DESIGN AND IMPLEMENTATION OF TRANSFORMERLESS MOSFET INVERTER FOR A GRID CONNECTED SINGLE PHASE PHOTOVOLTAIC SYSTEM

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Abstract - *This paper is an attempt to obtain a topology of transformerless semiconductor inverter with different pulse width modulations, which would provide the best output voltage with high efficiency and less distortion. MOSFET and silicon carbide diodes are used in this topology. Pulse width is obtained by sinusoidal waves to develop high efficiency. The proposed topology of inverter is for the single phase system. The reverse recovery problem of MOSFET is avoided by using super junction MOSFET instead of conventional ones. No dead time required for the main switches as IGBT is avoided in this topology. Instant switching is done during high frequency commutations as MOSFET switches are used. Common mode fluctuation voltage problems are avoided due to the added clamping branch to the DC link midpoint in the system. The freewheeling voltage is clamped at DC input voltage at its half during the freewheeling period. Grid zero crossing will gives us a low distortion at output. The comparison is done in MATLAB SIMULINK. The best pulse width modulation is applied on the hardware.*

Key Words: Photovoltaic, Transformerless, Grid Connected, High Efficiency, Inverter.

1. INTRODUCTION

Solar energy produced by photovoltaic system is 100 percent carbon free, renewable, silent and clean. A Photovoltaic system consists of components like PV panel, inverter, battery etc. It is highly durable and nearly has a lifespan of 25 years. The energy produced from solar is in exhaustible. Photovoltaic cell efficiency is 15 percent so that electricity about one sixth can be produced from solar energy. The solar energy delivered by a photovoltaic array when the sun's light is converted to electric energy with the help of photovoltaic cells. The function of a Photovoltaic cell is in such a way that when light hits the cell electrons in them started to move and an electric current is produced from their movement. Photovoltaic modules make electricity from sunlight with no moving parts they sit in the sun and, can be used to for working of appliances, batteries charging, or construct energy intended for the utility grid which is simple, effective, and durable. The energy collector is a PV array and the solar generation via the photovoltaic effect. Photovoltaic effect discovery was in 1839 through Edmund Becquerel a French physicist. PV cells produce electricity as of the energy reside in photons of sunlight is the way in which the photovoltaic mechanism. When sunlight falls in a PV cell, some of the photons are absorbed by the cell and the photons energy is converted to an electron in the semiconductor material. The energy is derived from photon; the electron will get away its customary position inside the semiconductor atom becomes a component of the current in an electrical circuit.

1.1 Types of PV System

Mainly there are three types of PV system 1) Stand alone 2) Grid Tied 3) Hybrid. Stand alone PV system in which there is separation among the system and the grid. The inverter accrues its DC energy on or after batteries charging done by photovoltaic arrays. This type does not border any connection with the grid and not mandatory to done anti-islanding protection. Grid tied PV system in which there is no segregation between the system and the grid. They equal phase by means of a grid-abounding sine wave. Grid-tied inverters were premeditated towards shut down by design upon loss of grid energy supply for protection problems. During utility outages available backup power is absent in this type. No battery is useful in this type system. Hybrid PV system are added equally with stand-alone and grid-tied system. This type inverter is accomplished of providing AC supply to particular masses during a grid supply cuts. There is a necessity to do anti-islanding safeguard as a solution for precaution. Photovoltaic system chooses as per the need of energy consumption. Photovoltaic system has become famous only after the semiconductor sector. The initial cost of system is high. It is durable method of energy production since the source is inexhaustible. Now Photovoltaic industry is the fastest growing sector in the world [1].

1.2 Some Exiting MOSFET Topologies in PV grid tied

Many existing topologies of the transformer-less inverter are used in Photovoltaic system now-a-days. Development of semiconductor sector helped in this theory of inverters. Mainly IGBT & MOSFET are used in these inverters. Combinations of them with diodes are also available. In each case of MOSFET based inverters topologies the problem is low reverse recovery and in IGBT base topology is the dead time. HERIC, HB-ZVR, H5, H6, oH5 are some existing topologies of these inverters.

HERIC: Topology of inverter with MOSFET switches highly proficient and dependable inverter in which it has two switches on Alternative Current part in full bridge for the purpose of decoupling photovoltaic section from grid for the time of freewheeling period [1]. There will be a common mode voltage during this period so clamping should be done at input voltage side of Direct Current midpoint [5]. HB-ZVR: H bridge zero voltage rectifier replaced HERIC topology. The switches are made up of MOSFET. Two freewheeling switches are replaced in this topology with one bidirectional switch and four diodes. Another diode D5 is added for elimination of leakage current. Only the one directional clamping is done in this topology when (VAN – VBN) is upper than DC link midpoint voltage. There is also a common mode voltage oscillation occurs in reverse condition but it is comparatively less than HERIC. Conduction losses are less in both the topologies as the grid current flows from beginning to end the switches during complete grid period H5: Switches are made by the combination of MOSFET and IGBT. An additional switch added on DC part of the full bride inverter which is MOSFET. In the period of half cycle of the positive, freewheeling current flows all the way through body diode of switch S3 and switch S1. During the half cycle of negative freewheeling current flows from beginning to end switch body diode of switch S1and S3. In the freewheeling of current no implemented with MOSFET because it has low reverse recovery problem in its body diode. Higher conduction losses are there since output current flows from end to end three switches in the active approach of full grid cycle. Common mode fluctuation is also seen due to no clamping by the side of the mid-point of DC link side. oH5: This topology made up of switches with the combination of MOSFET and IGBT. An additional switch S6 is supplementary for the clamping purpose which is IGBT [5]. Since using IGBT the dead time to be added between S5 and S6 switches to stay away from input split capacitor short circuit. Common mode fluctuation is obtained during dead time. High conduction losses are seen since grid current flows in the course of switches in active mode. H6: The topology made up of IGBT switches with two diodes on Direct Current side of full bridge inverter. Common mode voltage fluctuation is better than the other topologies as there is bidirectional clamping branch. Diode D1 or D2 conduct (VAN – VBN) is higher or lower than the link voltage of half of the DC. Higher conduction losses will be obtained when flow of grid current through four switches [3].

2. PROPOSED TOPOLOGY

This topology is obtained from the existing transformerless inverters for the grid tied PV systems. To obtain high efficiency there are some modifications are made in the structure of the existing topology.

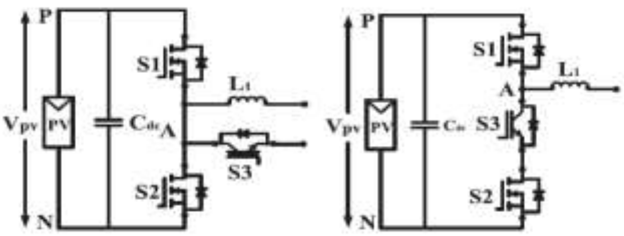

Fig-1: Modification of an HERIC method

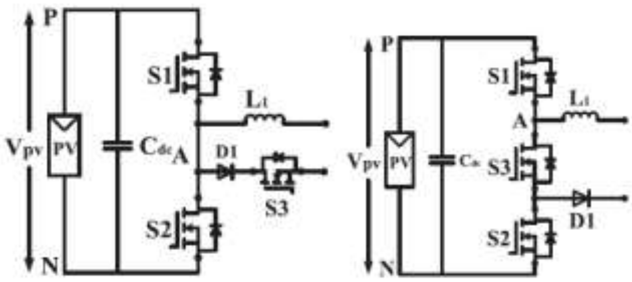

Fig-2: Modification of an H5 method.

The inverter is structured by the super junction MOSFET and silicon carbide diodes. In the HERIC topology of this family one of the leg basically with IGBT switches are replaced to the MOSFETs and diodes to form one leg and other leg is formed by replacing the IGBT switches of H5 leg to MOSFET and diode to form an asymmetric legs. The positions of the freewheeling switches are divider is clamped to the half input side of the DC so common mode voltage will clamped during the cycle [2]. Superjunction MOSFET and the SiC diode help for the increase in the efficiency and fast switching.

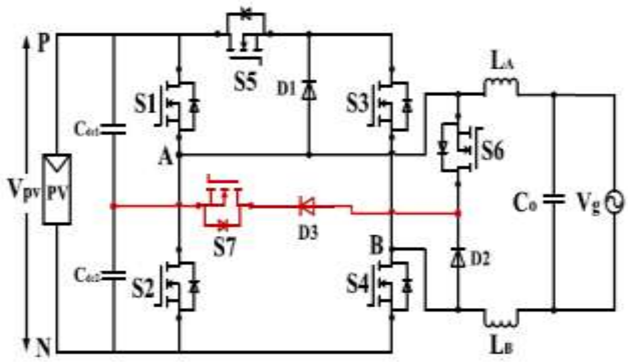

Fig-3: Proposed topology of MOSFET transformerless inverter

The modification in the design combined to form the asymmetric legs of the proposed topology in which the switches are divided to the high and low switches. In this case the switches S_1,S_2,S_4 and S_5 are switches of high frequency. S_3 and S_6 are switches of low frequency freewheeling. By using the super junction MOSFET the charge balancing mechanism is applied here so only the breadth of the epitaxial defines the blocking voltage. As a consequence, the super junction structure has a linear relationship between on-resistance and breakdown voltage. The on-resistance increases linearly by means of an increase in breakdown voltage. The low parasitic capacitance of a SJ MOSFET helps to increases the switching speed and reduces the switching losses. Switch S_7 and diode D_3 along with capacitor divider provide the unidirectional branch of clamping which clamps voltage of common mode at the middle of the DC link. Also have LC filter consists of inductors L_A and L_B, and capacitor C_O which is associated with the grid. V_{pv} represent the voltage of input to the topology. The PWM applied is a bipolar sine pulse width modulation output voltage with three-level. Super junction switches of MOSFET are used as no issues of reverse-recovery are the proposed mandatory for arrangement of the inverter for power factor of unity process. Subsequently, efficiency of whole PV system is increased

3. OPERATING PRINCIPLE

Half cycle of positive and negative current of the grid switches S_1,S_2,S_4 and S_5 at the frequency switching commutate by means of the indistinguishable order of commutation. Four modes of operation are planned to produce the voltage of output state of $+V_{PV}$ and $-V_{PV}$.

Mode 1: half cycle in the positive of current in the grid is called as the active mode. The S_1 and S_4 switches are activated in this mode.

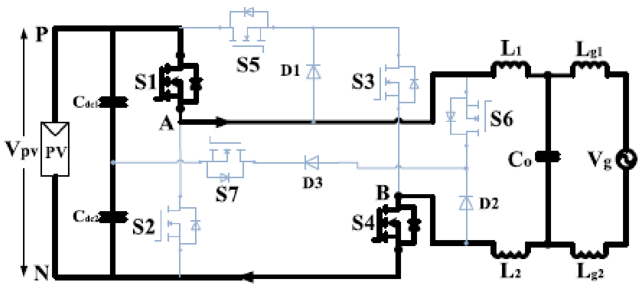

Fig-4: active mode in grid current positive half cycle

In this active mode when S_1 and S_4 are turned-on, increases of the inductor current i_L linearly from side to side grid. This mode shows $V_{AN} = V_{PV}$ and $V_{BN} = 0$ so $V_{AB} = V_{PV}$, the inductor current in the mode of active of the half of positive cycle is equal to

$$i_L(t) = \frac{V_{PV} - v_g}{L}(t). \quad (1)$$

Mode 2: within the half positive cycle of the current in the grid is the freewheeling mode. The switch S_6 and D_2 activated on this mode. The inductor current i_L will flow through S_6 and D_2 .

The inductor current flowing all the way during these switches reduces linearly because of the grid voltage. Due to this V_{AN} falls and this helps in the increase of V_{BN}. V_{BN} increases until both have equal values. The freewheeling flow of current is all the way through S_7 switch and diode D_3 to the the dc link midpoint, if ($V_{AN} \approx V_{BN}$) the voltages are higher than half of the voltage of the dc-link. This will result in the clamping of V_{AN} and V_{BN} at the midpoint of $\frac{V_{PV}}{2}$. So this mode gives us that $V_{AN} = \frac{V_{PV}}{2}$, $V_{BN} = \frac{V_{PV}}{2}$ thus the inverter voltage output $V_{AB} = 0$ and current of the inductor

$$i_L(t) = \frac{-v_g}{L}(t). \quad (2)$$

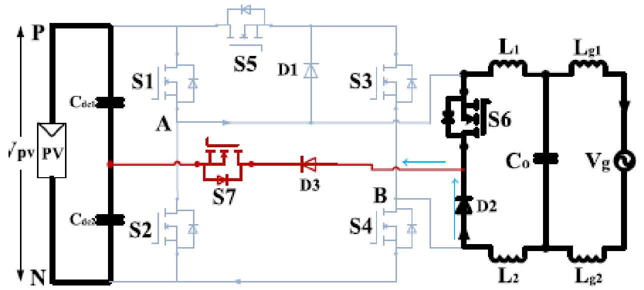

Fig-5: Freewheeling mode in grid current positive half cycle

Mode 3: it is in the half cycle of negative of current in the grid and called as the active mode. S_2, S_3 and S_5 switches are activated at this mode. When S_2 , S_3 and S_5 switches are switched on this mode the inductor current increases in contradictory direction. Just like the mode 1 but opposite direction the inductor current will flow. The voltage is given by V_{AN} =0 and $V_{BN} = V_{PV}$ thus $V_{AB} = -V_{PV}$ and the inductor current of this active mode is given as

$$i_L(t) = \frac{V_{PV} - v_g}{L}(t). \quad (3)$$

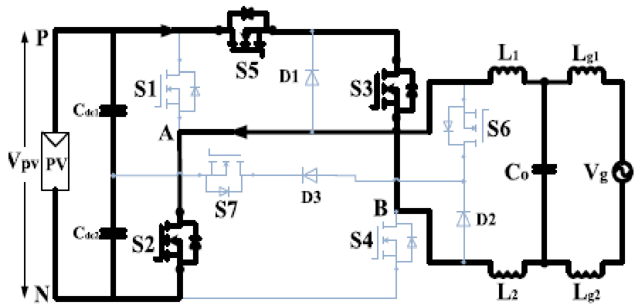

Fig-6: Active mode in grid current negative half cycle

Mode 4: it is in cycle of the negative current in the grid. This mode called as the freewheeling mode. The switch S_3 and D_1 are active during this mode.

The current in the inductor flows during S_3 and D_1 when turning-off S_2 and S_5 switches. The current in the inductor flowing through these switches reduces linearly because of the grid voltage. Due to this V_{AN} falls and this helps in the increase of V_{BN} just in the opposite direction. V_{BN} increases awaiting both has equal values. The freewheeling current flows in the course of Switch S_7 and diode D_3 to the dc link midpoint, if ($V_{AN} \approx V_{BN}$) the voltages are higher than half voltage of the dc-link. So this mode gives us that $V_{AN} = V_{BN} = \frac{V_{PV}}{2}$ thus the inverter voltage output $V_{AB} = 0$ and current of the inductor

$$i_L(t) = \frac{-v_g}{L}(t). \qquad (4)$$

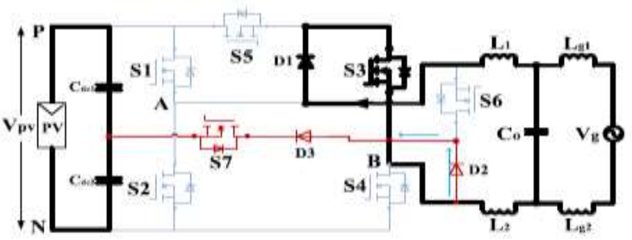

Fig-7: Freewheeling mode in grid current negative half cycle

4. GATE PULSES GENERATION

The typical importance of controlling voltage and current feed to the load is by the switch turning on and off at a fast rate. PWM helps to do this by switching done several times a minute [7][8]. In a pulse width modulation, the modulation of inverter to get the desired output sine-wave is prepared with a modulated sine wave onto a high or low frequency square wave as the carrier. This can be done using a high speed digital signal processor. The modulation by traditional approach using a comparator to perform is easier to understand. The frequency modulation index is define as m_f.

$$m_f = \frac{f_{tri}}{f_m}$$

Where f_{tri} is the carrier frequency and f_m is the modulation frequency. Pulse width modulated square wave which is the output of the modulation is used to manage the gates of the inverter.

Bipolar pulse width modulation is of a sine PWM type technique, where the pulses or the PWM developed from a sine wave which is always used as the suggestion. The gate pulses for this topology are generated through the bipolar pulse width modulation [4]. Sine wave and triangular waves are taken as reference and carrier. The pulses are produced when the both reference wave and carrier wave meet. PWM pulse equivalent to a given signal is the interceptive PWM; the sine wave is compared in the company of a saw tooth or a triangular waveform. The previous waveform is less than the earlier; the signal of PWM either is in state of high or else in the state of low. Generating different pulse width is possible as per the need of switches on and off time by managing the interception of the wave form.

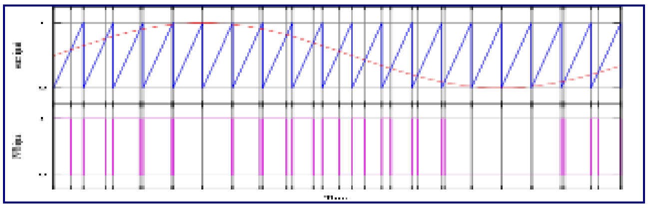

Fig-8: Bipolar PWM generation

The gate pulses for each cycle are produced. For each switches the respective gate pulses are given as G_1,G_2,G_3,G_4,G_5,$G_6$and G_7. During the positive cycle the gate pulsesG_1, G_4, G_6,and G_7 are activated and during the negative cycle G_2, G_3, G_5, and G_7.

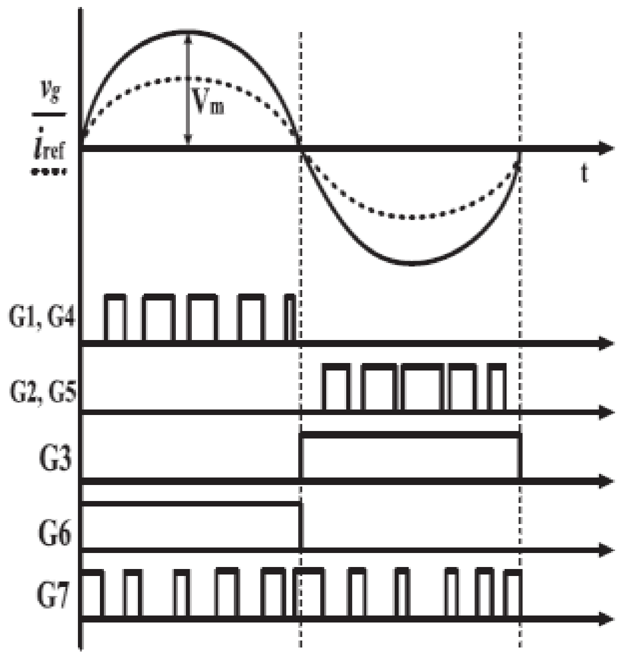

Fig-9: Gate pulses generation pattern

During the reference wave positive half cycle of this topology $S_1$and S_4 corresponding switches gate pulsesG_1, G_4 are activated on and off at regular intervals at the same time. The switch S_7 gate pulse G_7 will be high or on only when the gate pulses,G_1, G_4 are low or off. The freewheeling is only done when the switches have no current flow. The switch S_7 will turned on at that time and the freewheeling flow of current through it. The gate pulse G_6 for the switch S_6 will be in on state for the entire duration of half cycle of the positive reference wave but clamping of the common mode voltage is done only when switch S_7 or gate pulse G_7 is high.

During the half cycle of the negative reference wave of this topology the S_2 and S_5 corresponding switches gate pulses G_2 and G_5 are activated on and off at regular intervals at the same time. The switch S_7 gate pulse G_7 will be high or on only when the gate pulses G_2 and G_5 are low or off. The freewheeling is only done when the switches have no current flow. The switch S_7 will at that time turned on and the freewheeling flows of current through it. The gate pulse G_3 for the switch S_3 will be in on state for the period of the entire half cycle of negative the reference wave but clamping of the common mode voltage is done only when switch S_7 or gate pulse G_7 is high.

5. SIMULATION RESULT

MATLAB is a programming language where linear algebra programming was simple. Problem-based MATLAB examples have been given in simple and easy way to learning fast and effective. MATLAB is a fourth-generation high-level programming language which helps in interactive environment for numerical computation, visualization and programming.

5.1 Open loop Proposed Topology

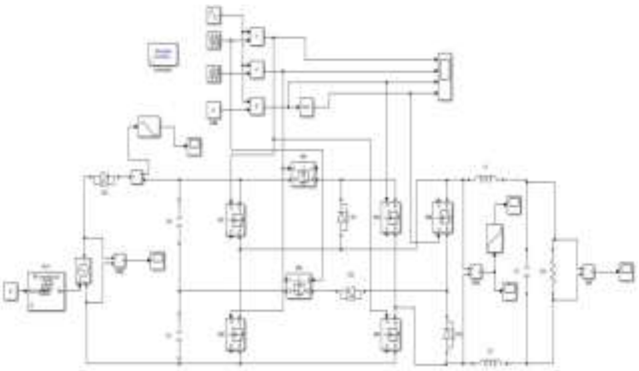

Fig-10: Open loop simulation circuit

In the open loop circuit model our photovoltaic modules which act as the source or the input of the method. The inverter consists of power MOSFET which controlled by the PWM generating units. The filters filter the harmonics and the output can be seen in the scope block. The input or the source of the system consist the PV module which produces voltage of DC as the input of the arrangement. The DC is given to the inverter through the capacitor divider made by two capacitors. The inverter is constructed in ordered to change the DC created by the solar panels to AC for the commercial uses or to send to the grid. Grid consists of the AC which have frequency which the DC don't have; so inverter have to convert and produce AC which have same frequency as the voltage of grid. The inverter output is filtered by using a necessary capacitor and inductor to avoid the harmonics before its send to the grid.

Employing the bipolar sinusoidal pulse width modulation, in which requirement of single sinusoidal wave as the reference wave and two saw tooth to produce pulses for the two legs of the inverter. In such way obtaining the proper and desired output from the inverter is possible. The pulses are produced in such way that during each freewheeling period the leakage current is avoided by clamping it to the DC link during the half cycle of positive and negative.

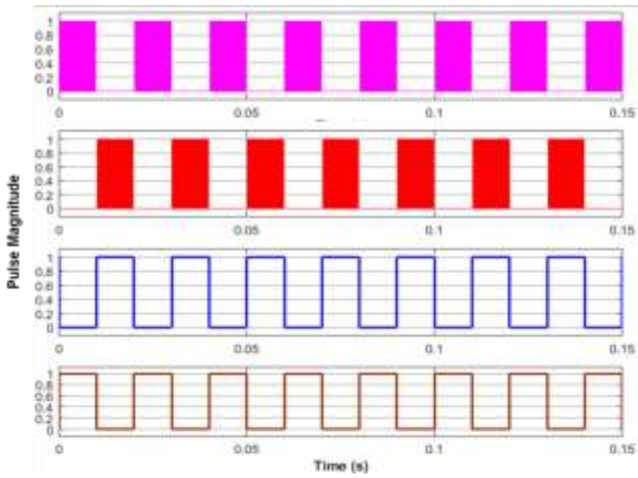

Fig-11: Pulse width modulation for open loop model

A square output for the transformerless inverter obtained as it passes this through the filter limbs it will be converted to the sine formation.

The output commencing the inverter unit is load connected and the output can be obtained in the scope. Obtaining a wave of sine with frequency and less harmonic and high efficiency as output is done by this.

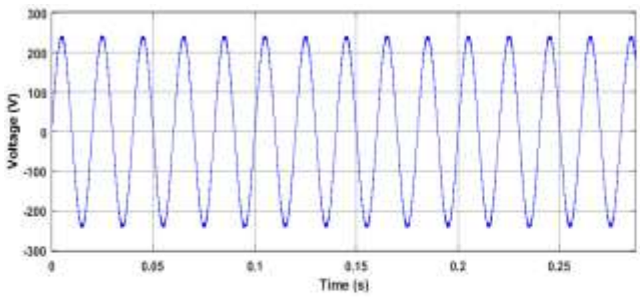

Fig-12: Output voltage of open loop circuit with filter

5.2 closed loop

The entire simulation will be closed or controlled in this method; desired output can be maintained in this method rather than the open loop.

In closed loop simulation a controlling unit which helps in controlling the entire output through changeable input to the inverter. In this method our PWM generated is controlled by checking the output.

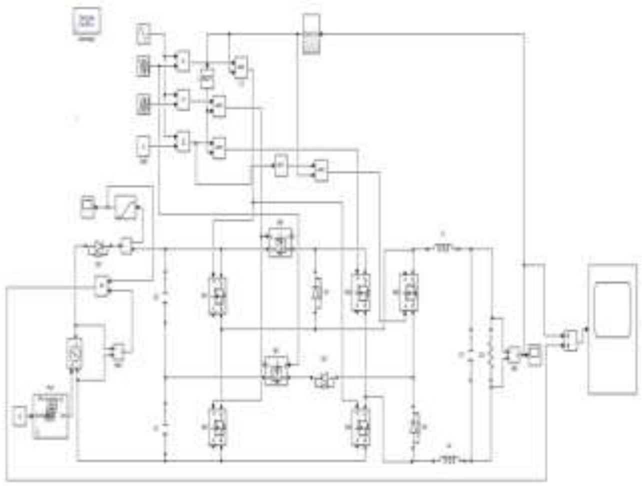

Fig-13: Closed loop simulation circuit

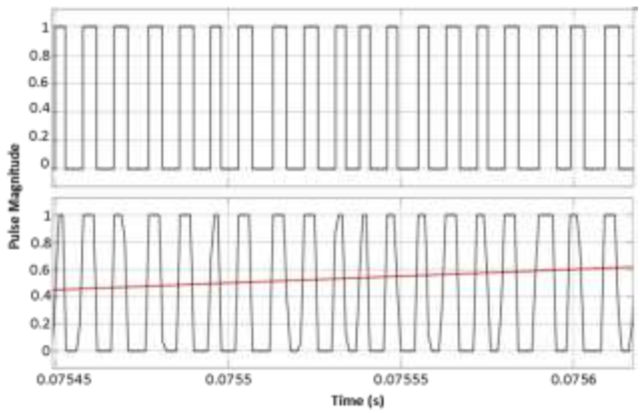

Fig-14: Pulse width modulation for closed loop

In this method the output variations are checked and the pulses are controlled by the comparators. The needed pulse width is produce either by reducing or increasing the width. By this a required regulated output is obtained.

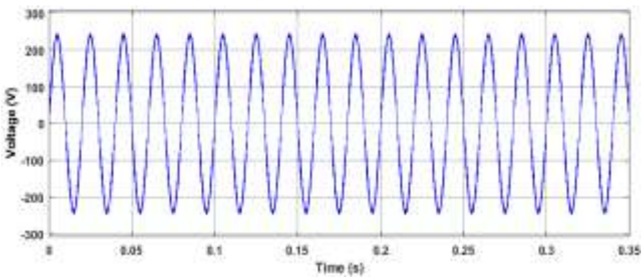

Fig-15: The output of closed loop simulation with filter

In this case of closed loop also getting the output of the inverter as square but there will be a regulation in the pulses after the comparison with the final output. The output of the closed loop inverter also has to pass through the filter to get the sine form.

The final output waveform obtained in the closed loop will be sinusoidal. It will be constant also because it's from closed loop module which helps in adjusting the output.

6. HARDWARE SETUP

Fig-16: Full hardware setup

The hardware setup of this module is done in open loop with the help of resistor as load. PIC16F72is used as the controller in this model. The inverter model is constructed with help of the SPW47N60C3 MOSFETs. The supply to the board is provided by the transformers and it is converted and bucked to match the need of gate circuits and as well as the controller. One full bridge and one half wave rectifiers are used for the conversion of AC to DC. The super-junction MOSFETs physical structure is based on the idea of charge balancing. The charge in the surrounding N regions under reverse bias are cancelled since the drift region now has multiple P columns. Due to this the N_{epi} can now be thinner and heavily doped. The combined structure offers a much higher resistance to applied reverse voltage. The primary function of a power supply is to convert electric current from a source to the correct voltage, current, and frequency as the load required. The input and output are usually hardwired circuit connections but it always have a controlling unit for the purpose of regulating the input and output voltages, currents, frequencies etc as an external monitoring and control. PIC16F72 is used as the controller for here. A gate driver is a power amplifier ; it in take a low-power input from a controller IC and produces a high-current drive input for the gate of a high-power transistor, like power MOSFET. It consists of a level shifter in combination with an amplifier; which helps in switching or turning on and off of the power MOSFET or other power transistors. A regulated power supply is an embedded circuit. It helps in converting unregulated AC into a constant DC. The process is done with the help of a rectifier; it converts AC supply into DC. Its function is to provide a stable voltage or less often current to a circuit or device that must be operated within certain power supply limits. The output from the regulated power supply may be alternating or unidirectional but always nearly DC supply.Two transformers are used in this hardware. The first is the combination of transformer, rectifier and filter. A transformer will help in converting the input AC voltage to a higher or lower AC voltage. A rectifier is used to convert the transformer output AC voltage to a varying DC voltage. This voltage is in turn is passed through an electronic filter to convert it to an unregulated DC voltage. So using this combination circuit instead of the solar panel source; produces DC voltage for our inverter. The DC voltage input source is produced by the transformer with rectifier and filters. The input Dc is passed to the inverter unit to produce the sine wave output. The controller unit will control the entire system voltage, current and the pulse generation. It controls the gate drive pulses. The gate drive unit will control the switching of the inverter switches. It helps in producing the necessary PWM for the system to get the desired output wave.

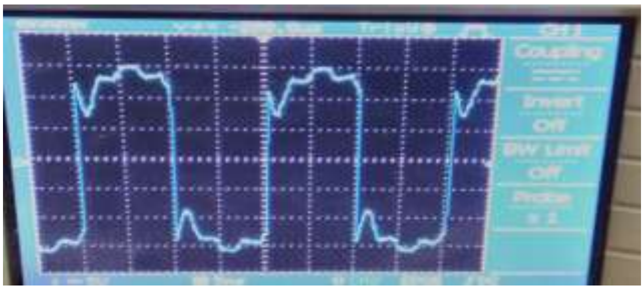

Fig-17: The output of the hardware setup

7. CONCLUSIONS

The transformerless inverter constructed with super-junction MOSFET for the grid tied system can produce a high efficiency in excess of a wide choice of loads. Low leakage current due to the clamping branch which clamps the CM voltage and this helps it remain constant during the entire operation. Since no dead time for the switches thus obtaining low distortion. It is very suitably destined for the full bridge of single phase applications. The bipolar PWM is easy to implement practically rather than the unipolar PWM. The frequency distortion will be low since ability to increase the carrier wave frequency high. Obtaining two levels output since using this PWM. Efficiency of the system is maintained high. Using super-junction MOSFETs for the inverter switch which avoids reverse recovery effects of a MOSFET switch. Producing only one reference sine wave for the pulse generation is possible. Also achieving switching frequency stability and low frequency harmonics is possible by this experiment.

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