3-Level NPC Inverter Testing on Different Loads

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***Abstract*--- There are basically three types of Multilevel Inverter topologies are available, but we use only the Three Level Diode Clamped Inverter Topology which is also known as NPC [Neutral Point Clamped] Inverter. The main advantage of this topology is that we can achieve the output voltage into the step formed which is more similar and nearest to the sinusoidal waveforms. So, ultimately we can achieve the better response and efficient performance of the Induction Motor Drive. The Carrier based sinusoidal PWM [Pulse Width Modulation] technique is used to switching the power switches and also we can reduce the harmonic content or distortion on the output waveform of the inverter. The high frequency triangular waves are used as a carrier wave and Sinusoidal wave used as a sample wave.**

In this paper, we just simulated the star connected pure resistive load [R-Load] and Resistive-Inductive Load [R-L Load] and measure the Phase Voltages, Line Voltages and Line Currents of both types of loads respectively on MATLAB R2012a.In future work, the same NPC inverter configuration is used for open loop as well as closed loop V/f Control strategy for 3-Phase Induction Motor Drive.

***Key words*--- Three Level Diode clamped inverter; Carrier based sinusoidal PWM Generator, Multi-Level Inverter.**

I INTRODUCTION

A) Multi-level Inverter

An array of power semiconductor devices and capacitor voltage sources to produced the stepped voltage waveforms at the output of the inverter is known as "Multi-Level" Inverter.

There are basically three types of Multilevel Inverter available in now days:

- H-Bridge Cell Multilevel Inverter.
- Flying Capacitor Multilevel Inverter.
- Diode Clamped Multilevel Inverter.

B) H-Bridge Cell Multilevel Inverter.

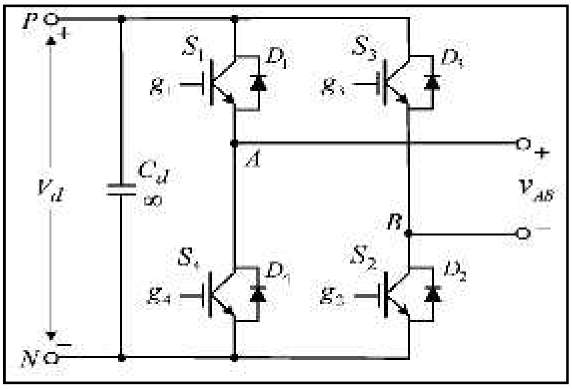


Fig. 1 Single Phase H-Bridge Inverter or H-Bridge Cell

In H-Bridge Cell type multilevel inverter, the H-Bridge cells are used. The IGBT/diode or MOSFET/Diode is used as a power switches. The Fig.1 shows the single Phase H-Bridge Inverter or also known as H-Bridge Cells. As the level of voltage increases, the no. of H-Bridge Cell per phases is increased. There are basically two topologies are shown in the modern trend. Symmetric and Asymmetric type H-Bridge multilevel inverter. The main disadvantage of this topology is we have to give individual dc sources for each cells. As voltage level increases, the no. of dc sources are increased. In symmetric type topology, all the dc sources voltages are on the same rate. While, in the Asymmetric topology, the different dc voltage sources are used for each cells.

C) Flying Capacitor Multilevel Inverter

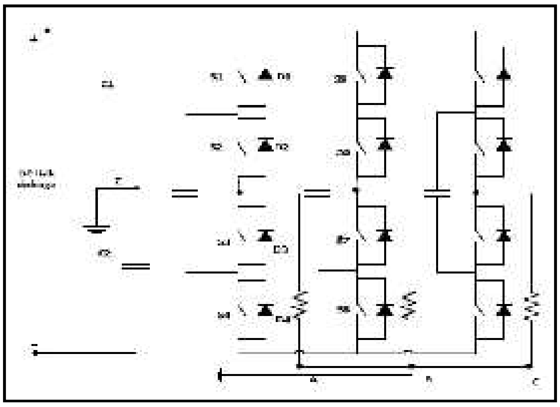
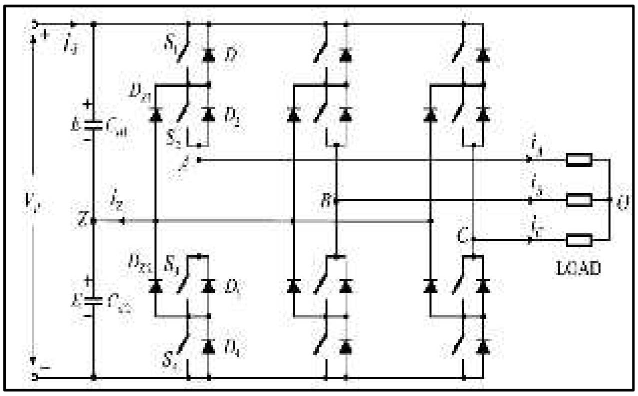


Fig. 2 Three Level Flying Capacitor type Multilevel Inverter

In Flying Capacitor type multilevel inverter. The flying capacitor is used in parallel between two co-sequent power switches. In producing the same output voltages the inverter can involve different combinations of capacitor allowing charging or discharging of individual capacitors. This flexibility makes it easier to manipulate the capacitor voltages and keep them at their proper values.



D) Diode Clamped Multilevel Inverter

Fig. 3 Three-Level NPC Inverter

The diode-clamped multilevel inverter employs clamping diodes and cascaded dc capacitors to produce ac voltage waveforms with multiple levels. The inverter can be generally configured as a three-, four-, or five-level topology, but only the three-level inverter, often known as Neutral-Point Clamped(NPC) inverter, has found wide application in high-power Medium-Voltage (MV) drives. The main features of the NPC inverter include reducing dv/dt and THD in its ac output voltages in comparison to the two-level inverter. More importantly, the inverter can be used in the MV drive to reach a certain voltage level without switching devices in series. The main advantage of this inverter is we don't required no. of individual dc sources as used in H-Bridge cell multilevel inverter.

In the Flying Capacitor type Multilevel Inverter, the flying capacitors are connected in parallel between 2 bridge cells instead of clamping diodes as a NPC inverter. We can also minimize the problems of the diode clamped multilevel inverter.

Fig. 3 shows the simplified circuit diagram of a three-level NPC inverter. The inverter leg *A* is composed of four active switches S_1 to S_4 with four anti-parallel diodes

D_1 to D_4. In practice, either IGBT or MOSFET [3] can be employed as a switching device.

E) Switching State

The operating status of the switches in the NPC inverter can be represented by switching states shown in Table 1.

Table 1

Definition of Switching States

Switching State	Device Switching Status (Phase-A)				Inverter Terminal Voltage
	S_1	S_2	S_3=S_1'	S_4=S_2'	v_{AZ}
P	On	On	Off	Off	E
O	Off	On	On	Off	0
N	Off	Off	On	On	-E

II. ADVANTAGESOF NPC INVERTER

- No dynamic voltage sharing problem**.** Each of the switches in the NPC inverter withstands only half of the total dc voltage during commutation.
- Static voltage equalization without using additional components.
- Low THD and *dv/dt*.The waveform of the line-to-line voltages is composed of five voltage levels, which leads to lower THD and *dv/dt* in comparison to the two-level inverter operating at the same voltage rating and device switching frequency.
- Also in H-Bridge cell Cascaded Multilevel Inverter, each H-Bridge cell required independent individual DC source in each phase, while in case of NPC Inverter, only one DC source is required to achieve the same voltage level.[1]
- Multilevel carrier-based PWM offers many more degrees of freedom than traditional two-level PWM. In multilevel PWM, the switching frequency can be less than or greater than the carrier frequency and is a function of the displacement phase angle between the carrier set and the modulation waveform. By adjusting the displacement phase angle in multilevel PWM switching strategies, switching losses can be minimized for a more efficient multilevel inverter.[7]

III. LIMITATIONS OF NPC INVERTER

- Additional Clamping Diodes are required.
- Complicated PWM switching pattern design.
- This topology does not guarantee voltage sharing between the open switches. To avoid this problem we can use the Space Vector Modulation [SVM] technique. [2]
- In the NPC Inverter, the SVM and other techniques are only employed to reduce the Harmonic contents from the line-to-line and phase voltage waveforms. But these techniques are not capable to reduce the Switching losses in NPC and other high voltage level clamped inverter. And as the level increases the Switching losses are the main serious problem. But by using the Closed Loop Carrier Based PWM method we can minimize the Switching Losses in NPC and other High Voltage Level Inverter. [4] Also, The imbalance limits the switching frequency and the rated current due to temperature rise. [8]

IV. APPLICATION OF NPC INVERTER

- Neutral-Point Clamped(NPC) inverter can be used in the MV drive to reach a certain voltage level without switching devices in series. For instance, the NPC inverter using 6000-V devices is suitable for the drives rated at 4160 V.
- To Achieve High Power and High Voltage capability.[4]
- The Diode Clamped Multilevel Inverter topology is also used in direct driven variable speed constant frequency (VSCF) wind power system to

improve the voltage quality by using FPGA [Field Programmable Gate Array] method. It is applied to generate the driving Gate signals of the Switches in Inverter. It's the single programmable chip which have several functions like, to generate triangular carrier wave, sample sine wave generation module, compare the modules, dead time module and so on.[5]

- The NPC and/or n-level diode clamped inverter can be applicable for independent voltage control in each solar array in the PV [Photovoltaic] Power System. Also with the help of n-level diode clamped inverter in PV power system, reduces the voltage rating of the devices, allows one to operate without transformers to step-up the voltage, reduces the output harmonic distortion, and increases the efficiency of the power conversion.[6]

- Water Pumps, Centrifugal Fans, Blower, Air Handling Units, Chillers, etc. [Variable Torque Applications]

V. SIMULATION ON MATLAB AND RESULTS

The NPC inverter is connected to the different types of load which is given below:

- Star Connected Pure Resistive Load
- Star Connected R-L Load

Here, we can compare the three different types of loads one by one. Also, we can compare the Phase Voltages, Line Voltages and Line Currents respectively in MATLAB Simulinkmodels.

Before starting simulation first of all we try to understand the basic subsystems which are used in my simulation. i.e., Three Level NPC Inverter and Carrier Based Sinusoidal PWM Technique Subsystems are introduced respectively.

a) Sub-Systems of the Simulation of the NPC Inverter Three Phase NPC Inverter

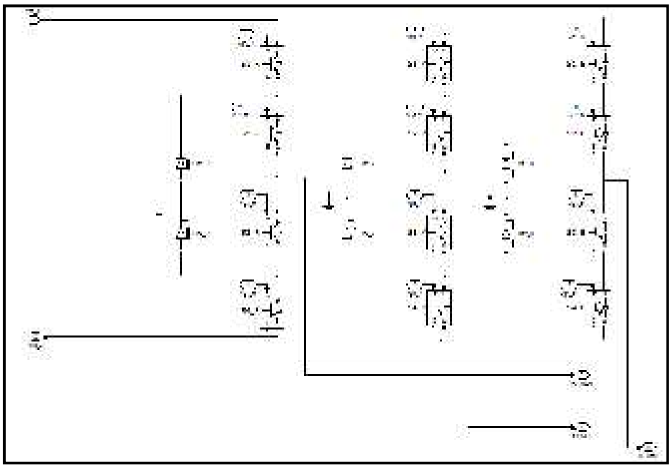


Fig 4 Basic Configuration of three phase NPC Inverter

In this configuration, as shown in Fig. 4, we used IGBT/diode configuration as a power switch. There are total 4 IGBT/diode combinational switches per phase are used. Also, Two Clamping Diodes are used for clamping operation per phase respectively. We apply dc supply as an input and take the ac voltages as an output as shown in Fig. 9. Also, we apply the proper gate pulses in each power switches in each and every phases respectively as per requirement.

b) Carrier based Sinusoidal PWM Generator forR-Phase

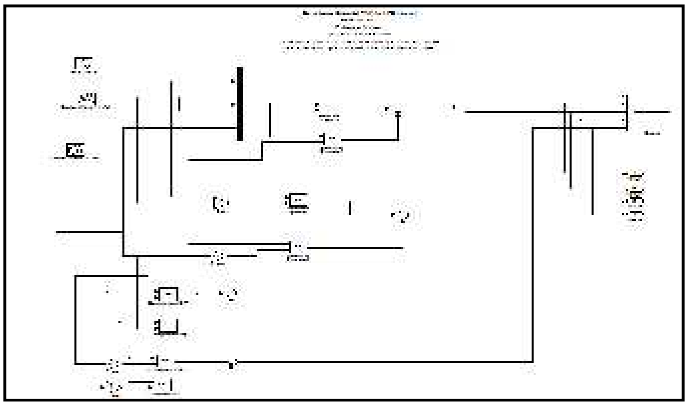


Fig. 5 Carrier Based Sinusoidal PWM Generator for R-Phase

As shown in Fig.5, This PWM [Pulse Width Modulation] configuration contains two triangular carrier waves and one sinusoidal sample wave. The main function of this entire PWM generator is to give the proper Gate pulses to the particular power switches and also reduced the harmonic contains from the output waveforms.

Here, we used only the IPD [In Phase Disposition] Carrier Based sinusoidal PWM strategy. In this IPD strategy, the both carrier waves Carrier + wave and Carrier – wave are in the same phase. In this strategy, we are used Triangular wave as carrier waves and Sinusoidal wave as a Sample wave.

Also, we set the carrier wave voltages and sample wave voltages magnitude same at 1 volt respectively. Also, we set the carrier frequencies of both the carrier waves are same at 1000 Hz. Our sample wave frequency is same as our ordinary supply frequency at 50 Hz.

$$V_{cr1} = V_{cr2} = V_s = 1 \text{ volt}$$

$$f_{cr1} = f_{cr2} = 1000 \text{ Hz}$$

$$f_s = 50 \text{ Hz} = 50*2*pi = 100*pi \text{ radian.}$$

Also, as per switching sequence of three levels NPC inverter, we can achieve the four gate pulses for each phase.

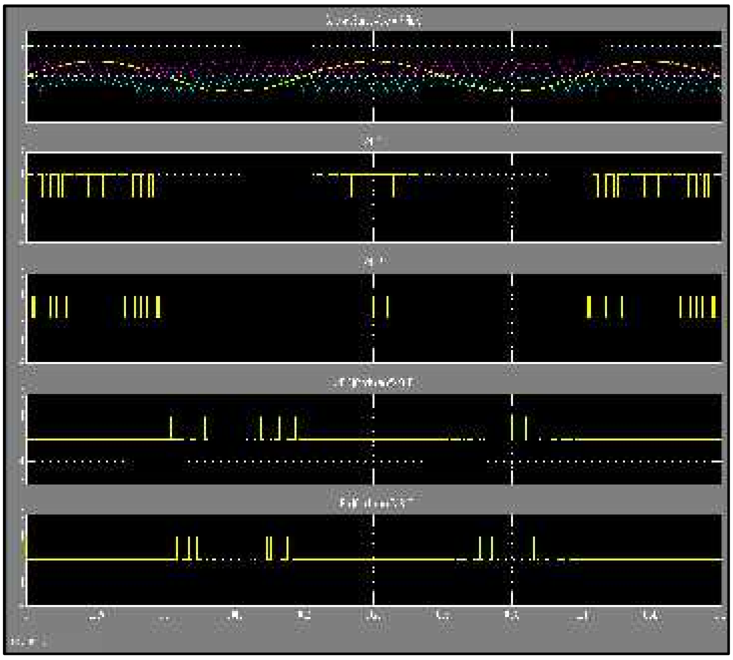


Fig. 6 Waveforms of PWM for R-Phase

Similarly, with the help of the same strategy, just by changing the sample wave time at + (2*pi)/3 and – (2*pi)/3 radian, we can get the similar waveforms of the gate pulses for Y-phase and B-Phase respectively.

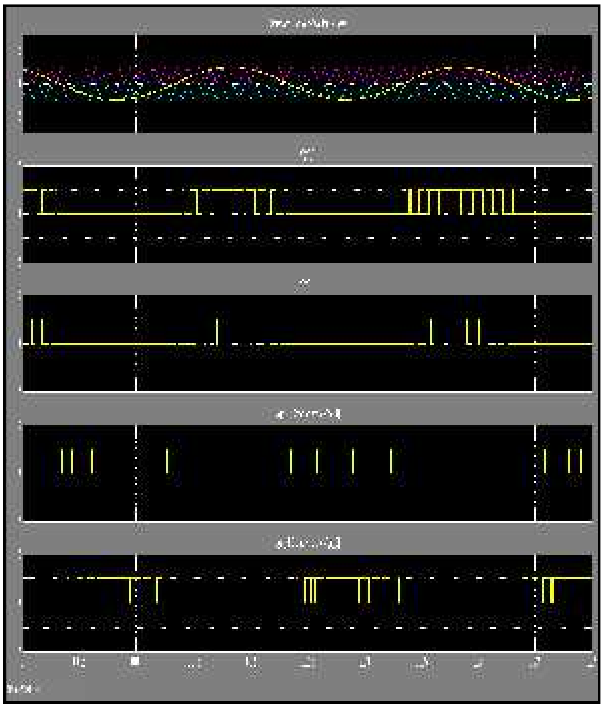


Fig. 7Waveforms of PWM for Y-Phase

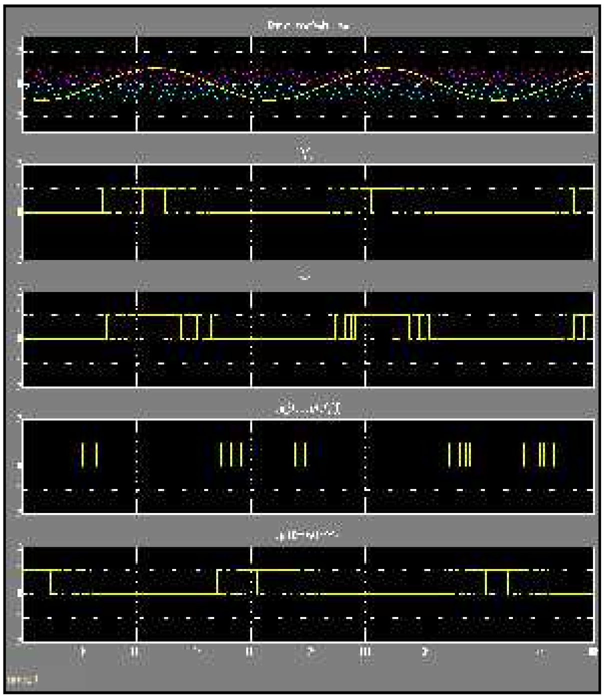


Fig.8Waveforms of PWM for B-Phase

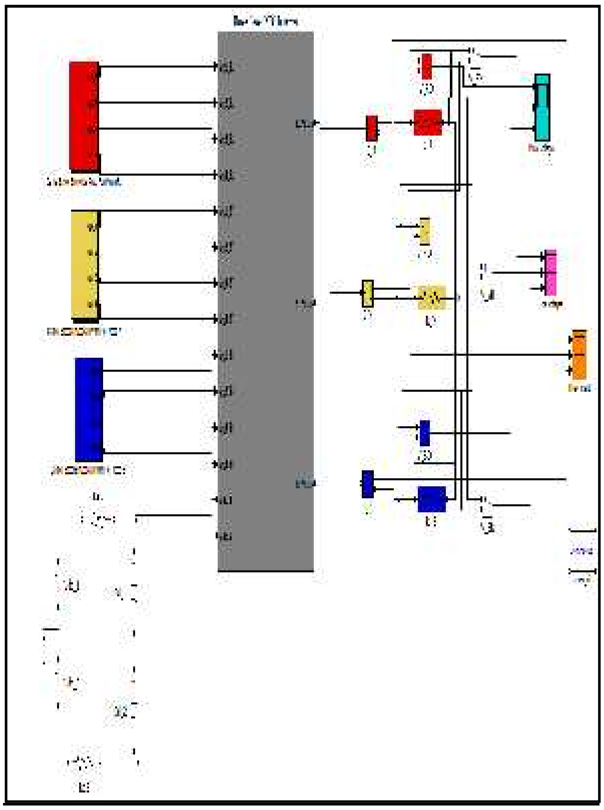


Fig. 9NPC Inverter with Star connected R Load

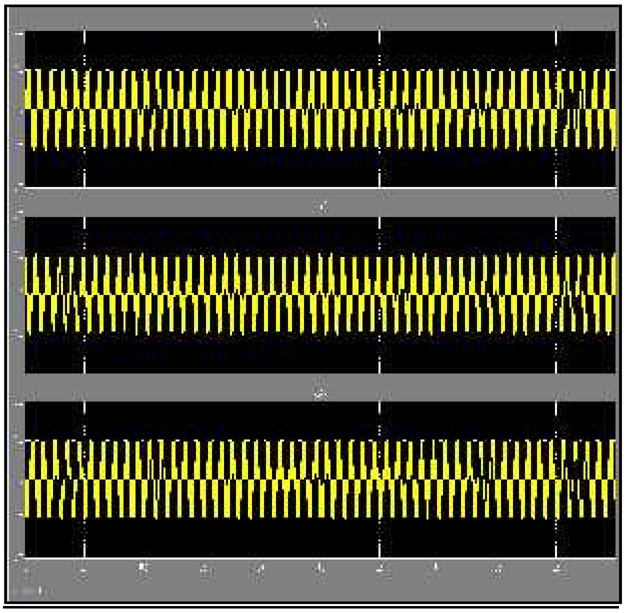


Fig. 10 Waveform of Phase Voltages of R Load

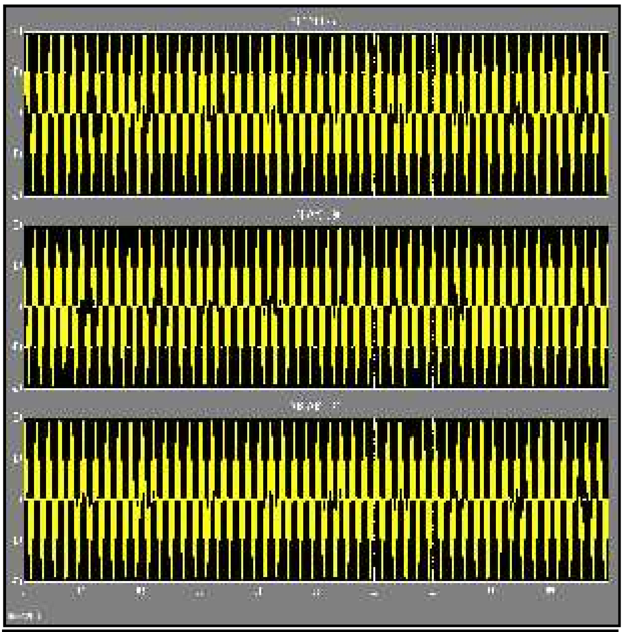


Fig. 11Waveforms of Line Voltages of R Load

As shown in Fig.11, Here, the relation between Line Voltages and Phase voltages is given by,

$$V_{RY} = V_{RO} - V_{YO}$$

$$V_{YB} = V_{YO} - V_{BO}$$

$$V_{BR} = V_{BO} - V_{RO}$$

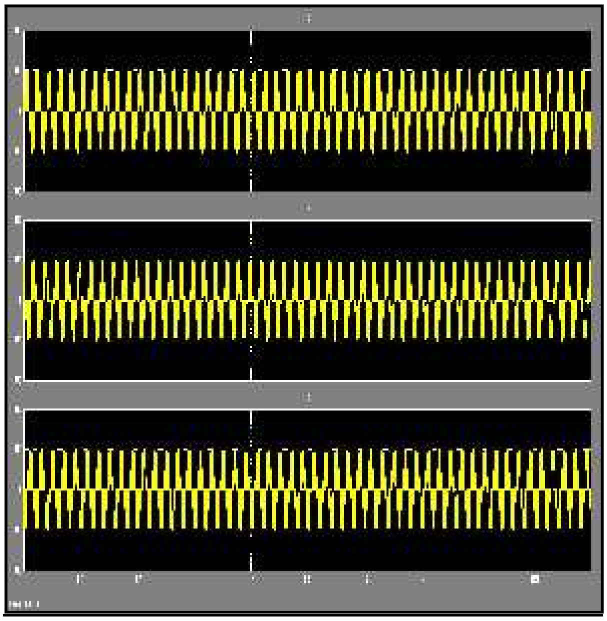


Fig. 12 Waveforms of Line Currents of R Load

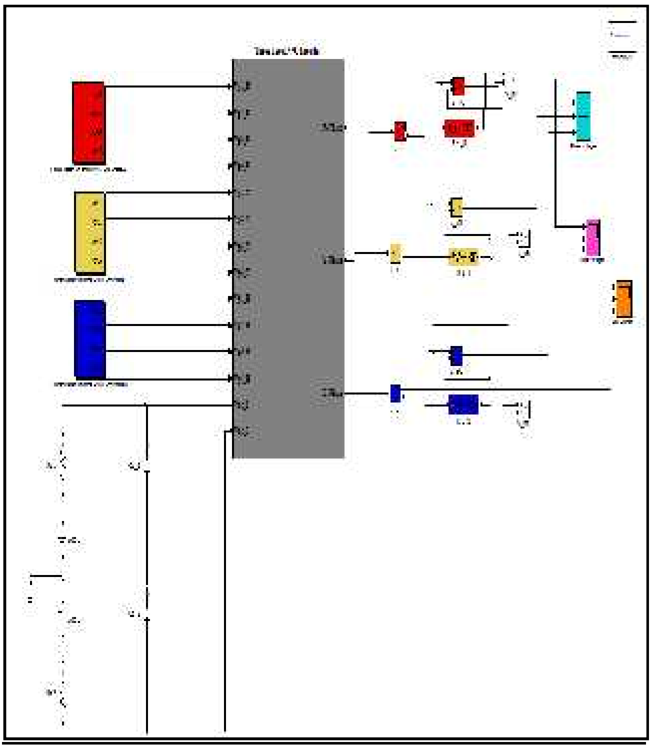


Fig. 13 Three Phase NPC Inverter with R-L Load

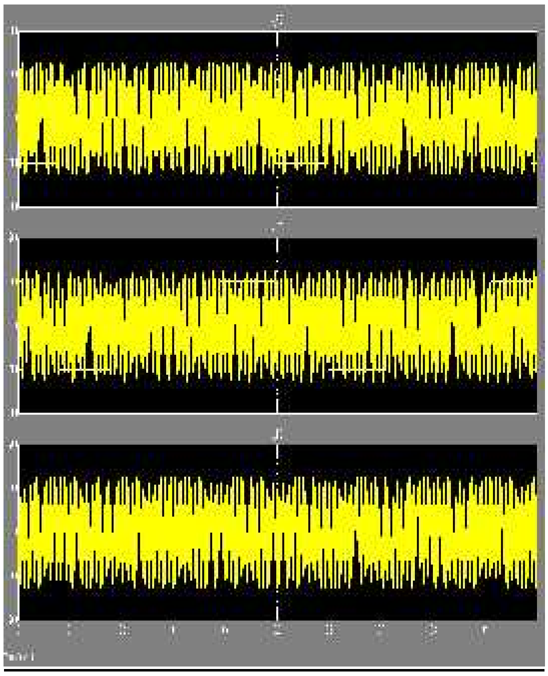


Fig. 14 Waveform of Phase Voltages of R-L Load

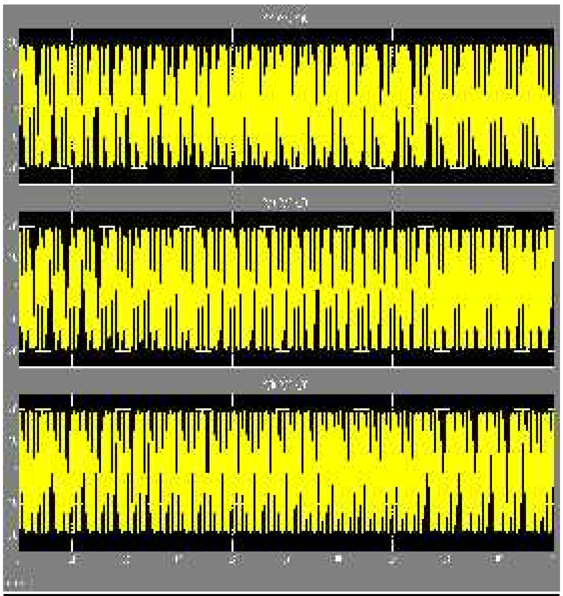


Fig. 15Waveform of Line Voltages of R-L Load

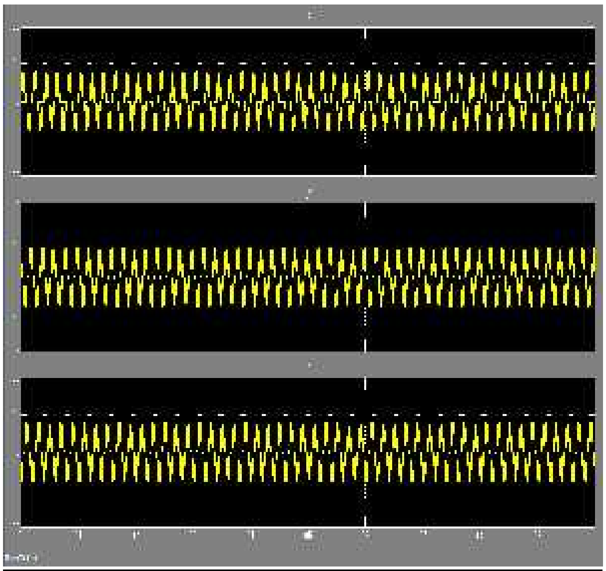


Fig 16Waveform of Line Current of R-L Load

VI. CONCLUSION

During this dissertation phase-1, the three level NPC inverter has been simulated for Star connected pure Resistive Load (R-Load) and R-L Load respectively. Also, we can compare Phase voltages, Line Voltages and Line Currents waveforms for both types of loads respectively.

In future, with the help of same configuration, we can simulate the Induction motor load and compare the simulated waveforms with the actual one.

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