Electric Traction System Technology as a Solution to African Transportation Industries

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Abstract:

The electric traction system in the case of Africa is highly advantageous in terms of transportation. The electric traction system is designed to provide a DC output source from an AC source of 33kV/230V for suitable mobility of tract devices without minimum frequency change. In this work, electric traction system analysis was obtained using mathematical models and simulation of tracts system components using MATLAB. Due to the application of FACTs devices, a 12-pulse thyristor rectifier is used for rectification. The system components are an energy source, harmonic filter, step-down transformer, rectifier substation, and DC load. The maximum current of total harmonic distortion obtained is certified with the IEEE standard 5% total harmonic distortion. The output voltage is purely stable, and the power factor quality is improved.

Keywords: traction devices, 12-pulse rectifier, harmonics.

Introduction

In the context of transportation, the system that moves a vehicle forward is called the traction system. For many forms of transportation, such as electric cars, trains, trams, and even some kinds of bicycles, this system is essential. The traction system typically involves the conversion of electrical, mechanical, or other forms of energy into the necessary force to move the vehicle (Wu, et al., 2021). Traction systems are divided into two categories electric and non-electric. Both types of systems are crucial parts of many different kinds of transportation, including electric cars and railroads. A steam engine drive, which was the first locomotive system in operation before the introduction of true electric traction systems, is the best example of a nonelectric traction system. A nonelectric traction system is one that uses no electrical energy at all to move a vehicle. Although some or all of the stages of locomotive movement need the use of electricity, there are three types of electric drive available in this system: battery-operated, diesel-electric, and direct electrical. automobiles. Under this approach, the movement of the vehicle is produced by electrical motors that are driven by batteries or utilities diesel generators. However, the conventional or non-electric traction systems used by Africa’s central railway transportation system are unreliable and fraught with a number of issues, such as high operating costs,
detrimental environmental effects, long hauling times, low starting torque, and reduced efficiency. Additionally, research has looked into the African railway network’s construction differentiation trends and evolution (Wang, et al., 2021).

**Traction system in Africa**

In Africa, traction systems play a crucial role in various sectors such as transportation, agriculture, and even legal frameworks. The use of traction systems, including animal traction and mechanization, has been a subject of research and policy discussions in the region. The traction system in African transportation is a critical component that significantly influences the efficiency and reliability of various modes of transportation. Traction systems are fundamental in providing the required power for trains, trams, and other vehicles to operate. In the African transportation context, the development and optimization of traction systems are essential for improving the overall transportation infrastructure in the continent.

An essential consideration in traction systems is the type of power supply utilized. Research indicates the prevalence of various traction systems, such as the 3 kV DC traction systems present in countries like South Africa, which are vital for powering electric trains and urban transit systems (Panda, Poikilidis, & Nguyen, 2023). Furthermore, studies emphasize the importance of power quality and harmonics analysis in traction systems to ensure optimal operation and minimize energy losses (Dovgun, et al., 2020). The African traction system can be converted into a contemporary electrified traction system, however the majority of traction systems in use in the continent are conventional or non-electric, which present a number of issues that must be resolved.

Traction systems in Africa are confronted with a multitude of issues that impede their efficacy and efficiency. The dependability of the traction system is a major issue, particularly in applications where safety and mission are at stake (Gong, et al., 2020).

The seamless operation of traction systems in Africa is significantly hampered by this reliability issue. Furthermore, the expansion of railways especially high-speed railways, which are expanding quickly around the world is hampered by the challenges with the traction power supply system, including neutral portions and power quality problems. Diode rectifiers and transistor rectifiers such as the 6 and 12-pulse rectifiers are frequently used in railway traction substations. These rectifiers have been around for a long time and are still widely used in contemporary rail systems (Coffey, et al., 2021).

These rectifiers are essential in transforming incoming power into a format that the traction system can use. To guarantee power quality and effective operation, the traction power supply system in railroads is a crucial component that needs to be carefully monitored and evaluated. Monitoring systems for traction power should not only focus on the power supply but also consider the integration with the high-speed train system to address power quality issues effectively (Zhu, et al., 2021).

**Electric Traction System**

Since electricity is now the primary power source for railway travel, the service is quick, easy, and environmentally benign. But this also presented the electrical grid with a fresh difficulty. Power electronics technology has advanced rapidly, and the use of these devices in the railway industry has increased. This exposes the traction power supply system to a distorted waveform caused by harmonic currents introduced into the system by non-linear loads, which impacts the network's overall performance (Assefa, Kebede, & Legese, 2021).

In a wide range of applications, such as trains, electric cars, and industrial machinery, electric traction systems are essential. These systems depend on efficient traction motors to provide the necessary power for propulsion (Kondratieva, 2023). Strict requirements, such as high performance, speed sensor-less control, dependability, efficiency, and stability at various speeds, must be met by the electric traction...
In electric traction systems, electric motors provide the propulsion power required. Traction motors for electric traction systems in electric cars need to fulfill certain requirements, such as speed sensor-less control, stability, efficiency, and dependability at various speeds (Hadraoui, et al., 2022). A comparison of different traction drive control systems for electric locomotives has brought to light the advantages and disadvantages of vector control and direct torque control with respect to power consumption, torque overshooting, torque pulsations, and speed regulation (Goolak, et al., 2023). Furthermore, in traction applications like electric trains or ships, modulation and control strategies for multilevel inverters are essential for maximizing power efficiency by employing greater DC-link voltages to lower current ratings (Poorfakhraei, et al., 2021).

Proposed Simulation to Improve the Reliability of Electric Traction System in Africa

There is a high need for diversifying the entire African railway system into a fully electrified traction system. This paper focuses on modernizing the African traction system into an electric system connected to an AC source and designing and simulating in MATLAB a 12-pulse rectifier using a thyristor to provide a DC output source and overcome harmonic distortion.

Traction Power System Modelling

Modelling for power systems engineering refers to mathematical models that specify the different component interactions and provide DC output. The output voltage can be calculated using Fourier series analysis.

\[
V_0 = \frac{3\sqrt{3}}{\pi} V_m + \frac{6\sqrt{3}}{35\pi} V_m \cos 12\omega t + \frac{6\sqrt{3}}{143\pi} V_m \cos 24\omega t + \ldots \tag{1}
\]

\[
V_{dc} = \frac{3\sqrt{3}}{\pi} V_m \tag{2}
\]

Traction Supply Network

This network is intended to provide electricity to electric vehicles (trains). Various substations are using three-phase AC supply to step-down transformers that convert it to a usable level, 33k/230V (AC/DC).

Rectifier Transformer Model

The rectifier transformers are transformers that have a primary winding delta and a secondary winding star connection.

Figure 1. 12-Pulse Thyristor Rectifier

AC Harmonics Filter

The filter reactor is defined to provide a series resonance impedance (low impedance) at the harmonic frequency to be suppressed. At this resonance frequency, capacitor and inductor impedances are equal in magnitude.

The impedance is given by.

\[
Z_0 = j\left(\omega L - \frac{1}{\omega C}\right) \tag{3}
\]

The resonant frequency \(f_s\) and the resonant parallel frequency

\[
f_s = \frac{1}{2\pi\sqrt{LC}} \tag{4}
\]
The harmonic filter can give a high percentage value of reactive power for power factor correction. Capacitor KVA can connect with real power KW to increase the power factor quality.

\[ f_p = \frac{1}{2\pi\sqrt{(L_s + L)C}} \]  

(5)

The quality factor provides the quick response of the turning of the pass filter, the value is fluctuating between 0.5 to 5%.

\[ q_f = \frac{X_L}{R} \text{ or } q_f = \frac{X_C}{R} \]  

(7)

**Simulation Analysis and Result**

The result obtained from the simulation for voltage and current has an RMS value of 43.55kV and a power factor of 0.7. The AC side filter of voltage and current are shown in Figure 2 and 3 also the THD current is reduced to 0.52%. the DC output voltage of 230V with a maximum less harmonic is shown in figure 2 and 3. The TDD is 0.052% as shown in figure 4 and 5 the THD is approximately equal to the IEEE standard for the voltage distortion limit of 1kV < V ≤ 69kV total harmonic distortion is 5%.
Conclusion

The electric traction system was designed and simulated using MATLAB R2023a. Based on simulation results obtained, THD agrees with the IEEE standard 519-1992. limit (5%) for 1kV < V ≤ 69kV. The 12-pulse rectifier could produce an output DC voltage of 230V which is exactly with the secondary voltage of the transformer before the rectification. The power factor improved up to 0.72 because of less harmonic distortion. The systems play a major role in modern transportation, its cleanliness, absence of air pollution, low maintenance cost. The electric traction system is a good energy for better transportation.

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