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Fault Analysis and Reduction of Harmonics of Three-Level Three Wire and Four-Wire Neutral Point Clamped Inverter using PWM Switching Technique

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Abstract- **Energy generation through wind and solar is increasing with the rising interest in the renewable and clean form of energy. Due to energy crises, the world is shifting from nonrenewable energy resources to renewable energy resources. Renewable energy resources are the green and eco-friendly sources and do not affect the climate like the other fossil fuels. Renewable fuels gain popularity due to their sustainability and low carbon emission. To get energy from renewable energy sources, well-defined mechanisms and control devices must be needed. Therefore, the reliability and stability of the system are required. The inverter is one of the tools which have a significant contribution in controlling the operation of the energy conversion system. The inverter is an accessory that changes a Direct Current (DC) source into an Alternative Current (AC) source. By using that AC source, we can easily drive AC appliances and drive the loads. To gain more power or to derive large power motors whose power ratings are up to several kilo/Megawatts, we need multi-level inverters. One of the types of multi-level inverters is the Neutral Point Clamped (NPC) inverter. NPC inverters are used where considerable power is required, such as of several megawatts. The main contribution of this research paper is to design the three levels of neutral point clamped inverters by using the Pulse width Modulation (PWM) and Space Vector Modulation (SVM) Techniques.**

***Index Terms*— Renewable energy, Alternative Current (AC), Direct Current (DC), Neutral Point Clamped (NPC), Pulse width Modulation (PWM) and Space Vector Modulation (SVM)**

I. INTRODUCTION

As to get energy from renewable sources, we must have to discuss the factor which has a major contribution in getting renewable energy fuels which is the inverter. There are many types of inverter that are depending upon their control of the operation. The classification of inverters depending upon the type of high power drives is shown in the Fig-1. The keen focus of this research paper is the implementation of the Neutral Point Clamped with Voltage Source Inverters. Neutral point clamped or NPC inverters are broadly utilized for multi-level inverters. NPC inverters are used in the circuits or the devices where we require more power. It can easily be said that NPC inverters are used for high power applications. These kinds of inverters are used where we must deal with the high-power ratings such as when we must deal with the power ratings of the level of megawatts, we use neutral point clamped inverters. Nowadays, in our industries or every field of our life, we want to have better results by providing the specified level of input [1]. If we talk about our industrial sector we want to have maximum efficiency from our machines, means we want to take more work from our plants for that particular task either we have to increase the power ratings of the machines, or we have to increase the size of the equipment installed [2].

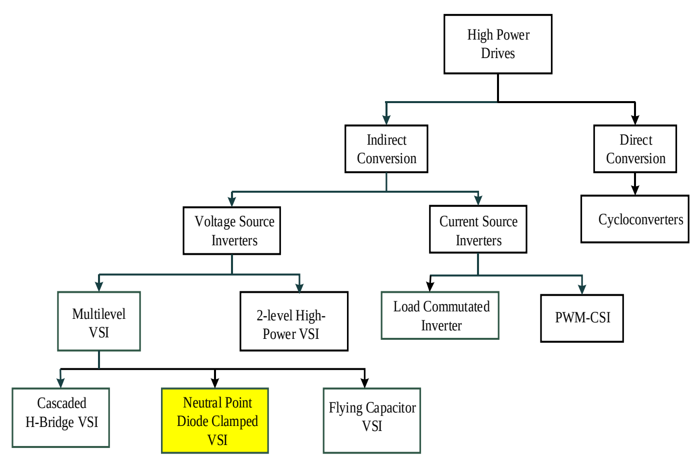

FIGURE 1: Classification of High-Power Inverters

We can increase the power ratings by two best possible ways. One of them is that we use the devices which have high voltage bearing capabilities ranges up to several megawatts. The second way is to introduce multi-level inverters. Here PWM technique is used to derive our circuit [3-7]. By using the PWM technique, we can change the frequency of the system as well as the time duration of control switching. The main contribution of this research paper is to design an efficient electronic neutral point clamped inverter with the help of PWM technique and mitigate the harmonics level.

II. METHODOLOGY

As we increase the level of the inverter, the number of switching devices and the clamping diodes increases. We are using the no. of full brides in that circuit. We also know that each full wave-controlled inverter of full-bridge consists of the four switching devices [8-11].

A. ELECTRIC EQUATION OF NPC

So, as we increase the level of the inverter number of components in the circuit increases.

$$Vsources = \frac{N-1}{2} \tag{1}$$

No. of switching devices= 2*(N-1) (2)

No. of clamping diodes= 2*(N-2) (3)

N= no. of the level of the inverter under discussion

All the above equation will provide us with information about how many switching devices, clamped diodes and DC voltage sources are required to construct our circuit. All the above equations provide us with information about the single-phase, as shown in Fig-2. To yield the results for three-phase three-wire and four-wire systems described by (4,5,6,7) are used, respectively.

No. of switching devices for three-wire/ Leg=6*(N-1) (4)

No. of clamping diodes for three-wire / Leg = 6*(N-2) (5)

No. of switching devices for four-wire/ Leg=8*(N-1) (6)

No. of clamping diodes for four-wire / Leg = 8*(N-2) (7)

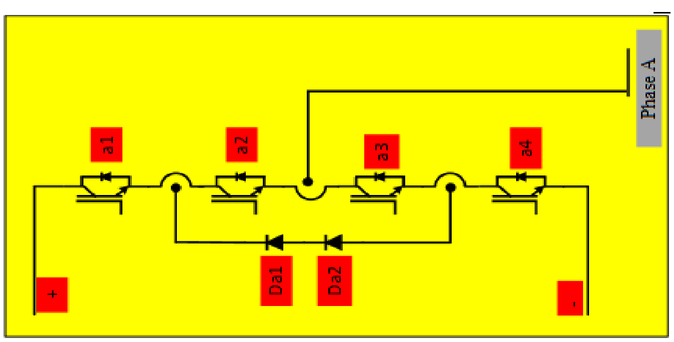

FIGURE 2: Single Phase Diagram of Three-level inverter [4].

The no of switches of used in NPC is shown in Table-1

Table 1: Requirement of no. of components

Scheme of Discussion	No. of Switches	No. of clamped diodes	No. of DC voltage sources
Three level 3- Leg NPC VSI	12	6	2
Three level 4- Leg NPC VSI	16	8	2

$$\vec{v} = \left(v\alpha.\overrightarrow{v\alpha} + v\beta.\overrightarrow{v\beta} + vo.\overrightarrow{vo}\right) \tag{8}$$

$$\begin{bmatrix} V\alpha \\ V\beta \\ V\gamma \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & \frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} Van \\ Vbn \\ Vcn \end{bmatrix} \tag{9}$$

$$\begin{cases} V\alpha = \sqrt{\frac{2}{3}}\left(Van - \frac{1}{2} - \frac{1}{2}Vbn - \frac{1}{2}Vcn\right) \\ V\beta = \frac{1}{\sqrt{2}}(Vbn - Vcn) \\ V\gamma = \frac{1}{\sqrt{3}}(Van + Vbn + Vcn) \end{cases} \tag{10}$$

No. (8, 9 and 10) helps us to understand the calculations of the line to line and alpha, beta, and gamma coordinates voltages when we go to the three-phase complex systems.

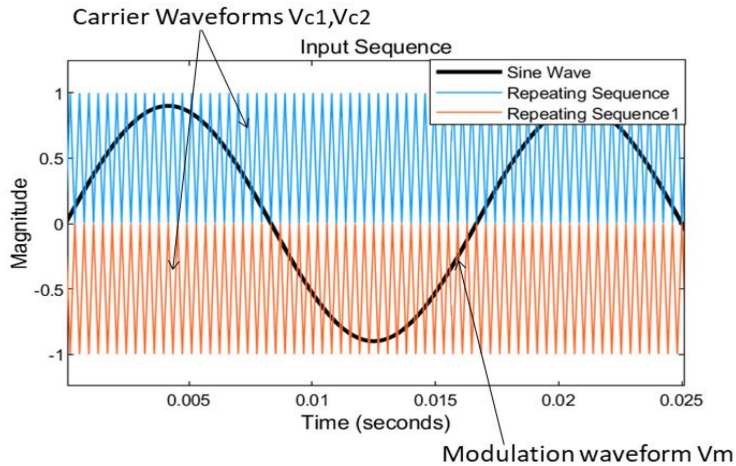

FIGURE 3: Input switching

The results for the input sequence, which have been applied into the circuit are shown in Fig. 3. In a normal condition, a sine wave is analyzed, as shown in Fig. 3. It is observed that pure sine wave is achieved with the fundamental frequency, which is applied to the switching devices to turn them on and off for the required time [4]. The fundamental frequency which I have applied is of 50 Hz.

III. RESULTS AND DISCUSSION

The model is simulated in MATLAB and analyzed the characteristics of the system in the normal condition and in the filtered as well as at the faulty conditions.

- THREE PHASE THREE LEVEL NEUTRAL POINT CLAMPED INVERTER

The three-level neutral point clamped inverters which are commonly utilized in applications for three-level three-wire systems; on a ground level, they have the structure of split dc capacitors [9-15]. The dc split capacitors act like the input voltage sources which are supplying the input dc voltage to the circuit.

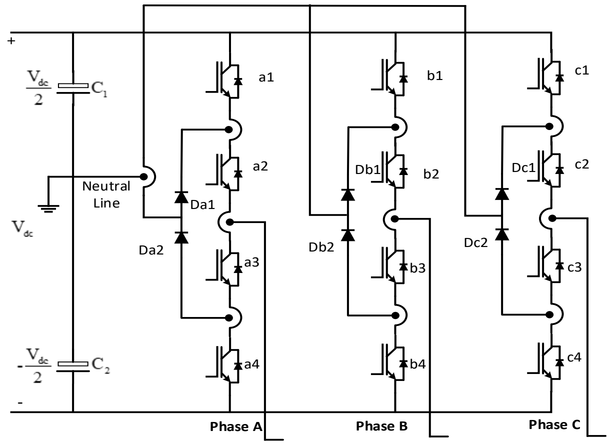

FIGURE 4: Three-level diode neutral-point clamped inverter 12].

So, the present dc neutral point can be straightforwardly utilized as the ground return. As mentioned in the component discussion three-level, NPC inverters consist of twelve exchanging gadgets and bracing diodes as well as shown in Fig. 4.

The selection of switching devices is totally upon us. The internal structure of the NPC may vary according to our requirements. By applying suitable changes in the basic circuit, we can easily get our results. Here we are using carrier-based PWM as an input source to derive the circuit. In NPC inverters we use the dc clamping diodes to join the neutral point to the midpoints of the switching devices which we have used.

A. AT NORMAL CONDITIONS

The model of neutral point clamped inverter for the three-phase three-level system is successfully designed with better switching techniques. As at the input terminals of the switching devices, we have applied the pulse width modulation technique, so our output results inherit the characteristics of the PWM waveforms. In the end, these results are filtered out means they can be converted into the smooth sinusoidal waveforms. Fig-5 (a, b) provides us with the information about the Line to Line voltages of the three-level three-phase neutral voltages during the normal functioning of the neutral point clamped inverter. The phase difference between the line to line voltages is seen in the fig5 (a, b). From the results shown above it has been analyzed that there is no difference between the line to line (L-L-L) voltages of the three-phase system [16-19].

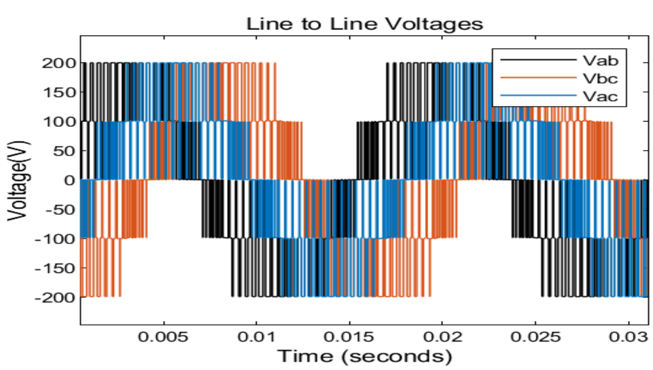

FIGURE 5(a): Three Phase Line to Line voltage

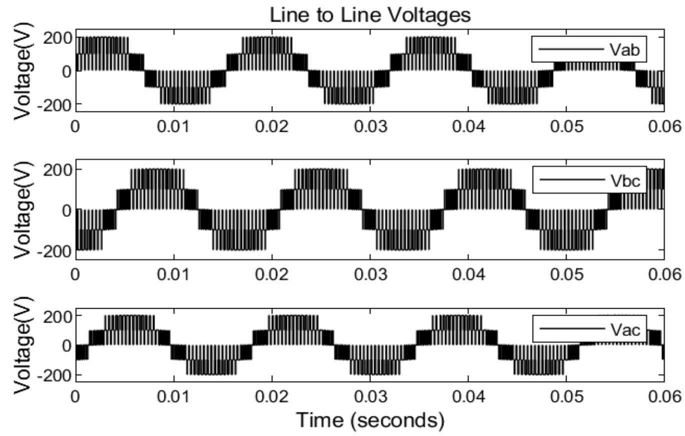

FIGURE 5(b): Three Phase Line to Line voltage

B. FILTER DESIGNING

The basic equation for the modelling of the filter is listed below.

$$XL = R \pm j\omega \quad (11)$$

$$Xc = 1/_{R \pm j\omega} \quad (12)$$

$$\omega = 2\pi f \quad (13)$$

$$f = {}^{\omega}/_{2\pi} \quad (14)$$

$$f = 1/_{2\pi\sqrt{lc}} \quad (15)$$

$$L=(R*\sqrt{2})/\omega \quad (16)$$

$$C = 1/_{\omega R * \sqrt{2}} \quad (17)$$

An LC filter is also called as the tuned circuit. The results of the neutral point clamped inverter using the Inductive, Capacitive (LC) filter are shown in Fig. 6. It has been analyzed that by applying the LC filter, the output waveforms of the line to line voltages are beautified means they are more shifted towards the sinusoidal output waveforms. Moreover, the decrease in the line to line output voltage has also been analyzed.

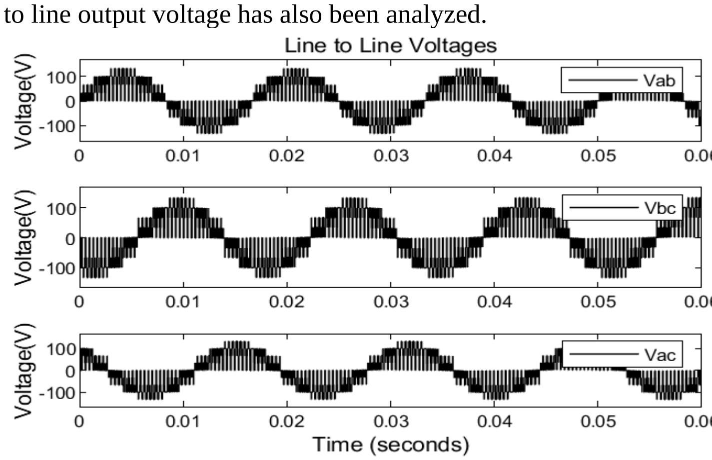

FIGURE 6: Three Phase L-L voltage With LC filter

It has been analyzed that with the use of Inductance and Capacitance (LC) filter, the maximum peak voltage is reduced to some extent. The decrease in voltage is because the capacitor is used in an LC filter, and the capacitor has a voltage storing capability as it is known that for the inductive filter the ripple voltages are directly proportional to the load resistance. Similarly, capacitive filter ripple voltage or distortion count is inversely proportional to the load resistance. So, for the combination of the inductive and capacitive filter, the ripple count does not depend upon the load filter.

C. AT ABNORMAL CONDITIONS

Three-phase three-level Neutral point clamped inverter is also analyzed for symmetrical fault.

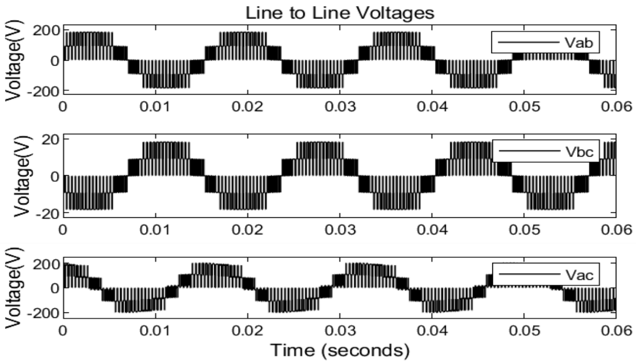

FIGURE 7: Three Phase Line to Line voltage during fault conditions

There can be different types of faults such as hardware designing fault, stability fault, noise fault, unbalanced input voltage, fault due to the unbalanced loads into the symmetrical systems and fault due to asymmetrical models. Disturbance observer can be designed to compensate for the disturbances. It has been analyzed the three-level three-wire neutral point diode clamped inverter for the study of fault conditions. The symmetrical fault is generated, and it is observed that due to the symmetrical fault the voltages of all the lines are different from each other [20-26]. The maximum and minimum amplitudes are different from each other. Moreover, a huge voltage difference between the line to line voltage of (b) and (c) phase has been analyzed and is shown in Fig. 7. It has also been analyzed that there is the swell and sag in the line to line voltages which are due to the fault generated in our system the fault is generated in our system by using the fault block parameter in the MATLAB SIMULINK Model.

D. LINE TO NEUTRAL VOLTAGE

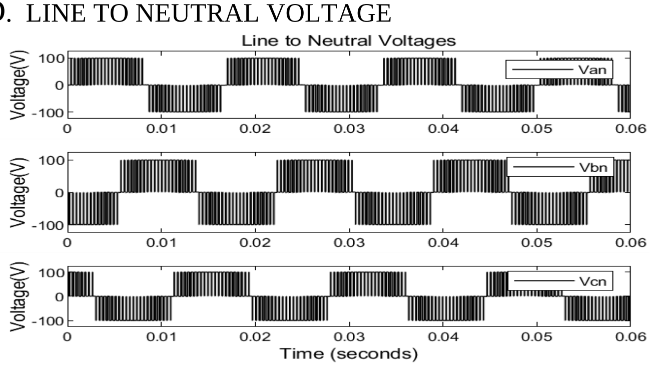

FIGURE 8: Three Phase Line to Neutral voltage

The line to neutral voltages of phase a, b and c has also been analyzed. It has been analyzed that here the output voltages are in the form of a square wave and they have smaller magnitudes as well. Their output voltages are less, which means that their maximum amplitudes values are smaller than that of the line to line voltages which are shown in Fig. 8. The three-level output has been observed between the line to neutral voltages.

E. TOTAL HARMONIC DISTORTION AT NORMAL CONDITIONS

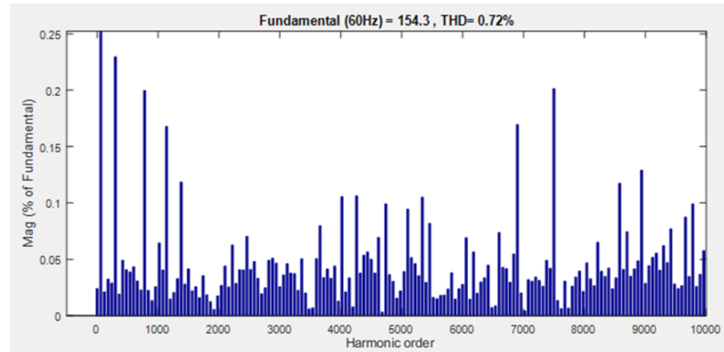

FIGURE 9: THD of NPC for 3 levels

From Fig. 9, it has been analyzed that the total harmonic distortion is nearly equal to 1%. Which is large enough as nowadays the devices are already present whose distortion rates are nearly equal to 0% and these devices are more efficient. To reduce the distortion levels, the use of the filter is necessary the attachment of the filter in any device is another part which also increases the cost of the device. The removal of harmonics is primarily a matter of great concern to get maximum efficiency. Here in our system, the harmonics are present in small amount, and these harmonics can also be removed using a resonant or tuned circuit which is discussed previously.

- THREE PHASE THREE LEVEL FOUR WIRE NEUTRAL POINT CLAMPED INVERTER

The three-level four-wire neutral point clamped inverters are commonly used as shunt power quality equivalents for three-phase four-wire system as shown in Fig. 10.

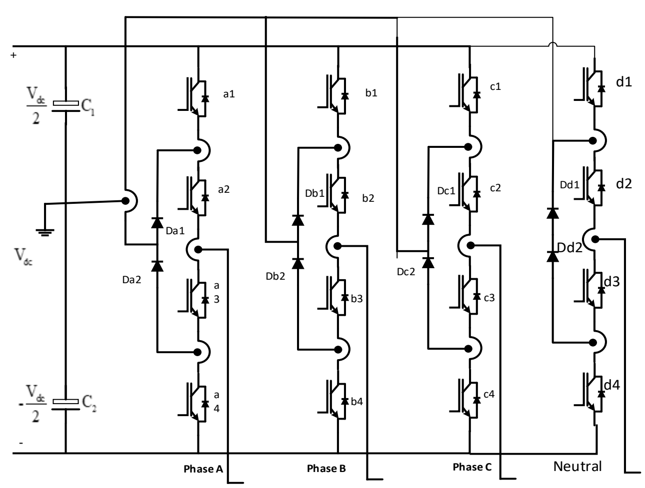

FIGURE 10: Circuit diagram of Neutral Point Clamped inverter for Three-Level four-wire system

The requirement of the total number of components for the three phases three-level four-wire systems has been mentioned in the table listed above. Here we have added the fourth leg to provide the neutral connection. As the number of legs is increased in the three-phase/level four-wire system, the no of switching devices and circuits complexity level also increases.

A. AT NORMAL CONDITIONS

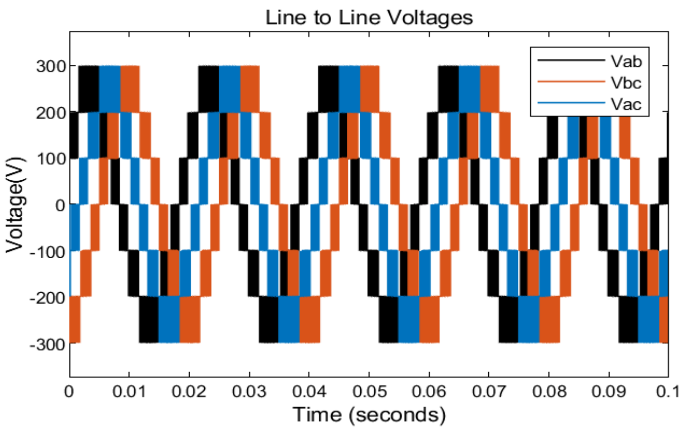

FIGURE 11: Three Phase Line to Line voltage

Like that of the three-level NPC inverters, the line to line voltages of the three-level four-wire systems has also been analyzed. In this, it has been analyzed that the output of line to line voltages is greater concerning the three-level three-wire systems, as shown in Fig. 11. The phase difference between the line to line voltages is also seen clearly.

B. FILTER DESIGNING

The filter designing parameters for three level-four wire system are explained in the filter designing of three level-three wire systems. All the calculation parameters are the same. It has also been analyzed the three-level four-wire neutral point clamped inverter by applying the (LC) filter whose results are shown in the Fig. 12 (a, b). we analyzed that after applying the LC filter the phase difference between the line to line voltages becomes clearer. Moreover, it can also be seen that with the use of filter the line to line voltages are moving on the sinusoidal wave pattern and the maximum and minimum values of the line to line voltages as decreases which is because of the reason that the voltage and current storing devices are used in the inductive capacitive filter.

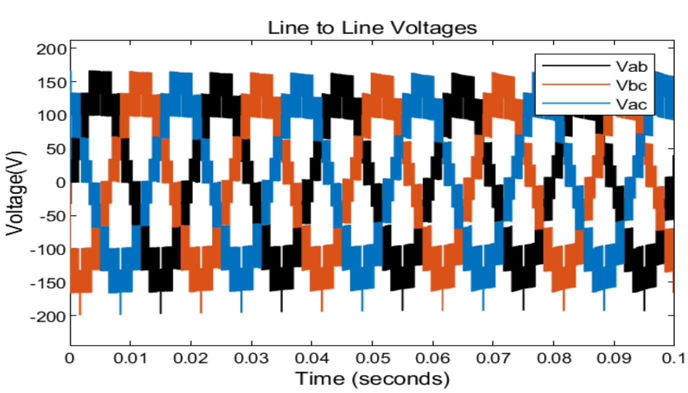

Fig-12(a): Three Phase L-L voltage with LC filter

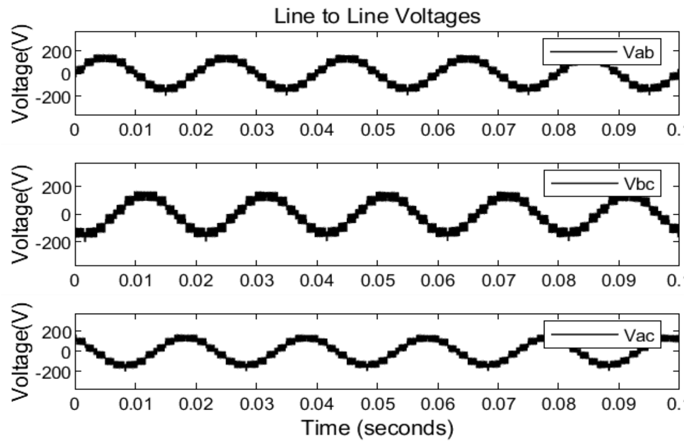

FIGURE 12(b): Three Phase L-L voltage with LC filter

C. AT ABNORMAL CONDITIONS

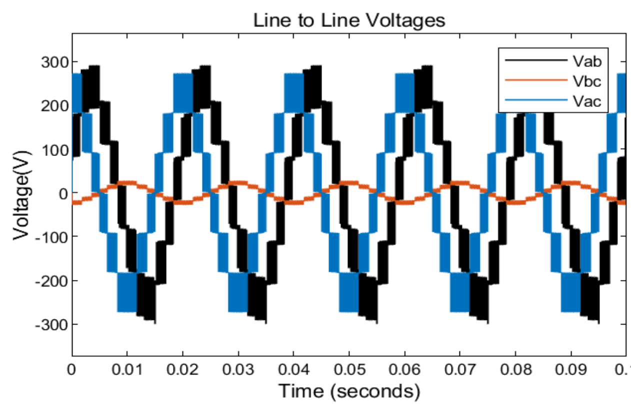

FIGURE 13(a): Three Phase Line to Line voltage during fault conditions for four-wire system

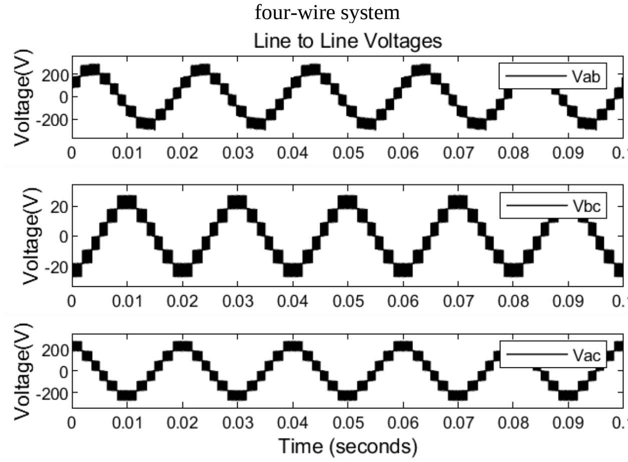

FIGURE 13(b): Three Phase Line to Line voltage during fault conditions for the four-wire system

In this point, the symmetrical fault between the L-L-L of the three-level four-wire NPC inverter has been analyzed. Here in this case, the line to line voltage between the (b) and (c) phase is disturbed. A voltage swell is observed here. Here the fault is generated on phase b due to which there is a decrease of 80-90% in the voltage. It has also been analyzed that due to symmetrical fault, the voltage between the other phases also becomes slightly unbalanced as well, and the current across the phase b abruptly increases, as shown in Fig. 13.

D. LINE TO NEUTRAL VOLTAGE

Here It has been analyzed that the line to neutral voltages whose results are seen in Fig. 14. It has been observed that for the same dc voltage which is applied in the three-level three-wire system the output line to neutral voltage have a greater magnitude than that of the three-level three-wire system as there are more switching devices which are capable of boosting the voltage to a limited extent.

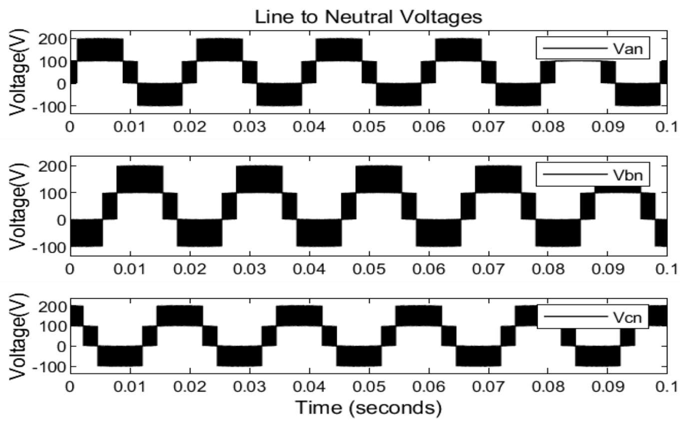

FIGURE 14: Three Phase Line to Neutral voltages

E. TOTAL HARMONIC DISTORTION AT NORMAL CONDITIONS

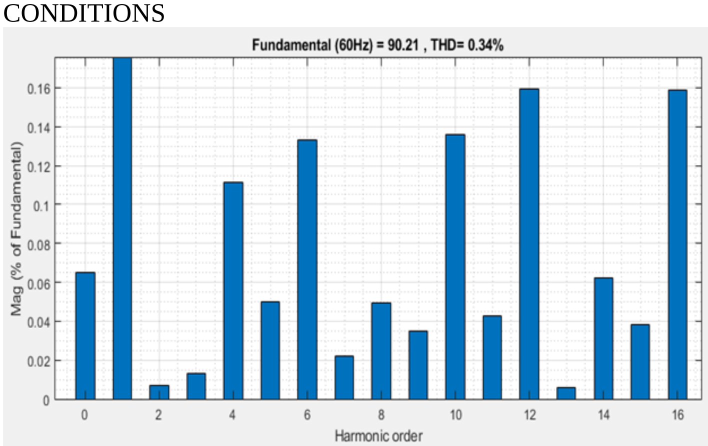

FIGURE 15: THD of Neutral Point Clamped inverter for Three-Level four-wire system

It has been analyzed that the THD for the three-level four-wire system is less as shown in Fig. 15. The distortion of the components depends upon the number of switching devices used in the circuit. The more is the number of switching devices, and the lesser is the harmonic distortion.

IV. CONCLUSION

The working principle of the three-level three wire and four wires neutral point clamped inverters has been presented in this research paper. The harmonics of the 3-phase inverter has been mitigated with the help of LC Filter. Here the results clearly show that both types of inverters can be used to compensate the line to neutral and line to line voltages in the systems. It has been observed that three levels of four-wire systems have greater output voltage values than that of the three levels three-wire system. From the FFT analysis, it has been observed that the harmonic distortion contents in the four-wire system are less than that of the three-wire systems. It has been observed that the design and implementation capacity of NPC inverters is low as compared to the other high-power inverters. Moreover, the power quality is equal and operational power, and fault-tolerant ability is greater than the other high-power rated voltage source inverters.

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