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Design and Development of General Purpose 3-Phase 3-level Inverter

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ABSTRACT
This paper proposes and describes the design and operational principles of a three-phase three-level nine switch voltage source inverter. The proposed topology consists of three bi-directional switches inserted between the source and the full-bridge power switches of the classical three-phase inverter. As a result, a three-level output voltage waveform and a significant suppression of load harmonics contents are obtained at the inverter output. The harmonics content of the proposed multilevel inverter can be reduced by half compared with two-level inverters. A Fourier analysis of the output waveform is performed and the design is optimized to obtain the minimum total harmonic distortion. The full-bridge power switches of the classical three-phase inverter operate at the line frequency of 50Hz, while the auxiliary circuit switches operate at twice the line frequency.

Keywords - ***Two-level inverter, Multi level inverter, Three level output waveform inverter.***

1. INTRODUCTION
Inverter is a power electronics based control scheme or circuitry that converts DC quantity to alternating (AC) quantity. The input voltage, output voltage, frequency, and overall power handling capacity of the inverter depend on design as per load parameters. A conventional inverter gives output at load side which is less than the input voltage, containing harmonics. A multilevel inverter is a power electronic device which is capable of providing desired alternating voltage level at the output using multiple lower level DC voltages as an input. Mostly a two-level inverter is used in order to generate the AC voltage from DC voltage[1]-[2].
Multilevel inverter continue to receive more and more attention because of their high voltage operation capability, low switching losses, high efficiency and low output Electro-magnetic Interference. Multilevel inverters are becoming increasingly popular in medium power application[3]. Multilevel inverters have the ability to meet the demand of power quality associated with reduced harmonic distortion and lower electromagnetic interference. The concept of multilevel Inverter (MLI) is kind of modification of two-level inverter. Multilevel inverters don't deal with the two level voltages. In order to create a smoother stepped output waveform, more than two voltage levels are combined together and the output waveform obtained in this case has lower dv/dt and also lower harmonic distortions[4]. Smoothness of the waveform is proportional to the voltage levels, as we increase the voltage level the waveform becomes smoother but the complexity of controller circuit and components also increases along with the increased levels.
The need of multilevel converter is to give a high output power from medium voltage source. Sources like batteries, super capacitors, solar panel are medium voltage sources. The multilevel inverter consists of several switches and the arrangement switching angles are very important. Two-level inverters are basic inverters which have drawbacks like reduced voltage at the output, it creates lots of harmonic distortion, electromagnetic interference (EMI) and high dv/dt stress on switches. Multilevel inverters are introduced and are being developed now to meet increased power demand. With an increasing number of dc voltage sources in the input side, a sinusoidal like waveform can be generated at the output. As a result, the total harmonic distortion (THD) decreases, and the output waveform quality increases which are the two main advantages of multilevel inverters. Moreover, the multilevel inverters consist of modularity, simplicity of control, reliability and they require the reduced number of power semiconductor devices to generate a particular level. As a result, the losses and total cost of these inverters decrease, and the efficiency will increase. With the proposed topology there is reduction in the number of power switches, driver circuit and dc voltage source is the advantage of the developed single-phase cascaded multilevel inverter. As a result, the installation space and cost of inverter are reduced.
Basically multilevel inverters are of three types and are named as the Diode Clamped Multilevel Inverter (DC) which is also called as Neutral Point Clamped Multilevel Inverter (NPCMLI), the Flying Capacitor Multilevel Inverter (FCMLI) and a Cascaded H-Bridge Multilevel Inverter (CHBMLI)[1].In the NPC type of multilevel inverter main concept is to use diodes along with the capacitor banks in series which provides multiple voltage levels. Flying Capacitor Multilevel Inverter uses capacitors for switching like diodes in NPC inverter[5]. Both these types of inverters require high switching frequency and imposes problem of capacitor balancing. So these inverters are limited to five levels only.

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1.2 Proposed Work Objectives:

- To study various topologies of multilevel inverters.
- Simulation study of 3-ph 3-level Diode Clamped inverter.
- Prototype design of power circuit and various sub circuits (major circuit 3-ph DCMLI, DC Source, Gate-Driver circuit).
- Testing and verification of laboratory prototype.

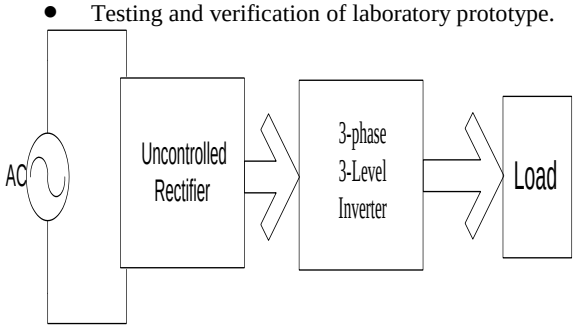

Fig. No 1 Basic Block Diagram

2. PROTOTYPE DESIGN & DEVELOPMENT

Now a day, inverters are commonly used industrial applications for motor control. Voltage source inverters (VSI) are commonly preferred in many applications due to their ease in control compared in current source inverters (CSI)[18]. The conventional 2-level inverter produces output which is approximately equal $2V_{DC}$ (peak-peak) of the input voltage. These inverters have large THD contents in the out-put voltage and needs filter at the out-put before load. These are preferred in small power requirements where cost of the inverter plays a major role. Multilevel inverters are widely used for medium voltage medium to high power applications, since they offer more benefits over the conventional like better THD contents, reduction in filter cost requirements reduced stress on power semiconductor devices. Among these inverters the Neutral Point Clamped (NPC) inverter is one of the most widely used topology. This inverter is popular in the area of interfacing renewable energy sources to utility-grid, medium voltage drive with reduction in CMV, traction and many more. The NPC inverters offer low modularity, reduced cost of design and implementation, fewer requirements of electronic devices.This dissertation work presents a simplified orderly method for basic design of 3-ph, 3-level voltage source inverter for laboratory prototype and to fulfil small application requirements. It also includes rating selection for power devices for inverter, calculation of losses in the power devices, heat-sink requirement, and driver circuit. The sample loss calculations are presented based on assumed switching frequency of 2250Hz.

2.1 Praposed Work

Fig. 2 shows simplified circuit diagram of a 3-level NPC inverter. Each leg of the inverter is composed of four active switches S_1 to S_4 with four antiparallel diodes D_1 to D_4. IGBT is used as power switching device and D_{Z1} and D_{Z2} are clamping diodes of each leg. Notations of elements of leg B and leg C are same as that of the leg A. Z is the neutral point of Proposed NPC Inverter which is connected to neutral point of clamping diodes of each leg.

The diode-clamped inverter consists of two pairs of series switches (upper and lower) in parallel with two series capacitors where the anode of the upper diode is connected to the midpoint (neutral) of the capacitors and its cathode to the midpoint of the upper pair of switches; the cathode of the lower diode is connected to the midpoint of the capacitors and divides the main DC voltage into smaller voltages.

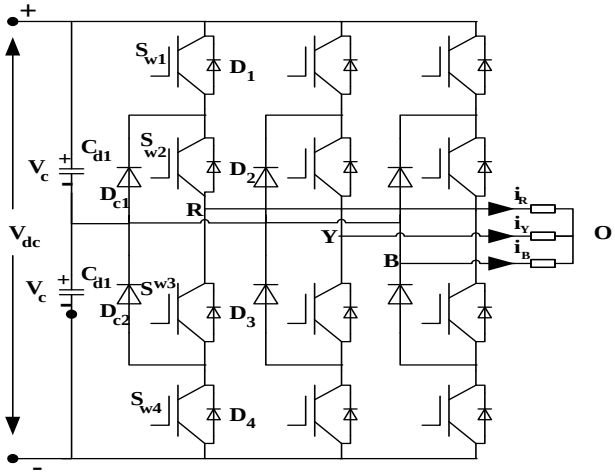

Fig No 2 Proposed Work

The middle point of the two capacitors can be defined as the "neutral point". The NPC uses a single dc bus that is subdivided into a number of voltage levels by a series string of capacitors. For a three-level diode-clamped inverter if the point O is taken as the ground reference, the output voltage has three states E,0,-E.

2.2 Software Tool

MATLAB Simulink software is used for software implementation of 3-ph 3-level Diode Clamped Inverter. The proposed prototype of three phase three level NPC inverter is simulated using MATLAB /Simulink. The simulation parameter used here are V_{DC} = 200V, switching Frequency, f_s = 2250 Hz and modulation index m_a=0.8.It consists of 12 IGBT switches, 6 clamping diodes and 2 DC link capacitors are connected with single DC source.

3. SIMULATION RESULTS

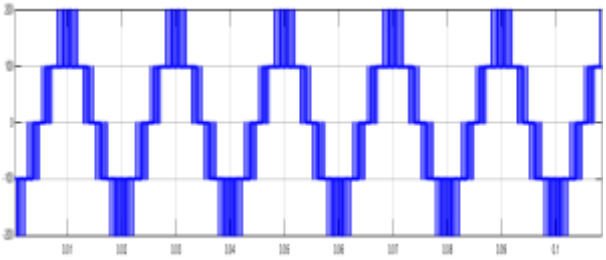

Fig No 3 Output Voltage of 3-ph 3-level Diode Clamped Inverter

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Line voltage of 400 V is obtained at inverter output as shown above simulation result which is required output in this proposed prototype.

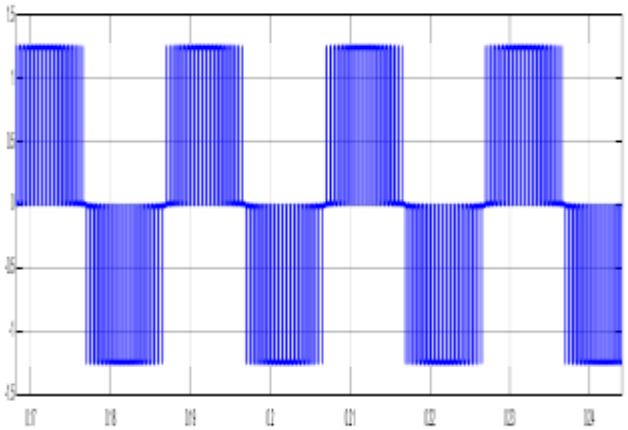

Fig No 4 Output Current of 3-ph 3-level Diode Clamped Inverter

Output Line current waveform of inverter which is shown in fig. 4 is required output current in this proposed prototype.

3.1 THD analysis

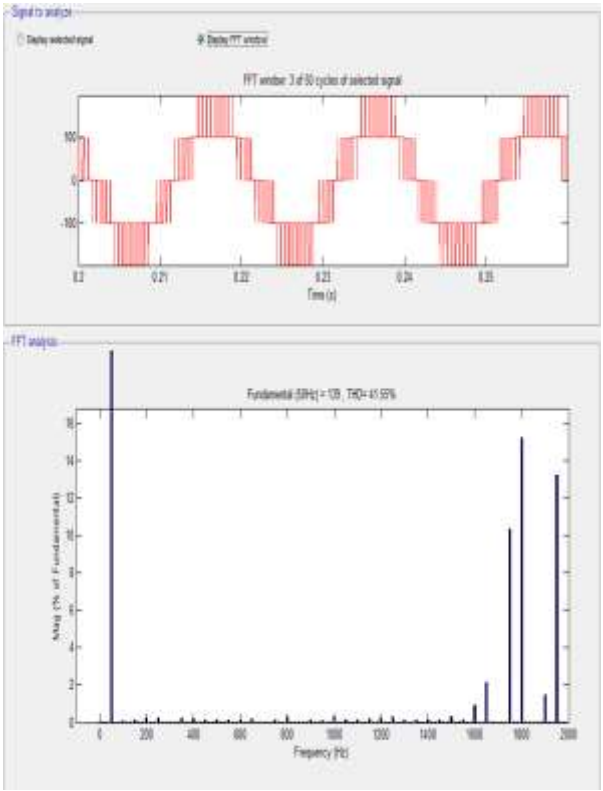

Fig No 5 THD for line Voltage

THD analysis is performed to determine the quality of output waveform. THD value for output voltage of proposed 3-phase 3-level inverter is 41.55% which is illustrated in fig. 5.

4. HARDWARE IMPLEMENTATION

4.1 Power Supply

A DC power supply is one that supplies a constant DC voltage to its load. Depending on its design, a DC power supply may be powered from a DC source or from an AC source such as the power mains. The AC mains input is directly rectified and then filtered to obtain a DC voltage. The resulting DC voltage is then switched on and off at a high frequency by electronic switching circuitry.

Fig No 6 DC Power Supply

When input voltage of 5 V AC is given to bridge rectifier then rectified DC is obtained. This rectified DC voltage of rectified is filtered through capacitor to obtained pure DC voltage of 9.32 V.

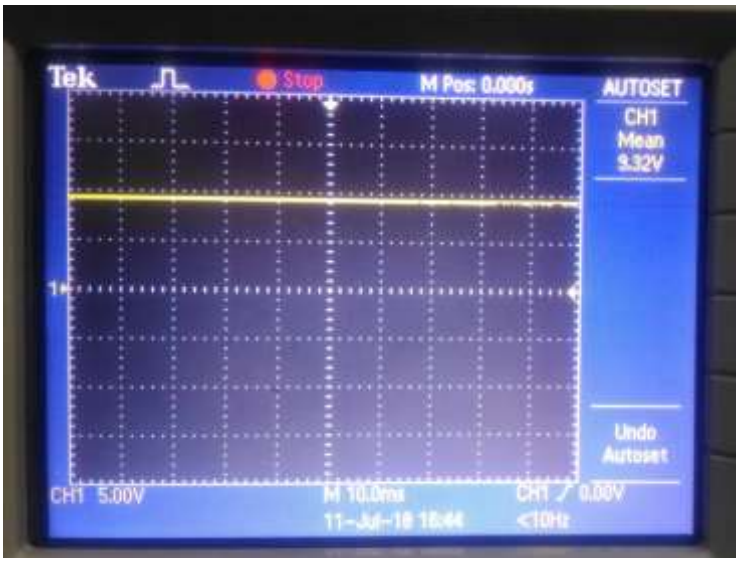

Fig No 6 Filtered DC Waveform

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4.2 Power Circuit

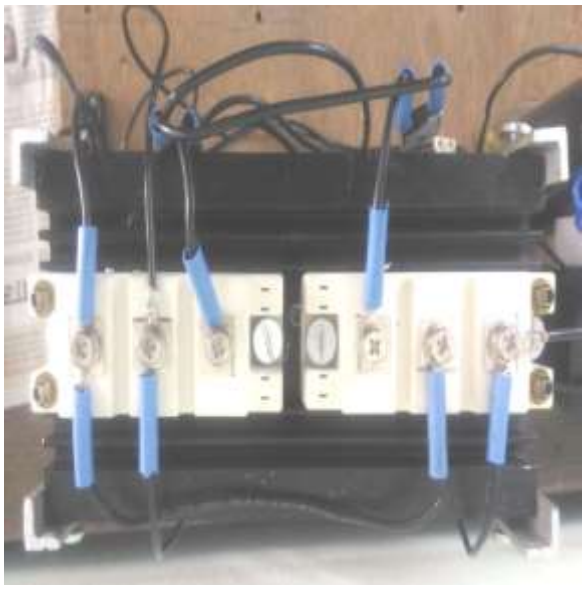

Fig No 7 Power Circuit

Proposed NPC inverter shown in fig.7 consists of 12 IGBT switches and 6 clamping Diode is each leg of the inverter consist of 4 IGBTs and 2 clamping diode which works for single phase. In this laboratory prototype IGBT module SKM50GB063D and clamping diode RHRG75120 are used. Single IGBT module consists of two IGBT switches, so two IGBT modules are used in series. So, 6 IGBT modules are used for 3-phase 3-level NPC inverter.

4.3 Driver Circuit

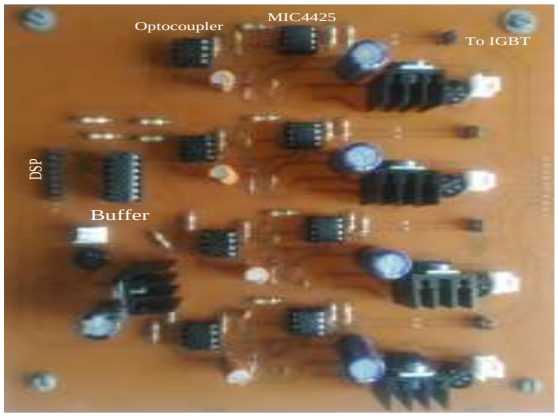

Fig No 8 Power Driver Circuit

Fig.8 shows the hardware implementation of driver circuit for NPC inverter.Driver circuit used for the giving the switch pulse to power circuit. Pulses for driver circuit given from Dspace. This single from buffer, opto-coupler to MIC4425 in then giving pulse to IGBT.

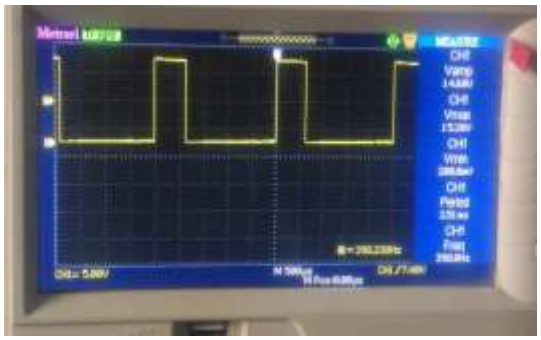

Fig No 9 Driver circuit output

For testing the driver circuit PWM pulses is given through Arduino Uno to obtained desired output pulse for switches as shown in fig. 9.

4.3 Hardware Implementation of 3-ph 3-level NPC inverter

Fig No 10 Laboratory Prototype Model

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Fig. 10 shows hardware setup for laboratory prototype for 3-ph 3-level NPC inverter. In this model induction motor is taken as load and dSPACE is used as controlling unit.

4.4 Hardware Results

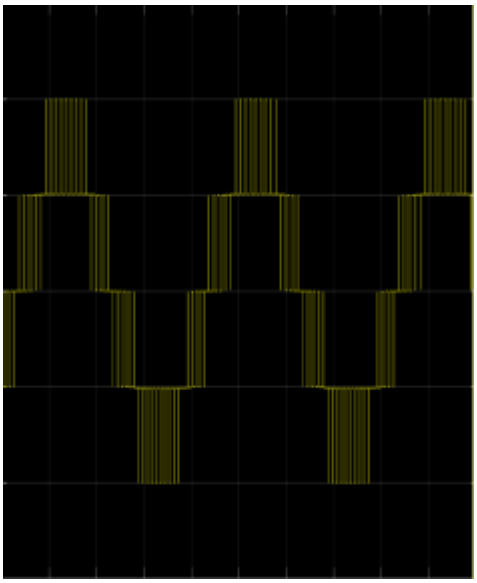

Fig No 11 Output Voltage of 3-ph 3-level NPC Inverter for Single Phase

(scale: magnitude - 1 div=100V time- 1 div=5mSec) Fig. 11 shows the output voltage of 3-ph 3-level NPC Inverter for single phase.

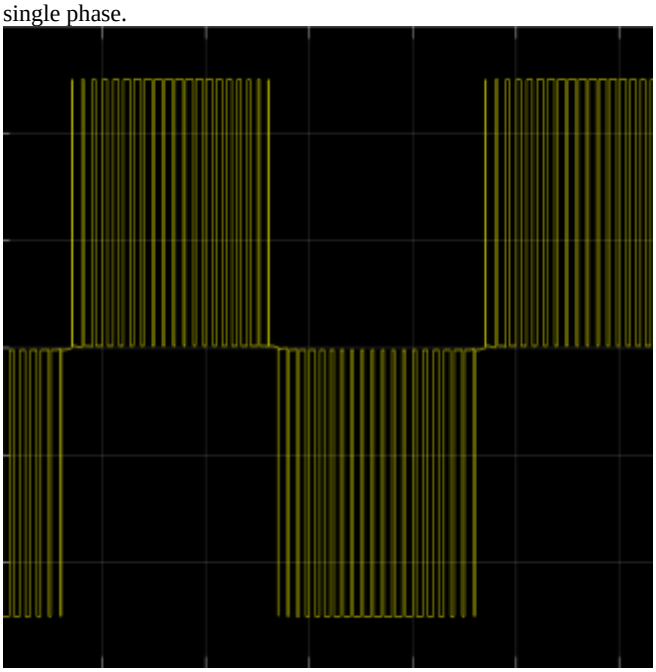

Fig No 12 Output Current of 3-ph 3-level NPC Inverter for Single Phase

(Scale: magnitude- 1 div=0.5A, time-1 div=5mSec) Fig. 12 shows the output current of 3-ph 3-level NPC Inverter for single phase.

CONCLUSION

The performance of the 3-phase 3-level twelve switch inverter has been observed that performance of the inverter is improved by employing SPWM control scheme. From the simulation results, it is observed that the generated voltage spectrum is much improved with the increase in steps or level of the inverter. The total harmonic distortion (THD) value is reduced as the level of the inverter is increases. The multilevel inverters with 3-level output is designed and developed. The performances of commonly used carrier based modulation techniques are compared. The comparison between 2-level and 3-level inverter performance on the basis of parameters like %THD, rms value of fundamental voltage, line-to-dc bus capacitor neutral voltage or dc bus voltage utilization shows that the 3-level inverter gives better % THD , same fundamental voltage for the same value of dc bus voltage for all values of modulation indices. Therefore % THD with other voltage ranges of dc bus voltage is almost the same. From the results it is clear that the 3-level inverter gives better performance as compared to 2-level inverter.

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