



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJIRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 9, September 2021

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 7.569

Combination of Cuk & Flyback Converters for Grid Connected Photovoltaic Systems

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ABSTRACT: This paper proposes a special type of grid-connected inverter system for photo voltaic applications. Here the inverter system is an interleaved high power flyback inverter, ie to implement an improved grid-connected interleaved flyback inverter based on photovoltaic. The existing micro inverter topology based on flyback converter. Therefore the main objective of this paper is to design a new flyback inverter system at high power with good performance. The flyback inverter system designed for 2 KW and it is achieved by interleaving of three flyback cell. In a Grid Connected Photo-voltaic System (GCPVS) maximum power is to be drawn from the PV array and has to be injected into the Grid, using suitable maximum power point tracking algorithms, converter topologies and control algorithms. Usually converter topologies such as buck, boost, buck-boost, sepic, flyback, push pull etc. are used. Loss factors such as irradiance, temperature, shading effects etc. have zero loss in a two stage system, but additional converter used will lead to an extra loss which makes the single stage system more efficient when compared to a two stage systems, in applications like standalone and grid connected renewable energy systems. In Cuk converter the source and load side are separated via a capacitor thus energy transfer from the source side to load side occurs through this capacitor which leads to less current ripples at the load side. The converter is operated in discontinuous current mode (DCM) for easy and stable generation of ac current at grid interface. The system simulation confirms the performance and design of the proposed system using MATLAB Simulink.

KEYWORDS: Central type PV inverter, Decoupling capacitor, Discontinuous current mode (DCM), Flyback inverter, Interleaving, Photovoltaic, P&O algorithm

I. INTRODUCTION

- I. This Project present, a grid connected central-type photovoltaic inverter based on the interleaved flyback converter topology. The interleaved flyback converter used to maximize the power level, which can reduce current ripple, reduce the size of the passive component and reduce the overall cost. The existing system the flyback topology used in micro inverter at very low power. The main aim of this paper is to design flyback converter at high power and prove its practicality with satisfactory performance as a central-type photovoltaic inverter. The design of flyback inverter using interleaving of 3-stage flyback converter.
- II. The combined benefits of flyback converter to diminished size of passive filtering component. This converter works in discontinuous current mode (DCM), it provides the fast dynamic response, easy control, no reverse recovery losses and no turn ON losses. The operation principles are discussed in details. The proposed converter is simulated in MATLAB software.

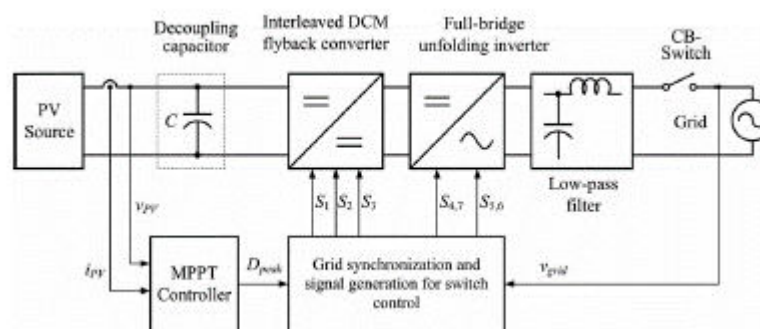


Fig.1. Block diagram of the proposed system

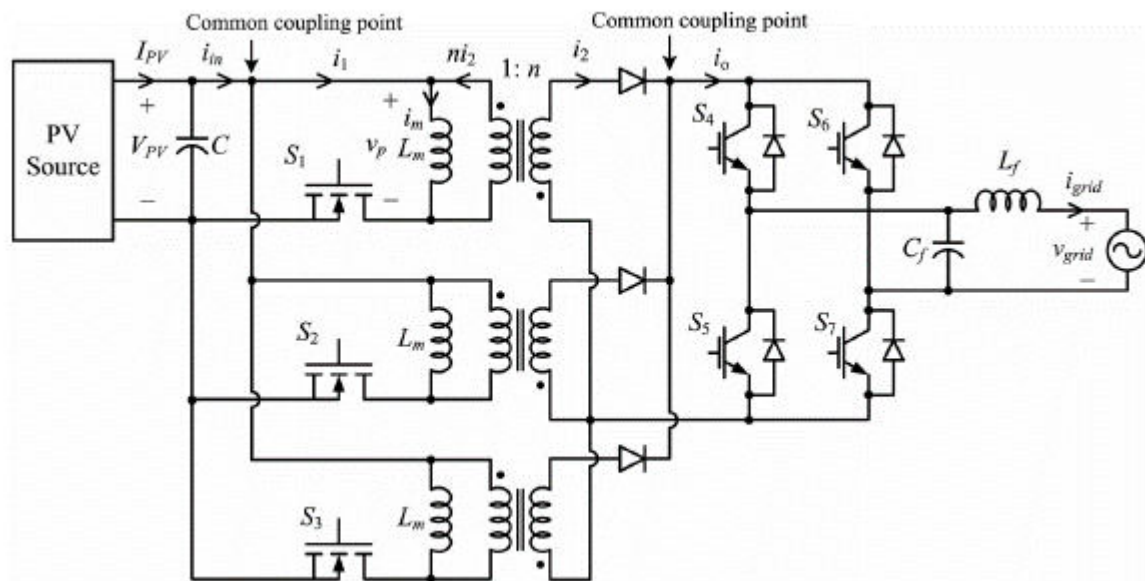


Fig.2. Circuit diagram of proposed topology

Practical implementation of a transformer with relatively large energy storage capability is always a challenge. The air gap is where the energy is stored, so a high-power flyback converter design needs a relatively large air gap. As a result of this, the magnetizing inductance is going to be quite small. The aforementioned challenge is actually achieving such a small magnetizing inductance with low leakage inductance. A flyback converter built with a transformer that has large leakage flux and poor coupling will have poor energy transfer efficiency. Mainly for this reason, the flyback converters are generally not designed for high power. As a result, the flyback topology finds a limited role in PV applications only at very low power as micro inverter. In this technology, every PV panel comes with a dedicated energy conversion unit; a micro inverter attached to the output terminals. For this reason, the technology is also named as ac PV module application. In this practice, many such ac PV modules are connected in parallel to get the desired power output. The maximum harvesting of solar energy in this method is the best since there is a dedicated maximum power point tracker (MPPT) for each PV panel. However, the overall cost of this application is higher compared to the central-type inverter systems. The interleaving of these high-power flyback stages (cells) facilitates developing a central-type PV inverter. The added benefit of interleaving is that the frequency of the ripple components (undesired harmonics) at the waveforms are increased in proportion to the number of interleaved cells. This feature facilitates easy filtering of the ripple components or using smaller sized filtering elements. The ability to reduce the size of passive elements is beneficial for reducing the cost and obtaining a compact converter.

The choice of operation mode for the converter is discontinuous current mode (DCM). It provides very fast dynamic response and a guaranteed stability for all operating conditions under consideration. The diodes exhibits reverse recovery problems in CCM operation which cause noise, electromagnetic interference problems, and additional losses.

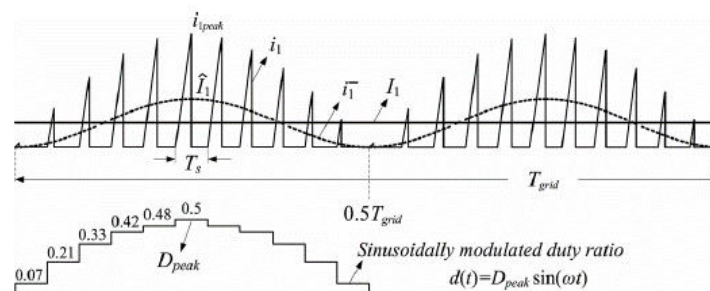


Fig.3. Flyback converter input current over a one grid period

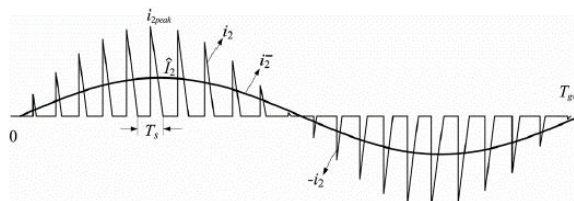


Fig.4. Flyback converter output current after full-bridge inverter

So, DCM operation eliminates all these complications. In DCM it is easy to control. No need for a feedback loop for the control of the grid current. Only an open-loop control is enough to synthesize a sinusoidal current with good total harmonic distortion (THD). This makes the implementation of the control system less complex for DSP and allows faster execution time

II. PROPOSED TOPOLOGY

To meet the requirements i.e. low cost and higher efficiency, the entire system was designed to use a PV module. The maximum power developed by the panel is fed to H-bridge inverter through a interleaved flyback converter. Fig. 1 shows the block diagram of the proposed system. This topology is derived from conventional flyback micro-Inverter by interleaving three flyback cells. Block diagram consist of mainly five blocks. In which PV source is applied to the flyback converter through a decoupling capacitor. Then the output of the flyback converter fed to the full bridge unfolding inverter. There is a low pass filter block after the inverter to reduce harmonics in the output current. The control block is used to perform two important control jobs. For the first job, it should regulate proper DC input PV current and PV voltage. For the second job, it should provide control to convert DC current into AC current at the grid interface for power injection. The purpose of interleaving of winding reduces the amount of leakage flux and improve coefficient of coupling, so the transformer can transfer more power from one side to another side.

III. METHODOLOGY

Exemplar based Inpainting technique is used for inpainting of text regions, which takes structure synthesis and texturesynthesis together. The inpainting is done in such a manner, that it fills the damaged region or holes in an image, with surrounding colour and texture. The algorithm is based on patch based filling procedure. First find target region using mask image and then find boundary of target region. For all the boundary points it defined patch and find the priority of these patches. It starts filling the target region from the highest priority patch by finding the best match patch. This procedure is repeated until entire target region is inpainted.

IV. PRINCIPLES OF OPERATION AND CONVERTER ANALYSIS

The circuit diagram of the proposed topology. The current IPV from the PV source is applied to the three cell flyback converter through decoupling capacitor C; it is used to reduce harmonics in the input PV current. There are three metal-oxide-semiconductor field-effect transistor (MOSFET) used in primary side as a flyback switch for switching purpose. When the flyback switches (S1, S2, S3) are turned ON, a current flows from the PV source into the magnetizing inductance of the flyback transformers, and energy is stored in the form of magnetic field. When switches are ON, current do not flows to the output due to secondary diodes. When the flyback switches are turned OFF, the energy stored in the magnetizing inductances is transferred into the grid in the form of current. So, the flyback inverter acts like a voltage-controlled current source.

The H-bridge inverter is used for unfolding the sinusoidal modulated dc current packs into ac at the right moment of the grid voltage. The switches of the inverter are operated at the grid frequency, So the switching losses are insignificant. However, for easy control also the availability in the laboratory for fast prototyping, we prefer using insulated-gate bipolar transistor (IGBT) switches for this design. But, the final prototype will not use IGBTs. The low-pass filter after the IGBT inverter is responsible for supplying a current to the grid with low THD by removing the high frequency harmonics of the pulsed current waveforms. The converter is operated in DCM for easy and stable generation of ac currents at the grid interface. The DCM operation of converter under open-loop control produces triangular current

pulses at every switching period. If sinusoidal pulse width modulation (PWM) method is used for control, the inverter will regulate these current pulses into a sinusoidal current in phase with the grid voltage. Fig.3 and Fig.4 shows the conceptual input and output current. There are three component ie, instantaneous flyback converter input current (i_1), instantaneous average of i_1 over one switching period and dc component (I_1) for input current and instantaneous flyback converter output current (i_2), instantaneous average () for output current. In order to reduce output current distortion and for the good performance of the converter a decoupling capacitor placed before the converter input and sized in such a way that both low and high frequency ac components are bypassed sufficiently and only dc component is allowed to supply by PV source.

The circuit can be analyze using circuit schematic shown in Fig.2 and only consider the first flyback cell; this is done for the designing purpose. Fig.5 shows the control signal for the flyback switch, flyback transformer primary voltage (v_p), and magnetizing current component (i_m). Analysis done for particular switching period when both grid voltage and duty ratio (D_{peak}) are at their peak values.

V. ANALYSIS WHEN FLYBACK SWITCH IS TURNED ON

When flyback switch S_1 is turned ON in Fig. 2, the PV voltage V_{PV} is applied to the primary winding and current flows in the primary circuit. The current starts from zero initial value and increases linearly with positive slope. The magnetizing current shown in Fig.5 can be defined as Where L_m is the flyback transformer magnetizing inductance. At the end of the switch on time, primary current reaches its peak value as follows:

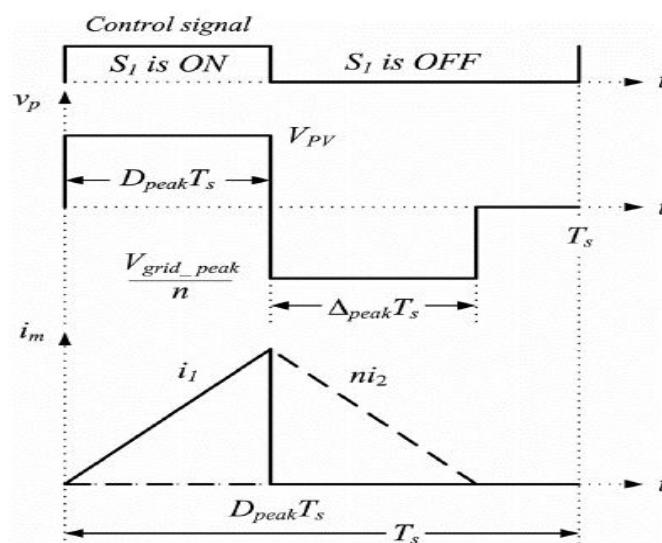
$$I_L = I_m = \frac{V_{pv}}{L_m} t$$

Where f_s is the switching frequency, this particular maximum is the peak value of the largest of the sinusoidally modulated triangular current pulses within a half-grid period shown in Fig.3. The area of this triangle also gives the peak value of the twice the line frequency component of the flyback input current, which is given as follows:

$$I_{L \text{ peak}} = I_m \text{ peak} = \frac{V_{pv} D_{peak}}{L_m f_s}$$

The half of gives the average dc current I_1 , that is drawn from the PV source.

$$\hat{I} = \frac{V_{pv} D_{peak}^2}{2 L_m f_s}$$



CONTROL SIGNAL FOR FLYBACK SWITCH, FLYBACK TRANSFORMER PRIMARY VOLTAGE (V_P), MAGNETIZING CURRENT (I_M)

Where n_{cell} is the number of the interleaved cells and I_{PV} is the current delivered by the PV source. So, the relationship between the flyback converter parameters and the PV source output power can be written as follows:

$$I_l = \frac{I_{pv}}{n_{cell}} = \frac{V_{pv} D^2_{peak}}{4 L m f_s}$$

At the design stage, the desired value of the magnetizing inductance of the flyback transformer (L_m) is computed using (5) based on the selected switching frequency, the optimum number of the interleaved cells, and the optimum D_{peak} value. The D_{peak} value is generated by the MPPT controller for maximum harvesting of the solar energy under different irradiation levels and applied to the flyback switches.

$$P_{pv} = V_{pv} I_{pv} = \frac{n_{cell} V_{pv}^2 D_{peak}^2}{4 L m f_s}$$

Where V_{PVmax} is the maximum PV voltage, is the peak value of the maximum grid voltage and ΔV is the transient voltage that may occur due to the leakage inductance of the transformer and the parasitic inductances in the circuit during

$$V_{Diode_max} = n V_{pvmax} + \hat{V}_{grid_max}$$

The decoupling capacitor works as buffer and provides the power balancing between the PV source and the grid. So, the major sizing criterion of the decoupling capacitor is the effectiveness in diverting the double line frequency component away from the PV source by creating a low impedance path and so maintaining a low ripple at the PV terminals. The following gives the peak-to-peak voltage ripple across the decoupling capacitor

$$V_{Diode_max} = n V_{pvmax} + \hat{V}_{grid_max}$$

Consequently, using (15), the minimum value of the decoupling capacitor based on the desired peak-to-peak voltage ripple specification can be computed as follows

Where

ΔV_c – maximum to maximum ripple voltage

ΔI_c – current ripple

X_c - Decoupling capacitor reactance

$$C \geq \frac{2 I_{pv}}{(2 \cdot 100) \Delta V_{pv}}$$

VI. CONVERTER DESIGN

The converter is designed mainly for small electric power system including residential applications. Here the power rating is selected as 2 KW and switching frequency selected as 40 KHz in order to achieve high efficiency. The choice of switching device should have fast current fall time (t_f) to reduce the turn-off losses, So we use MOSFET as the flyback switch. The MOSFETs with low voltage ratings have much lower on-state resistance ($R_{DS(on)}$) and more efficient as far as the conduction losses are concerned, we prefer low voltage design. Table I gives the specifications to be used for the design of the proposed inverter system. The maximum converter input voltage 108.5 V for the selected PV module arrangement. The next important design step is to determine the ideal number of the interleaved cells (n_{cell}). This number selected based on following strategies

- Interleaving reduces the passive filtering efforts to the practical minimum.
- To determine the ideal power rating for the single flyback cell. The three cell rated at 700 W are connected in parallel in order to reach 2 KW.

Design parameters	Specifications
PV model and maximum power	BP365, 65 W
Open circuit voltage and short circuit current per panel	21.7 V, 3.99 A
PV panel group arrangement	5 panels in a string and 6 strings in parallel
Voltage and current at the maximum power point per panel and per the selected panel group arrangement	17.6 V, 3.6932 A 88 V, 22.16 A
Total maximum dc power from the panel group	1950 W
MPPT energy harvesting efficiency	>98%
Grid characteristics	Single-phase, 220 V, 50 Hz 143–264 V RMS 45.5–54.5 Hz

Based on the selected switching frequency and the cell number, the ripple frequency at the current waveform at the common coupling points (see Fig. 2) becomes 120 kHz. This frequency is high enough for easy filtering of the switching frequency harmonics with relatively small passive elements. Using cell number we can find peak duty ratio as $D_{\text{peak}} = 1/n_{\text{cell}}$.

Flyback Transformer Design

The success of the proposed inverter system is very much related to the success in the design and the practical realization of the flyback transformers. As aforementioned, the flyback transformers have to store large amount of energy

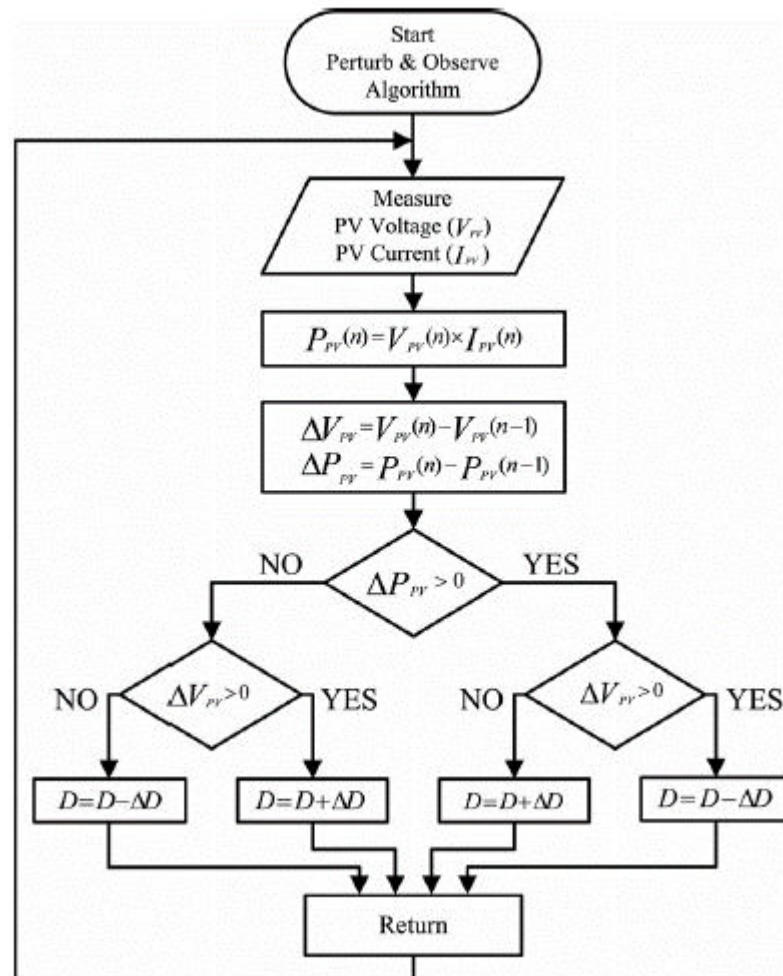


FIG.6 FLOW CHART OF P & O ALGORITHM

then transfer it to the output through magnetic coupling at every switching cycle. Therefore, during the design process, the strategies that first create the most effective energy storage mechanism and second the most optimum and efficient energy transfer path must be employed. Firstly, the magnetizing inductance of the flyback transformer L_m is determined under nominal conditions. Using 88 V for V_{PV} , 40 kHz for f_s , 1950 W for P_{PV} , 3 for n_{cell} , and 0.3333 for D_{peak} in (5), L_m is calculated as 8.27 μH . Rounding this result to 8 μH and reworking (5), the practical value of D_{peak} is calculated as 0.3278. Then, the turn's ratio of the transformer is determined for the minimum the grid voltage. Using 202 V for V_{grid} (minimum peak grid voltage), 88V for V_{PV} , and 0.3278 for D_{peak} in (11), the turns ratio (n) is determined as 4.7. But, it is selected as 4.5 for practical implementation.

Control System design

The control system is designed to perform two important control jobs simultaneously without using a feedback loop. While it is harvesting the maximum power available in the solar cells, it must pump that power into the utility grid with high power quality. For the first job, it should regulate a proper dc current I_{PV} and voltage V_{PV} at the PV interface for maximum energy harvesting. For the second job, it must provide control to convert the dc current, which comes from the panels and continuously regulated for the MPPT purpose

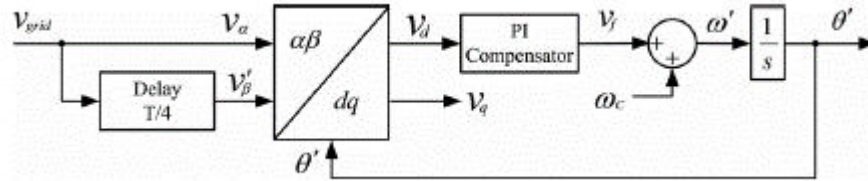
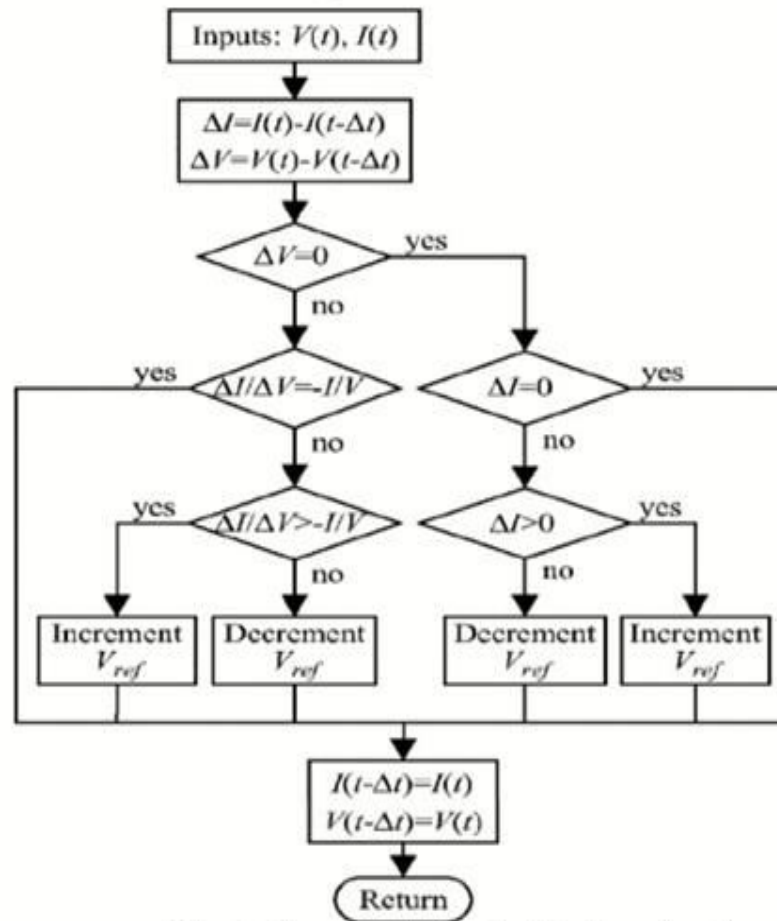
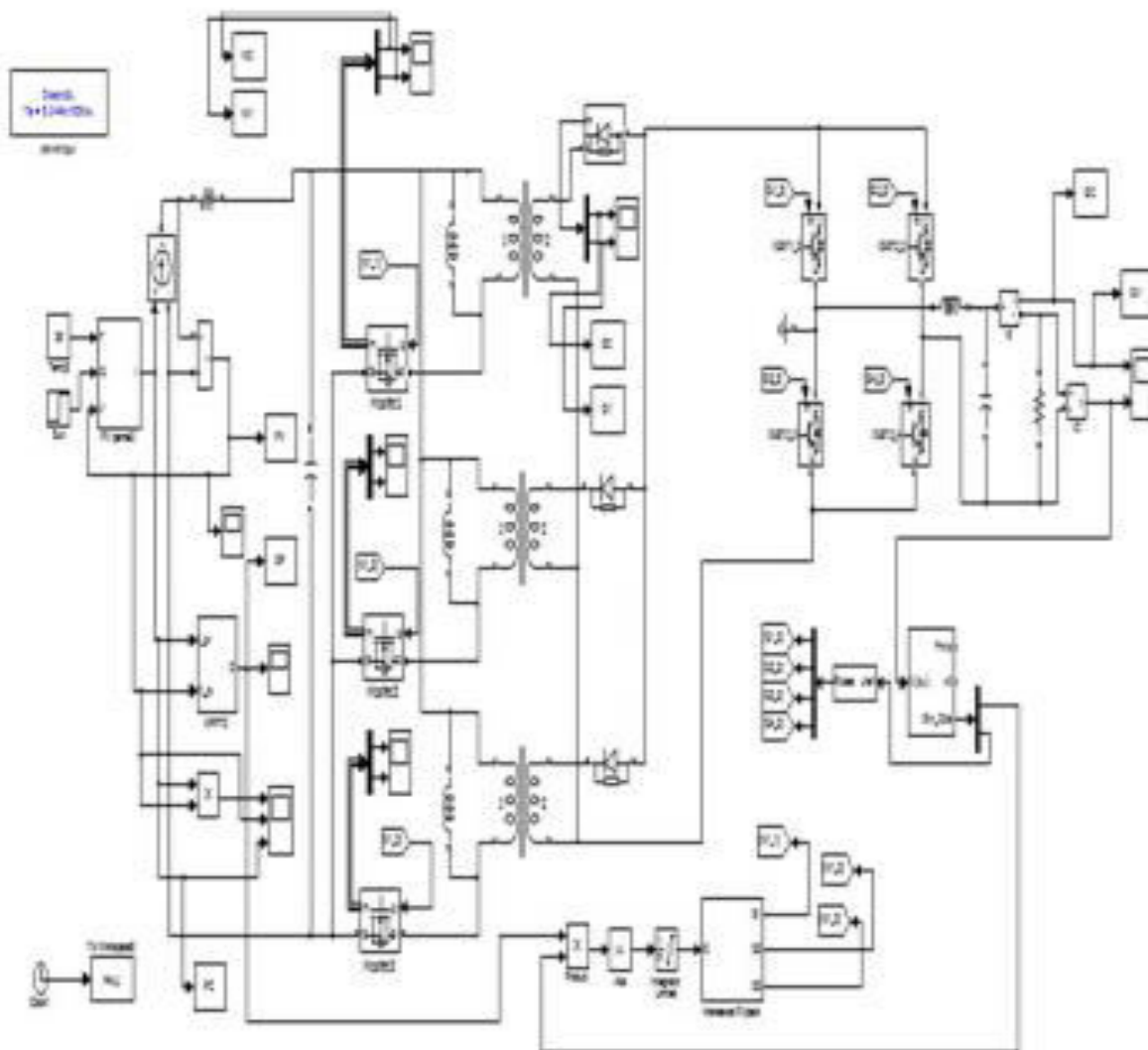


Fig.7. PLL structure based on T/4 transport delay technique

in to ac current at the grid interface for power injection. In addition, this ac current should be synchronized with the grid frequency, should have low harmonic distortion, and a power factor close to unity. Because of its implementation simplicity, the perturb and observe (P&O) method is selected as the MPPT algorithm.



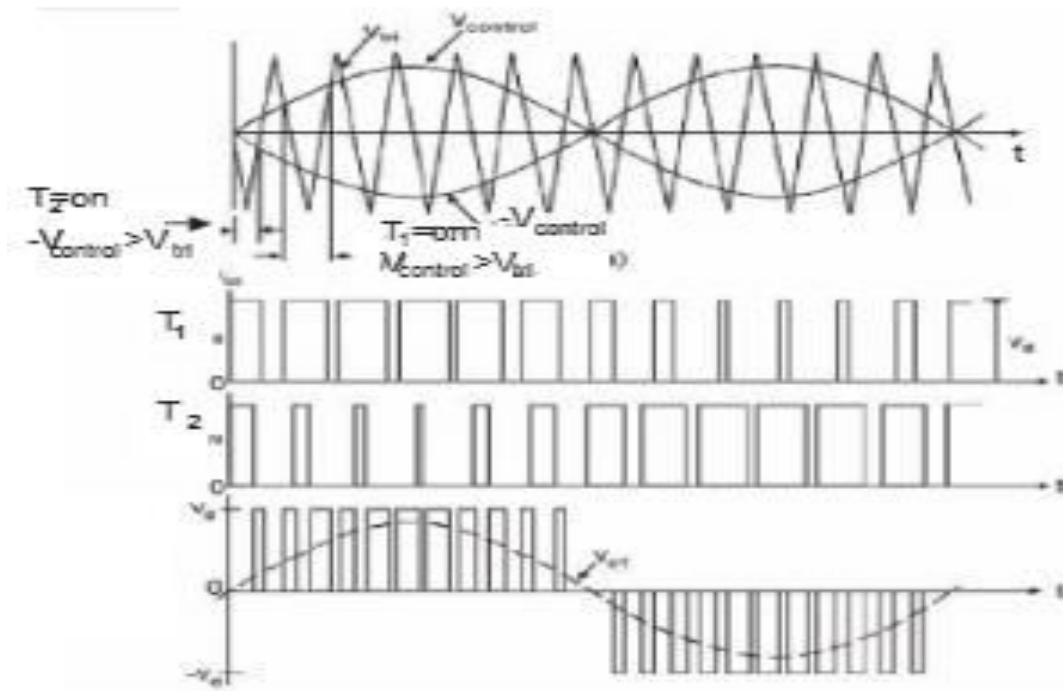
SIMULATION SET UP & DISCUSSIONS



PWM techniques Diagram

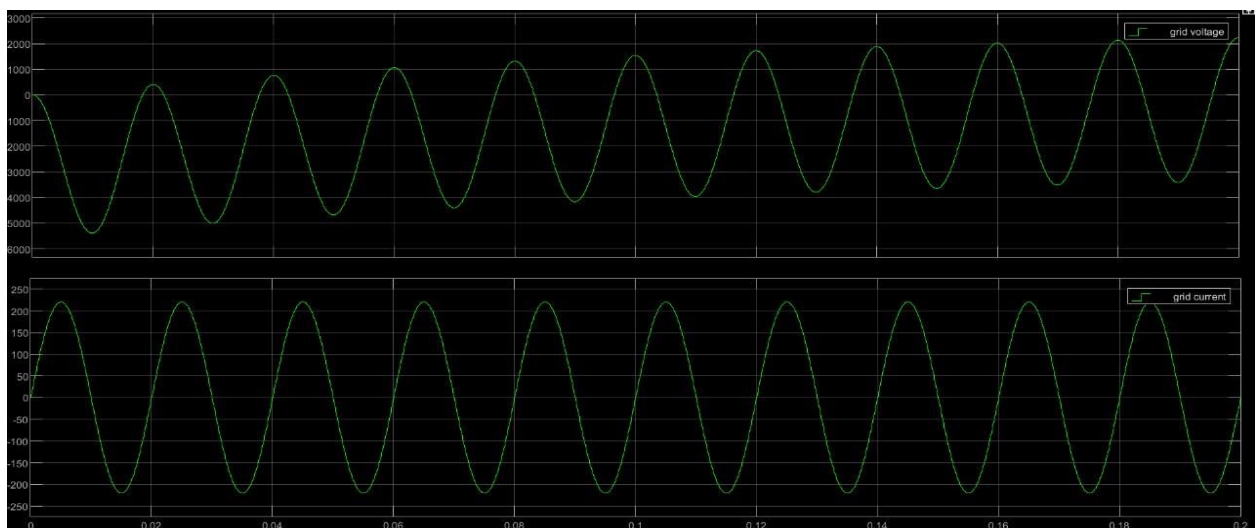
The represented diagram corresponds with two control loops: an internal one, that allows controlling the inverter output current and an external one that controls the dc bus voltage V_{dc} . The proposed control is that the output current I_{out} is controlled varying the amplitude modulation index. The digital pulse -width-modulation (DPWM) converts the stored code in the look up table in pulsating signal and generates the driving signals of the switches. The duty cycle depends on the stored code for each pattern defined by m_a .

The synchronization of the I_{out} and the V_{grid} is assumed with the zero crossing detectors (ZCD). The synchro-signal starts the shifted phase counter. Initially loaded from the look up table to the phase register the code corresponding with the actual value of the phase according with a PWM pattern that satisfy the output current reference.

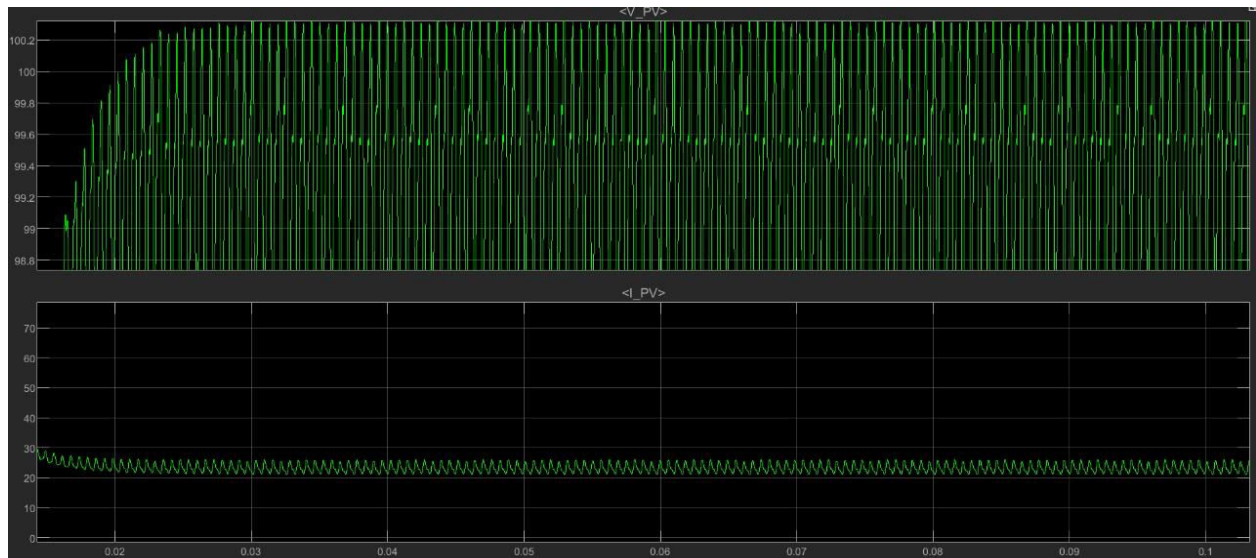


Waveforms when switch is ON

In this type of control when switches (IGBT S) compute, the output voltages between the +Vdc and -Vdc has the advantages of doubling the switching frequencies, where the harmonics components approaches multiple of the twice the switching frequency. The V_o waveforms is shown

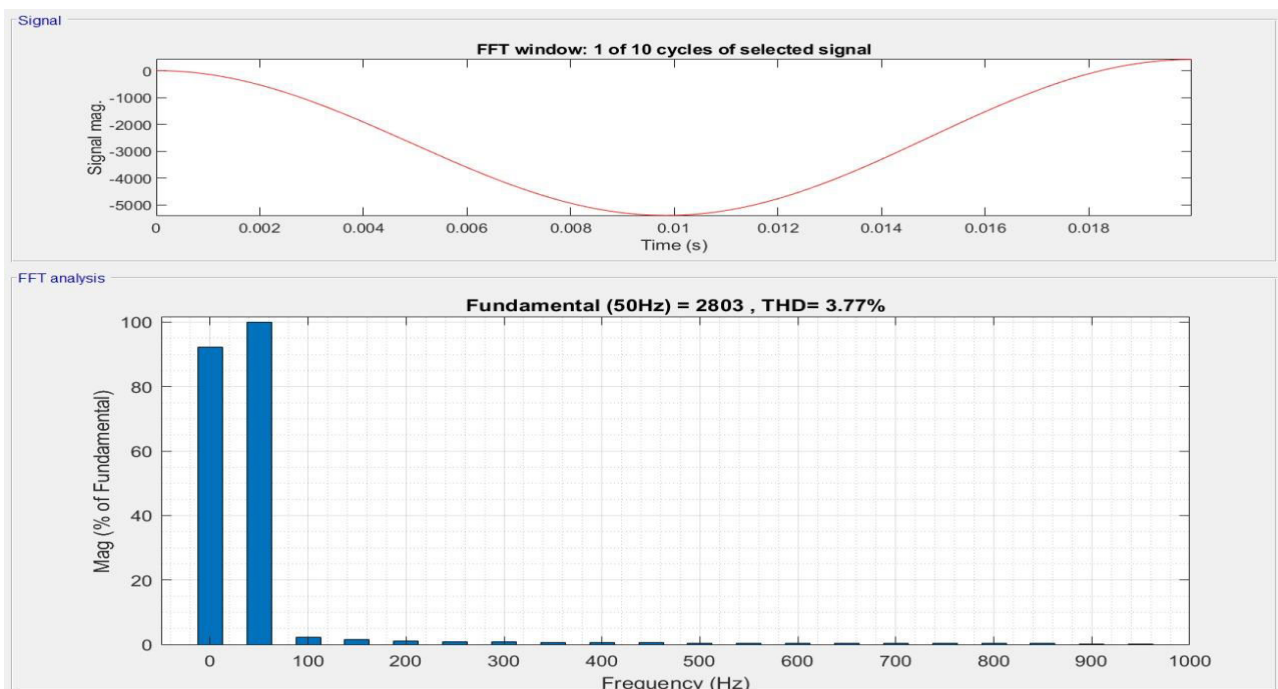


Single-phase Inverter simulated using PWM



Pv array voltage ,6(b)current

Existing Method THD Analysis



Existing method THD analysis

Conclusion

The “Grid connected interleaved high power flyback inverter for photovoltaic application” is presented. The flyback topology is introduced effectively with interleaving the 3-flyback cells. This flyback converter rated at 2kW and this power level is achieved by each interleaved cell are designed at 700W. This flyback converter operated with the discontinuous current mode (DCM). The central-type photovoltaic inverter is based on the flyback topology it gives the effective output for photovoltaic application. The flyback DC-DC converter topology is preferred because of its simplicity in design and easy power flow control with at high power quality output at the grid integrate. Here maximum power point tracking and phase lock loop controller used to operate the switches. In the proposed system some cost



advantages as compared to other isolated topology. The performance of this converter is analyzed in MATLAB simulation to prove the validity of the theoretical analysis.

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