



# **Enhanced Flyback CCM Inverter for Voltage Stability Under non-linear Loads**

**Nayas Qudrathulla.P.P<sup>1</sup>, P.Balaji<sup>2</sup>**

PG Student [PED], Dept. of EEE, Paavai Engineering College, Namakkal, Tamilnadu, India <sup>1</sup>

Assistant professor, Dept. of EEE, Paavai Engineering College, Namakkal, Tamilnadu, India <sup>2</sup>

**ABSTRACT:** The photovoltaic power generation system is used widely in the residential and industrial purpose day by day. The conventional methods used for the energy conversion need to be improved due to some drawbacks. Several researches are going on in the direction of cost and efficiency, the flyback DCM inverter has been emerged out as a low cost solution. However, the flyback DCM inverter operated under continuous conduction mode shows a better efficiency at low cost. Unfortunately, it causes unintended distortions in the output voltage and current. When connected to the grid under non-linear loads conditions it cause the voltage instability. In this paper, an unfolding type H-bridge switching techniques are introduced in order to reduce those drawbacks. The simulation are done on the basis of non-linear load conditions . The output current and voltage distortions are reduced by the unfolding type H-bridge switching techniques.

**KEYWORDS:** Distributed power generation, Flyback inverter, Photovoltaic AC module systems, Solar energy, Unfolding H-bridge.

## **I.INTRODUCTION**

Nowadays, distributed power generation in residential areas using solar panels, is well accepted and also supported by recent developments in building integrated photovoltaic systems as well as micro grid systems. However, when PV panels are connected in series to feed a string inverter with a global maximum power point tracker, a considerable power loss due to modular mismatches caused by both varying panel orientations and shading would occur. A major approach to solve this issue has been to package the PV panel with a module-integrated inverter [5], called an ac module, which directly serves the grid. Though requiring a large number of dc-ac conversion stages, the approach allows for easy plug and play system expansion. Also, only ac cable wiring is required, which simplifies the installation.

The acceptability of an ac module depends on its efficiency, cost effectiveness, and reliability. Three major trends are noted in the study of inverter topologies for this application. The first is the use of a transformer less inverter [3] that is motivated by the benefits of reduction in size and cost and also by possible efficiency improvement. However, the limited voltage boosting capability of such an inverter unit prevents the use of this technology in universal grid voltage range applications. Another trend is focused on an isolated cascaded scheme that includes one or more dc voltage boosting stage and a usual full bridge PWM inverter. Compared to other isolated inverters, this type of inverter has by far the highest reported efficiencies. Also, the power decoupling by the electrolytic capacitor can be replaced by a higher voltage film capacitor with longer life span. However, the consequence paid for this approach is more component count and hence higher cost.

Considerations of reducing the cost have led to a third approach based on an unfolding type inverter. Here, the dc-dc converter performs the voltage boosting, isolation, and output current shaping and then followed by a low-frequency unfolding stage. A simple overall system of flyback inverter having center-tapped secondary windings is often adopted. However, in this scheme, the flyback is operated in the discontinuous conduction mode emerged as a low cost solution. The operation of the flyback inverter under discontinuous conduction mode which is hard to increase power conversion efficiency, due to its large RMS and peak current values. The high current stress across the switches leads to lower efficiencies. This is mainly true in low voltage and high-current applications such as the ac module under concern. Even though higher efficiency can be achieved under continuous conduction mode, the [9] shows the designing of the flyback inverter under continuous conduction mode, the output current and voltage stresses are reduced. But it shows

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some output current and voltage distortions when connected with grid. During the non-linear load operation the high voltage stresses across the switches and voltage instability are occurred. So some specialized techniques have to be made to overcome these problems. The flyback inverter has an unfolding H-bridge design configuration will be presented. The major objective of the present work is to reduce the distortion of output current and voltage of the CCM flyback inverter by the unfolding H-bridge switching. In the proposed method the current and voltage stresses are been reduced because of the four switches. The circuit is operated under non-linear load in order to investigate its stability. The LC filter reduces the ripples on output and the level of output voltage is increased there by the efficiency can increase.

## II. FLYBACK CCM INVERTER

The topology is the same as that used in a flyback ac module operating in discontinuous conduction mode and consists of an input capacitor C, a flyback dc-dc converter with two secondary windings together with a waveform unfolding arrangement as shown in the Fig .1. Secondary side switches Q1 and Q2 are turned ON and OFF respectively to generate the ac output during the positive and negative half cycles. In each half cycle, the inverter operates as a dc-dc flyback converter with the average output current shaped as a half sinusoid at the line frequency. The simple overall system of a flyback inverter with center tapped secondary windings is often adopted. However, the flyback is operated in the discontinuous conduction mode, which resulting in high current stress and lower efficiencies.

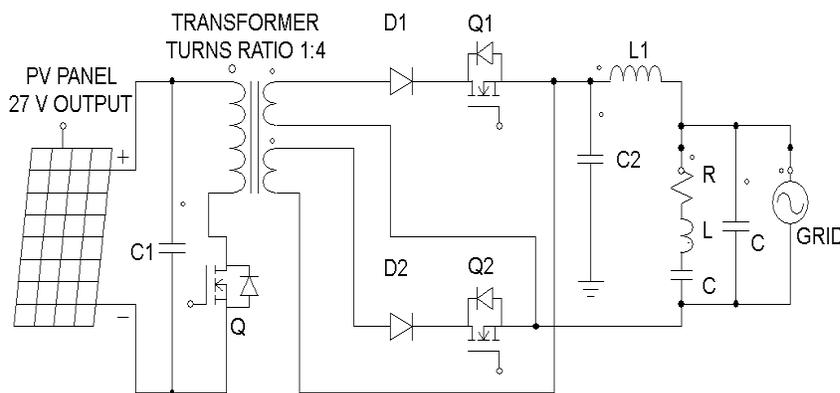


Fig. 1 Flyback CCM Inverter

When operated in continuous conduction mode, a flyback converter has lower peak currents and hence higher efficiencies. This has been exploited before in both dc-dc power conversion and ac-dc power factor correction applications. However, the control towards the output current transfer function in a flyback CCM converter has a right half plane zero, which causes complexity in controlling the output current of the converter effectively. The flyback operated under CCM mode of operation will possess a higher efficiency than DCM operation. But when it is connected with the grid, it shows some unintended distortions in the output current and voltage. The grid may contains the non-linear loads like power electronic equipments will make some voltage instability.

The output voltage of the flyback converter operated in CCM mode is given by

$$V_o = V_{in} \times \frac{D}{1-D} \times \frac{1}{n} \quad (1)$$

where D is the duty cycle of the switch,

$$D = \frac{T_{on}}{T_{on} + T_{pff}} = \frac{T_{on}}{T} \quad (2)$$

n is the transformer turns ratio. The output voltage of the flyback converter operated in DCM mode is given by

$$V_o = V_{in} \times D \times \sqrt{\frac{R_L}{2 \cdot L_p \cdot F_{sw}}} \quad (3)$$



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### A. Designing Steps

Step 1: Identify PV panel specifications. The voltage  $V_{pv}$  and current  $I_{pv}$  values given by the manufacturer correspond to MPP and vary with solar irradiance and temperature. For design purposes, a constant  $V_{pv}$  is used, the current change leads to the variation of power. In core based transformers, the first step is to select the core type and size in order to meet the given power requirements.

Step 2: Choose a switching frequency  $f_s$  considering the trade-off between the switching losses and the transformer size.

Step 3: The selection of the turn's ratio,  $n$ , so as to estimate the maximum stress across on the switch SW1 in the off state, ignoring the leakage inductance spike. The maximum voltage stress on the switch, SW1, at  $V_{in\_max}$ , by considering the 1volt drop across the flyback diode is given as.

$$V_{dsmax} = V_{in\_max} + n(V_o + 1) \quad (4)$$

Step 4: Since no dead time exists, as was the case of DCM, the total time period 'T' is the summation of the  $T_{on}$  and  $T_{off}$ . The duty cycle ratio D in continuous mode of operation is obtained as follows.

$$T_{on} = \frac{(V_o + 1) \times T}{(V_{in\_min} - 1) \times n^{-1} + (V_o + 1)} \quad (5)$$

Step 5: From the given output power 'Po', the current at the centre of the ramp of the secondary current pulse can be obtained by knowing the duty cycle and output voltage.

$$I_{cs} = \frac{P_o}{V_o \times (1 - D)} \quad (6)$$

Step 6: By assuming the energy efficiency to be 80%, the current at the centre of the ramp of the primary pulsed current can be obtained from 2.14 and 2.15.

$$I_{cp} = \frac{1.25 \times P_o}{V_{in\_min} \times (D)} \quad (7)$$

$$L_s = L_p \times (n^2)^{-1} \quad (8)$$

TABLE I  
Design of H-Bridge Flyback CCM Inverter  
(Specifications  $V_{pv} = 27V$ ,  $V_{rms} = 230V$ , Frequency = 50Hz)

Parameters	Proposed system
<b>Transformer Design</b>	
Turns ratio n,	1:4
Primary turns, Voltage	6, 100V
Secondary turns, Voltage	24,400V
<b>Circuit Design</b>	
Capacitor C1 (nF)	$1 \times 10^{-6}$
Inductor L1 ( $\mu H$ )	$633 \times 10^{-3}$
Capacitor C2 ( $\mu F$ )	$1 \times 10^{-9}$
<b>Switches and Diodes</b>	
Switches(MOSFET)	4
Diodes	4
Switching Period Q1,Q2	$20 \times 10^{-3}$
Switching period Q3,Q4	$20 \times 10^{-3}$
Phase delay (Secs)Q1,Q2	0
Phase delay (Secs)Q3,Q4	$10 \times 10^{-3}$
Rectifier	Full bridge rectifier

### III . UNFOLDING H-BRIDGE CONFIGURATION

The proposed circuit diagram is shown in Fig. 2, which consists of the unfolding type H-bridge. The flyback converter used in this circuit consisting of two stages. The first stage includes the conversion of the DC output of PV module to rectified-DC synchronized with grid voltage. Also, the shape of output current of the flyback inverter is determined by the switching of flyback converter. The second stage is about the unfolding H-bridge stage determines the direction of output current to be matched with grid voltage polarity. The unfolding switches Q1 and Q4 are turned-on and the Q2 and Q3 are turned-off during the positive period of grid voltage. During the negative period, the unfolding switches are operated oppositely.

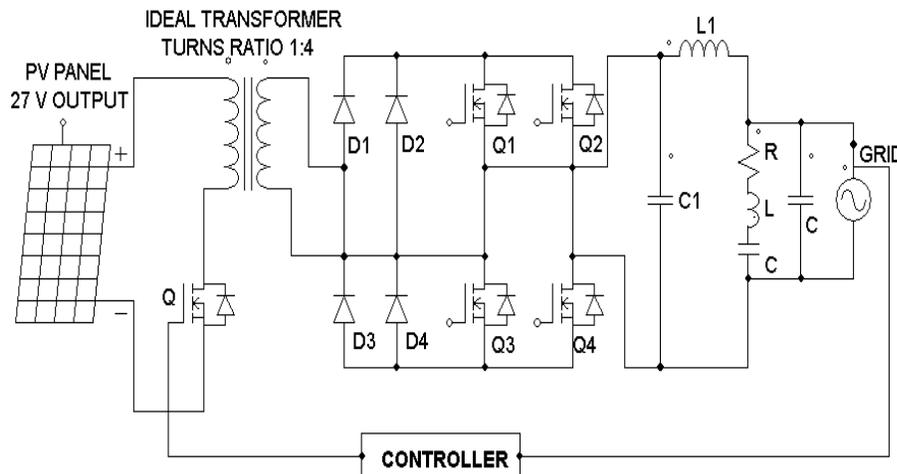


Fig. 2 H-Bridge Based Flyback CCM Inverter

As the power conversion systems for photovoltaic applications have to track the MPPT. In the flyback inverter shown in Fig. 2, the maximum power point tracking can be performed by peak point variation of the switching reference. Thus, MPPT determines the amplitude of output current reference. Because of the unfolding H-bridge determines only the direction of the output current conventionally, the flyback converter stage covers the output current shaping as well as the MPPT. Thus, the flyback converter switching is determined by rectified sinusoidal reference which synchronized with the phase of grid voltage.

#### A. H-Bridge switching technique

The flyback inverter used in the proposed system comprises of two stages, the flyback converter stage and unfolding H-bridge, while the conventional flyback inverter looks like a single-stage power conversion system. The flyback inverter composed of two stages has some advantages to get higher power conversion efficiency due to its H-bridge based unfolding method, while the single stage configured flyback inverter is a cost effective solution for photovoltaic AC module systems. In the single-stage flyback inverter a three winding transformer is required. It means that larger winding area is required even though the turns-ratio of the transformer,  $n$ , is same in the conventional method and proposed method.

Thus, the total loss of transformer used in single-stage flyback inverter can be much larger than that in the two-stage flyback inverter. On the other hand, the major difference between the unfolding H-bridge and the conventional unfolding stage is appeared in the voltage stress of the secondary switching devices. In conventional method the maximum voltage of the secondary active switches Q1 and Q2 is equal to  $2V_g(pk)$ , where  $V_g(pk)$  is the peak value of the grid voltage. Actually, the required voltage rating of the secondary active switches can be higher than  $2V_g(pk)$  due to the oscillation or ringing of the secondary current.

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In case of the 220Vrms grid applications, the voltage rating of secondary switches recommended to be higher than 800V. Unfortunately, higher voltage rating of the switching devices causes larger conduction losses. The unfolding H-bridge requires four active switching devices as shown in Fig .2. However, the maximum voltage of the unfolding switching device can be a half of that of the conventional unfolding stage. Thus, in the power conversion efficiency point of view, the unfolding H-bridge can be more useful solution.

The output current of flyback inverter  $i_g$  is in Equation 3.1 as follows,

$$I_g = \frac{1}{L_f} \int V L_f dt = \frac{1}{L_f} \int (V_{cf} - V_g) dt \quad (9)$$

where  $L_f$  is filter inductance,  $V L_f$  is voltage of the filter inductor  $L_f$  and  $V_g$  is the grid voltage. During the positive period of grid voltage, the voltage of filter capacitor,  $V_{cf}$ , is equal to link voltage,  $V_{Cs}$ , due to the unfolding bridge operation. If the voltage drop of unfolding H-bridge is neglected, the  $I_g$  can be written in Equation 10

$$I_g = \frac{1}{L_f} \int (V_{cf} - V_g) dt \quad (10)$$

Consequently, it is obvious that the output current can be controlled by the link voltage,  $V_{Cs}$ , under the normal unfolding bridge operation.

### B. Controller

The MPPT controller has adopted in this proposed circuit as shown in Fig. 3. The voltage stability analysis done on the basis of the MPPT controller. The output has feed back to the MPPT controller. The non-linear load has introduced. The output voltage stability may changes. It may compare with a reference value like triangular wave to generate the compensation wave may control the flyback switch. The modelling of the MPPT controller has done on the basis of the MPPT algorithm. Therein an MPPT controller it may generate compensation signal by a PI controller with the PV panel voltage and current. Even if there is any change in the output occurs, that signal may compare with the reference signal.

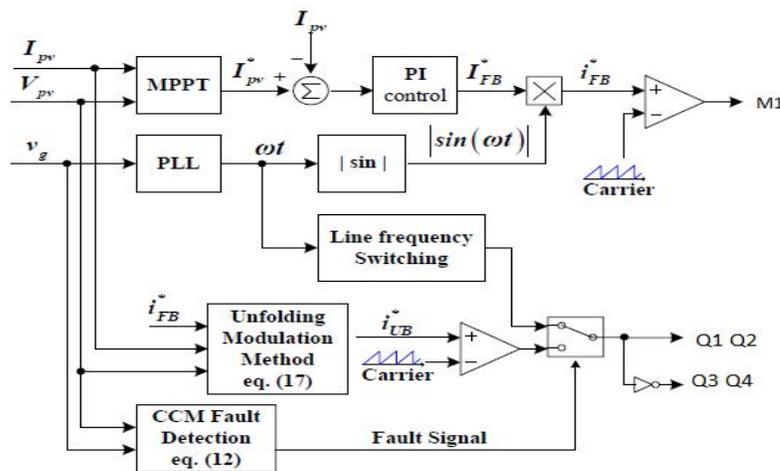


Fig. 3 MPPT Block Diagram

## IV. SIMULATION RESULTS AND DISCUSSION

The conventional Flyback inverter shows a voltage dip in the initial stage. The voltage and current distortions are occurred in some stages as shown in the Fig .5. Those drawbacks have been reduced by the unfolding H-bridge switching techniques as shown in the Fig .6. As in the non-linear load conditions the proposed systems shows a better voltage stability. The linear transformers are used instead of the multi winding transformer. The losses due the increased number of switches are negligible because of the reduced transformer losses on the other side.

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## A. Based on Closed Loop (With MPPT Controller)

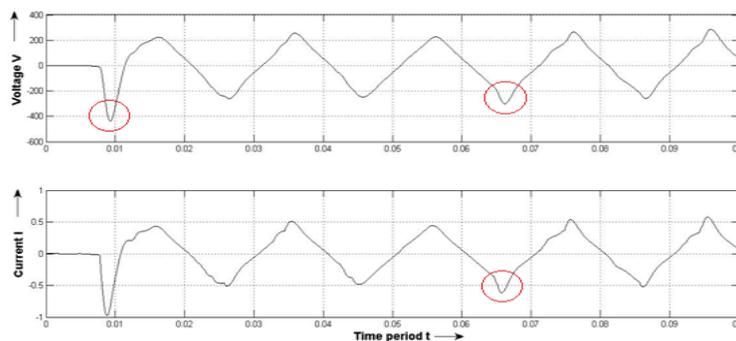


Fig .5 Conventional Flyback CCM Inverter

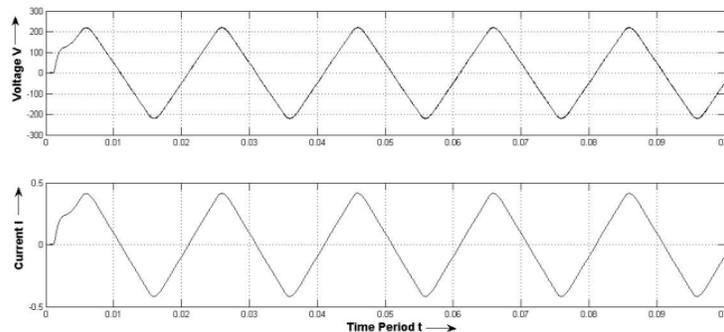


Fig. 6 H-Bridge Based Flyback CCM Inverter

The conventional flyback CCM inverter as shown in Fig. 5, when subjected to non linear load operation with MPPT controller shows an initial voltage dip and output distortions at some points. It shows a maximum 400V in the initial stage then it attains the stable state. It gives 230V voltage and current .4A.

The proposed H-bridge flyback inverter as shown in Fig. 6, when subjected to non linear load operation with MPPT controller doesn't show any voltage dip and distortions in the output as present in the conventional system. It shows a 230 V voltage and .4A current. If any voltage fluctuations or any other disturbances are occurred, the voltage and current stresses across the switches will not increase as there exists 4 switches. The efficiency is better than the conventional system.

## B. FFT Analysis for THD Calculation

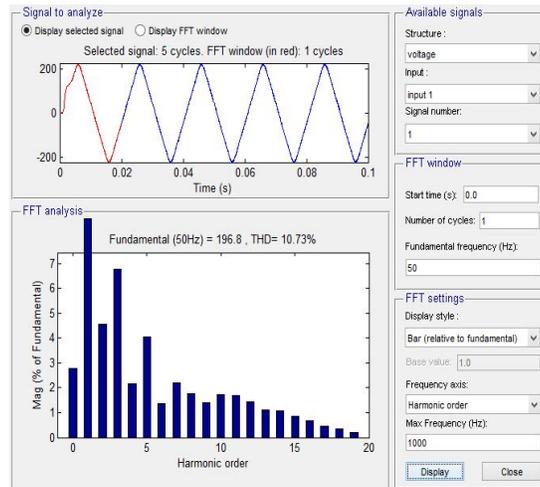
The Fast Fourier Transform analysis are done are done for the THD calculation. When comparing the two values obtained, it shows a large difference between the conventional system and proposed system. The conventional system had shown 95.62% as shown in the Fig.7 (b). The proposed system had shown 10.73% as shown in the Fig.7 (a). From the results, it can be validated as the increased number of switches doesn't make any deviation in the overall output and it gives better efficiency than the conventional system.

The conventional system shows the THD more is only due to the increased current stress across the switches when the load fluctuation occurs. Even it contains a half bridge having 2 switches. The proposed H-Bridge contains four number of switches. Which having a withstand capacity under the non linear load conditions. The FFT analysis for two systems and the output showing better results over the conventional method.

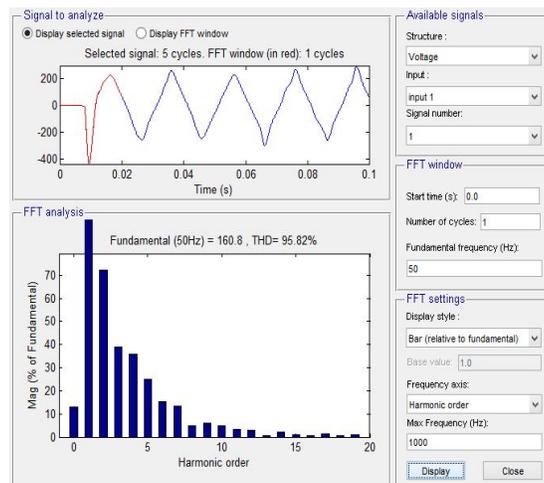
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(a)



(b)

Fig. 7 FFT Analysis for THD (a) Proposed H-Bridge Flyback CCM Inverter (b) Conventional Flyback Inverter

## V. CONCLUSION

In this paper, the flyback CCM inverter composed of H-Bridge switching technique is applied. The flyback DCM inverter operated under CCM has been recognized as an attractive solution for grid connected PV-AC module system due to its simple controller and circuit configuration. The conventional system shows unintended distortions in the output current and voltage due to the high voltage stresses across the switches. The proposed system uses 4 switches in order to reduce the stresses. When the conventional system and the proposed systems are connected to grid under non linear load conditions, the proposed system shows a better efficiency than the conventional system. The simulations are done on the basis of non linear load conditions. The proposed system has reduced the distortions present in the output. The THD calculations are done by using the FFT analysis, the proposed system shows a large reduction when compared with the conventional system.



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## BIOGRAPHY



**Nayas Qudrathulla.P.P** received the B.Tech Degree from the University of Calicut, Kerala, India in 2011. He is currently pursuing Master Degree in Power Electronics and Drives under Anna University, Chennai, Tamilnadu, India.. His Previous works were based on Monitoring and Tracking of Electric locomotives. His Current Project Area is Sustainable Energy, which focuses on Efficiency Improvement using Photovoltaic Grid Connected Inverters. His main research Areas includes Electric Drives, Inverters and Power Systems.



**Balaji.P** was born in Taminadu, India. He Received the Master Degree from Anna University, Chennai, India. He is currently working as Assistant Professor in Paavai Engineering College, Tamilnadu, India. He has published a Book and 07 Papers in various International Journal and Conferences. His Major Research Areas are Power Electronics and Nanotechnology.