

# A Review of Three Phase Inverters Used in Railway System

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**Abstract:** Nowadays, increasing demand for worldwide environmental safety, considering the development of an efficient, economical, high capability to transportation, fast response, and eco-friendly railway system is a must. By using different types of advanced power electronic technology such as inverter we can develop an efficient system. An inverter is for regenerative braking, supply auxiliary equipment as well as to control the induction motor drives in the railway system. In railway application Multi-Level Inverter (MLI) used to reduce Electro Magnetic Interference (EMI) increasing efficiency of the system. This paper discusses different inverter topologies and its applications in the railway system. Different types of multilevel inverter topologies with their advantages for reducing the number of power semiconductor devices are studied and presented.

**Keywords:** Three phase Inverter, Multi-Level Inverter, MLI Topologies, and Application in railway system.

## I. INTRODUCTION

A railway system has a main application in the transportation of goods and people. Traction system means the use of electrical railways instead of conventional railways because, it reduces the greenhouse gases, provide a clean, eco-friendly environment and easy control. Power electronic converters have found wide application in the railway system due to medium as well as high power and frequency control [1]. Converters are broadly classified as DC-DC converter (chopper), DC-AC converter (Inverter), AC-DC converter (rectifier), etc. Figure 1 shows the block diagram of electronic power and auxiliary services on AC EMU (Electrical Multiple Unit).

In a railway system, the use of AC Linear induction motor is more preferred compared to DC motors due to the absence of commutator and brushes. Hence the system becomes more efficient and more reliable as well as the maintenance cost is reduced, it is also robust in construction less expensive and has high overload capabilities [2]. The induction motor has characteristics in which the input voltage frequency is corresponding to the obtained slip frequency of the motor. Hence the machine gets accelerated and supply frequency goes on increasing to optimize frequency we need to control the supply current. For the different range of power control on a wide speed range of linear induction motor requires an inverter. The inverter is the device used to convert DC input voltage or current into sinusoidal AC voltage or current [3-4]. The inverter is also used for the regenerative and auxiliary power supply.

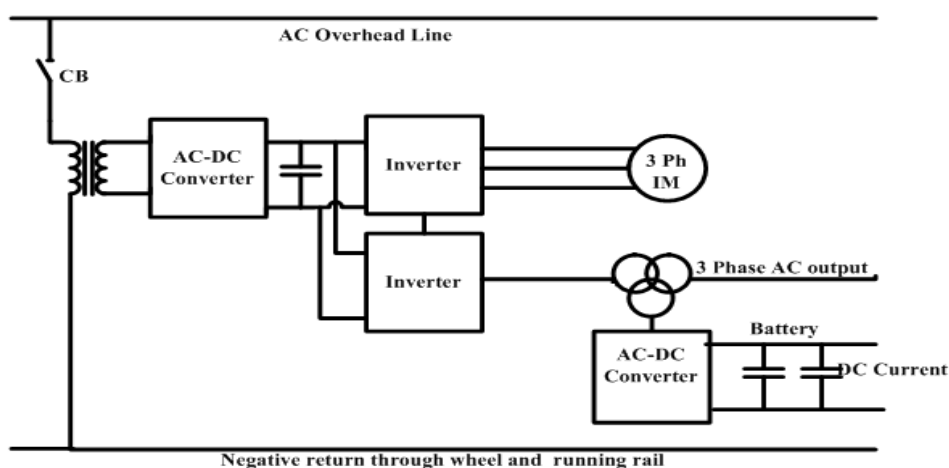


Fig 1. Block diagram of electronic power and auxiliary services on AC EMU

In the impulsion inverter drive, the output is three phase of variable frequency whereas in supplementary inverter drive output can either be single-phase or three-phase with a fixed frequency. In a railway system for improving the efficiency of the converter as well as to reduce the filter circuit capacity, Multi-Level Inverter (MLI) [5] is designed to increase steps in output voltage. A multi-level inverter provides medium voltages and high output power levels with minimum harmonics distortion compared to the two-three level inverter and Pulse Width Modulation Technique (PWM).

## II. TYPES OF INVERTER

Depending on the input AC controlled parameter is either voltage or current. Inverters broadly classified [5] as Current Source Inverter (CSI) & Voltage Source Inverter (VSI). The CSI supplies constant input current from source with high input impedance and the VSI supplies high input voltage with lower/zero input impedance. Moreover, depending on the output of inverter it can be classified as single phase as well as three phase inverter. But in a railway application, the need for power supply is more for the purpose of driving the railway. Hence only three phase inverters are used.

### A. Three Phase Inverter

Figure 2 illustrates the circuit diagram of the three phase inverter which converts single DC-link voltage into three phase AC voltage with the help of power switches like IGBT. It consists of six switches of three legs delayed with  $120^\circ$ , in each leg two switches are connected which complement each other like a half-bridge inverter. An output of the three phase inverter is a six-step line to line voltage with each switch can be conducted at  $120^\circ$  or  $180^\circ$  conduction mode.

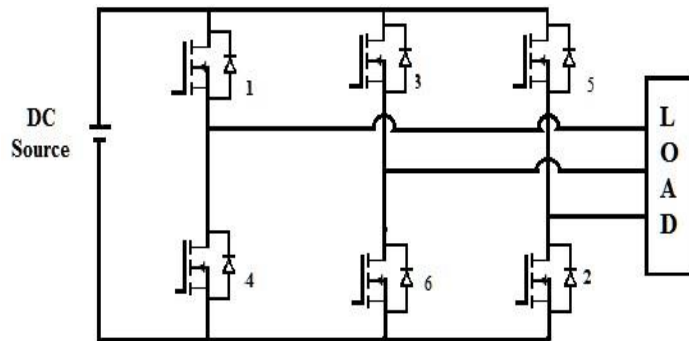


Fig 2. Circuit diagram of three phase inverter

#### i. $180^\circ$ conduction mode

In  $180^\circ$  conduction mode each switch is in conduction mode for  $180^\circ$  where these switches are ON at  $60^\circ$  time intervals. Figure 3 shows the waveform of  $180^\circ$  conduction mode.

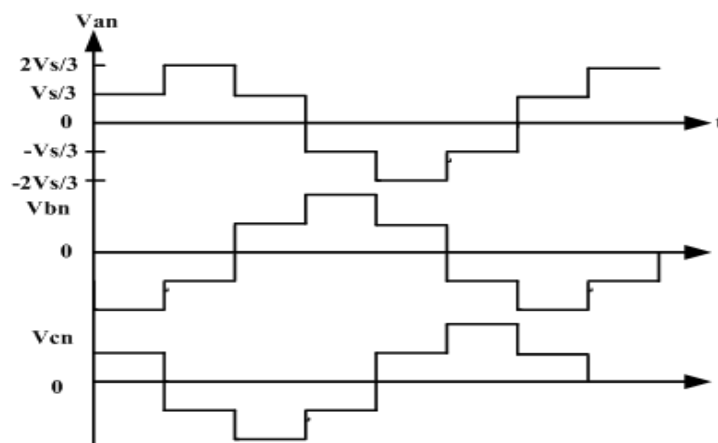


Fig. 3 Phase-line voltage of  $180^\circ$  conduction mode

The output terminals are A, B, & C of the bridge are connected to the three-phase balanced star or delta attached load. By considering balanced star connected load for period  $0-60^\circ$  the switch S1, S5 & S6 are conducted. The output terminal of a load A and C are connected to the positive point, and terminal B is connected to the negative point. To generate load voltage and line voltage, the necessary equations are given below.

Load voltages, 
$$V_{an} = \frac{v}{3}; V_{bn} = \frac{-2v}{3}; V_{cn} = \frac{v}{3} \quad (1)$$

Line voltages, 
$$V_{ac} = V_{an} - V_{cn} = V \quad (2)$$

$$V_{bc} = V_{bn} - V_{cn} = -V \quad (3)$$

$$V_{ca} = V_{cn} - V_{an} = V \quad (4)$$

ii.  $120^\circ$  conduction mode

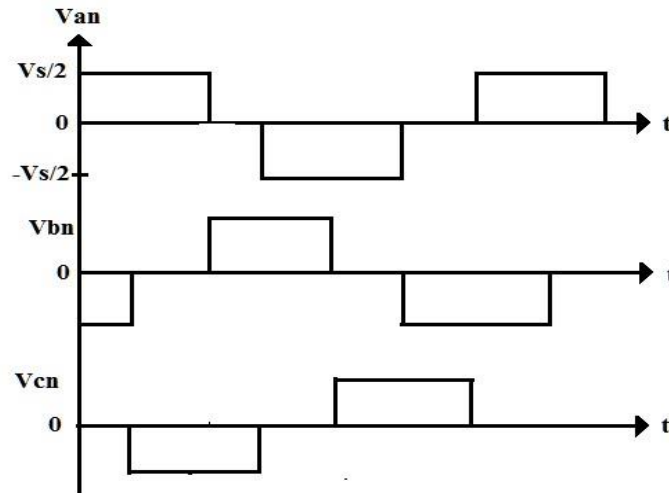


Fig 4. Phase-line voltage of  $120^\circ$  conduction mode

In this mode of conduction, every switch is in conduction mode for  $120^\circ$ . Figure 4 shows the waveform of  $120^\circ$  conduction mode. In this mode only two switches are conducted at a time because this mode, conducts at only  $120^\circ$ . In this mode, load voltage and line voltage are equal and are represented as follows

Line voltages= phase voltage 
$$V_{an} = V_{ab} = V \quad (5)$$

$$V_{bn} = V_{ab} = -\frac{V}{2} \quad (6)$$

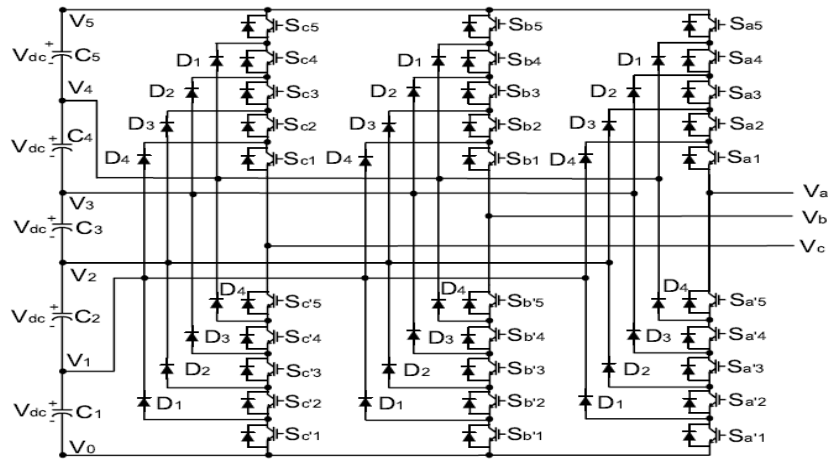
$$V_{cn} = V_{ca} = -\frac{V}{2} \quad (7)$$

B. Multi-Level inverter

Three phase inverter have disadvantages of Electro-Magnetic Interference (EMI) problem, high switching frequency, high switching losses, & high harmonic distortion. To overcome this drawback, the input DC voltage source is added to increase the stages in the output voltage. The multilevel inverter has three main types of conventional topologies namely Diode Clamp MLI (DCMLI), Capacitor MLI (CSMLI) and Cascaded MLI (CMLI) [5].

i. Diode Clamped MLI

A DCMLI uses the diodes to clamp the voltage in order to destroy the voltage strain across the power switches. It is also termed as Nuclear-Clamped Multi-Level Inverter. These topologies were firstly proposed in 1981 by Nabae, Takashi and Akagiin.



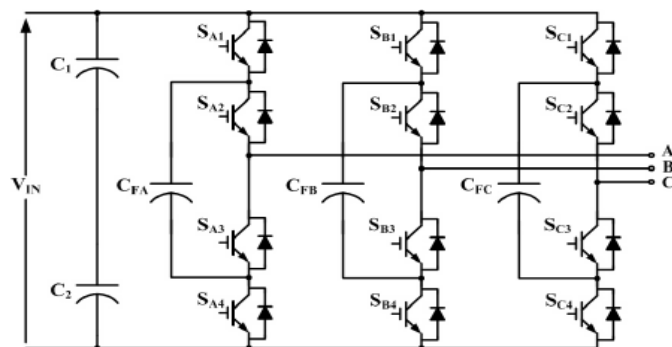
**Fig 5. Three phase six level diode clamped MLI**

Figure 5 shows the circuit diagram of three phase, 6-Level diode clamped MLI [5-7]. Each leg of three phase inverter share a common DC link voltage, these voltages can split into five input capacitors providing six -level phase output voltage level having the same voltage across each capacitor is same (i.e.  $V_{dc}$ ). With the use of clamping diode, voltage stress across each power devices can be reduced. The switches used in the DCMLI are complementary to each other. This method has some drawback which is given below

- Stress across switches and clamping diode are different.
- No. of switches are more.

**ii. Flying Capacitor MLI**

This type of MLI configuration is the same as that of Diode Clamped MLI but the only difference here is that instead of diodes, capacitors are used for the reducing voltage stress across the power devices. This topology was proposed in 1992 by Meynard and Foch Ladder. Figure 6 shows the circuit diagram of three phase three-level FCMLI.



**Fig 6. Three phase three-level flying capacitor MLI**

This topology has a cascaded arrangement of DC side capacitors, wherever the respective capacitor has a different voltage than others. When the capacitor voltage increases, the number of steps in output can also be increased [5]. FCMLI has significant advantages as supplementary switching states help to keep charge balance in the capacitor. But the few drawbacks observed are as mentioned below

- Difficult start and control voltage across capacitor.
- Low Efficiency.

**iii. Cascaded MLI**

A cascaded MLI consists of various units of single phase H-bridge inverter which are connected in cascade. Here, each bridge contains 2 legs connected in parallel and fed by a separate DC source. Every leg consists of two series coupled switches. Figure 7 shows the circuit diagram of three phases five levels cascaded MLI. This type of cascaded multilevel

inverter further classified depending on the type of source used such as symmetrical and asymmetrical MLI. Symmetrical MLI uses the same DC voltage source and asymmetrical MLI has different voltage source. As compared to symmetrical MLI, asymmetrical MLI has a capability to generate a maximum number of the level using less number of voltage source [8].

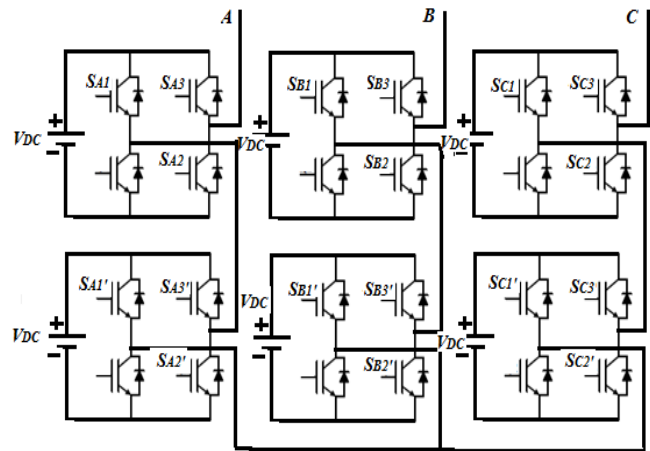


Fig 7. Three phase five level cascaded multilevel inverter

Table I shows the comparison of conventional topology of MLI with the basis of component used. Where m is output phase voltage is tabulated in a table as under.

TABLE I: COMPARISON OF VARIOUS COMPONENTS USED FOR CONVENTIONAL MLI

Component	DCMLI	FCMLI	CMLI
Input capacitor (Voltage source)	(m-1)	(m-1)	$\frac{(m-1)}{2}$
Clamping diode per phase	(m-1) * (m-2)	0	Centre
Number of Flying capacitor	0	$\frac{(m-1) * (m-2)}{2}$	0
Switches per phase	2(m-1)	2(m-1)	2(m-1)

### III. OTHER MLI TOPOLOGYS

#### A. With H bridge inverter

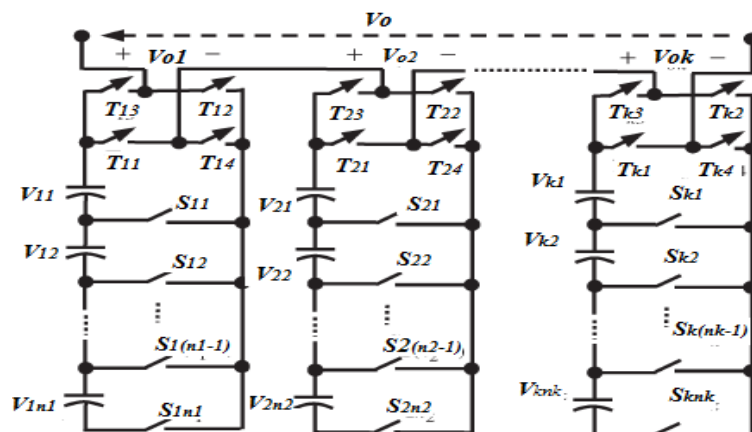
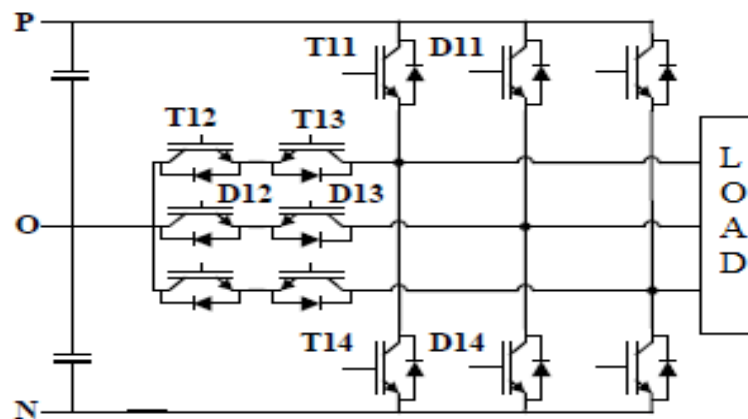


Fig 8. New MLI topology with reduced number switch

Javad Ebrahimi [10] proposed an innovative topology by a reduced number of switches. This topology deals with the combination of a multilevel module (MLM) & full-bridges converter structure as shown in figure 8. The basic unit consists of 'n' numerous capacitors (with dc voltages) and 'n' bidirectional switches. Sub multilevel converter produces output voltage waveform with positive polarity. The H bridge inverter is used to reverse the input voltage to generate positive and negative staircase voltage waveform. A proposed topology design to provide 125 level output voltage by using 28 IGBT. It has been a good resolution for the application that necessitates high power quality.

**B. T-Type MLI topology**

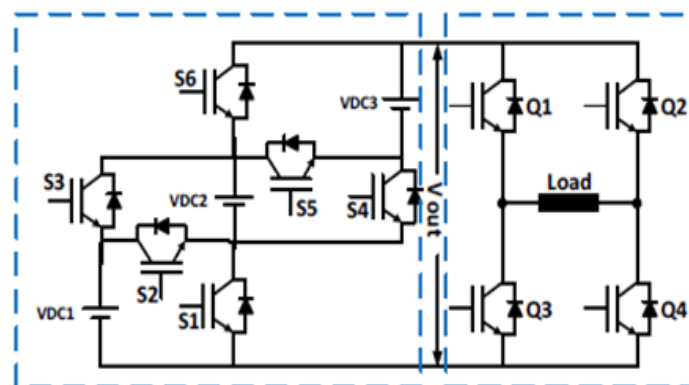
This topology utilizes one bidirectional switch instead of two clamping diodes for reducing the number of a component in diode clamp Multilevel Inverter. Conventional topology has various drawback like voltage stress across switches is different as it uses only low voltage application. The new topology of T-type inverter increases the voltage as well as power, therefore considered for railway application [11]. Figure 9 shows T- type topology in which T-NPC (T-type Nuclear Clamp) inverter controls, balances DC-Link capacitor voltage and decoupled PWM inverter strategy is provided.



**Fig 9. T-type inverter**

**C. SSPS MLI topology**

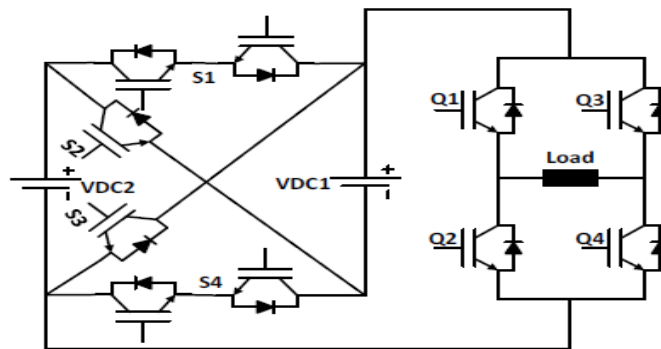
The switched series and parallel source (SSPS) type of topology are familiarized by Hinago [12]. In this topology, it encloses two quantities called as a level generation part which consist of DC sources to harvest a step DC voltage through +ve polarisation & another one is a polarity-generation portion in which Changing step DC voltage into AC voltage as presented in figure 10. By using this topology the operation is built on asymmetrical structure. Also, it can create the amount of output voltage level with a fewer number of switches. The Switched Series-Parallel Source topology is broadly implemented for electrical automobile application. Wherever the direct current source is made by some cascade coupled battery that can be re-arranged by using the Switched Series-Parallel Sources, therefore decreased the necessity of switching strategies. Furthermore, it can be able to tie numerous sources in dissimilar flexible arrangement to comprise railway necessities.



**Fig 10. Switch series and parallel source inverter with 2 DC source**

**D. Crisscross cascaded Multi Level Inverter topology**

Mahdi Toupchi Khosroshahi [13] introduces new cascaded H-bridge inverter topology. It reduces the number of component i.e. switches and a gate driver circuit. It comprises of two DC voltage source as well as four switches in which switches S2 & S3 are unidirectional and other S1, S4 are bidirectional which has the capability to conduct and block the voltage with common emitter configuration as shown in figure 11. This topology involves two parts of generation i.e. level generation and polarity generation. In polarity generation, it lies 4 switches (Q1, Q2 Q3 & Q4). Advantages of this topology over conventional CHB inverter is to a reduced volume by reducing the number of a power semiconductor device, minimum cost, and to generate a high voltage level. Moreover, peak inverse voltage is lower than CHB inverter.

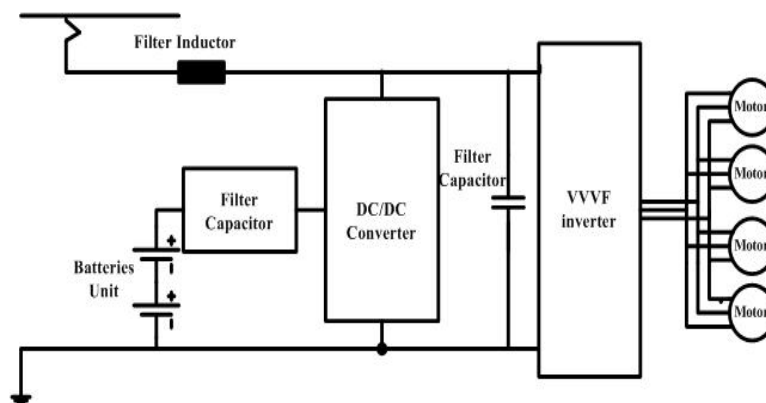


**Fig 11. Crisscross cascaded 5- level with 2 DC source inverter topology.**

**IV. APPLICATIONS**

**A. Regenerative system and motor control [14]**

Regenerative energy system used to develop vehicles which are equipped with power-storing devices such as the battery, capacitors, flywheels, etc. Figure 12 illustrates the block diagram of the regenerative system consisting of VVVF (Variable Voltage Variable Frequency) inverter with the battery system. In the regenerative system battery and pantograph supplies electrical energy during the accelerating period. The stored energy of the battery can be enhanced with the help of converter and pantograph. At peak demand, the motor can accelerate using pantograph and battery via an inverter.



**Fig 12. Configuration of regenerative system circuit**

**A. Auxiliary power supply [15]**

**i. For DC electrical railway**

Figure 13 shows the block diagram of the auxiliary power supply for the DC electrical Railway. The input DC voltage is about 1500 V, 750V or 600V. Input voltage for a DC feeding system is 1,500 V, 750 V or 600 V DC. As the requirement of output, power semiconductor switch (i.e. IGBT) can select the optimum voltage and current which can be fed to the power circuitry (AC load) through an inverter. The inverter used to convert DC voltage into AC which is fed to the transformer to step up the voltage.



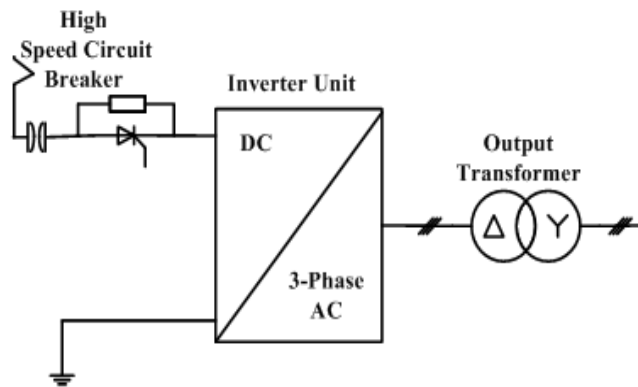


Fig 13. Auxiliary power circuit for DC electrical railway

ii. For AC electrical railway

The AC electric railway loads associated with the auxiliary power circuit are indicator lamps, inner lighting, etc., having a small capacity. However, since these types of loads require continuous auxiliary power supply. Figure 14 illustrates the AC auxiliary power circuit for an electric railway. In this case, a single phase traction transformer is used which steps down voltage to feed the rectifier circuit. A rectifier converts this AC voltage into DC & then IGBT chopper supplies DC power towards DC load. Designed for the AC load, DC power is changed by using an inverter and the output is transferred into single phase AC power and then delivered to the AC load.

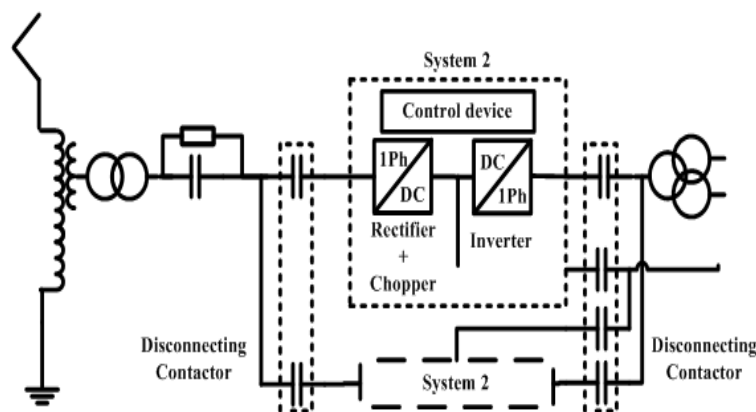


Fig 14. Auxiliary power circuit for AC electrical railway

### III. CONCLUSION

This paper presents a three-phase inverter used in railway for motor control as well as for the regenerative application. A multilevel inverter is used to reduce the THD (Total Harmonic Distortion), electromagnetic interference and reduced voltage stress across the semiconductor switches which is superior as compared to the three phase six switch inverter. Accordingly, the multilevel inverter circuit can be modified by reducing the number of components to minimize the complexity of the gate driver circuit and increasing the level of output voltages.

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