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# Power Converters for Three Phase Electric Locomotives

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**Abstract**—This paper is about the simulation study of auxiliary converters used in 6000 HP electric locomotives used in India. Simulation is a mirror of the operation of a real-world method or system. The process of simulating a system first requires that a model be designed. This model represents the key behaviors, characteristics, and functions of the selected physical or abstract system. It helps to analyze the behavior of the system without even building it. The results obtained are accurate in general when compared to the analytical model. It also helps to find unexpected errors and behavior of the system. Simulation is easy to perform "What-If" analysis. For this purpose, MATLAB/Simulink was used.

Keywords---converter, inverters, locomotives, matlab, rectifier.

# Introduction

A Locomotive or engine in a rail transport vehicle that provides the motive power for a train, If a locomotive is capable of carrying a payload, it is usually rather referred to as multiple units, motor coaches, power cars; the use of this self-propelled vehicle is increasingly common for passenger trains. Traditionally, locomotives pulled trains from the front, however, push-pull operation has become common, where the train may have a locomotive (or locomotives) at the front, at the rear, or each end. A steam locomotive is a type of railway locomotive that produces its pulling power through a steam engine. These locomotives are fueled by burning combustible material usually coal, wood, or oil – to produce steam in a boiler (Saad et al., 2021; Tabunshikov et al., 2021). The steam moves reciprocating pistons which are mechanically connected to the locomotive's main

wheels (drivers). Both fuel and water supplies are carried with the locomotive, either on the locomotive itself or in wagons (tenders) pulled behind. A steam engine is a machine that burns coal to release the heat energy it contains- - so it's an example of what we call a heat engine, It's a bit like a giant kettle sitting on top of a coal fire. The heat from the fire boils the water in the kettle and turns it into steam. But instead of blowing off uselessly into the air, like the steam from a kettle, the steam is captured and used to power a machine.

#### **Auxiliary converters**

Auxiliary converters convert single phase power from Locomotive step-down Transformer to three phases 50Hz power to supply to all the auxiliary loads of an Electric locomotive. Auxiliary converters form part of the auxiliary drive system in an ac locomotive which is primarily used to supply power to the auxiliary loads of an electric locomotive. Auxiliary loads include oil circulating pumps, oil cooling radiator blower, air compressors, motors to operate pantographs, transformer cooling pumps, traction motor cooling pumps, etc. It is typically of IGBT configuration that is fed from the auxiliary windings of the locomotive transformer. The auxiliary converter units (ACU) solve all the vehicle's power conversion needs by switching the input voltage from the overhead lines or 3rd rail power supplies, which is often unstable, into constant regulated voltage. The auxiliary converters are used in electric locomotives. An electric locomotive is powered by electricity from an overhead line, a third rail, or onboard energy storage such as a battery (Widharma et al., 2017; Arcentales et al., 2017). As a locomotive that is in motion that is why this paper focuses on making components of low dimensions and mass, higher efficiency, and simplified maintenance as small as possible so that it can attain more speed with lesser power required to pull itself. An electrical engine comes into the picture after realizing that it is more efficient as compared to a diesel engine. The range of load to be carried out is very large and it can attain variable speed with immediate change.

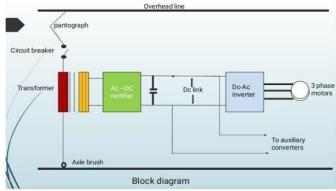


Figure 1. General block diagram

#### Rectifiers

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one

direction. The process is known as rectification since it "straightens" the direction of the current. Physically, rectifiers take several forms, including vacuum tube diodes, wet chemical cells, mercury-arc valves, stacks of copper and selenium oxide plates, semiconductor diodes, silicon-controlled rectifiers, and other silicon-based semiconductor switches (Tao et al., 2018; Jackman, 2020; Rinartha et al., 2018). Historically, even synchronous electromechanical switches and motors have been used. Early radio receivers, called crystal radios, used a "cat's whisker" of fine wire pressing on a crystal of galena (lead sulfide) to serve as a point-contact rectifier or "crystal detector".

#### **Inverters**

A power inverter, or inverter, is a power electronic device or circuitry that changes direct current (DC) to alternating current (AC). The resulting AC frequency obtained depends on the particular device employed. Inverters do the opposite of "converters" which were originally large electromechanical devices converting AC to DC The input voltage, output voltage, and frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power; the power is provided by the DC source. A power inverter can be entirely electronic or maybe a combination of mechanical effects (such as a rotary apparatus) and electronic circuitry. Static inverters do not use moving parts in the conversion process.

Three-phase inverters are used for variable-frequency drive applications and for high power applications such as HVDC power transmission. A basic three-phase inverter consists of three single-phase inverter switches each connected to one of the three load terminals. For the most basic control scheme, the operation of the three switches is coordinated so that one switch operates at each 60-degree point of the fundamental output waveform. This creates a line-to-line output waveform that has six steps. The six-step waveform has a zero-voltage step between the positive and negative sections of the square wave such that the harmonics that are multiples of three are eliminated as described above. When carrier-based PWM techniques are applied to six-step waveforms, the basic overall shape, or envelope, of the waveform is retained so that the 3rd harmonic and its multiples are canceled (Rahman, 2007; Farhani et al., 2020).

#### Sine pulse width modulation

Pulse width modulation allows the user to vary the range of results by manually changing the time the signal is high (5V) or low (ground) i.e by manipulating the duty cycle in an analog fashion while maintaining the sinusoidal proportionality. It is used in an inverter circuit. It has many advantages such as signal remaining digital from input to output, increased noise immunity making the signal strength, and increasing the length of a communications channel increasing the overall efficiency of the signal.

#### **Switches**

The Semiconductor device is made up of a material that is neither a good conductor nor a good insulator, it is called a semiconductor. Such devices have

established wide applications because of their reliability, compactness, and low cost. These are discrete Components that are used in power devices, compactness optical sensors, and light emitters, including solid-state lasers. They have a wide range of current and voltage handling capabilities, with current ratings of more than 5,000 amperes and voltage ratings of more than 100,000 volts. More importantly, semiconductor devices lend themselves to integration into complex but readily build-microelectronic circuits. They are having probable future, the key elements of the majority of electronic systems including communications with data-processing, consumer, and industrial- control equipment (Cheng et al., 2018; Fernandez et al., 2011).

# **Thyristor**

The thyristor is a four-layered, three-terminal semiconductor device, with each layer consisting of alternately N-type or P-type material, for example, P-N-P-N. The main terminals, labeled anode, and cathode are across all four layers. The control terminal, called the gate, is attached to p-type material near the cathode. (A variant called an SCS—silicon controlled switch— brings all four layers out to terminals.) The operation of a thyristor can be understood in terms of a pair of tightly coupled bipolar junction transistors, arranged to cause a self-latching action.

#### Thyristors have three states:

- Reverse blocking mode Voltage is applied in the direction that would be blocked by a diode
- Forward blocking mode Voltage is applied in the direction that would cause a diode to conduct, but the thyristor has not been triggered into conduction
- Forward conducting mode The thyristor has been triggered into conduction and will remain to conduct until the forward current drops below a threshold value known as the "holding current"

### **IGBT**

IGBT is a relatively new device in power electronics and before the advent of IGBT, power MOSFETS and Power BJT were common in use in power electronic applications. Both of these devices possessed some advantages and simultaneously some disadvantages. On one hand, we had bad switching performance, low input impedance, secondary breakdown, and current-controlled Power BJT and on the other, we had excellent conduction characteristics it. Similarly, we had excellent switching characteristics, high input impedance, voltage-controlled PMOSFETS, which also had bad conduction characteristics and problematic parasitic diode at higher ratings. Though the unipolar nature of PMOSFETS leads to low switching times, it also leads to high ON-state resistance as the voltage rating increases. Thus the need was for such a device that had the better of both PMOSFETS and Power BJT and this was when IGBT was introduced around the early 1980s and became try popular among power electronic engineers because of its superior characteristics. IGBT has PMOSFET like input characteristics and Power BJT-like output characteristics and hence its

symbol is also an amalgamation of the symbols of the two-parent devices. The three terminals of IGBT are Gate, Collector and Emitter. Figure below shows the symbol of IGBT.

#### Related work

Auxiliary converters are used in 6000 HP electric locomotives used in India. Simulation is a mirror of the operation of a real-world method or system. The process of simulating a system first requires that a model be designed. This model represents the key behaviors, characteristics, and functions of the selected physical or abstract system. It helps to analyze the behavior of the system without even building it. The results obtained are accurate in general when compared to the analytical model. It also helps to find unexpected errors and behavior of the system. Simulation is easy to perform "What-If" analysis. For this purpose, MATLAB/Simulink was used. Single-phase 1000V AC supply from overhead lines is converted into single-phase 700V DC supply using AC/DC rectifier circuit. One major problem faced during this type of conversion is that since the AC supply is coming through the pantograph placed overhead, is not constant and a variation of around 10- 15 % is possible in the input supply. The output of the rectifier should be 700 V in all cases. Hence a closed-loop system with an error detector and amplifier is placed in-between so that it can modify the output DC voltage until the required 700V is obtained. The second stage is DC/AC inverter circuit which further converts the single phase 700 DC into three phases 415 AC supply used by the auxiliary circuit. SPWM is used as a common inverter control method. With SPWM control, the switches of the inverter are controlled based on a comparison of a sinusoidal control signal and a triangular switching signal. The sinusoidal control waveform fixes the desired fundamental frequency of the inverter output, while the triangular waveform fixes the switching frequency of the inverter (Cipek et al., 2019; Acikgoz et al., 2020).

The voltage unbalances for AC electric railway systems. The development is based on MATLAB/Simulink program to determine voltages at the substation. The voltage unbalance factor (VUF) is used for this evaluation. Suvarnabhumi Airport Rail Link (ARL) in Bangkok, Thailand, is chosen for the test. This test system is supplied by a cyclic winding connection of two single-phase traction transformers in which its primary side is connected to the 69-kV transmission system of MEA(Metropolitan Electric Authority) power grid. The AC railway power feeding is a direct feeding schemevia 25-kV overhead catenary system. The total service distance of the ARL is 28.298 km with 8 passenger stations. The multi-train movement simulation is developed and embedded into the MATLAB program. The simulation results show that the operating voltage and the VUF during the train service can be obtained. In urban rail systems with high dense traffic, it has an impact on following the train's speed profile when the preceding train is delayed at the station. The impact is that the following train will decelerate, even to stop, to wait until the station area is clear [1]. Asymmetric loading of the three = phase power supply system is one of the most relevant influences of single = phase AC electric railways operation. The rate of voltage unbalance in the three = phase system can theoretically be caused by all the elements involved in the production, transmission, and power consumption. In the operation practically the only reason is one or two = phase load. As the primary source of voltage unbalance or load must be considered. The voltage unbalance on the system impedances, which in turn affects other consumers of electricity (Nwaigwe et al., 2019; Haidong et al., 2018).

As the use of renewable energy sources are increasing and will going to be increased to a large extend in the future. Especially, solar energy will going to play a huge role as a major energy source. The output of the inverter is direct current, so an inverter becomes a critical component for the flow of electricity from solar modules to the storage battery, loads and grids. A three-phase voltage source inverter Sinusoidal Pulse Width Modulation based inverter is going to be utilized. The High-frequency triangular carrier wave is compared with the sinusoidal reference wave of a desired frequency. The width of each pulse is varied in proportion to the amplitude of a sine wave called SPWM. The advantage of SPWM technique is that it reduces the harmonic contents of the output voltage compared to single pulse width modulation and multi-pulse modulation. The advantage of an inverter with two stage three-phase bipolar SPWM is good performance and efficiency as it doubles the switching frequency of inverter voltage and so the output filter becomes smaller, cheaper and easier to implement. A three-phase two-level SPWM inverter-based voltage source inverter is going to be simulated for with and without filter across resistive load using MATLAB and the Total Harmonic Distortion of both is compared. The application of SPWM inverter in speed control of three phase induction motor by volts/hertz method is implemented. MATLAB simulation for speed control of induction motor is simulated and its THD analysis along with current and voltage is carried out. A hardware implementation of speed control of induction motor is made. Keywords: SPWM (Sinusoidal Pulse Width Modulation), PWM (Pulse Width Modulation), MATLAB, Inverter, Induction Motor, Frequency Modulation, Speed Regulation of AC Motor, MOSFET, Diode, DC Link, triggering si (Yazdaninejadi et al., 2019; Mohd et al., 2010).

#### Methodology

Since the paper is about the implementation of Auxiliary Converters of various ratings required in different 3-phase electric locomotives that is here 1000V single-phase AC supply is getting converted into 415V three-phase AC supply. For this purpose, we have divided our project into two different cases

Case 1: Conversion of single phase AC to DC1.AC to DC converter

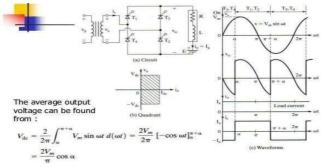
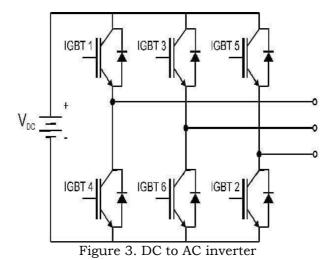


Figure 2. AC to DC converters

#### Single-phase, full-wave AC to DC converters

AC to DC converter and DC converters serves as Rectifiers. They convert AC to DC in several industrial, domestic, agricultural, and other applications. Rectifiers are used as stand- one unit feeding single and multiple loads and as input stages of ac systems because they have virtually unlimited output power and fine controllability. Thyristors are the main line-commutated power switches. To turn on a thyristor, an injection of a current pulse into its gate is required. Here, a 1000V single-phase AC power supply given to the circuit is converted into 700V DC voltage with help of rectifiers and thyristors.

Case 2: Conversion of three-phase DC to ACDC to AC converters are known as inverters. Here 700V DC output obtained from case 1 is used as an input which in turn gets converted into 415V three-phase AC which is used to feed the auxiliary loads of the locomotives. The inverter has power switches that can be controlled by using different PWM techniques (eg Sine PWM where a reference sine wave and a high-frequency triangular waveis compared using a comparator and the output is fed to gate of the power switches) or by frequency control, although PWM technique is highly preferred. The switches can a MOSFET switch or an IGBT switch depending upon the load and switching frequency. In this project, we will prefer to use IGBTs as it has a Very low on-state voltage drop due to conductivity modulation and has superior on-state current density. So smaller chip size is possible and the cost can be reduced.



# Results

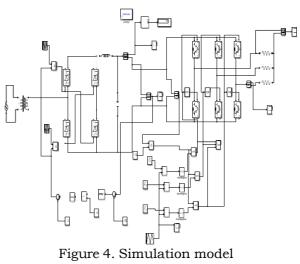




Figure 5. Inverter output

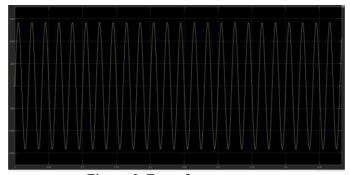


Figure 6. Transformer output

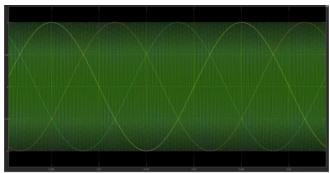


Figure 7. Sinusoidal PWM

#### Conclusion

A full-wave bridge rectifier does not require a special center-tapped transformer thereby reducing the size and cost considerably. The output of the rectifier should be 700v in all the cases hence the closed-loop system is placed. From this, we can make components of low dimension, mass, and higher efficiency so that it can attain more speed with lesser power.

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