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Harmonic Analysis for High-Speed Rail Installation 132kV

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Abstract: The purpose of this paper is to simulate an AC traction circuit with an AC locomotive load. It also investigates current and voltage distortion in the power system supply as a result of harmonic analysis. The system mentioned before was studied for harmonics analysis of a projected 132kV high speed rail installation. The MATLAB/SIMPOWER system is used to simulate the major components of the electric traction system for harmonic analysis. In addition, a mathematical model of the supply network is being built to quantitatively assess voltage distortion at different buses. This system depicts a study of the effect of a harmonic enhancement filter on AC traction linked to an AC locomotive load. Accordingly, the simulation result at stage of speed at 25%, 50%, 75% and 100% the value of total harmonic distortion (THD) for voltage is 5.05% and a THD for current is 57.50% in worst scenario. Next the simulation result at full cycle without passive filter, the result a THD for voltage is 5.58% and a THD for current is 55.53%. It also has worst result for this simulation. Lastly the simulation result at the full cycle with passive filter, the value of THD for voltage is 0.62% and a THD for current is 0.77%, which are below IEEE 519 standard limits and TNB standard. This shows power quality and EMC improvement of the traction power supply system.

Keywords: AC Traction, AC Locomotive, Voltage THD, TNB standard, IEEE 519

1. Introduction

In the railway power-supply system, electrical locomotives create harmonic currents. As a result, the supply network's current and voltage waveforms are continuously distorted. This distortion causes overheating, vibration and torque decrease of spinning machinery, increased losses of lines and transformers, interference with communication systems, failures of protective relays, measurement instrument inaccuracy, and other negative effects in traction power-supply systems. As a result, the distortion in the voltage and current waveforms at different places in the traction system should be quantified and studied in accordance with international standards such as IEEE 519-1999 [1].

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Harmonic waves are mostly caused by non-linear loads. Since non-linear loads use semi-conductor components that can change over time, they are designed to be more efficient and conserve energy. On the other hand, the use of semi-conductor components produces interference in the form of distorted voltage and current signals that return to the electrical power system. A harmonic disturbance is what is happening here [2].

A crucial component of power systems, total harmonic distortion (THD), should be kept as low as practical. Lower THD is a sign of higher power factor, lower peak currents, and better power system efficiency. International standards like IEC 61000-3-2 govern the harmonic currents of specific kinds of power equipment since low THD is such a crucial aspect of power systems [3].

In order to travel significantly quicker than conventional rail traffic, high-speed rail (HSR) employs an integrated system of specialized train stock and dedicated rails. High-speed lines are often defined as those built to handle speeds greater than 250 km/h (155 mph) and upgraded lines exceeding 200 km/h (124 mph), while there is no universal definition of the term [4]. High-speed rail is an antiquated form of transportation since it necessitates costly, specialized infrastructure that serves no other function than to transport passengers who could travel more affordably by car or plane [5].

2. Materials and Methods

This section discusses the methodology used to achieve the project's goals. The goal of this project is to compare the total harmonic distortion level of the system with the current standard. This study's methodology is to measure the voltage and current distortion limit at 132 kV. The MATLAB Software was used to obtain the results.

2.1 Flowchart

Figure 1 depicts the flow of this project, with the first step being the collection of project-related literature reviews from journals. The simulation model must then be developed using the MATLAB Simulink software and must be accurate with the standard. If it is not correct, the simulation model must be troubleshooted again. If the standard is correct, it may be defined by utilizing the scope of operation with the required parameter.

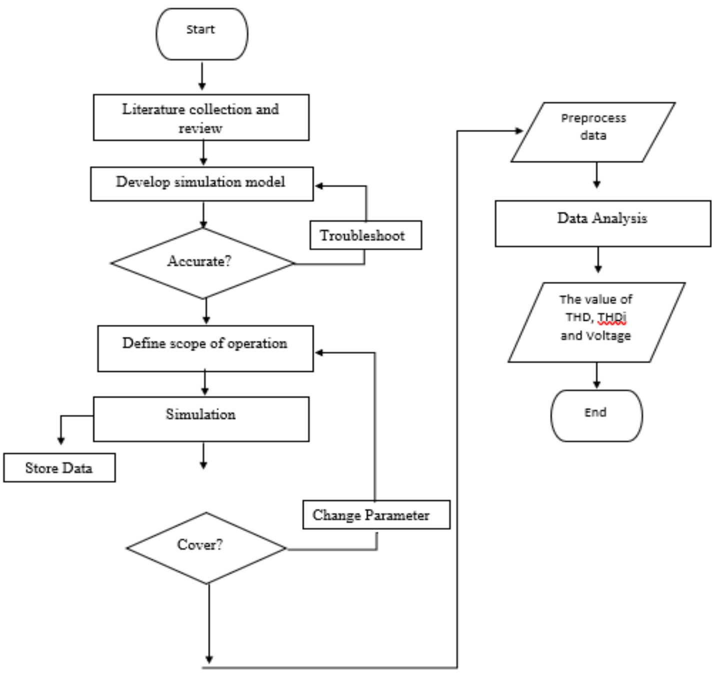


Figure 1: Flowchart of this project

The simulation will then be performed using the MATLAB Simulink software, and the results will be saved in the data store. If it covers the result, then the parameter must be changed to obtain a different result. Then, after the result is obtained, it will pre-process and evaluate the data that was obtained. Finally, the THD, THDI, voltage, and current values must be compared to the current standard at IEEE 519.

2.2 Simulation Railway Model

The simulation railway model for to show the AC electric traction systems at 132 kV. Figure 2 shows the example of AC traction after harmonic filter model by using MATLAB Simulink software. This simulation determined the influence factor affecting the harmonic filter at AC traction.

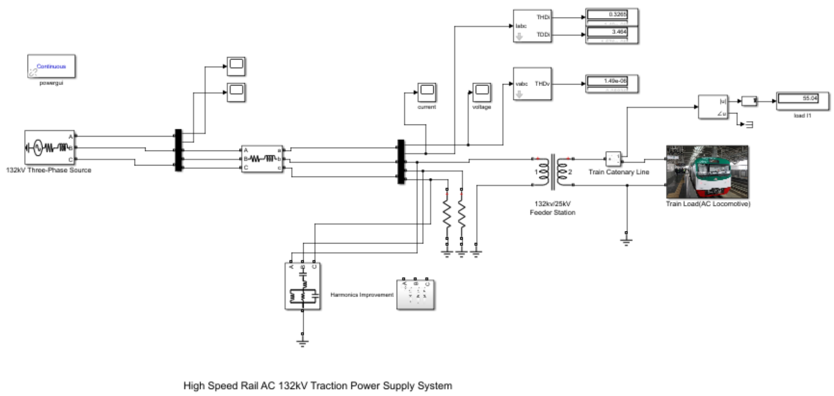


Figure 2: AC Traction After harmonic filter Model

2.3 AC Locomotive Load

An outline of the working parts of an AC locomotive load is illustrated in Figure 3. With the aid of a Pantograph, the electric locomotive receives power from the overhead equipment (OHE), which is then transformed into mechanical energy by traction motors that spin the wheels. The locomotive is equipped with the required parts to allow the loco pilot to regulate the voltage provided to the traction motors, which perform this duty, to control the train's speed.

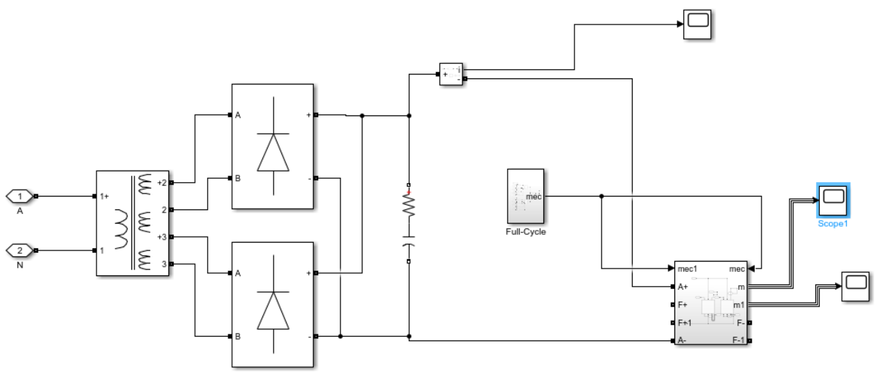


Figure 3: AC Locomotive Load

2.4 TNB Requirement.

TNB defines requirements that users must meet in order to reduce the impact of electromagnetic disturbances in the electrical system, such as voltage sags, transients/surges, and so on [6]. The TNB power quality criterion is shown in Table 1.

Table 1: TNB Requirement for Power Quality

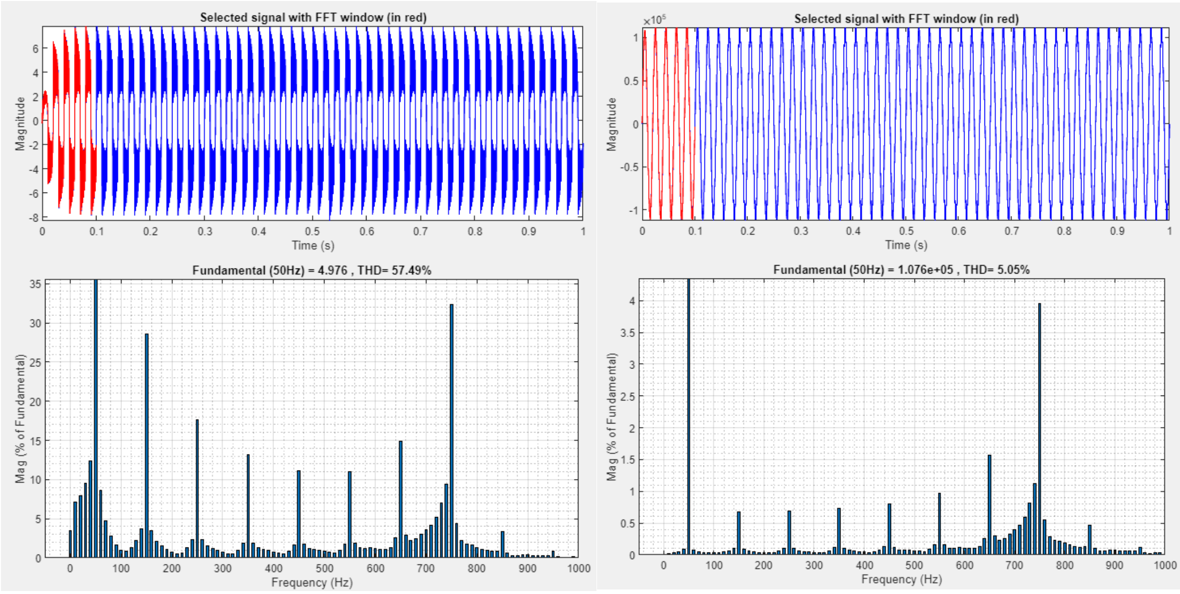
Type of Disturbance	Indices	Value that is within acceptable bounds at the common coupling point (PCC)	Reference document
Voltage Step Change	ΔV %	1% - Starting, switching, and/or disconnecting a load on a regular basis	**UK's Engineering Recommendation P28**
		3% - Loads are only occasionally single-started, single-switched, or single-disconnected once every two hours or more.	
		6 % - Sometimes beginning or switching.	
Voltage Fluctuation and Flicker	Absolute Short Term Flicker Severity (Pst)	1.0 and 132 kV above	**UK's Engineering Recommendation P28**
		0.8 and 132 kV above	
	Absolute Long Term Flicker Severity (Plt)	0.8 and 132 kV above	
		0.6 and 132 kV above	
Harmonic Distortion	Total Harmonic Distortion Voltage (THDV) %	5 % at ≤ 400 Volt	**Engineering Recommendation ER G5/4**
		4 % at 11kV-22kV	
		3% at 33kV	
		3% at 132kV	
Voltage Unbalance	Negative Phase Sequence Voltage %	2% for 1 minute	**UK's Engineering Recommendation P29**
Voltage sag	Immunity requirement	Voltage sag immunity is a need for all key machinery and operations.	**IEC 61000-4-11 & IEC 61000-4-34**

3. Results and Discussion

This section describes the findings of a software simulation approach used to assess the impact of THD on a 132 kV high-speed rail project. The findings are obtained by modeling the alternating current at 132 kV with the MATLAB Simulink software. This section will examine the impact harmonic analysis to AC traction circuits with high speed rail load. This section will also examine the THD level of the system in comparison to the existing standard. The harmonic analysis for high-speed rail at 132 kV is then discussed in this section.

3.1 Line Power Quality during Stage of Speed

The speeds that are employed are 25%, 50%, 75%, and 100%. Only the voltage's THD value can be visible depending on the speed being employed. 5.05% is around the same for each THD value for voltage for a range of 25% to 100%, while 57.5% is roughly the same for each THD value for current. Based on the 3% THD figure for voltage standard limit established by TNB. The applied voltage is 132 kV. The speed is input into the train load and placed on the AC Locomotive load. Figure 4 shows the result for speed without passive filter for total harmonic distortion voltage and current. Table 2 also shows all results for the comparison TNB standard with difference stage of speed.



(a) **(b)**

Figure 4: Speed without passive filter (a) THD for Current (b) THD for Voltage

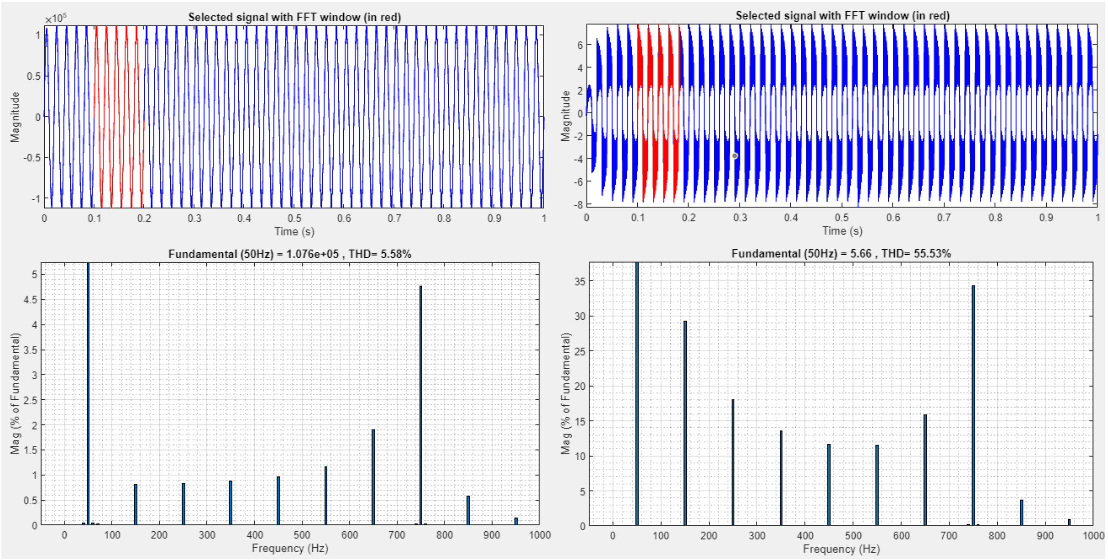
Table 2: Difference stage of speed for THD for voltage.

Speed	THDv	TNB Standard
25%	5.05%	
50%	5.05%	3%
75%	5.05%	
100%	5.05%	

3.2 Power Quality during The Typical Drive Cycle without Passive Filter

This section shows the value of THD for current and voltage for the typical drive cycle without passive filter. Figure 5 shows the full cycle subsystem for the train load. The upper section of this whole cycle subsystem represents acceleration, while the lower part represents deceleration. It is to demonstrate the train accelerating at a steady and gradual speed. As a result, you can view the THD number while it is operating and whether it is within the TNB specification.

Figures 5(a) and 5(b) display the THD value obtained by employing the FFT analysis approach. The THD value for current and voltage is shown on the graph. According to TNB's requirements, the standard established at 132 kV voltage is less than 3%, and figure 5's THD value for the voltage is 5.58%. (a). This is because it is an important component of power systems and should be kept as low as possible. Reduced THD is a sign of higher power factor, lower peak currents, and better power system efficiency. Since they fluctuate at the same frequencies as the transmit frequency, these higher order harmonics can likewise disrupt communication transmission lines. Increased heat and interference can significantly reduce the lifespan of electronic devices and harm power systems if they are not controlled.

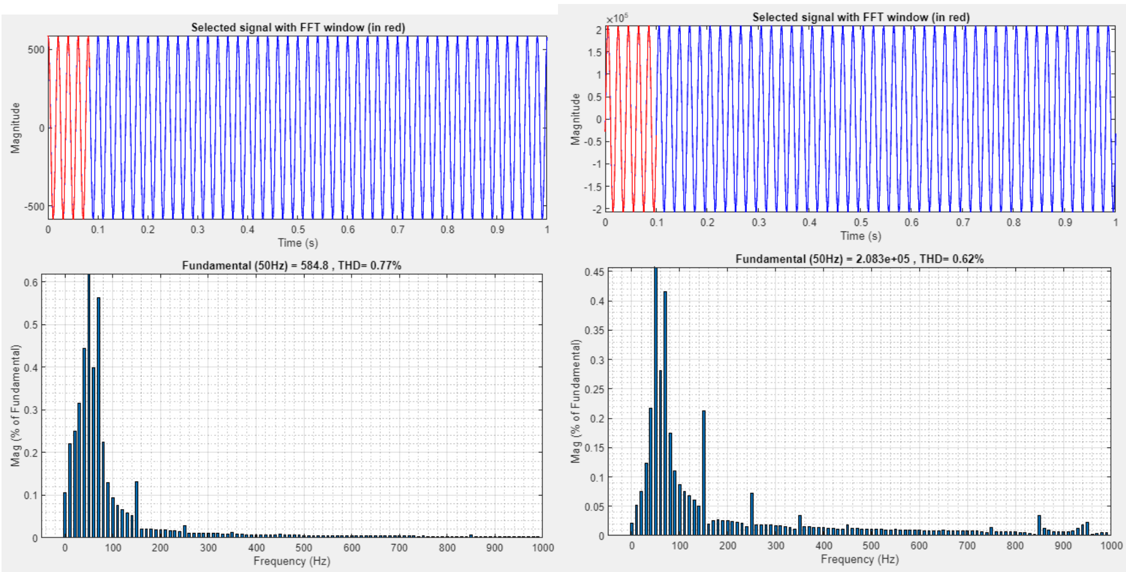


(a) **(b)**

Figure 5: Full Cycle without Passive Filter (a) THD for Voltage (b) THD for Current

3.3 Power Quality during The Typical Drive Cycle with Passive Filter.

Figure 6 shows the result for full cycle with passive filter and Table 3 shown the comparison the result of THD for voltage with TNB standard result. The THD value produced by utilizing the FFT analysis approach is shown in Figures 6 (a) and 6 (b) The graph depicts the THD value for current and voltage. The standard established at 132 kV voltage is below 3% based on the specifications given by TNB and the value of THD for voltage is 0.62% based on Figure 6 (a). Based on the results, it is clear that the outcome is less than 3%, which is a respectable result. In power systems, lower THD leads to higher power factor, lower peak currents, and greater efficiency. As low THD is such an essential part of power systems, international standards like IEC 61000-3-2 establish limitations on the harmonic currents of various types of power equipment.



(a) (b)

Figure 6: Full Cycle with Passive Filter (a) THD for Voltage (b) THD for Current

Table 3: Comparison with and without passive filter at TNB standard

Condition	THDv	TNB standard
Without Passive Filter	5.58%	3%
With Passive Filter	0.62%	

4. Conclusion

Ultimately, the project's goal has been accomplished. Creating a simulation model to mimic the AC electric traction systems at 132 kV was the initial goal. This objective has been achieved at the section 2.2. For the second objective, to simulate the model by using MATLAB Simulink software. This objective has been achieved also at the section 3.3. For the last objective, to analyze the harmonic contents of the system and compare they're with the current standard. This objective also has been achieved at the section 3.3. The value of THD for voltage is 0.62% lower than the value of the standard given is 3%. It is the good impact the harmonic analysis to AC traction.

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