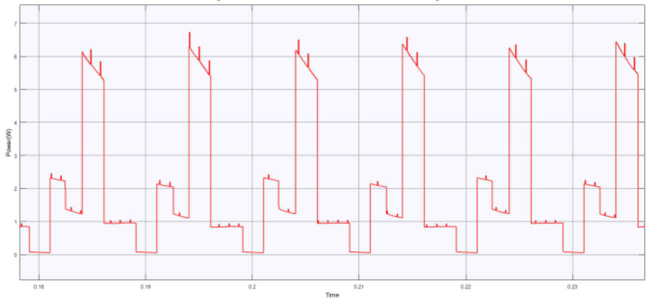

Fig. 16 Power output waveform
(Power vs Time axis)

The results show that the voltage output is of 24.8 volts and the current output is of 0.246 ampere and an output power is of 6.1 watts.

E. Comparison between P&O and InC MPPT Algorithms

The iterations required by InC MPPT method is less compared to P&O method. So the tracking speed of InC method is faster compared to P&O method because of which we do not get proper steps in converter in InC method that leads to small spikes in the above waveforms which is fine as the accuracy of tracking in InC method is high than P&O method.

Simulations of the P & O and InC MPPT algorithms are performed and compared. Whenever the atmospheric conditions are constant or varies slowly, P&O method oscillates around the MPP but InC method reaches the MPP accurately even at changing conditions. Comparisons between the two algorithms for various parameters are given in table II.

TABLE II. Comparison between P&O and InC MPPT Algorithms

MPPT	Output Voltage	Output Current	Output Power	Accuracy
P&O MPPT	19.6V	0.195A	3.8W	Less
InC MPPT	24.8V	0.246A	6.1W	Accurate

V. EXPERIMENTAL SETUP

Block diagram of experimental setup is shown in fig. 17. It consists of Battery of 12V as dc supply. The 12V dc supply is fed to voltage regulator and converted to 5V regulated supply which is then fed to components like driver circuit and PIC microcontroller. We are using PIC microcontroller for producing switching pulses required to drive the MOSFETs used in diode clamped multilevel inverter.

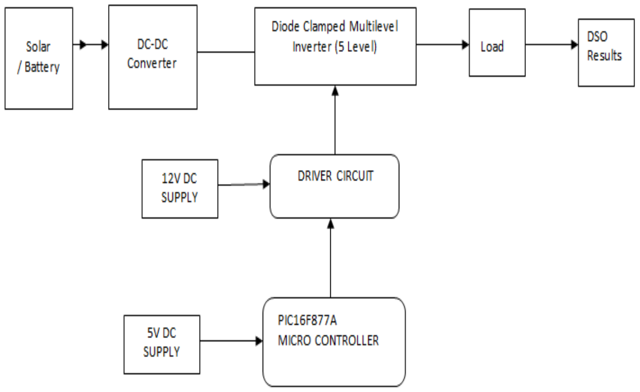

Fig. 17 Block Diagram of experimental setup

A. Hardware Design specification

DC source	Dc supply
Voc, Isc	12V, 1.3A
No of Battery	2
Pic controller	PIC16F877
Optocoupler	MCT2E
Gate driver	IR2110
Step-Up Transformer	1 (12VAC /230V AC)

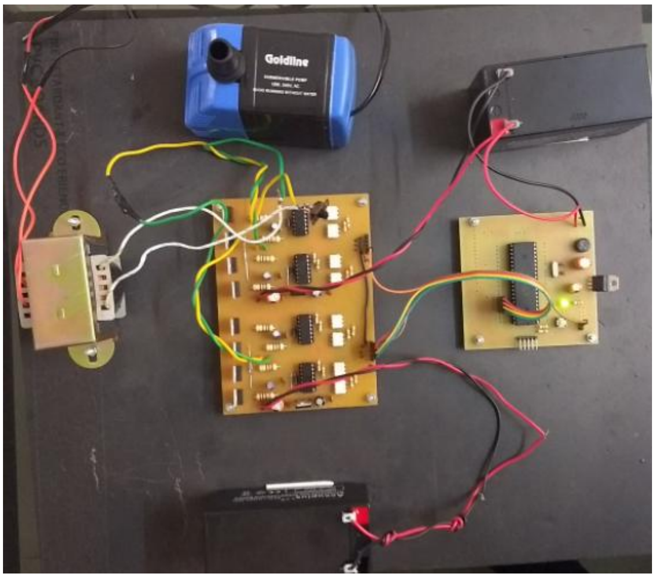

Fig. 18 Experimental setup for Solar based water pumping system

➢ **Calculations of Hardware**

Battery 1 output= 21.06 W
Battery 2 output= 11.2464 W
Total input power = 32.3064 W

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Inverter output power = Input power – inverter losses
Inverter losses calculated is found to be 0.563 W
Inverter output power = 32.3064 W-0.563 W= 31.73 W
Inverter efficiency= 98.23%,
Transformer efficiency= 93.28%
Overall Efficiency of electrical system = 0.9823*0.9328*100= 91.63%

B. Hardware Results

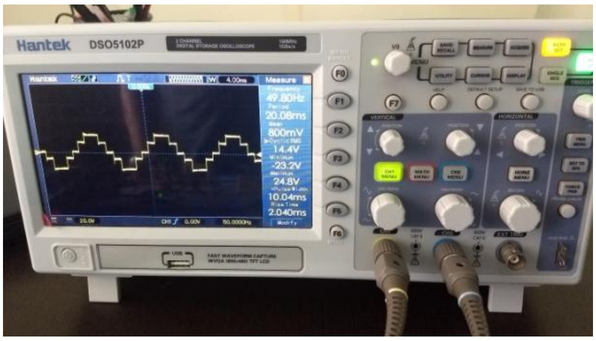

Fig. 19 Output voltage waveform of multilevel inverter on DSO

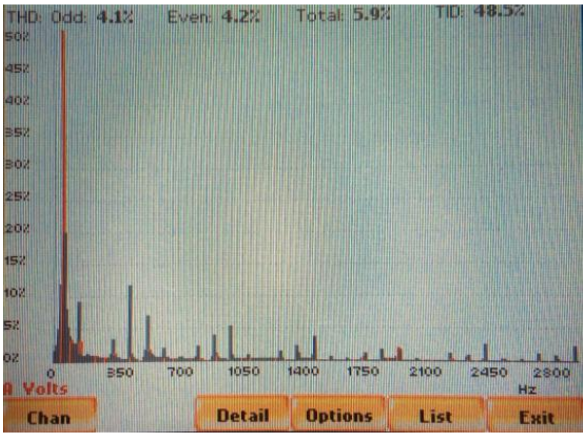

Fig. 20 Total Harmonic Distortion (THD) with linear load

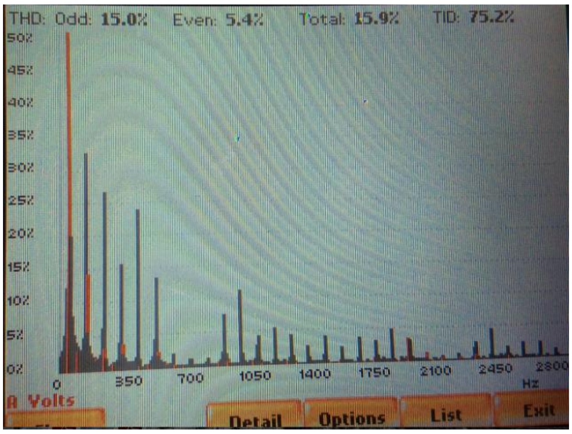

Fig. 21 Total Harmonic Distortion (THD) with non linear load

From the Fig. 20 and fig. 21 we can see that THD with linear load is 4.1% which is less than the THD of 15% with non-linear load because load used is induction motor which is a non-linear load. As per IEEE Standard 519, THD limit is between 15-25%. So the THD in the proposed system is within limits which can be acceptable.

VI. CONCLUSION

In this paper, the mathematical modeling of a 40W photovoltaic panel is developed with MATLAB/Simulink tool. The P&O and Incremental conductance MPPT algorithms are examined and their simulation results are compared. It is proven that Inc Cond. algorithm is having better interpretations than P&O algorithm. A dc-dc boost converter which converts a variable dc voltage into a constant high dc voltage, then the inversion of this dc voltage into single phase ac voltage using diode clamped multilevel inverter which is controlled by SPWM technique has been designed which supplies single phase induction motor and its performance has been analyzed. Hardware implementation shows the output waveform of multilevel inverter and THD % with linear and non-linear load. The efficiency of multilevel inverter is 98.23% and that of transformer is 93.28%. Thus the overall efficiency of the proposed system is 91.63%. So this system is simple, reliable, and efficient and need less maintenance.

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