H-Bridge 7 Switches Transformerless MOSFET Inverter to Improve Efficiency of Grid-Tied Photovoltaic System

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Abstract: This paper proposes a new type of high-efficiency transformerless single phase photovoltaic inverter that uses super-junction MOSFET as the main power switches. The main power switch does not require any reverse recovery problems, and the voltage on the switch is half of the DC input voltage. For this reason, super-junction MOSFET have been used to improve efficiency. The two additional switches in the traditional full H-bridge topology ensure that the PV module is disconnected from the grid in freewheeling voltage that causes leakage current minimized. The proposed topology does not require PWM dead time, which reduces AC output current distortion.

Keywords- Common Mode Voltage (CM), Photovoltaic PV, High efficient and reliable inverter concept topology (HERIC), total harmonic distortion (THD), H-bridge zero voltage rectifier (HB-ZVR)

I. INTRODUCTION

Nowadays, because of the harmful effects of oil, gas, and nuclear fuels, new energy sources are being used and developed at an increasing rate. As a result, renewable energy sources, solar PV system have risen to the forefront of electricity generation. Photovoltaic system offer a wide range of use, from tiny power supply to power grid [7]. Photovoltaic system that are connected to the grid offer a number of benefits, including ease of installation, high efficiency, reliability, and flexibility. PV technology appears to be an efficient form of power generation due to a reduction in system cost [2]. Generally, a grid-connected solar power system consists of a solar panel and an inverter that converts direct current to alternating current. This study examines a transformerless converter topology that can reduce harmful leakage currents between solar power generation and the power supply. Electricity network. In grid-connected systems, transformers are used for safety reasons to establish galvanic isolation between the PV modules and the grid. [7]. Most grid-connected photovoltaic inverters use linear inverters; however, due to the lower frequency of power frequency transformers, their size, cost, and weight are higher. Another option is a high-frequency transformer. The number of power levels, which has a negative impact on efficiency. When these transformers are removed, a galvanic connection between the solar module and the grid is established, which causes possible fluctuations between the photovoltaic field and the ground. The potential variation causes the flow of common mode leakage current which must be minimizes, otherwise there is an issue of electromagnetic distortion, harmonics and other power quality issues [7].

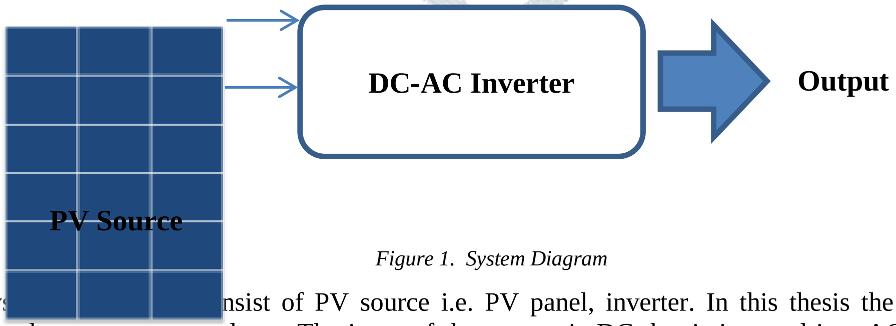

Figure 1. System Diagram

Figure 1 is of sy nsist of PV source i.e. PV panel, inverter. In this thesis the direct current voltage is converted into the alternate current voltage. The input of the system is DC that is inverted into AC system with the help of MOSFET. In this system, seven MOSFET are used to perform the inverting operation. This system is implementing to increase the efficiency of inverter compared to present inverter system [2].

II. INVERTER

Inverters perform DC to AC operation. The inverter converts the DC voltage to the AC voltage without changing their magnitude and frequency. The output voltage of the inverter could be fixed or variable at a fixed or variable frequency. The inverter gain is defined as the ratio of the output voltage to input voltage [1]. The output voltage waveform of inverters could be sine wave. If the waveform is not pure sine wave then it contains certain amount of harmonics. The inverter output voltage waveform can be a square wave, a quasi-square wave or a sine wave with little distortion. The output voltage can be controlled by the switch on the driver. The output voltage of the inverter. This kind of inverter is called a PWM inverter. If it is not a sine wave, the output voltage of the converter contains harmonics. Using a suitable control loop can reduce harmonics.

2. Classification of Transformerless Inverter:

2.1 Highly Efficient and Reliable Inverter Concept Topology (HERIC):

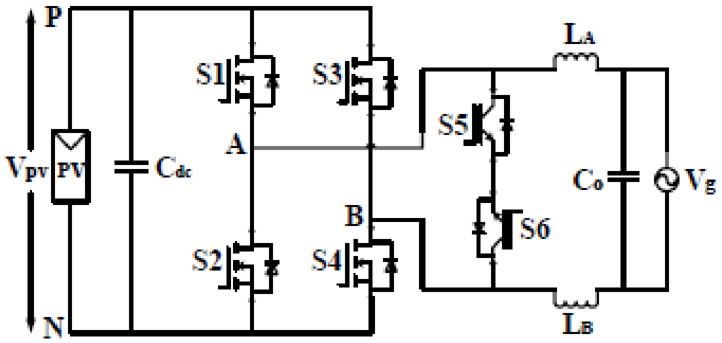

Figure 2. HERIC Topology [5]

The above circuit diagram is of HERIC topology. These types of inverters are used in commercial inverters. In this topology, two switches S_5 and S_6 are attached at the output of the inverter. The switches S_5 and S_6 are operate in freewheeling mode. The freewheeling path is not connected to the half of the DC link sot that there is fluctuation in the CM voltage [5].

2.2 H-Bridge Zero Voltage Rectifier (HB-ZVR):

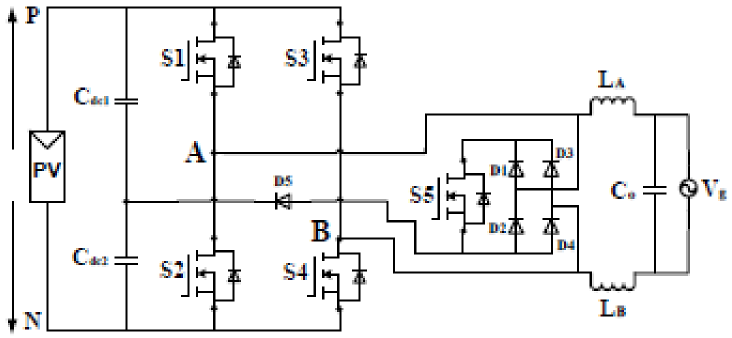

Figure 3. HB-ZVR Topology [5]

In this topology, the two switches are replaced by one-bidirectional switch S_5 four diodes, which are connected at the output side of the inverter. In this topology, the clamped branch is attached to the half of the DC link. The diode D_5 is clamped and the freewheeling current flows in one direction. It works only if the freewheeling voltage is higher than the half of the DC link voltage for positive cycle. In negative half cycle, the CM voltage varies or fluctuates because the freewheeling path does not clamed [5].

2.3 H5 Topology:

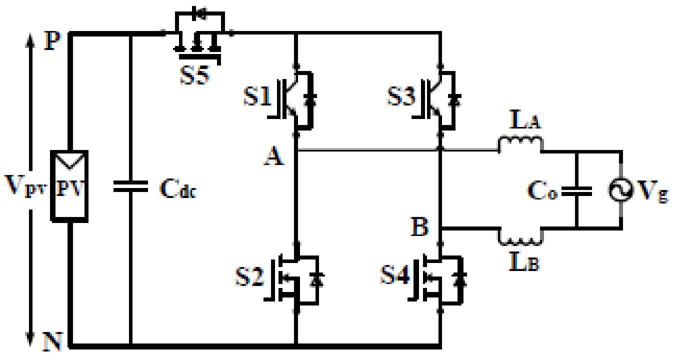

Figure 4. H5 Topology [3]

In this topology, the extra switch S_5 is connected at the DC side of the full-bridge inverter. In this topology, the freewheeling current flows through switch S_1 and body diode of S_3. For negative half cycle, the freewheeling current flows through switch S_3 and body diode of S_1. The conduction losses are high because in active mode current output flows through three switches [3].

2.4 H6 Topology:

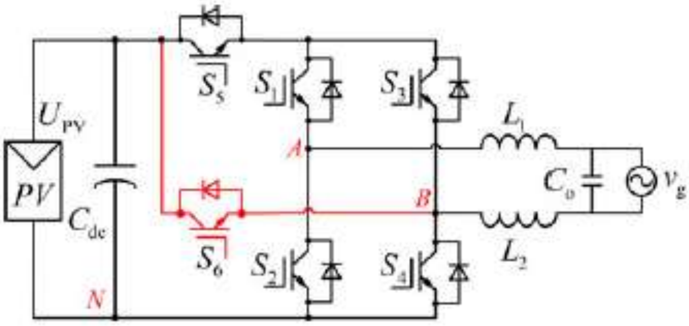

Figure 5. H6 Topology [7]

In this topology, two switches S_5 and S_6 and two diodes are connected at the input side of inverter. In this topology, bi-directional clamping branch is connected to the DC link so that the CM mode voltage has better characteristics. In freewheeling mode, diode D_1 or D_2 will be conducted to the DC link when freewheeling voltage is higher than the half of the DC link voltage. The conduction losses are higher because current flows through four switches in active mode [7]. The modes of operation are described as follows.

A) Mode 1:

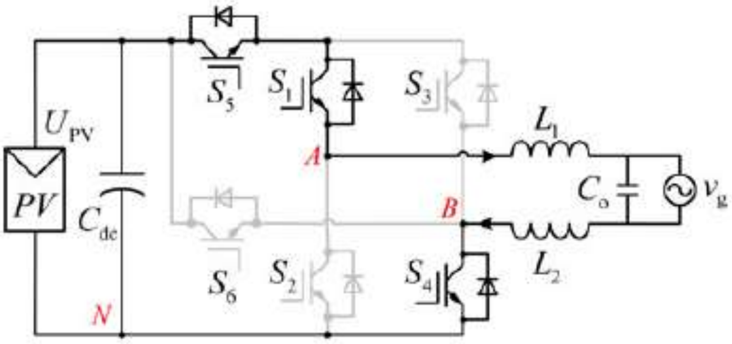

Figure 6. Mode 1[7]

Mode 1 is the active mode for positive half cycle. In this mode switch S_1, S_4 and S_5 turned ON. The inductor current flows through switch S_1, S_4 and S_5. The inductor is charged. The voltage of $V_{AN} = V_{PV}$, $V_{BN} = 0$, so that $V_{AB} = V_{PV,}$ thus the CM voltage is

$V_{CM} = (V_{AN}+V_{BN}) / 2= 0.5\ V_{PV}$ [7]

B) Mode 2:

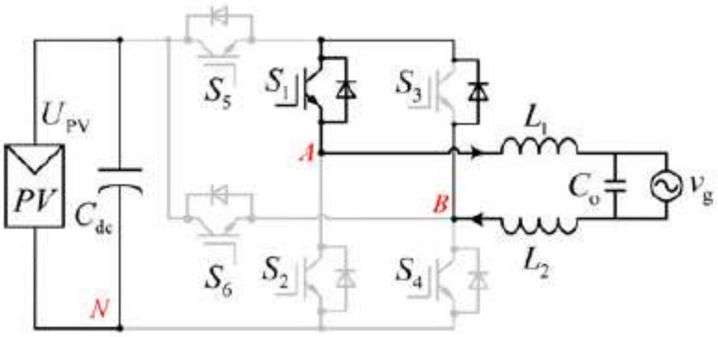

Figure 7. Mode 2 [7]

Mode 2 is a freewheeling mode for positive half cycle. In this mode switch S_1will be turn on and the freewheeling current flows through it. The inductor current is flows through switch S_1 and body diode of S_3. The other switches are off. $V_{AN} = V_{BN} = 0.5\ V_{PV}$, thus $V_{AB} = 0$. The CM voltage is

$V_{CM} = (V_{AN}+V_{BN}) / 2= 0.5\ V_{PV}$ [7]

C) Mode 3:

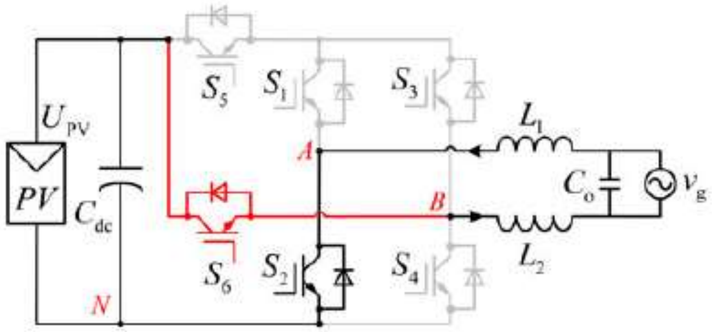

Figure 8. Mode 3 [7]

Mode 3 is active mode in negative half cycle. In this mode switches S_2, S_3 and S_6 are turned ON. The inductor current flows through switch S2 and S6. The switch S_3 is turned ON but there is no current flowing through it. So there is no conduction loss in S_3. In this mode, $V_{AN} = 0$, $V_{AB} = -V_{PV}$, thus $V_{AB} = -V_{PV}$. The CM voltage is

$V_{CM} = (V_{AN}+V_{BN}) / 2= 0.5\ V_{PV}$ [7]

D) Mode 4:

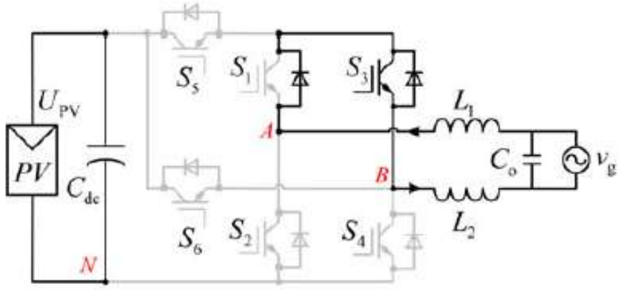

Figure 9. Mode 4 [7]

Mode 4 is the freewheeling mode for negative half cycle. The inductor releases its energy through switch S_3 and the body diode of S_1. In this mode, $V_{AN} = V_{BN} = .05\ V_{PV}$, thus $V_{AB} = 0$ then CM voltage is

$V_{CM} = (V_{AN}+V_{BN}) / 2= 0.5\ V_{PV}$ [7]

The gate drive signal for switches is as follows:

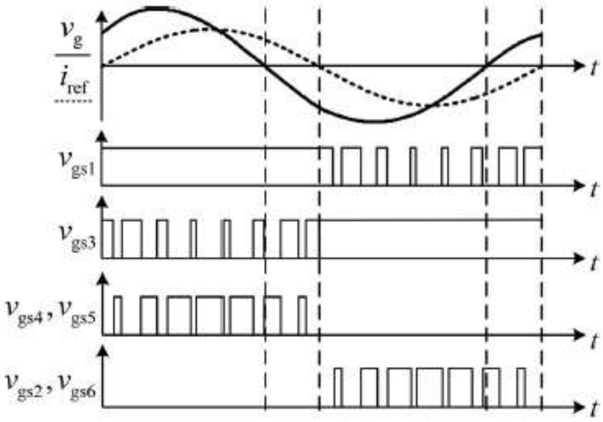

Figure 10. Gate Drive Signal [7]

III.METHODOLOGY

3. H-Bridge 7 Switches MOSFRT Inverter for Efficiency Improvement of Grid-Tied PV System:

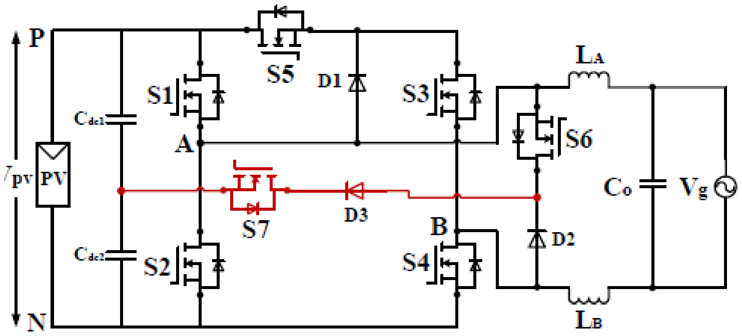

Figure 11. Circuit Diagram of Transformerless MOSFET Inverter [1]

The proposed H-bridge 7 switches transformerless MOSFET PV inverter topology is shown in Fig. 11 which is derived according to the derivation method described in the prior section, where S_1, S_2, S_4, & S_5 are high frequency switches, and S_3 & S_6 are low frequency freewheeling switches. The unidirectional clamping branch is constructed using switch S_7 and diode D_3 is connected to the midpoint of dc link. LA, LB, and Co are filters that used at the output side [1].

3.1 Operating Principle:

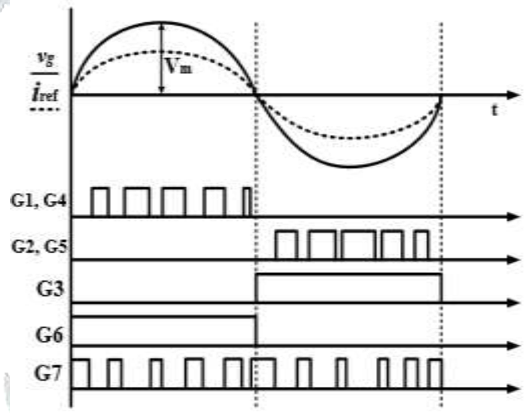

Figure 12. Gate Drive Signal [1]

The operating principle of proposed system is shown in figure 12 respectively. The above signal diagram is of gate driver circuit of the proposed system. The gate G1, G2, G3, G4, G5, G6, and G7 are the gate signals of switches S1, S2, S3, S4, S5, S6, and S7 respectively. The switches S1, S4 and switches S2, S5 is turn-on at the same time in positive and negative cycle. The S7 switch is turn-on in positive and negative cycle in freewheeling mode [1]. The operating principle of the inverter is shown in above figure. There are four modes of operation to generate output voltage state of +Vpv, 0 and –Vpv, which is described as follows.

A) Mode 1:

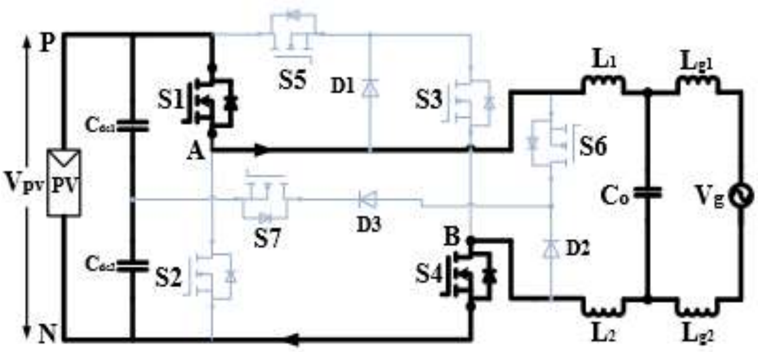

Figure 13. Mode 1 [1]

Mode 1 is for the positive half cycle of the grid current. In this mode, switch S_1 and S_4 will turn-on and current flows through the inductor [6]. The inductor current i_L, increases linearly through grid. $V_{AN}= V_{PV}$ and $V_{BN}= 0$, thus $V_{AB}= V_{PV}$ and the inductor current:

$$iL(t) = \frac{Vpv - Vg}{L}(t)$$

B) Mode 2:

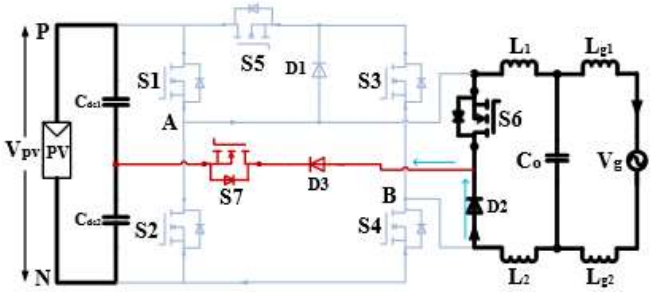

Figure 14. Mode 2 [1]

Mode 2 is the freewheeling mode, as shown in figure 14 in this mode the inductor releases its energy through S_6 and D_2. In this state, V_{AN} falls and V_{BN} rises until their values are equal. If the voltages ($V_{AN} \approx V_{BN}$) are higher than half of the dc link voltage, freewheeling current flows through S_7 and D_3 to the mid-point of the dc link, results V_{AN} and V_{BN} are clamped at $V_{PV}/2$. Therefore, at mode 2, $V_{AN} = V_{PV}/2$, $V_{BN} = V_{PV}/2$, the inverter output voltage VAB = 0 and the inductor current:

$$iL(t) = \frac{-Vg}{L}(t)$$

C) Mode 3:

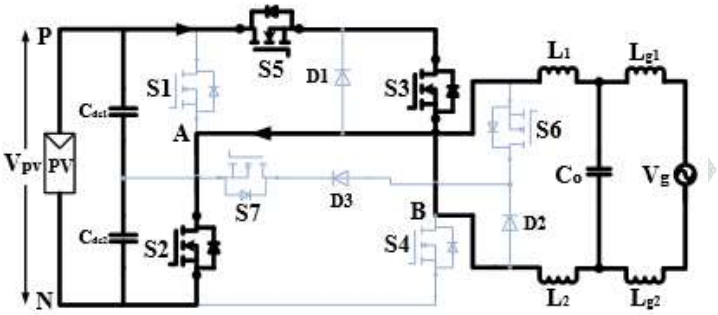

Figure 15. Mode 3 [1]

Mode 3 for the negative half cycle. In this mode S_2, S_3 and S_5 are turned-on, the inductor current increases in the opposite direction. In this mode, the voltage $V_{AN} = 0$ and $V_{BN} = V_{PV}$, thus $V_{AB} = -V_{PV}$ and the inductor current:

$$iL(t) = \frac{Vpv-Vg}{L}(t$$

D) Mode 4:

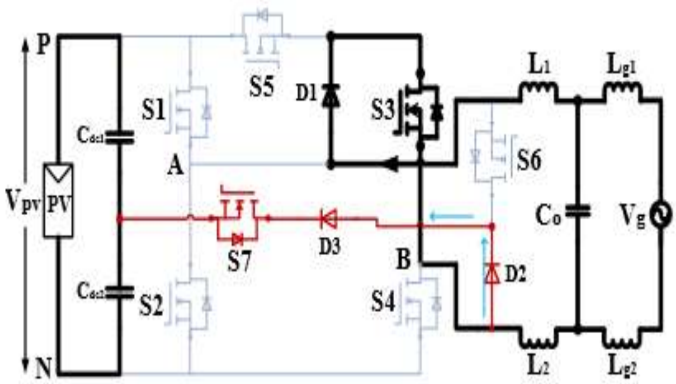

Figure 16. Mode 4 [1]

Mode 4 for the negative half cycle of grid current. When S_5 and S_2 are turned-off, the inductor current flows through S_3 and D_1. Similar to mode 2, If the voltages ($V_{AN} \approx V_{BN}$) are higher than half of the dc link voltage, freewheeling current flows through S_7 and D_3 to the mid-point of the dc link, results the voltages V_{AN} and V_{BN} are clamped at $V_{PV}/2$. Therefore, in this mode, $V_{AN} = V_{BN} = V_{PV}/2$, $V_{AB} = 0$, and the inductor current:

$$iL(t) = \frac{-Vg}{L}(t)$$

IV. SIMULATION / MATLAB

4.1 Conventional Method:

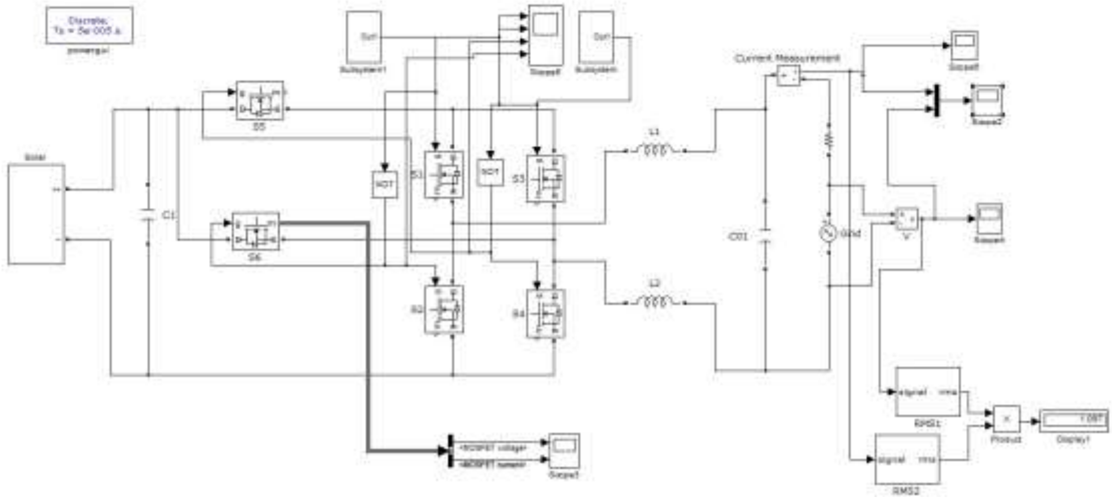

Figure 17. Simulation of Conventional Method

Above fig. 17 show simulation diagram of conventional method (H6) topology. For simulation MATLAB R2010a software used. This circuit has six MOSFET. If the gate signal of MOSFET falls to zero when current is negative, current is transferred to the antiparallel diode. For triggering the gate signal of MOSFET two subsystems are build. One subsystem triggers MOSFET S_1, S_4, S_5 respectively and another subsystem triggers S_2, S_3, S_6. The gate signal is in the form of combination of triangular and sine wave. Power GUI block is necessary for simulation of any Simulink model. It is used to store equivalent circuit. There are four types of method is used to solve any Simulink circuit i.e. continuous method, ideal switching continuous method, discrete method and phasor solution method. In this simulation discrete method is used to solve Simulink circuit. There are two RMS block is used to compute true RMS value (including fundamental, harmonic and DC component) of input signal. The RMS value is calculated over a running window of one cycle of the specified frequency and it is set to 50 Hz.

- Parameters:

  Inductor: 3mH, 3µH

  Capacitor: 0.47 µF

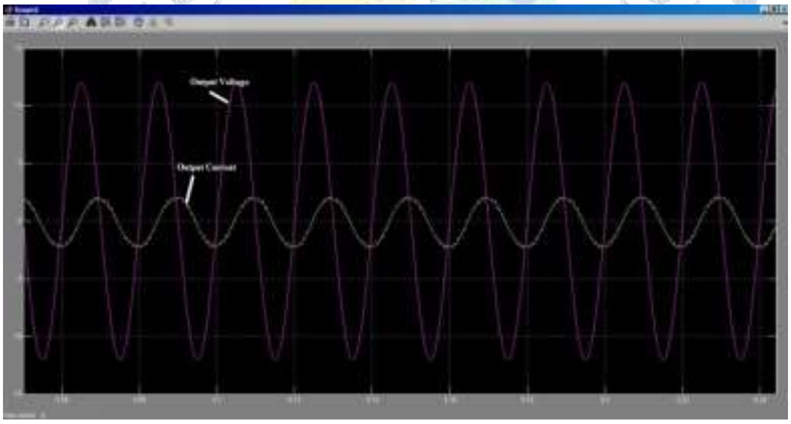

Figure 18. Output voltage and current waveform

Figure 18 shows voltage and current waveform. The value of voltage is 12V and current is 2A. As indicated that there are harmonics present in the system. Harmonics are in the form of noise. With the help if Power GUI block in Simulink circuit, it can calculate percentage of harmonics present in the system at 50Hz.

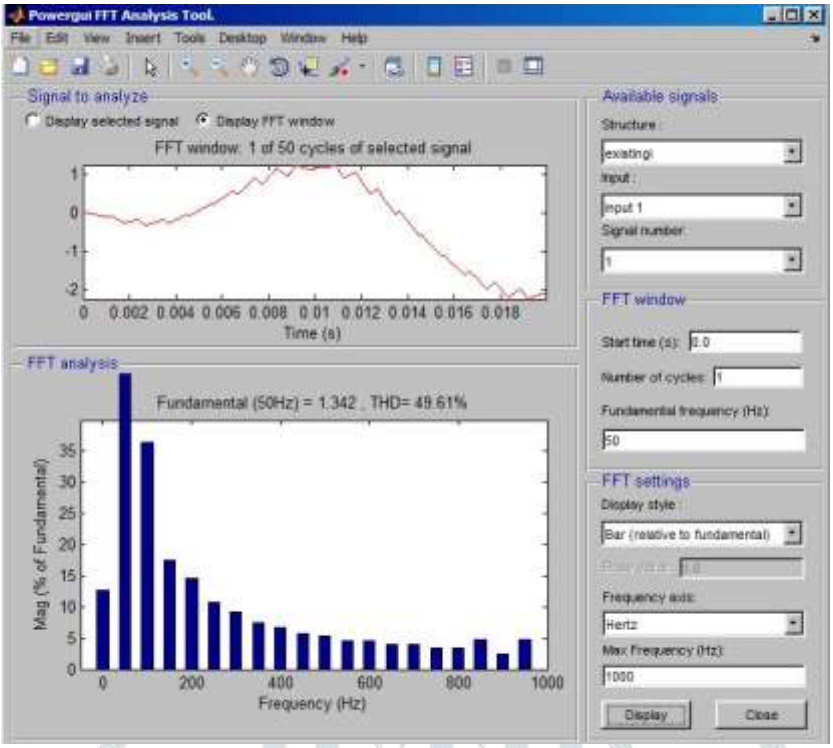

Figure 19. Percentage of THD

Total Harmonic Distortion is defined as the ratio of the sum of the power of all harmonic components to the power of fundamental frequency. All electrical power is in the form of sinusoidal wave. Harmonics are present in the normally sinusoidal network. Sources of harmonics are nonlinear load like power supply, UPS, battery etc. and electromagnetic interference. Let assume that the fundamental frequency is set to 50Hx then second harmonics should be on 2*50 i.e. on 100 Hz and so on.

$$THD = \frac{RMS\ of\ Total\ Harmonics}{RMS\ of\ Fundamentsl\ wave}$$

4.2 Proposed Method:

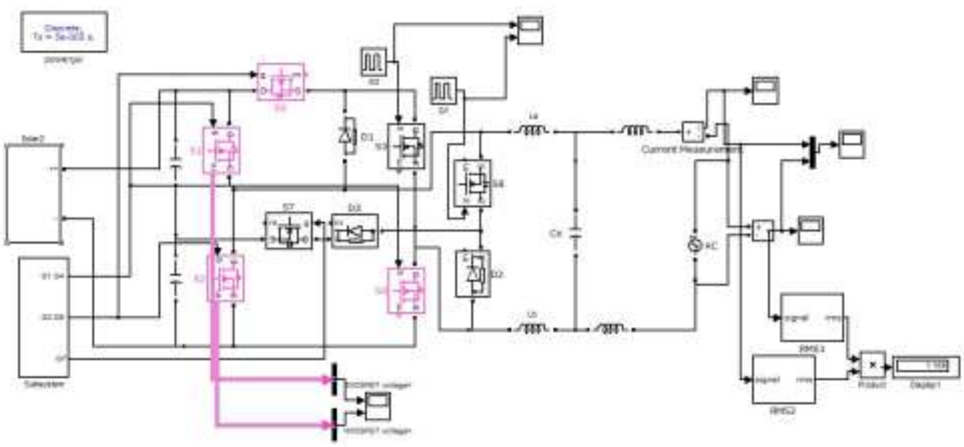

Figure 20. Simulation of Proposed Method

Above fig. 20 show simulation diagram of proposed method topology. For simulation MATLAB R2010a software used. This circuit has seven MOSFET and three freewheeling diode. The clamping branch is connected with extra switch and freewheeling diode. If the gate signal of MOSFET falls to zero when current is negative, current is transferred to the antiparallel diode. For triggering the gate signal of MOSFET one subsystems are build. The gate signal is in the form of combination of triangular and sine wave. Power GUI block is necessary for simulation of any Simulink model. It is used to store equivalent circuit. There are four types of method is used to solve any Simulink circuit i.e. continuous method, ideal switching continuous method, discrete method and phasor solution method. In this simulation discrete method is used to solve Simulink circuit. There are two RMS block is used to compute true RMS value (including fundamental, harmonic and DC component) of input signal. The RMS value is calculated over a running window of one cycle of the specified frequency and it is set to 50 Hz.

- Parameters:
  Inductor: 1 mH, 1mH, 150 mH, and 150mH
  Capacitor: 2200 µF

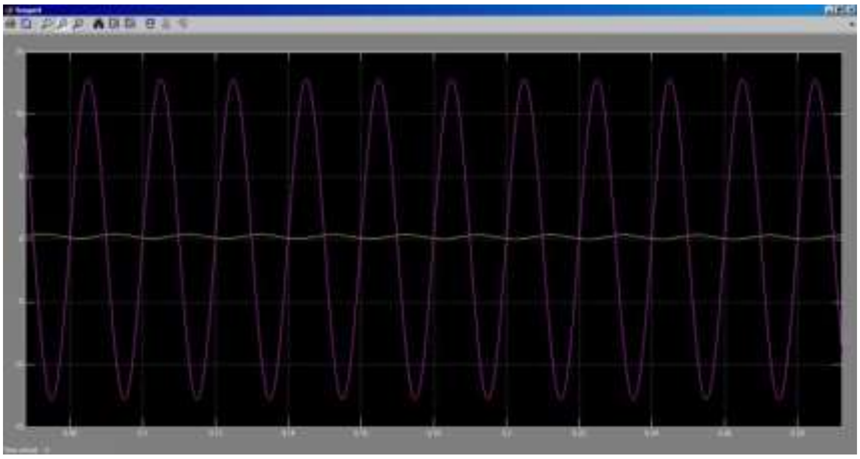

Figure 21. Output voltage and current waveform

Figure 21 shows voltage and current waveform. The value of voltage is 12V and current is 1.4A. As compared. With the help if Power GUI block in Simulink circuit, it can calculate percentage of harmonics present in the system at 50Hz. Total harmonic distortion is lee than the proposed system. With the help of Power GUI block it can easily calculate total harmonic distortion.

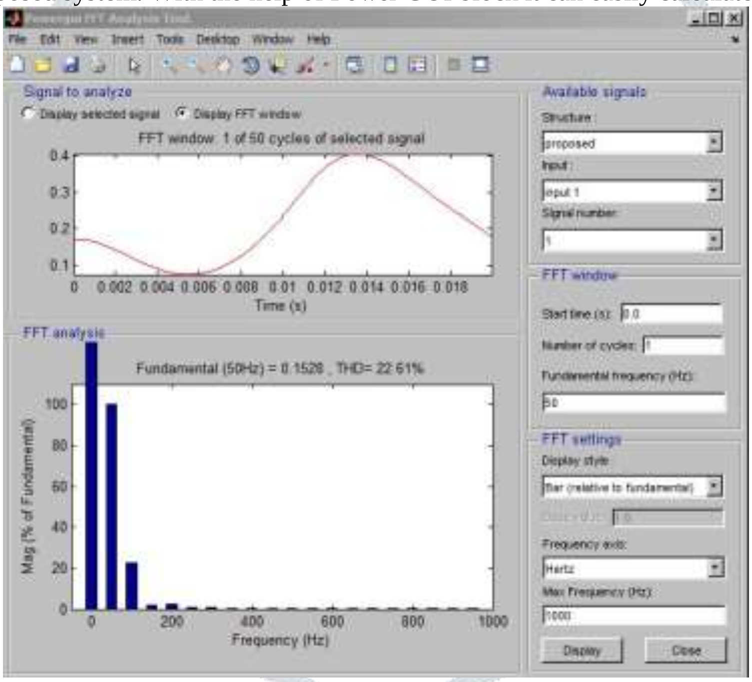

Figure 22. Percentage of THD

Total Harmonic Distortion is defined as the ratio of the sum of the power of all harmonic components to the power of fundamental frequency. All electrical power is in the form of sinusoidal wave. Harmonics are present in the normally sinusoidal network. Sources of harmonics are nonlinear load like power supply, UPS, battery etc. and electromagnetic interference. Let assume that the fundamental frequency is set to 50Hz then second harmonics should be on 2*50 i.e. on 100 Hz and so on.

$$THD = \frac{RMS\ of\ Total\ Harmonics}{RMS\ of\ Fundamentsl\ wave}$$

Calculation of Efficiency:
Proposed Method:

Efficiency (ŋ) = (Output power / Input power) × 100
= (1.159 / 1.161) × 100
= 99.82 %

Conventional Method:

Efficiency (ŋ) = (Output power / Input power) × 100
= (1.097 / 1.161) × 100
= 94.48 %

4.3 Comparison of Conventional and Proposed System:

Table 4.3 Comparison of Efficiency of Conventional and Proposed Method

Parameters	Conventional System	Proposed System
Current (A)	2.0	0.4
Voltage (V)	12	12
Efficiency (ŋ)	94.48%	99.82%
Total Harmonics Distortion	49.61	22.61%

V.HARDWARE APPROCH

5.1 Block Diagram:

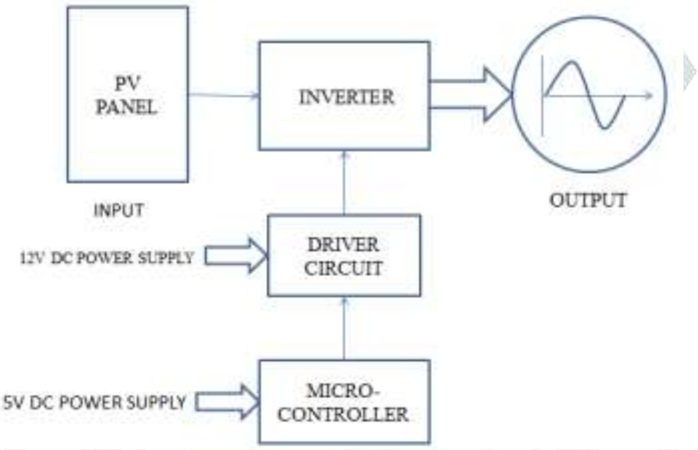

Figure 23. Block Diagram

5.2 Hardware Circuit Diagram:

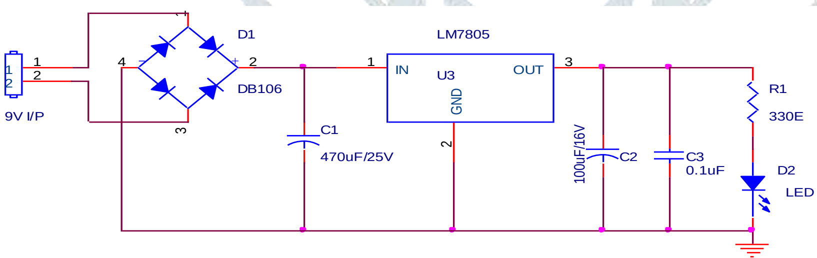

Figure 24. Power Supply Circuit for PIC16F877A

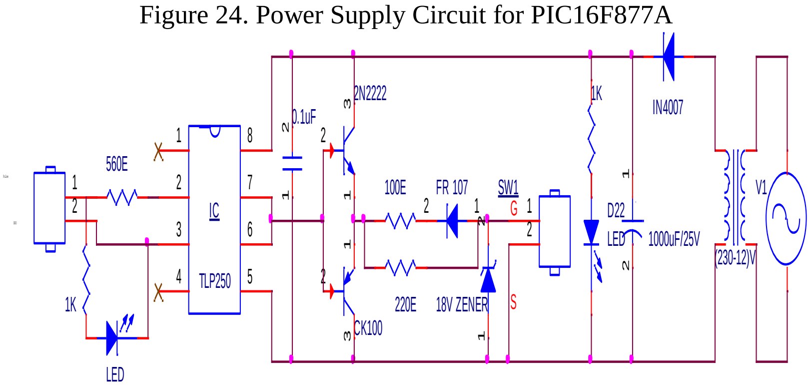

Figure 25. Driver Circuit

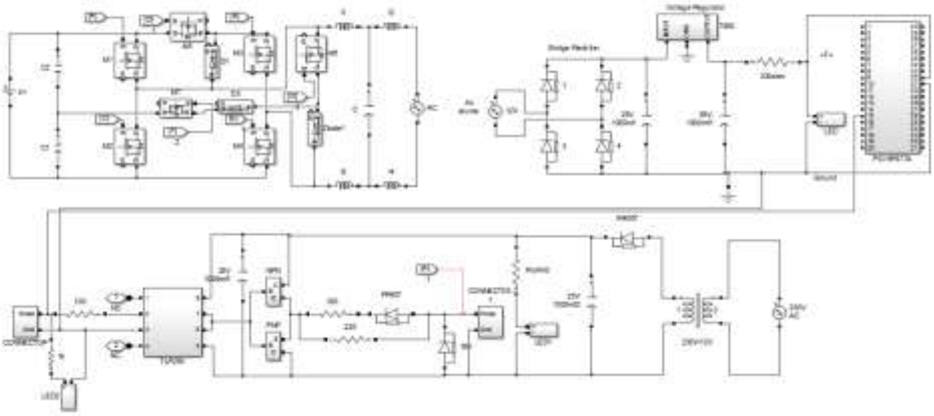

Figure 26. Full Circuit Diagram.

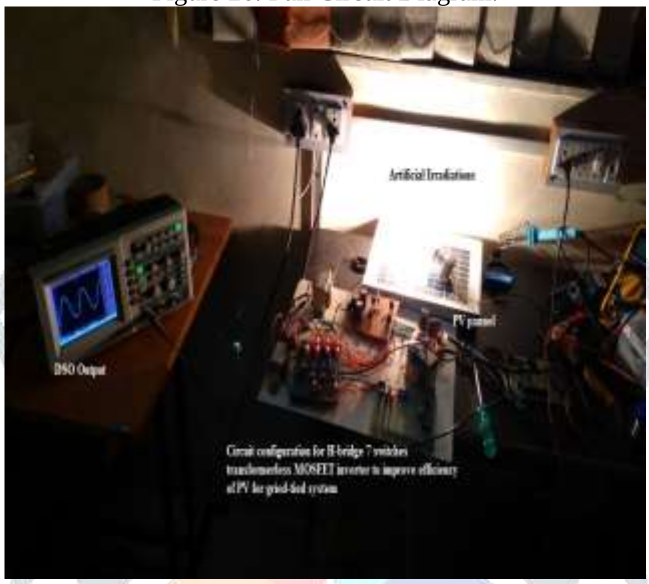

Figure 27. Hardware Image

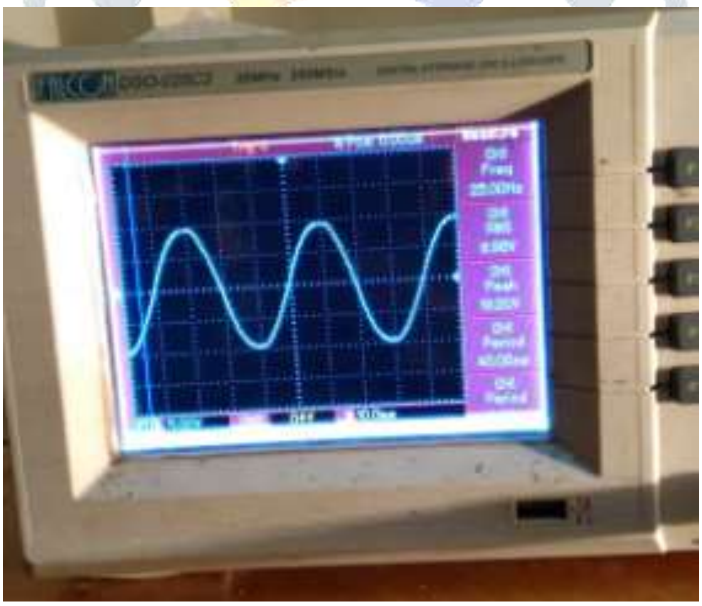

Figure 28. Output Voltage Image

Table 5.2 Cost details of components

S. No.	Component	Ratings	Quantity	Cost
PIC Details				
1	PIC Board		1	1750
2	PIC16F877A	40 Pin IC	1	450
2	Step down Transformer	230/12v	1	75

3	Bridge Rectifier	1 Amps	1	20
4	Capacitors	470uF, 10uF	Each1	20
5	Regulator IC	7805 IC	1	35
6	LED	Red 3.3v	2	6
7	Crystal Oscillator	10MHZ	2	30
8	Push Switches		5	10
9	Pot Resistor	5K ohm	2	20
Driver Circuit				
1	Transistor	CK100	3	75
2	Transistor	2n2222	3	75
3	optocoupler	TLP250	3	90
4	Diode	IN4007	20	100
5	LED	Red 3.3v	20	60
6	Driver PCB Board		1	1300
7	Zener Diode	15.5v	5	75
8	Capacitors	1000uF	5	60
Main Circuit				
1	Solar Panel	12v, 5w	1	1200
2	Step down Transformer	230/18v	1	140
3	Bridge Rectifier	6 Amps	1	90
4	Capacitors	1000uF & 100uF	Each 5	120
5	MOSFET Switches	IRF840	7	2240
6	Transformer	12v-6v-12v	2	160
7	inductor	1mH	5	110
8	Diode	IN4007	10	50
9	General Purpose Board		3	110
			Total	8471

V. CONCLUSION

The solar power is fed to the grid through inverter. There are two different topologies compare to obtain result. The conventional method is taken for analysis, design and simulation. Different components are selected to design. The results are obtained by comparing H6 and proposed method in simulation. THD percentage is also calculated.

The simulation of conventional and proposed system has been done and it can be seen that the efficiency is improve in proposed system as compared to conventional method. The THD is also reduced in the proposed method. Proposed method hardly generates any leakage current because the clamping branch is added to the DC link. PWM dead time is not required for main power switches that results in low distortion. The experiment results show 99.82 % maximum efficiency.

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