30 Level Multilevel Inverter with Two Switched Capacitor and Reduced Number of Switches

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***Abstract*-Multilevel inverters with a large number of steps can generate high quality voltage waveforms, good enough to be considered as suitable voltage source generators. An advanced multilevel inverter topology is proposed to optimize number of bidirectional switches. In this work the an five-level cascade H-bridge Inverter, which uses multicarrier based control structure and two capacitor with 10 switching MOSFETs topology is being presented. Analysis is done for RL and pure resistive load. The PWM strategy reduces the THD and this strategy enhances the fundamental output voltage. The experimental and simulated results show that total harmonic distortion of output voltage and current waveform shapes are 5.16 % and 5.77% respectively for RL load which are within the acceptable limits**.

***Keywords*: Multilevel inverter, Total harmonic distortion, PWM**

I.INTRODUCTION

Multilevel converters have received more and more attention because of their capability of high voltage operation, high efficiency, and low electromagnetic interference (EMI). The desired output of a multilevel converter is synthesized by several sources of dc voltages. With an increasing number of dc voltage sources, the converter voltage output waveform approaches a nearly sinusoidal waveform while using a fundamental frequency switching scheme. This results in low switching losses, and because of several dc sources, the switches experience a lower. As a result, multilevel converter technology is promising for high power electric devices such as utility applications. For these applications, the output voltage of the converters must meet maximum total harmonic distortion (THD) limitations; some kind of method must be used to control the harmonics. The traditional PWM method, space vector pulse-width modulation (PWM) method, sub-harmonic PWM method (SH-PWM), and switching frequency optimal PWM (SFO-PWM) for multilevel converters require equal dc voltage sources. For fundamental switching scheme, the transcendental equations characterizing the harmonic content can be converted into polynomial equations. Elimination theory has been employed to determine the switching angles to eliminate specific harmonics, such as the fifth, seventh, 11th, and the 13th. However, as the number of dc sources increases, the degrees of the polynomials in these equations are large and one reaches the limitations of contemporary computer algebra software tools (e.g., Mathematic or Maple) to solve the system of polynomial equations using resultants. Another method to eliminate harmonics in multilevel inverters is highlighted.

II.LITERATURE REVIEW

Kaustubh P. Draxe et al. [1] In this paper, a cascaded asymmetric multilevel inverter is proposed which contains minimum number of switches and can be employed in AC applications using solar energy. The proposed topology consists of 25 output levels using 10 switches with near sinusoidal output, thereby reducing gate driver circuitry and optimizing circuit layout. Asymmetric multilevel inverter is more advantageous than symmetric multilevel inverter in obtaining more number of output levels using same number of voltage sources.

KarthiKeyan. V et al. [2] This paper A New multilevel inverter with reduced number of switches and unequal DC sources is presented. Compared to conventional inverter this inverter produces higher number of output levels with less number of switches and thus harmonics are reduced and the power quality is improved. The switching angles of each level in the output are determined using simple sine property to reduce the output harmonics.

KarthiKeyan. V et al. [3] In this paper, simulation analyses as well as a case study are carried out to discover the effect of irradiance on the yield factor of the grid connected solar PV system. Now-a-days, solar energy is the alternate energy solution for many applications. It may be an isolated standalone solar system to provide power to the inaccessible area or it may be grid connected system. The isolated solar PV system is forever connected to a storage device to store the excess power when the generated power output is more than sufficient. Whereas grid connected solar PV systems are more trustworthy.

G. Vijaykrishna et al. [4] This paper presents the reversing voltage strategy for a multilevel inverter to enhance the power quality of the induction motor by reducing the THD with optimal no of switches. Method: The SPWM-PD technique was implemented to generate gate driver signals to regulate the 7 level and 9 level, reversing voltage multilevel inverter which requires only three carrier signals instead of six in conventional multilevel inverters.

III. OBJECTIVES

The work on the multilevel inverter deals with the following main objectives:

- To create a MATLAB SIMULINK model multilevel inverter having a proper topology such that it will generate a voltage output having 30 levels.
- To design a multi carrier based PWM controller to produce pulses to be sent to the switching MOSFETS
- To reduce the THD level in the output voltage and current waveform thus making it suitable for feeding different types of load.
- Analyzing the system for different loads such as RL and pure resistive load and checking the distortion level in both cases

IV. METHODOLOGY

The model was developed in the MALAB / SIMULINK environment. It is a high-level matrix / matrix language with instructions, functions, data structures, inputs / outputs and object-oriented programming functions. It has the following main characteristics:

- High level language for scientific and technical computing
- Desktop environment for iterative exploration, design and troubleshooting
- Graphics to display data and tools to create custom graphics
- App for curve fitting, data classification, signal analysis, control system optimization and many other tasks
- Additional toolboxes for a variety of technical and scientific applications
- Tools to create custom applications for the user interface
- Provisioning options for sharing MATLAB programs with end users

In cascaded multi-cell inverter structures, some power converters having two branches are arranged in series in each phase and the voltage of each phase is obtained by summing the voltages of the phase power converters. This structure is much simpler than the inverter schemes with diode and capacitor terminals.

The goal of the drive system is to perform highly efficient power conversion, sustain the ease and flexibility in the control method, reliability for wide range of operation. This is critical for important drive applications. Some additional advantages of the motor drive systems using the cascaded inverter are redundant switching operation to balance battery use, worst case operability which maintains operation at reduced performance. The separate DC sources can be switched on by using various ways to synthesize the output voltage, thus enhancing the drive system operability and system management flexibility. The cascaded H-bridge has drawn considerable interest since the mid-1990s, and has been used for ASD and reactive power compensation. The modular structure provides advantages in power Scalability and maintenance and fault tolerance can be achieved by bypassing the fault modules.

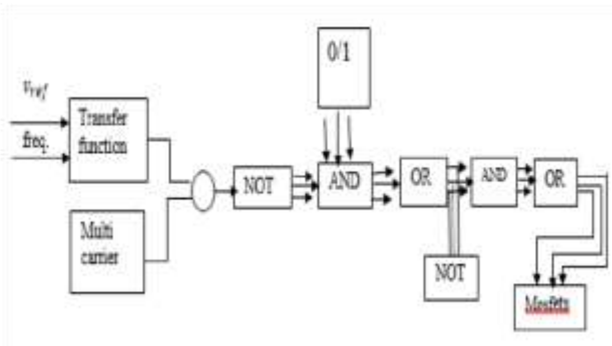


Figure 1 Flow chart of control

1) PWM Technique

Pulse width modulation is the method of choice to control modern power electronics circuits. The basic idea is to control the duty cycle of a switch such that a load sees a controllable average voltage [6]. To achieve this, the switching frequency or repetition frequency of the PWM signal is chosen high enough that the load cannot follow the individual switching events. Switching, rather than linear operation of the power semiconductors, is of course done to maximize the efficiency because the power dissipation in a switch is ideally zero in both states. In a typical case, the switching events are just a blur to the load, which reacts only to the average state of the switch. There are a number of different methods to generate periodic rectangular waveforms with a varying duty cycle.

A standard method is the so called carrier-based PWM technique, which compares a control signal with a triangle (or saw tooth shaped) waveform. . By comparing this signal with a reference level, which can vary between 0 and 1 V, a PWM signal with a duty cycle between 0 and 100% is generated. Because of the triangular carrier, the relation between the reference level and the resulting duty cycle is linear. This method works very well for duty cycles in the range from 5% up to 95% However, if the reference signal exceeds 100% or falls below 0%, the resulting PWM signal would be always on or always off, respectively. This is called over modulation. This regime must be avoided by proper conditioning of the control signal. In addition, for control signals resulting in PWM signals with duty cycle values as high as 99% or as low as 1%, the switch may never fully reach the opposite state and spend an undue amount of time in transitions. Therefore, it is typically recommended to limit the control signal to arrange, which avoids over modulation as well as extremely narrow pulses. The Duty Cycle is: Therefore root mean square value of AC output voltage will be:

D = Actual duration of pulsein half cycle duration of one half cycle

$V = DV_1$

The PWM technique is the most widely used and well accepted because it is the simplest technique to generate multilevel pulses to control individual power switches for any output level inverters by comparing reference signal with triangular signals.

a) Sinusoidal PWM

It refers to the generation of PWM outputs with sine wave as the modulating signal. The OFF and ON time of a PWM signal in this case can be obtained by comparing a reference sinusoidal wave (modulating wave) with a triangular wave of high frequency (the carrier wave) as shown in Fig. 3. Sinusoidal PWM technique is widely used in industrial applications and is abbreviated here as SPWM. The frequency of the modulating wave decides the frequency of the output voltage. The peak amplitude of modulating wave decides the modulation index and controls the RMS value of output voltage. By changing the modulation index, the RMS value of the output voltage can be varied.

As compared to other ways of multi-phase modulation this technique improves distortion factor more significantly and also it eliminates all harmonics less than or equal to 2p-1, where “p” is defined as the number of pulses per half cycle of the sine wave. The output voltage of the inverter is not fully filtered it contains some harmonics. The higher order harmonics can be removed easily by using filter

In order to implement Sinusoidal PWM using analog circuits, one has to use the given building blocks

(1) Triangular wave generator

(2) Sinusoidal wave generator

(3) Comparator

(4) Inverter circuits.

The peak of the sinusoidal modulating waveform is less than the peak of the triangle carrier voltage waveform. When the sinusoidal waveform is higher than the triangular waveform, the upper switch is turned ON and the lower switch is turned OFF.

Similarly, when the sinusoidal waveform is lower than the triangular waveform, the upper switch is OFF and the lower switch is ON. According to the switching states, either positive or negative half DC bus voltage is applied to each phase. The pulse widths depend on the intersection of the triangular and sinusoidal waveforms.

In addition to a DC reference signal, any other waveform could be used as the modulation signal as long as the highest frequency of its AC components are at least an order of magnitude less than the frequency of the carrier signal. To generate a sinusoidal output voltage for an inverter, which is often desired, the carrier can be modulated with a sinusoidal reference signal. The ratio between the carrier frequency and the frequency of the modulation signal is lower than recommended for actual implementation.

The resulting sinusoidal PWM voltage drives one phase lag of an inverter. If the voltage level is 1, the upper switch is on, and vice versa. After filtering out the switching frequency components, the resulting output voltage has the shape and frequency of the modulation signal. For the remaining phase legs, the same technique, with reference signals that are phase shifted by 120 and 240 degrees, is used.

The amplitude of the output voltage can be controlled by varying the ratio between the peak of the modulation signal and the peak of the carrier wave. If the amplitude of the modulation signal exceeds the amplitude of the carrier, over modulation occurs and the shape of the fundamental of the output voltage deviates from the modulation signal. Earlier, because the difference between the switching frequency and the fundamental is much larger. Therefore, the carrier frequency components can be easily removed with LC filters of small size.

In addition, the amplitude of the output voltage can be controlled simply by varying the amplitude ratio between the modulation signal and the carrier. If sixstep modulation is used, the DC bus voltage would have to be controlled in order to control the amplitude of the output voltage.

b) Multicarrier Pulse Width Modulation

Waveforms of practical inverters are nonsinusoidal and contain higher magnitude of certain lower order harmonics. For low and medium power applications, square wave and quasi square waveforms may be acceptable, but for high power applications sinusoidal waveforms with lower distortions are required. Harmonic contents present in the output of DC to AC inverters can be eliminated either by using filter circuit or by employing pulse width modulation circuits. Use of filters has the disadvantages of larger unit size, increased losses and hence the poor efficiency which results in higher cost for realization, whereas use of PWM techniques reduces the filter requirements to minimum or to zero, depending upon the type of applications and the control technique employed for the generation of firing pulses for the power switches and depending upon the type of application.

Harmonics are divided into voltage and current harmonics. Current harmonics is usually generated by the harmonics contained in the voltage supply and depends on the type of load such as resistive load, inductive and capacitive type load. Both harmonics can be generated by either the source or the load side. Traditional two level high frequency PWM inverters have several problems associated with high frequency switching, which produces high dv/dt stress across the power switches. While employing the certain control techniques to the multilevel inverters the output voltage harmonics are reduced significantly when compared to the conventional high frequency PWM techniques. Here the proposed PWM technique is implemented in MATLAB/ SIMULINK and the output waveforms were presented for different levels.

V. RESULTS AND DISCUSION

An electrical power inverter is basically a circuit that converts a DC signal into an AC signal. AC signal is more useful in our daily appliances and it travels easily. And it is easier to use multilevel inverters rather than using multiple power lines. Multilevel inverters give higher power .They are operated through multiple switches instead of one. They can use environmental friendly energies like wind and solar energy and convert them to AC. To convert a DC signal into an AC signal we require fast switching of DC signal giving us multiple levels. This turns into a staircase wave that is quite close to a sine wave.

Different positions of switches, determine different voltage levels. The circuit consists of diodes and switches. This is the most common type of inverter and usually uses Separate DC sources (SDCs).

We have designed an inverter that uses two switched capacitors and 10 switching MOSFETS for inversion. The aim is to convert DC voltage into capacitor voltage. Proper precautionary measures should be taken in order to avoid over charging of capacitors the work discusses the working of the control system with two cases.

CASE1: Multilevel inverter with RL load

CASE2: Multilevel inverter with R load The control structure that has been designed for operating the 10 MOSFET of the inverter for generating 30 levels of output voltage. The control structure uses different carrier signals for generating pulses that has been depicted.

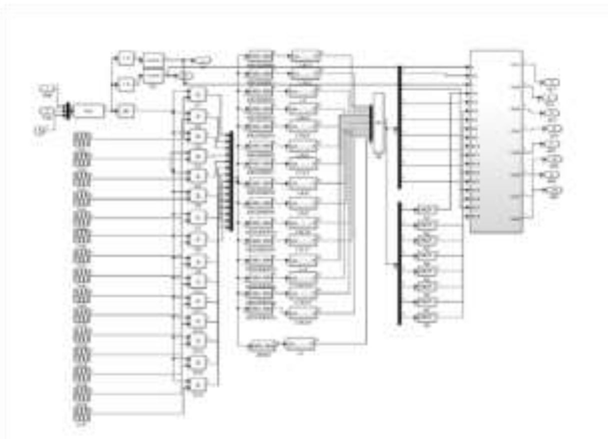


Figure 2: Proposed Control Structure Of Multicarrier Pulse Width Modulation

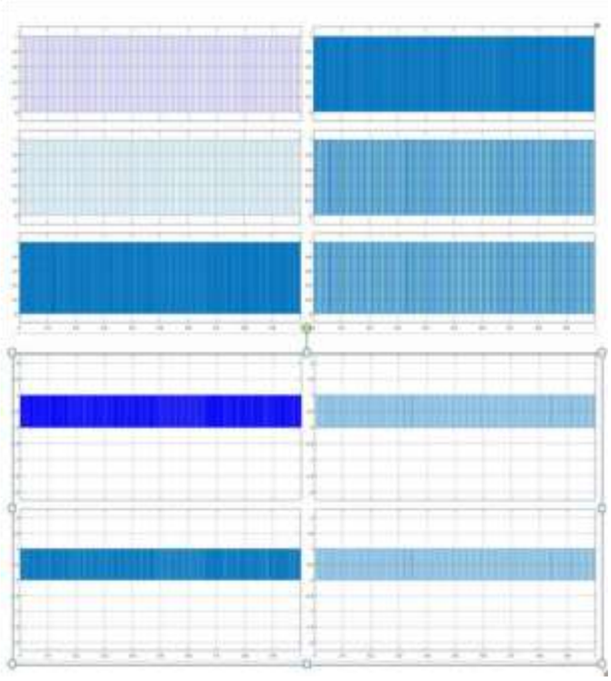


Figure 3 Generated 10 Pulses from the Control for Switches

CASE 1: Multilevel inverter with RL load

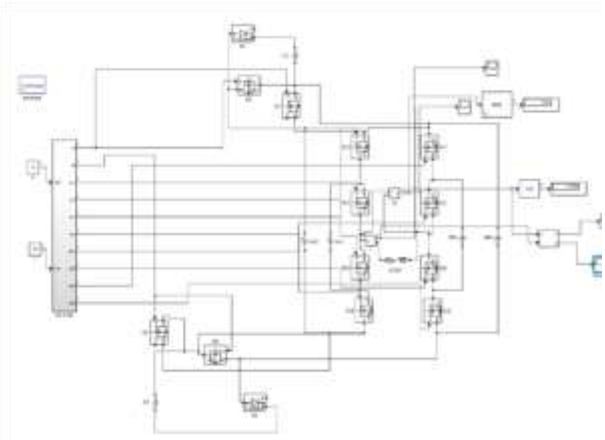


Figure 4 MATLAB/SIMULINK Model Of Designed Two Switched In Capacitor 30 Level Inverter With RL Load

The Matlab/Simulink model of the proposed inverter for 30 level output is shown in Figure 4.1. It consists of two switched in capacitors which are cascaded with 8 switching MOSFETs. The inv erter is made to feed a RL load. Simulation is performed for the proposed circuit with MATLAB/SIMULINK.

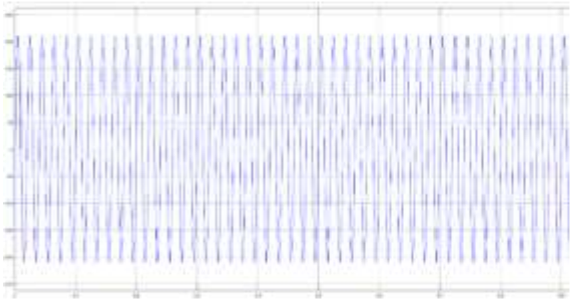


Figure 5 Voltage Output from the Inverter with RL Load

The amplitude of the inverter's output voltage waveform for 30 levels is 210 Volts which has be en depicted in figure4.4. The figure also shows the different levels of the voltage coming from the proposed topology of inverter

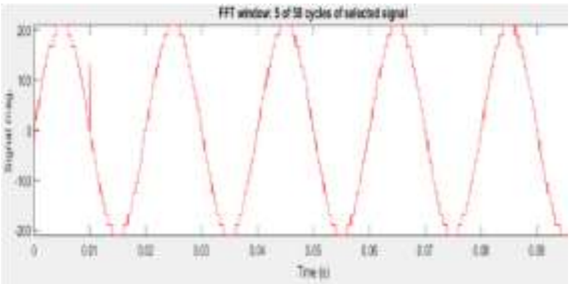


Figure 6 FFT Window Of 5 Cycles Of Voltage Signal With RL Load

inverter for 30 level output feeding a 100 ohm R load is shown in Figure 4.12. It also consists of same topology of two switched in capacitors which are

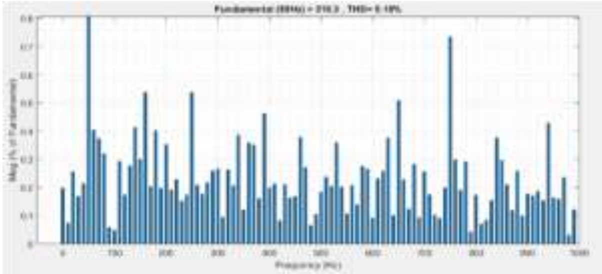


Figure 7 THD In Voltage Output From The Inverter With RL Load

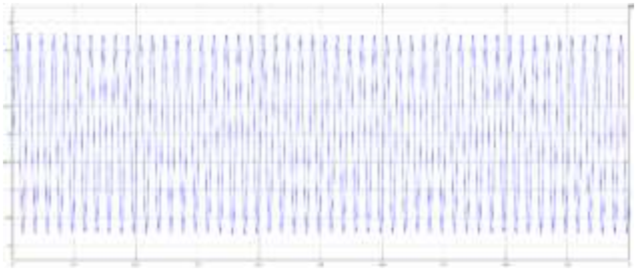


Figure 8 Current Output from the Inverter with RL Load

The amplitude of the inverter's output voltage waveform for 30 levels is approximately single phase 1.75 Ampere which has been depicted in figure4.7

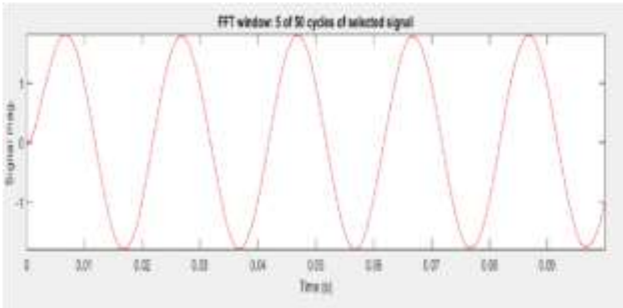


Figure 9 FFT Window Of 5 Cycles Of Current Signal With RL Load

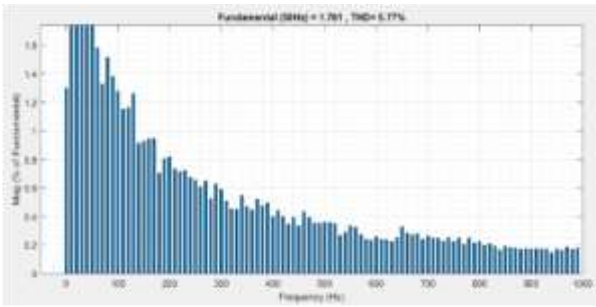


Figure 10 THD in Current Output from the Inverter with RL Load

FFT analysis of voltage and current output of the multilevel inverter has been done. Further the total harmonic distortion (THD) was calculated and was found to be 5.18% and 5.77%

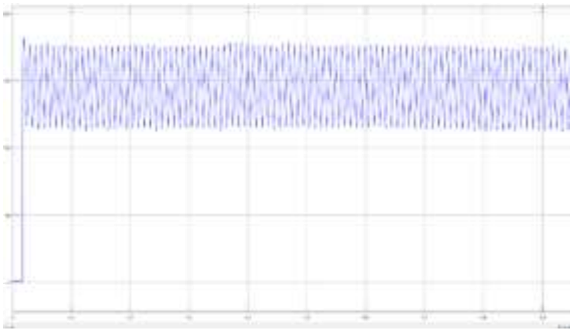


Figure 11 Active Power Output from the Inverter with RL Load

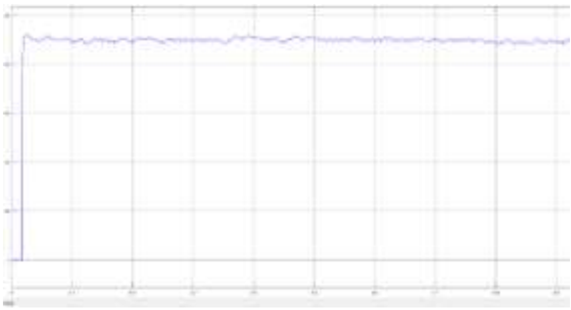


Figure 12 Reactive Power Output from the Inverter with RL Load

The active output from the inverter was found to be varying between 125 to 175 watt and reactive power output is approximately 85 Var at the RL load terminal

CASE 1: Multilevel inverter with R load

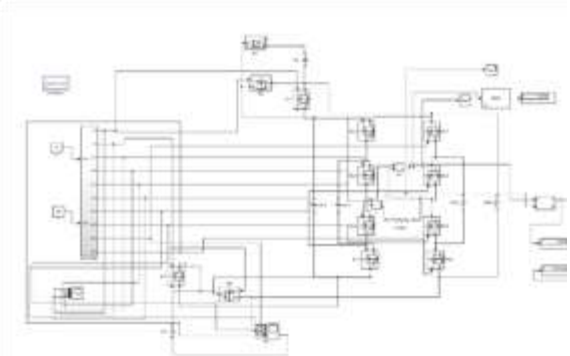


Figure 13 MATLAB/SIMULINK Model Of Designed Two Switched In Capacitor 30 Level Inverter With R Load

The Matlab/Simulink model of the proposed cascaded with 12 switching MOSFETs. Simulation is performed for the proposed circuit with MATLAB/SIMULINK

The amplitude of the inverter's output voltage waveform for 30 levels is approximately single phase 2.4 Ampere which has been depicted in figure4.16

Figure 18 FFT Window of 5 Cycles of Current Output From the

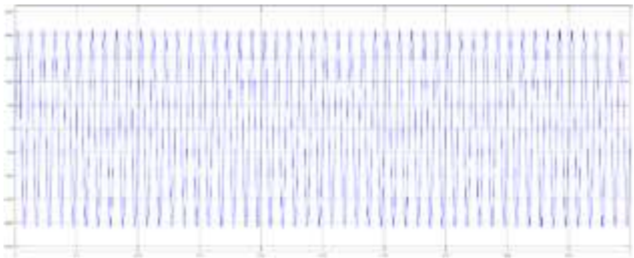


Figure 14 Voltage Output from the Inverter

The amplitude of the inverter's output voltage waveform for 30 levels is 210 Volts which has been depicted in figure4.4. The figure also shows the different levels of the voltage coming from the proposed topology of inverter. This is same as that of voltage outpu being measured in CASE1.

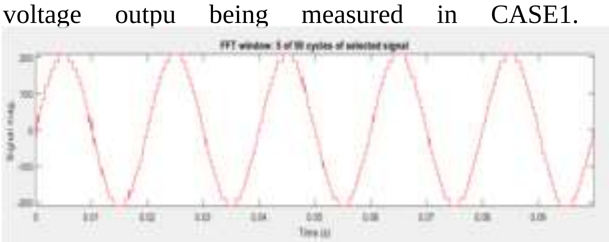


Figure 15 FFT Window of 5 Cycles of Voltage Signal

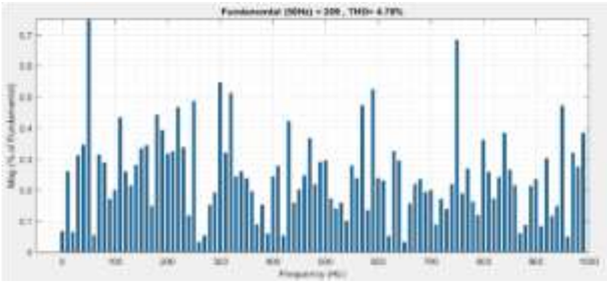


Figure 16 THD in Voltage Output from the Inverter

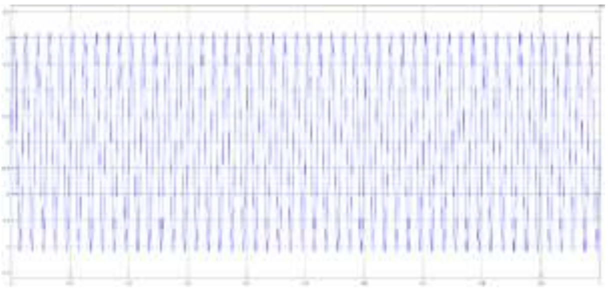
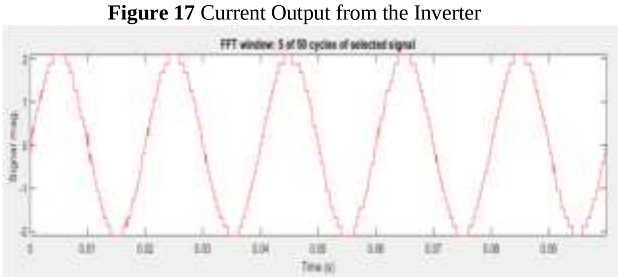
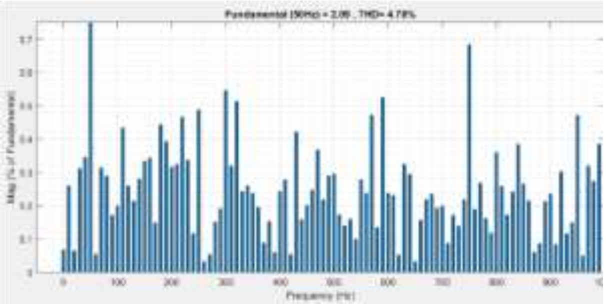


Figure 17 Current Output from the Inverter



VI. CONCLUSIONS AND FUTURE SCOPE

Inverter



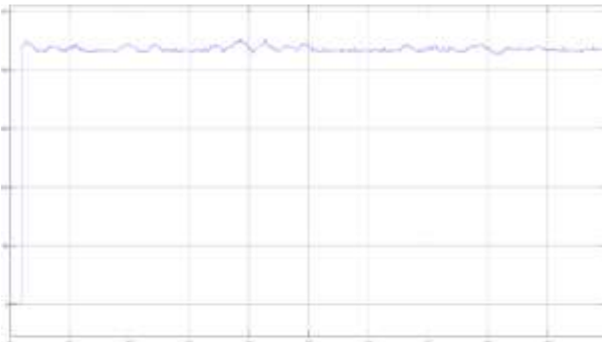


Figure 19 THD in Current Output from the Inverter

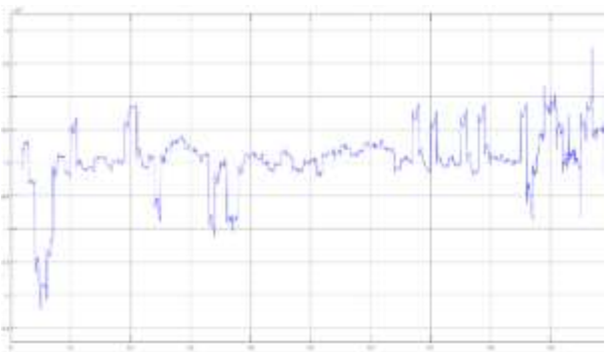
FFT analysis of voltage and current output of the multilevel inverter has been done. Further the total harmonic distortion (THD) was calculated and was found to be 4.78% and 4.7% respectively.

1. Conclusion

This paper presented a five-level cascade H-bridge Inverter, which uses multicarrier based control structure and two capacitor with 10 switching MOSFETs topology, The PWM strategy reduces the THD and this strategy enhances the fundamental output voltage. Circuits output wave shapes FFT analysis have been discussed here and also about their harmonics. The following results were drawn.

- There are 30 levels in the voltage output of the proposed multilevel inverter which is being modelled multi carrier based control signal having topology which contain MOSFET
- The total harmonic distortion in the voltage output of the proposed multilevel inverter with RL load was found to be 5.18 percent and that of current waveform was found to be 5.77%.
- The THD in the voltage output of the proposed multilevel inverter with R load was found to be 4.78 percent and that of current waveform was found to be 4.78%.
- the magnitude of voltage output in both the cases is 210 volts with different current being drawn according to the load resulting in different active and reactive power output

Figure 20 Active Power Output From The Inverter



The experimental and simulated results are show satisfactory results in term of total harmonic distortion and output voltage and current waveform shapes which are within the acceptable limits. Those schemes confirmed by simulation results.

2. Future Scope

- The topology cab be further extend to n levels in the output waveform.
- With enhancement in the output voltage waveform quality, this can be further integrated with the grid. The inverter can be designed for

Figure 21 Reactive Power Output from the Inverter

- The switching patterns adopted are applied at the cascaded multilevel inverter switches to generate 30 output voltage levels at 0.9 modulation index.

The active output from the inverter was found to be varying between 225 watt and 230 watts and reactive power output is zero as it is only resistive load.

- To verify the validity of the proposed multilevel inverter having 10 levels using multicarrier PWM, the results of both output voltage and FFT analysis are verified by simulating the main circuit using MATLAB. It is clear that as the number of level increases, distortion reduces.
    - improved number of levels to be brought to use with the renewable energy resources also.
    - The modulation technique is easy and simple to be implemented, use of proper facts devices can make it more robust and easy to handle inverter**.**
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