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Design and Implementation of Photovoltaic Inverter system using Multi-cell Interleaved Fly-back Topology

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Abstract : In the current scenario, the world's interest revolves around renewable energy. This project presents the design and implementation of photovoltaic inverter system using multi-cell interleaved fly-back topology operating in continuous current mode. The primary objective of this study is the design of fly-back converter where multi cell are interleaved. The most distinctive feature proposed in this paper is the design of reducing multi-celled transformers into one. Thus the overall cost is reduced by achieving the same efficiency. The output power of the PV module controls each interleaved converter cell. In the fly-back converter, a single controllable MOSFET switch is used with switching frequency is in the range of 100 kHz. It is based on zero voltage switching technique, thus reducing the switching losses. Thus the overall efficiency of the converter is increaser. The design of interleaving reduces the ripple and reduces the usage of capacitors and size of the filter. A MPPT-perturb and observe (P&O) algorithm is implemented in this project for tracking the maximum power from the PV panel. In this design the main heart of the hardware module is the micro controller for MPPT algorithm. The programming language used for developing the software to the micro controller is Embedded C /Assembly. For compilation and debug, KEIL cross compiler is used. Micro Flash programmer is used for burning the developed code on Keil in to the micro controller Chip. The simulation of this project is implemented in Matlab/ Simulink.
Keywords : photovoltaic inverter, fly-back topology, MPPT algorithm, interleaved converter.

Introduction

The demand for electrical energy grows globally, therefore the need for alternative energy sources that minimize impact on the environment increases. The generation of green (“clean”) energy has become increasingly and it is viable due to improvement in the technology and research. Photovoltaic power generation is one among the clean energy forecasted to have an impact in the global power equation, and has been demonstrated to be economically viable and technologically feasible. Therefore the efficiency has to be increased in the photovoltaic power generation. The DC-AC energy conversion plays a major part in affecting the efficiency of power generation in photovoltaic systems. Thus the primary objective of this paper to design the photovoltaic system with less number of components and decreased losses and total harmonic distortions (THD) in order to increase the overall efficiency. In this paper, design and implementation of photovoltaic inverter system using multi-cell interleaved fly-back topology is used. In the design, three cells of fly-back converter are interleaved. The interleaved topology facilitates to use smaller size filter for easily filtering the ripple components. This is due to interleaving; the frequency of ripple components is increased as the interleaved cell increases. Thus there is a decrease in overall cost of the inverter systems and its compact size. Fly-back converter is a low-cost converter with less number of components as the inductor for energy storage is combined with linear transformer [1]. A total of three switches and combination of inductor and linear transformer are interleaved in a three-cell fly-back topology. The fly-back converter with the transformer results in large leakage flux and poor energy transfer capability due to poor coupling in each transformer. The hysteresis and eddy current losses increase for each individual transformer. Thus overall losses produced due to three transformers is more. Therefore to overcome this disadvantage a common linear transformer for three cells is used which reduces the overall leakage flux, hysteresis and eddy current losses produced by individual transformer and increases the coupling, thus results in better energy transfer capability. In this project, a prototype is implemented with a central type inverter, where any number of solar panels can be connected in parallel to get the desired output. The maximum power can be produced from the solar panel connected by tracking the maximum power using the maximum power point tracker(MPPT) for each panel using the perturb and observe(P&O) algorithm. The maximum power point tracker arrangement is less costly for central type inverter systems when compared to micro-inverter which adds an advantage. The choice of operation of the converter is Continuous current mode (CCM) because of many disadvantages of the discontinuous current mode (DCM). The current waveform of DCM operation have higher form factor (RMS to mean ratio) than that of CCM mode [3]. This disadvantage results in power losses. Thus as a solution, switching devices and every current carrying path must contain low resistive path. In the DCM mode, large current peak pulses with high level of discontinuity.

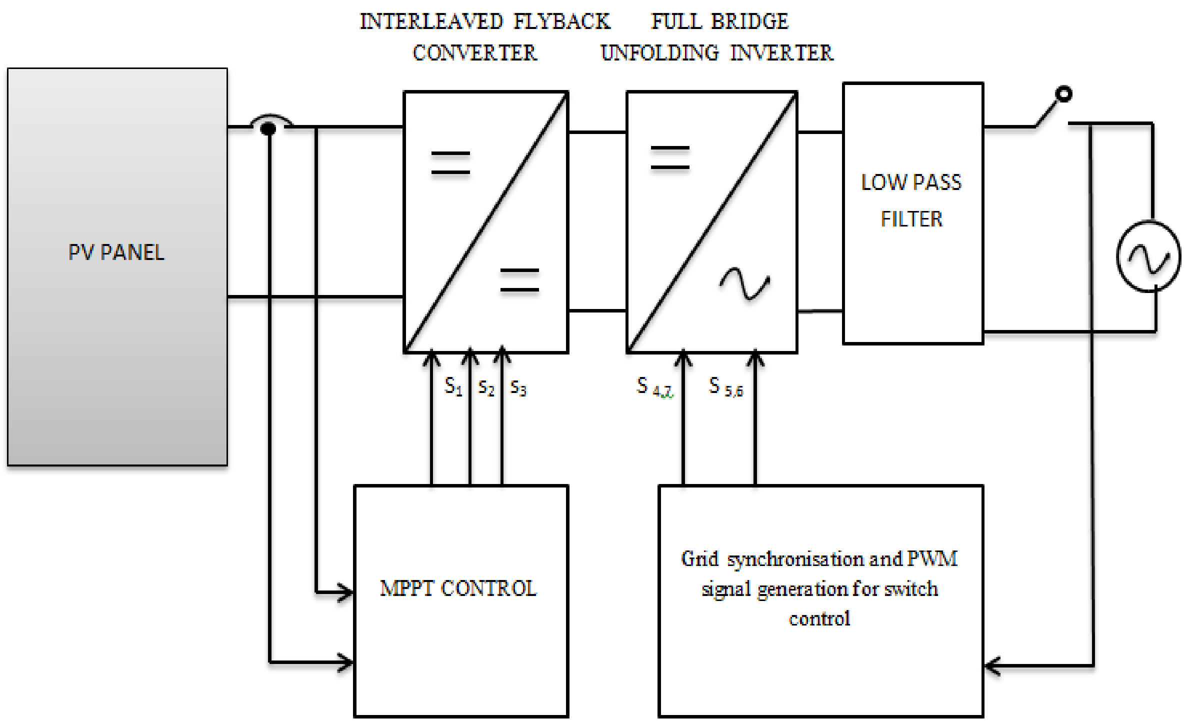

Fig.1. Block diagram of the proposed PV inverter system using interleaved multi-cell fly-back topology

In conclusion, this study has presented the design and implementation of the isolated grid connected PV inverter system using the interleaved multi-cell fly-back topology. Fig.1 shows the block diagram of the proposed block diagram. The improvement showed in the proposed system is that rather than using one linear transformer for each cell, a common transformer is used for multi-celled fly-back topology. Thus the proposed design achieves the lower power losses and a compact design with increased overall design. In this study, we have implemented only a prototype with central inverter type using only a single solar panel. But we can connect a series of solar panel connected in strings in a parallel fashion [4]. We consider this design as significant step in the research where we can achieve a compact PV inverter system achieving low cost when we setup a solar farm in a large scale.

The remainder of the paper is as follows: Section I describes the converter topology and its operating principles. Section III describes the design of PV inverter system. Section IV describes about the simulation and the experimental results. Section V provides the conclusion.

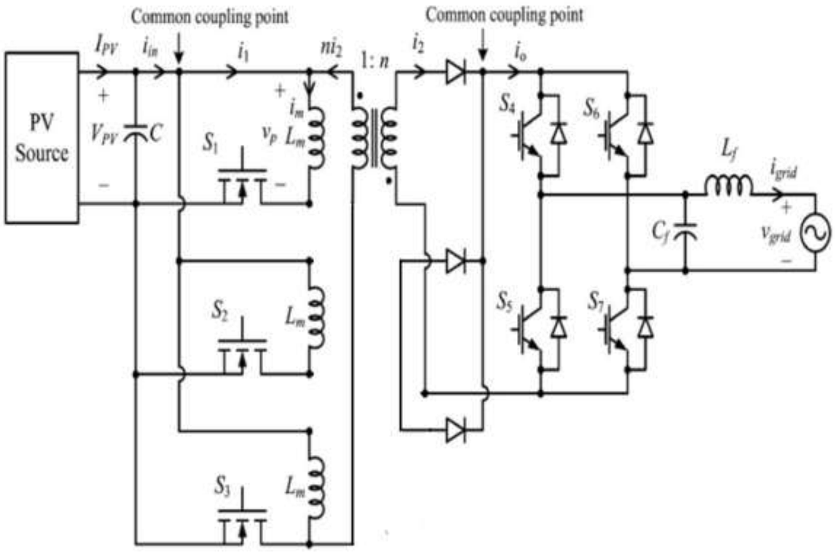

Fig.2. Circuit Diagram of the proposed PV inverter system

II. Converter Topology and its Operating Principles.

Fig.2. shows the proposed PV inverter system where the PV source is connected to converter based on the interleaved fly-back topology via the decoupling capacitor. Decoupling capacitor acts as local storage reservoir. They oppose quick changes of voltage. If the input voltage suddenly drops, the capacitor provides the energy to keep the voltage stable. Similarly, if there is a voltage spike, the capacitor absorbs the excess energy. In this system 3 cell fly-back converter are interleaved. Fly-back converter consists of Metal Oxide Semiconductor Field Effect Transistor (MOSFET) as the switch and inductor for each cell on the primary side and a linear transformer which is common for all cells and diode for each cell on the secondary side of the system. This topology also employs the full bridge inverter and the low pass filter together interfaced with the grid. The diodes on the secondary side consist of the snubber resistance which acts as the zero voltage switching (ZVS). The snubber resistance is employed in order to attain the continuous current mode (CCM) operation. In the primary side, the MOSFET switch is used because of its low switching losses and high dynamic performance. In the fly-back converter, the current flows from the PV source (common point) to the magnetic inductance of the fly-back transformer when the switches S1, S2, S3 are turned on. The energy is stored in the form of the magnetic field. During the ON time period, the energy stored does not reach the grid because of the diode present. During the OFF period the energy stored in the form of magnetic inductance is transferred in the form of current to the grid. Thus the voltage controlled current source is achieved in the fly-back topology. Control for the inverter is given using sinusoidal Pulse Width Modulation (PWM). Thus the output obtained at the grid is sinusoidal current and voltage. Insulated Gate Bipolar Transistor (IGBT) switch acts as the switch in the full bridge inverter. Full bridge inverter's purpose is to unfold the sinusoid modulated DC output from the converted into sinusoidal AC grid voltage. Switches of the inverter are operated at the grid frequency; therefore the switching losses at the output are less. The low pass filter after the IGBT helps to remove the high frequency harmonics of the pulsed current waveforms and achieve low total harmonic distortion (THD).

The control system for the converter is designed to obtain the maximum power from solar panel and to improve the power which is pumped into the grid. This control operation is done by maximum power point tracker (MPPT) [10]. Firstly, it should regulate the DC current I_{PV} and voltage V_{PV} at the PV interface for maximum energy harvesting. Secondly, it must provide the control to convert the DC current, and continuously regulated for the MPPT purpose, which comes from the panel. The regulated power is injected into AC current at the grid interface. The MPPT uses the Perturb and Observe (P&O) algorithm which operate by incrementing or decrementing the terminal voltage and comparing it with the PV output power of the previous perturbation cycle. Because of its simplicity in its implementation P&O algorithm is used. If the power is increased, solar panel continues in the same direction, otherwise it changes its direction (decreased in voltage). This step is followed until it reaches the maximum power point. If the maximum power point is reached then the algorithm oscillates around the constant value. To implement the algorithm the panel current and voltage is measured. Fig.3. shows the flow chart of the P&O algorithm. The amount of perturbation denoted as ΔD in the flow chart is 0.001. Duty cycle is obtained as the output from the MPPT algorithm which is used to control the switches of the converter. The whole control system is implemented in the PIC microcontroller. A regulated power supply is needed for the PIC microcontroller which is provided by the driver circuit. For compilation and debug, KEIL cross compiler is used. Micro Flash programmer is used for burning the developed code on Keil in to the micro controller Chip.

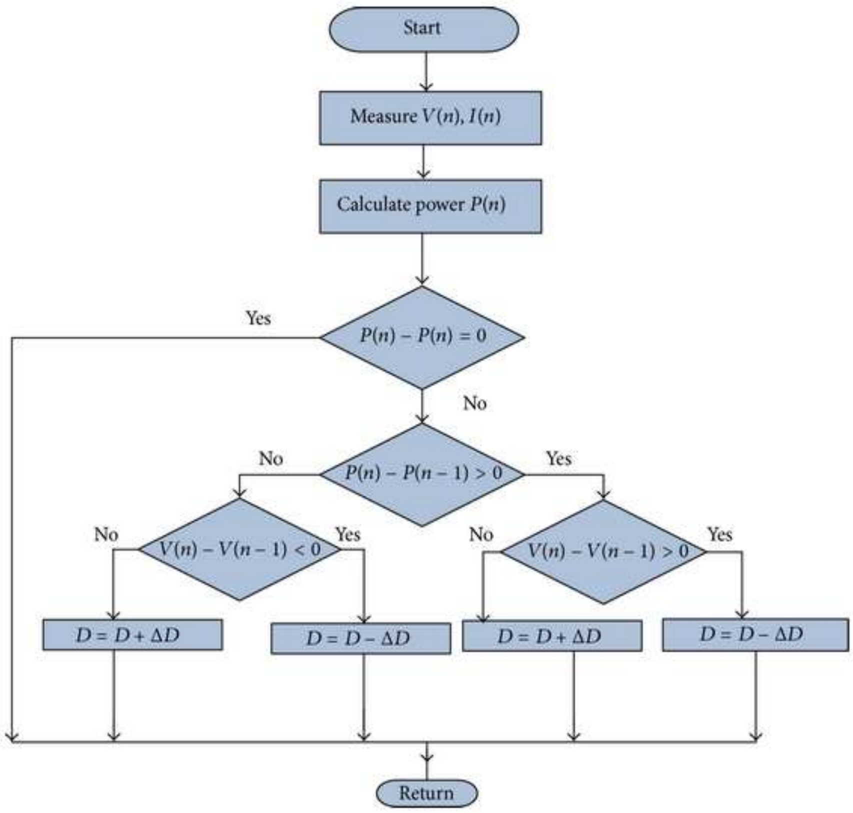

Fig. 3. Flowchart of Perturb and Observe algorithm

III. Design of the Pv Inverter System

Design of the PV inverter system is done especially for the small power systems including residential applications. Table1 lists out the specification used for design of the PV inverter system. The switching frequency (f_s) of the converter is selected as 100 KHz in order to achieve higher efficiency and less switching losses. The MOSFET is used for switching process with low voltage ratings because it has much lower on-state resistance ($R_{DS(on)}$) and more efficient as far as the conduction losses are concerned, we prefer low voltage design the turn- on switching losses are eliminated since the current starts from zero in DCM operation at every switching cycle ,but in return the switch itself will face large peak current stress which in turn results in high turn-off switching losses. The shapes of primary and secondary current waveforms in CCM operation are trapezoid instead of triangular in DCM operation. Therefore for the same output power situation the peak current and the equivalent RMS current are lower than in DCM operation. And also the conduction loss on the primary switch and secondary rectifier diode is less than that in DCM [2]. It will help to increase the total efficiency of the SMPS. Thus the continuous current mode is preferred. As shown in Table I, the maximum converter input voltage is 79.96 V for the two PV panels which is arranged in series. In addition, the fly-back switches face high voltage stress during turn off due to the leakage inductance of the fly-back transformer. So, a snubber resistance of the range 500Ω and capacitance of the range 250nF should be employed to keep the switching transients within the safe operating area of the selected devices. The inductor combined with MOSFET switch is of the range 100mH.The ideal numbers of interleaved cells are designed based on the strategies as follows: output power delivered is more when numbers of interleaved cells are more, which leads to increased number of components but losses due to components fall behind the total output power produced. The major objective of interleaving is to reduce the passive filtering to minimum. The ripple (harmonic) magnitude can be reduced while the ripple frequency can be increased simultaneously. So, increasing the number of cells contributes to this objective. The interleaved cell number yields the information for the duty ratio. It is optimum to select the nominal value of the peak duty ratio as D_{peak} = 1/n cell. The fly-back transformer couples the primary and secondary side in the tap ratio of 1:9. The whole control system for the converter is based on the MPPT-P&O algorithm is implemented in the PIC16F877A microcontroller. The driver circuit for the microcontroller is LM7805 which is the voltage regulator used to provide the regulated power supply. The driver circuit for inverter is IR2110. Fig 10 shows the prototype of the proposed system.

Table 1: Design Specifications

Design parameters	**Specifications**
Maximum power of per solar panel	12W
Open circuit voltage and short circuit current per panel	10V,5A
Number of panels arranged	Single
Maximum converter input	79.96V
MPPT energy harvesting efficiency	>97%
Inverter static efficiency	>95%
Grid characteristics	Single phase, 220V, 50Hz, 100V RMS
Grid current	6A
Power Factor	0.909
THD	<0.05
Switching frequency	100KHz
Number of interleaved cells	3

IV. Simulation Results

Before implementing the design practically, it is better to verify it using simulation. The simulation in this study is done using the Matlab Simulink software. Matlab acts as the virtual test bench running on the computer where we can change parameter values and view voltages/currents in the middle of a simulation and verify the design specifications. Using the Mat lab simulations, we can improve our power supply performance, increase the reliability and drastically reduce the time to market from design to the final product.

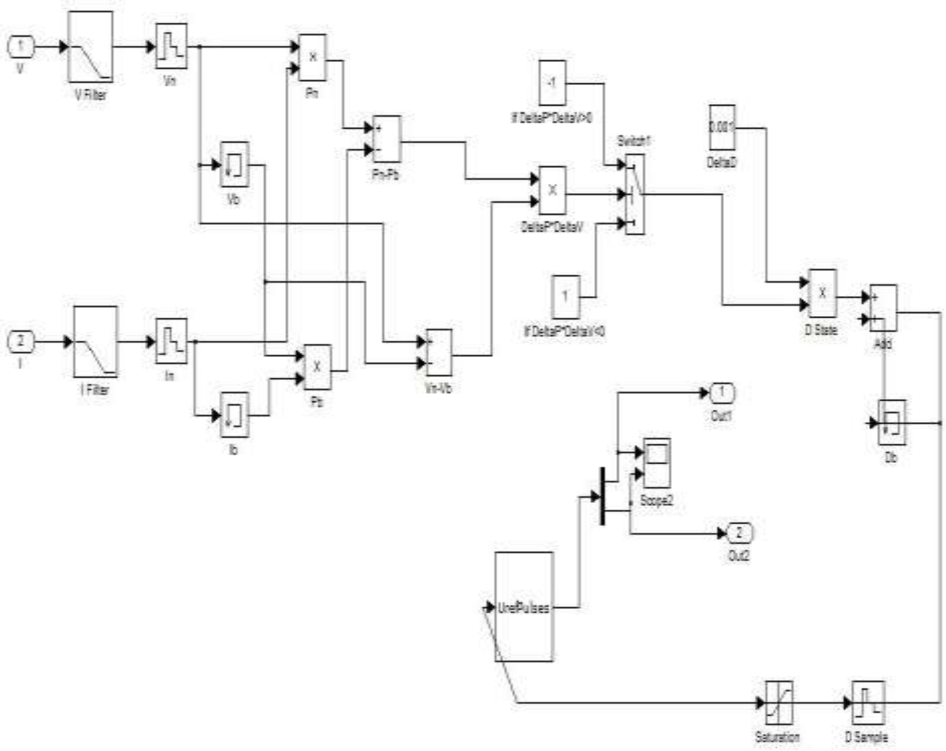

Fig.4. Matlab model / Simulink of the MPPT-Perturb & Observe algorithm

The simulation of the MPPT-P&O algorithm is shown in the Fig.4.The output from the MPPT block diagram is the duty cycle which acts as the control for the converter. The simulation model of the proposed of the PV inverter system is shown in the Fig.5. The DC output voltage from the solar panel is shown in the Fig.6. The maximum output DC voltage from the solar panel is in range of 75-80V.The output voltage of the converter is shown in the Fig.7. which ranges up to 140V.

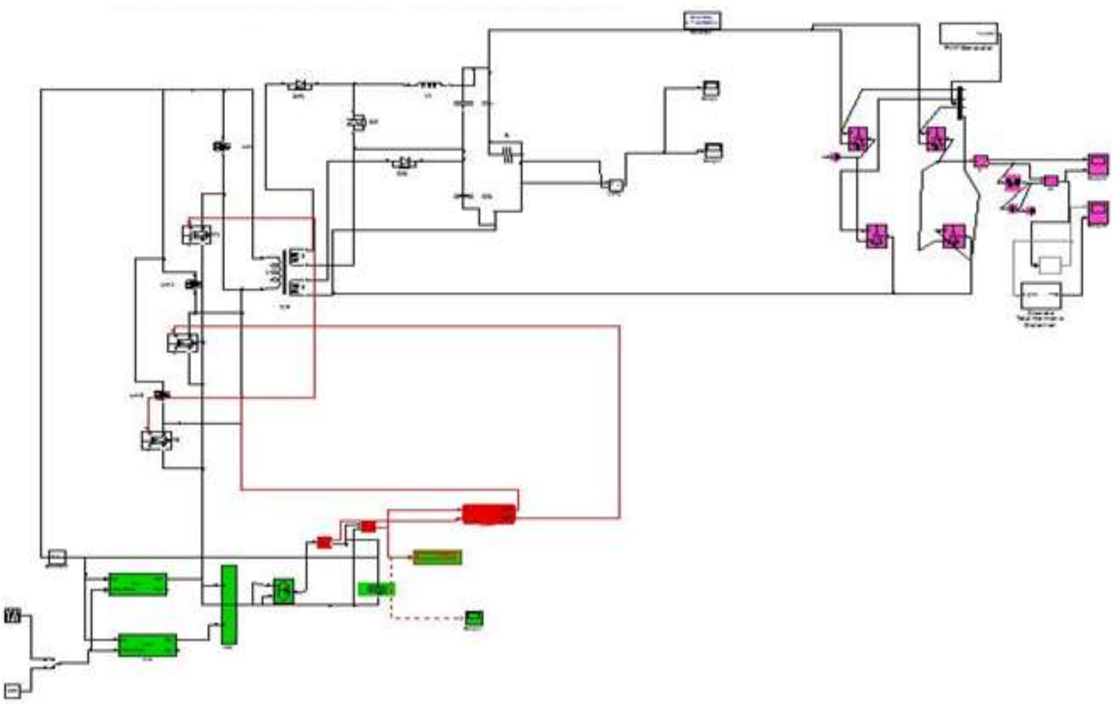

Fig.5.Matlab model / Simulink of the proposed PV inverter system

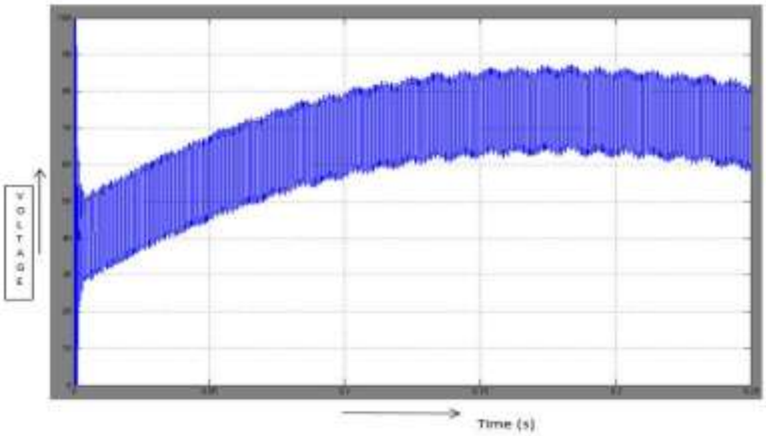

Fig.6. DC output voltage of the solar panel.

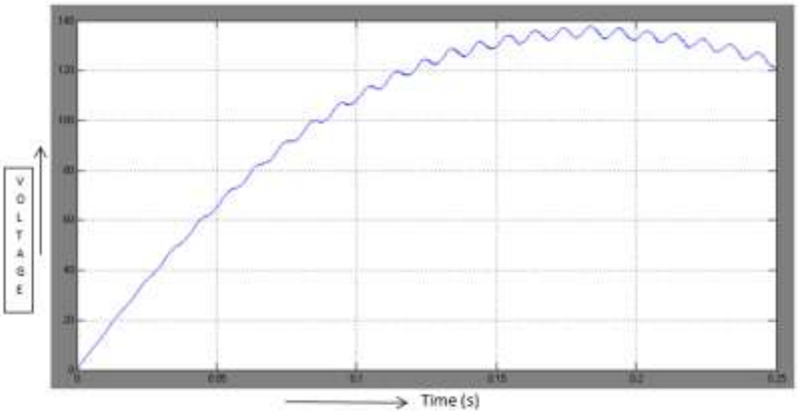

Fig.7. Output voltage of the converter.

Fig.8 shows the grid current and the RMS voltage. The grid current produced is 6A, and the RMS voltage is 100V. Fig.9. shows the grid voltage and the Total harmonic distortion. The THD produced is less than .1

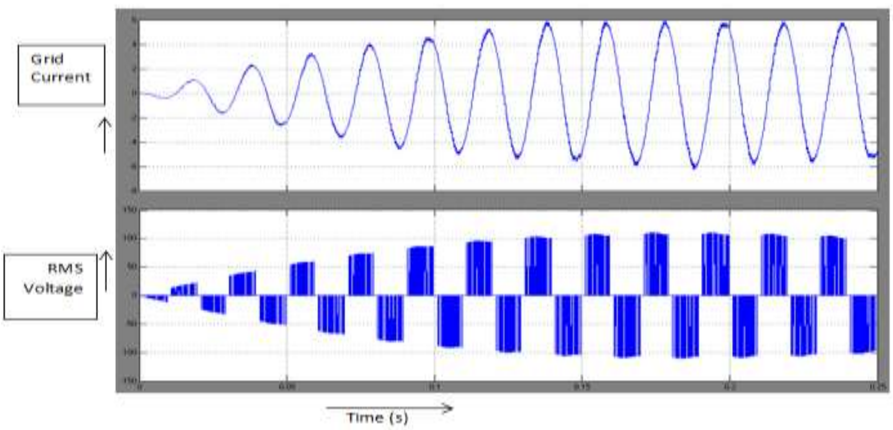

Fig.8. Grid current and the RMS voltage of the proposed system.

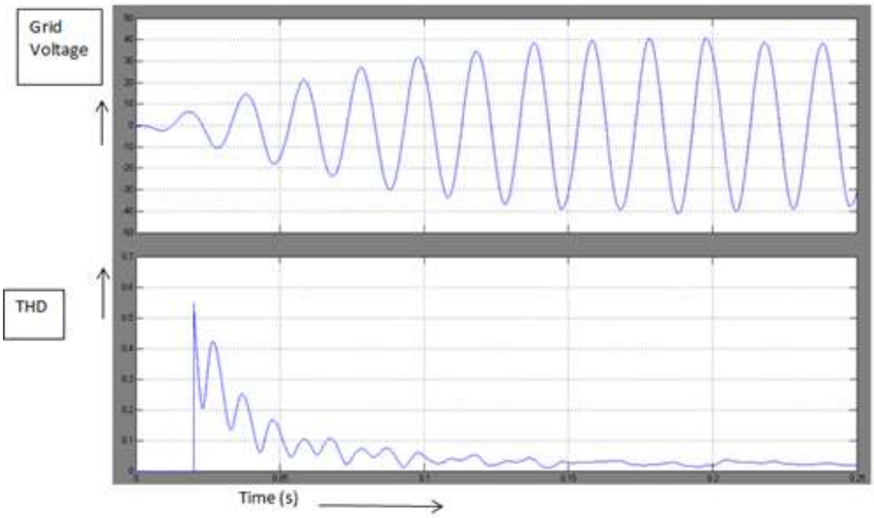

Fig.9. Grid voltage and total harmonic distortion (THD) waveform of the proposed system.

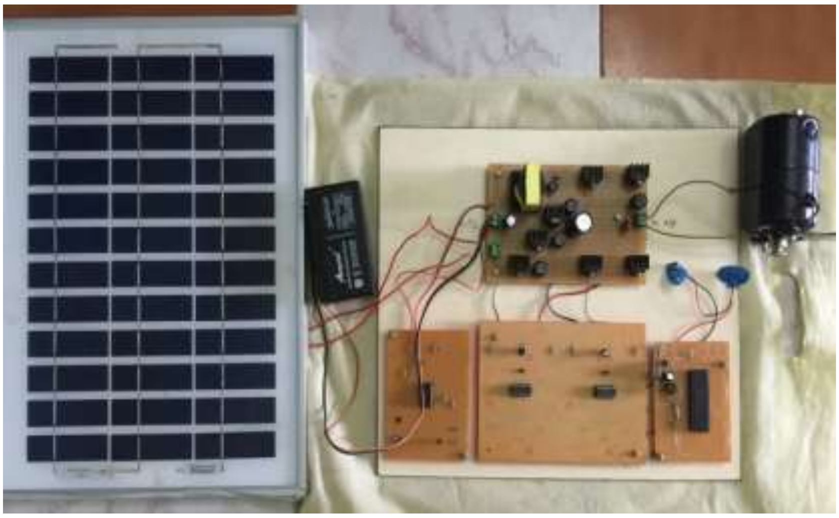

Fig. 10. Prototype of the proposed system.

V.Conclusion

Thus a central-type PV inverter is designed and implemented for small electric power system applications including the residential applications based on the interleaved multi-cell fly-back converter topology. In the design, we try to implement a prototype with the solar panel of 12W ratings at low cost with reduced number of components. The fly-back topology is selected because of its simple structure and easy power flow control which results in high power quality outputs at the grid interface. The experimental results prove the successful operation of the inverter with compliance to the design specifications. The energy harvesting efficiency of the MPPT controller and the inverter static efficiency are measured as 97% and 95% respectively. Also, the THD of the grid voltage is measured as 3.02% which are confirming in reduction of overall losses. Thus, the performance of the proposed system is comparable to the commercial isolated grid connected PV inverters in the market, and the proposed system has some cost advantage due to its topological benefit.

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