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Design and Analysis of Interleaved Fly-back Inverter Topology for PV Applications

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Abstract:
The main aim of this paper is to design and analysis of interleaved fly-back inverter topology for photovoltaic applications. The purpose of this inverter topology is to increase the output voltage of PV module and increase the overall efficiency of the system. Now a day's solar power conversion technology is one of the most extensively studied research area in the field of renewable energy sources(RES). Due to increased power demand, fuel consumption we should emphasize alternative RES's, such as solar energy which is pollution free and freely available in nature for power generation to meet the load demand. Also we should adopt some of the techniques such as Maximum Power Point Tracker(MPPT) to obtain maximum power from PV module with a high power conversion efficiency. Therefore, by using fly-back inverter topology with MPPT technique is more efficient than conventional technique, this is analyzed by MATLAB Simulink.

Keywords: *Photovoltaic(PV), Solar energy, Maximum Power Point Tracking(MPPT), Discontinuous Conduction Mode(DCM), Total Harmonic Distortion(THD).*

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I. INTRODUCTION

Now a days PV source is one of the most significant renewable energy resources. In the past few years' generation of electricity from solar cell became a very popular because, it is freely available to everyone and it is pollution free. Solar cells convert the light energy from the sun into electrical energy. Therefore, the main objective of this paper is to improve the performance and advancements in the PV inverter technology by adopting some of the new inverter topology for low and high power considerations.

So, the fly-back inverter topology is used because of its simple structure, easy power flow control with improved power quality at the grid, which are main requirements of this system [8]. The fly-back converter is available at low cost and it requires less number of passive components due to inductor combined along with transformer, so that voltage ratios will get multiplied with input and output voltage. It has an advantage of isolation between input and output ports. We must use solar power very properly through this interleaving method and also by adopting maximum power point tracker for PV system. Another important factor for the system is to select the mode of operation and it will be discontinuous current mode(DCM) which has several advantage such as, it gives fast dynamic response, no turn on losses, size of the transformer is small so cost is low, and it is easy to control the power flow.

Fly-back transformer is different from that of conventional transformers, because fly-back transformer has coupled inductors. Fly-back transformer core is made up of ferrite but in case of conventional transformer core is made of iron core. In fly-back transformer energy stored in non-magnetic air gap and it can be operated athigh frequency range up to 50-100kHz [9]. But, in case of conventional transformer is not able to store the energy. Fly-back transformer inductor coils are magnetically coupled, when current flowing through these coils energy stored in the inductor coil and when device is off energy transferred to secondary coils.

II. SYSTEM DESCRIPTION AND OPERATING PRINCIPLE

In the existing system three interleaved transformers were used which makes the circuit more complex and size of the circuit is increased. The general block diagram of fly-back inverter topology is shown below:

- PV Module: It is series and parallel combinationof solar cells connected in particular manner to get the desired output. The equivalent circuit of PV module is as shown in fig. 2and followed by some of the related equations.

- Interleaved Fly-back inverter: It is combination of fly-back converter and DC/AC inverter. First it converts PV module voltage to higher value then it supplies this voltage to full bridge inverter.
- Filter: Filter is connected at the output terminal of single phase full bridge inverter circuit. It is employed in the system to eliminate harmonics which are present in final output.
- Control Circuit: Simple PWM technique is used to generate the control signal pulses, which controls the switching operation of MOSFET switches

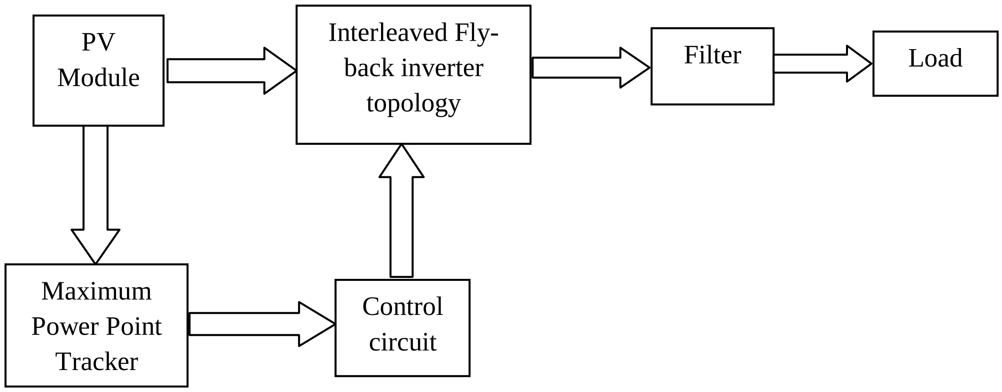

Fig. 1. General block diagram of proposed configuration.

From the above fig. 1, it shows different stages of power conversion from generation to load. It consists of different components such as, PV module, Interleaved fly-back inverter topology, filter, load, Maximum power tracking block, and control circuit. All these blocks are implemented in MATLAB/Simulink software and simulated.
The typical PV module equivalent circuit is as shown in fig. 2. It supplies power to interleaved fly-back inverter topology for the further power conversion and boosting purpose. It can be modelled by using equivalent circuit of PV cell, which is shown in the fig. 2. The current vs. voltage and power vs. voltage characteristics of PV module is as shown fig. 7 in the section IV.

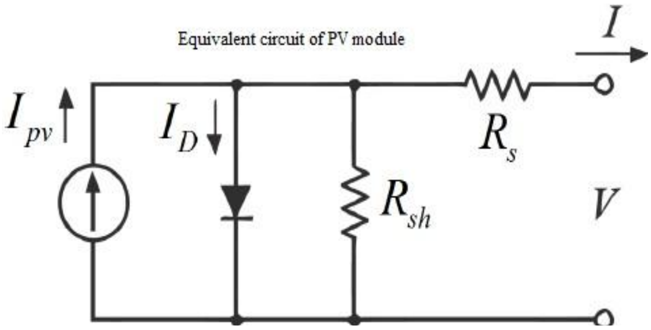

Fig. 2. Equivalent circuit model of PV module

The above circuit can be analyzed by using some of the equations given below, it gives relationship between voltage and current.

$$I = I_{PV} - I_d - I_{Rsh} \quad \text{……….} (1)$$

$$I = I_{PV} - I_O\left(e^{\frac{V+iR_S}{nV_T}} - 1\right) - \frac{V+iR_S}{R_{Sh}} \quad \text{…….} (2)$$

Where, V_T = Volt equivalent temperature.
I_o = Reverse saturation current.

$$V_T = \frac{kT}{q} \ \ldots\ldots\ldots (3)$$

$$I_O = KT^{-m} e^{\frac{-V_{GO}}{nV_T}} \ \ldots\ldots (4)$$

Open circuit voltage is given by equation (5)

$$V_{OC} = nV_T \ln(\frac{I_{pv}+I_o}{I_o}) \ldots\ldots. (5)$$

TABLE I. PV module standard parameters

Standard Parameters	Values
Boltzmann's constant (k)	1.3804e-23
Forbidden energy gap (V_{GO})	1.16 to 1.21 for Si
Electron charge (q)	1.6022e-19
Diode ideality factor (n)	0.9768

III. DESIGN and ANALYSIS OF PROPOSED SYSTEM

In the fly-back topology main switch and fly-back transformer are connected in series. When energy is supplied from PV module fly-back transformer not only boosts up the voltage it also provides galvanic isolation between PV module and load or gird. In the existing topology there are three interleaved cells are used [10].

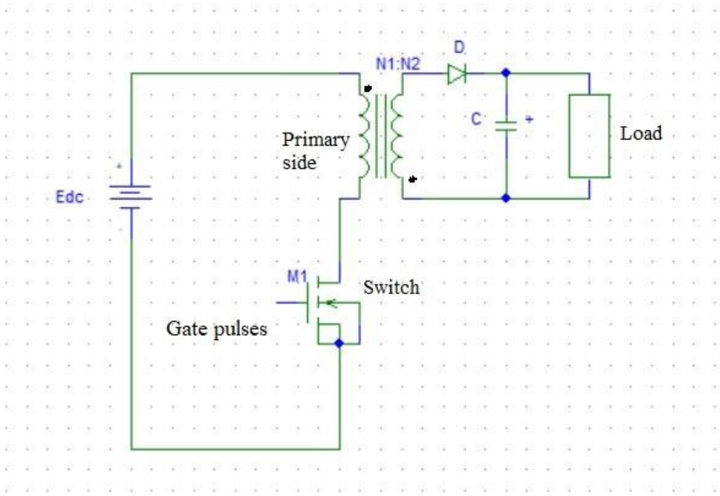

Fig. 3. Basic fly-back converter topology

When switch M1 is on, primary winding of a transformer gets connected to input supply voltage with dotted end connected to positive side. At this time diode 'D 'connected in series with secondary winding gets reversed biased due induced voltage in secondary (because of dotted end potential is higher) [9]. So when switch M1 is on primary winding is able to carry the current but current in the secondary winding is blocked due to reverse biased diode, this is mode-1 operation. So the relationship between the PV source and output voltage can written as below:

$$P_{PV} = I_{PV} \times V_{PV} \ldots\ldots\ldots\ldots. (6)$$

During mode-2 operation, when the switch M1 is turned off secondary winding starts conducting. For idealized circuit considered here, when switch is off secondary current abruptly rises from zero to I_P*(N1/N2). Where N1 and N2 are number of turns in primary and secondary.

$$P_O = \frac{1}{2} L_{pri} I^2{}_p f_s \ldots\ldots.. (7)$$

This entire energy is transfers to secondary at the end of mode-2 operation, it can be written as P_o is same as $V_O \times I_{Load}$. Where f_s-is switching frequency.

Design is done mainly for small scale power systems consisting of domestic applications,

The efficient working of proposed system depend on the design and practical implementation of fly-back transformers. So, fly-back transformers have to store more amount of energy and then it should transfer it to output.Here, we are using BP365TS PV module which gives around 54V dc voltage, which is V_{PV} after simulation,switching frequency of 100kHz and duty ratio which is obtained from MPPT controller is D=0.5025. The output voltage equation is given by below eqn. (8) [12]

$$V_O = nV_i(\frac{D}{1-D}) \ldots\ldots\ldots\ldots. (8)$$

Where n is turns ratio of secondary to primary, which can be written as n=N2/N1.

$$D_{peak} = {}^{1}/_{n_{cell}} \ldots\ldots\ldots. (9)$$

Peak duty ratio of overall system can be calculated from the eqn. (9). Where, n_{cell} is no. of interleaved cells is equal to 2.
$D_{peak} = \frac{1}{2} = 0.5$, this is theoretical value. But, from the simulation results it is found that peak duty ration is 0.5025 which is nearly equal to calculated value from the eqn. (9).

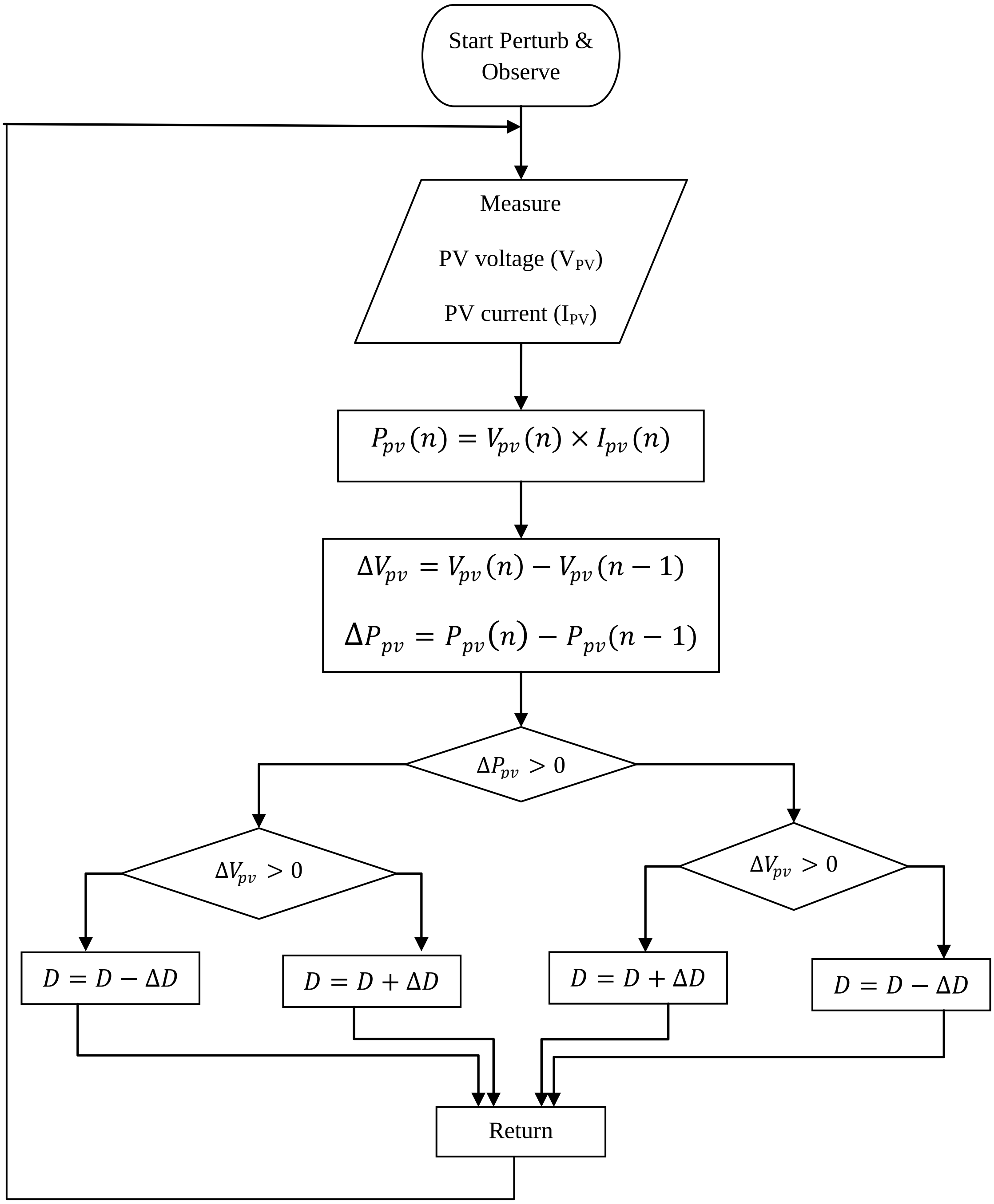

Fig. 4. P & O Algorithm for proposed system

The P&O is one of the most extensively used MPPT technique for PV applications because of its simple structure, efficient, robust and easy to implement by using low cost controllers. The flowchart of P&O MPPT technique is as shown in fig. 3. It senses the voltage and current by using sensors and calculates PV power. If there is small perturbation is introduced due to changes in the solar irradiation, power generated will be decrease hence, the duty ratio will be changed to track the maximum power point(MPP). This process is continued till it reaching MPP and output of the inverter will be controlled by duty cycle of pulses through this

MPPT technique [11]. From the output voltage and current of PV module, the power of PV panel is measured. The difference in voltage is obtained by calculating difference between present and past voltage. In the same way change in photovoltaic power is calculated. If change in power and voltage is positive at this time duty ratio is decreased. But if change in power is positive but change in voltage is negative then duty ratio will be increased. The required duty ratio can be obtained from MPPT algorithm.

TABLE II. DESIGN SPECIFICATIONS

Design Parameters	**Specifications**
PV Module type	BP365TS
Open circuit voltage and short circuit current	11V and 8.1A
PV Module group arrangement	5 panels in string and 6 strings in parallel
Voltage and current at MPP and Per panel group arrangement	8.7V, 7.5A and 43.5V, 45A
Total maximum dc power from PV module	1957.5W
Grid/Load characteristics	Single phase, 230 V, 50 Hz,
Switching frequency	100KHz.
No. of interleaved cells	2

IV. SIMULATION RESULTS

The solar system which is connected to interleaved fly-back inverter topology is simulated in MATLAB/ Simulink software environment, is as illustrated in fig. 5.

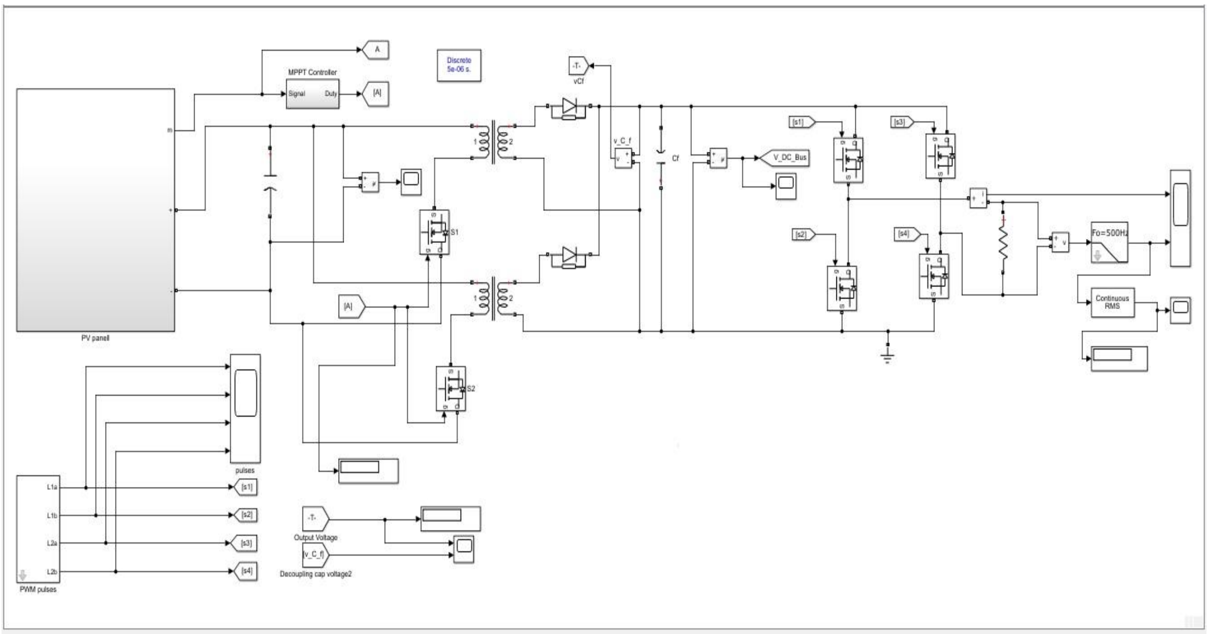

Fig. 5. Simulink model of fly-back inverter with PV module

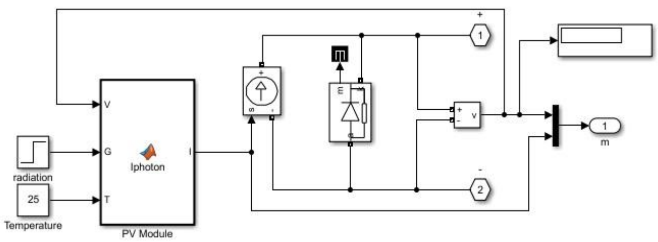

Fig. 6. Enlarged view of PV module

The output of the solar PV module is fed to fly-back inverter through decoupling capacitor. In this paper two interleaved fly-back converters are connected in parallel which will enhance the voltage from small output of PV module. Output voltage of PV module is around 54V. Duty ratio after the simulation got around 0.5025, which is very close to theoretical value obtained from eqn. (9), i.e., 0.5.Coupled inductors of fly-back converter store energy in magnetic form when switch is on, and during off period it transforms the energy through secondary coupled inductor. The voltage across the coupling capacitor C_f is pulsating DC.One of the key difference between conventional transformers and fly-back transformer is that, the couple inductors is shown in fig. 3. Core of fly-back transformer is made of ferrite whereas core of conventional transformer is iron core[1]. The I-V and P-V characteristics of PV module is as shown in below fig. 7.

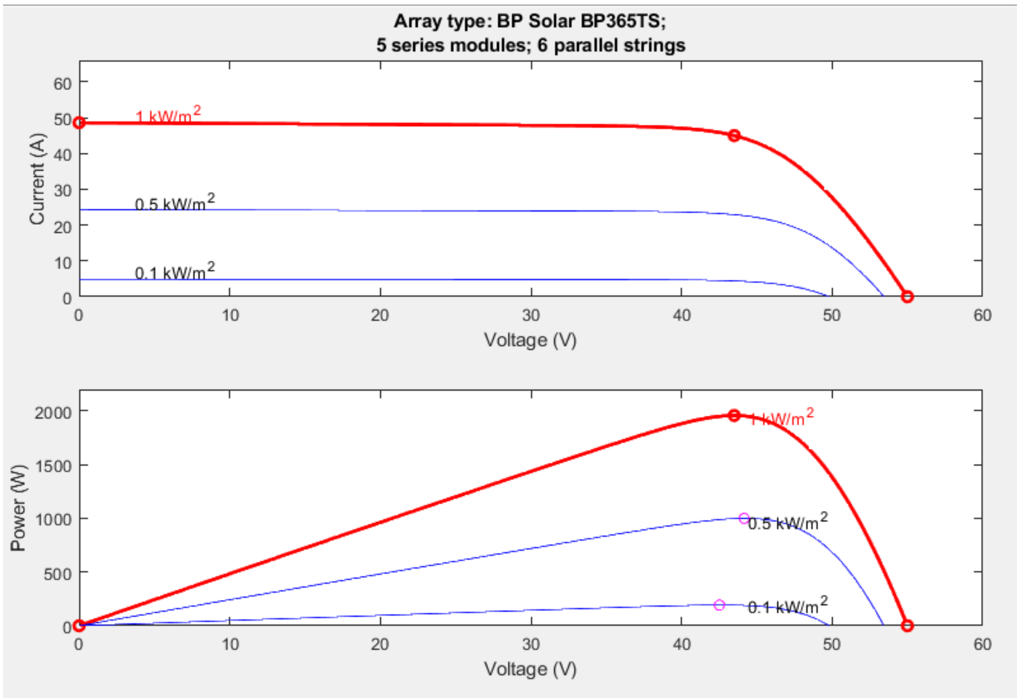

Fig. 7. I vs. V and P vs. V characteristics of PV Module.

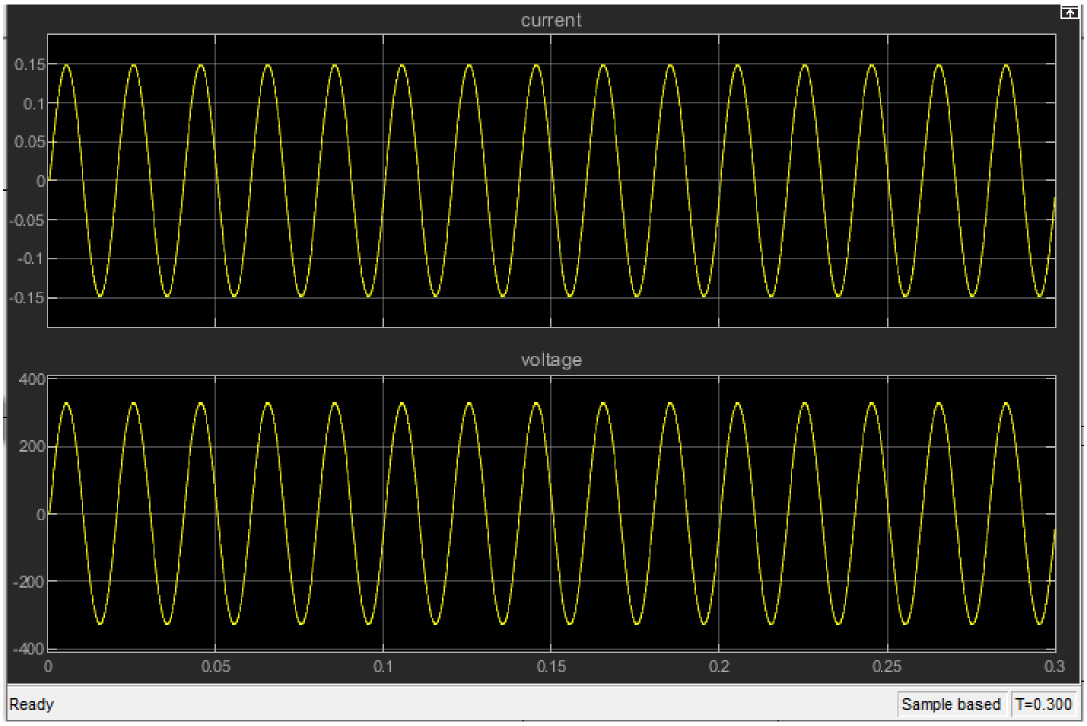

Fig. 8. Output voltage and current waveforms across the load.

The above fig. 7 shows the graph of output voltage and current vs. time waveforms. From the above waveforms it is found that peak value of current is about 0.15A and voltage is 327V.

By FFT analysis, THD value is analyzed in fig. 9. Which shows output voltage across the load that is 0.99% for frequency of 50Hz and for three cycles. Similarly, THD value for the output current is 0.99% for frequency of 50Hz and for three cycles is shown in below fig. 10. From both FFT analysis of voltage and current THD value is less than the capacitor clamping fly-back inverter topology.

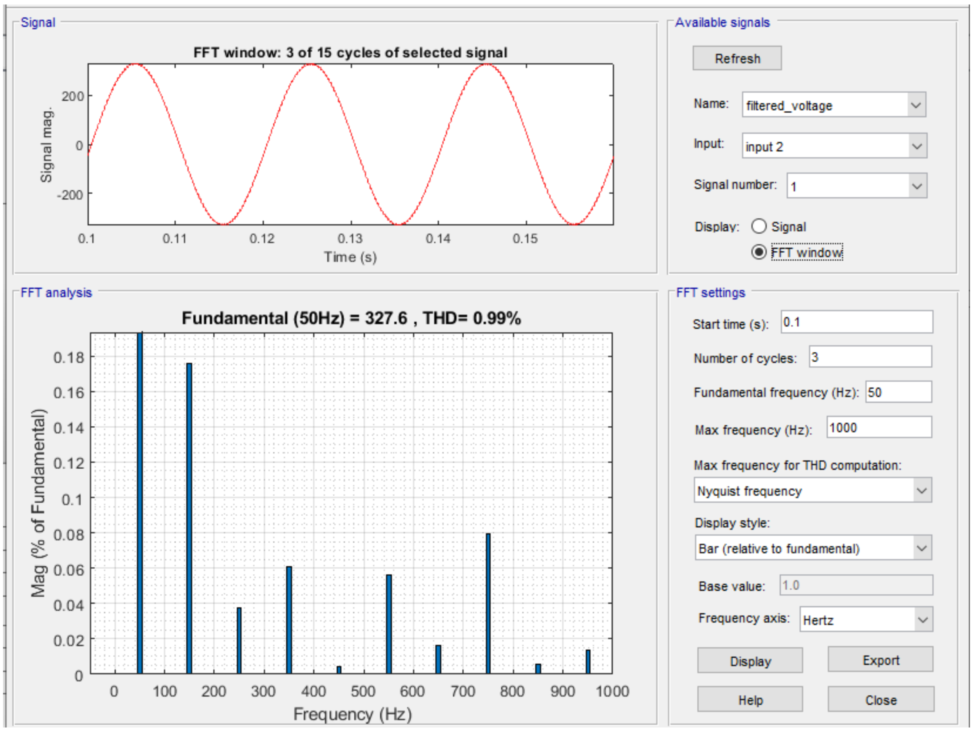

Fig. 9. FFT analysis of output voltage.

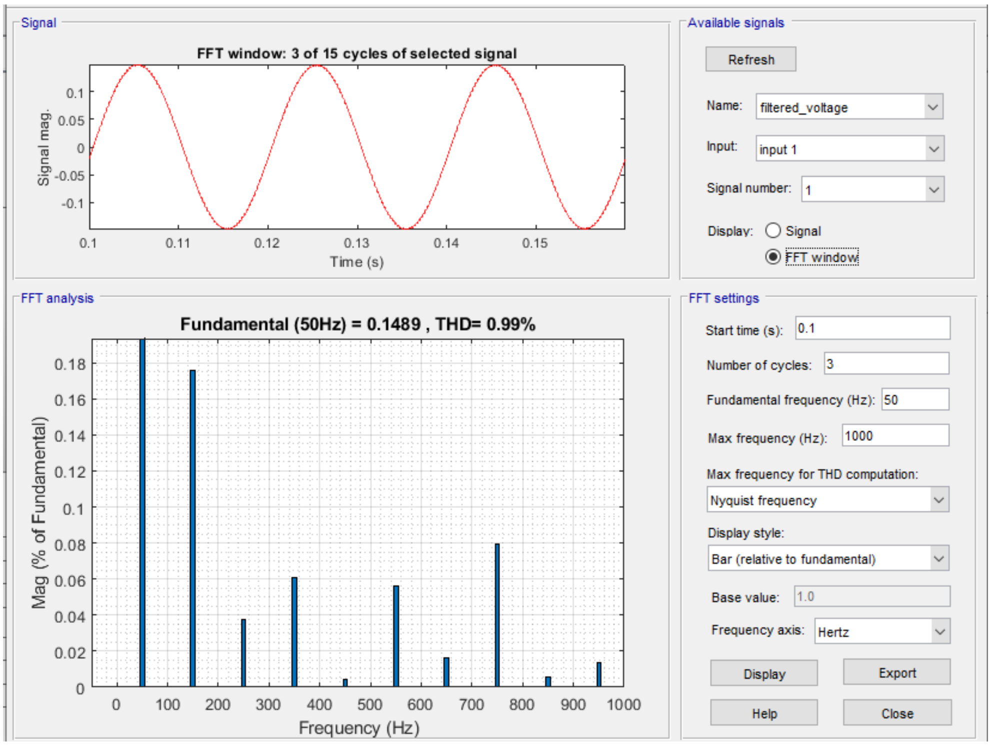

Fig. 10. FFT analysis of output current.

V. CONCLUSION

Interleaved fly-back converter has become one of the important component because of its less cost, easy power control and moreover it can operate light loads. By interleaving the fly-back inverters in parallel we can increases the power handling capacity of overall system and also it provides galvanic isolation between input and output. Existing conventional inverters have more size and lower efficiency hence fly-back inverter structure is best suited solutions for all these problems. Also by increasing the fly-back transformer turns ration we can increase the output voltage and overall performance. Therefore, from the simulation results it is found that efficiency of the inverter is 94.96 % and total harmonic distortion(THD) is 0.99% which is very less compare to other conventional technique and hence this is more efficient than the other topology.

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