



Simulation of a Traction Power Supply System for Vietnam's High-Speed Railway Using MATLAB Simulink

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ABSTRACT

Research on high-speed railways in Vietnam is a relatively new topic that has only recently gained attention. Among the key components of such a system, the traction power supply plays a critical role and requires comprehensive analysis across multiple technical dimensions. This paper presents a simulation-based study of an appropriate traction power supply model for Vietnam's future high-speed railway, aligned with modern international technological standards. Matlab Simulink is a professional visualization software widely used in the scientific and technical research community. The results demonstrate that the transformer configuration at the traction substation significantly influences the national grid at the point of common coupling. Specifically, the three-phase current unbalance index reaches 100% and 0% when using V/V and Roof-Delta transformers, respectively, under balanced loading conditions. When phase loads have unequal power factors (ranging from 1.0 to 0.98), the unbalance index increases to 142% for the V/V configuration and 2.94% for the Roof-Delta. Additionally, the simulation reveals a voltage drop of 21.1 kV at a point 10 km from the source, with corresponding active power of 10.28 MW and reactive power of 6.4 MVar. These findings form a technical foundation for recommending an optimal transformer configuration for Vietnam's high-speed railway development.

1. Introduction

The world's first high-speed railway began operation in Japan in October 1964, using 25 kV single-phase alternate current power at industrial frequency [1]. This marked a major milestone in transportation history and established the technological foundation for modern high-speed rail systems [2], [3]. High-speed rail systems in countries such as Japan, Taiwan, and various European nations [4]–[7] have demonstrated both operational

efficiency and technological advancement. Over the years, these systems have received substantial investment in research, technology transfer, construction, and operations. Notably, the world's largest high-speed rail network was introduced in China in April 2007 and completed within just 17 years, highlighting the vast potential of this mode of transport [8]. Currently, 20 countries worldwide operate high-speed rail systems with a total length exceeding 60,000 km. Of these, China accounts for approximately 50,000 km, achieved through over 17

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years of technology transfer and domestic development based on Japanese and European models. Additionally, eight other countries including Vietnam are in various stages of planning or constructing high-speed rail systems [9]–[12]. In recent years, public and governmental interest in developing high-speed rail in Vietnam has grown significantly, particularly regarding the North–South corridor and the proposed Ho Chi Minh City–Can Tho line.

Research on 25 kV electrification for railways in Vietnam remains a relatively new field, particularly concerning high-speed rail systems. High-speed railways are characterized by extremely high load flow, necessitating a power supply system that ensures reliable and flexible operation while minimizing the impact on the national grid. Given both the opportunities and challenges, early investigation into power supply solutions for high-speed railways is a crucial undertaking. Such preliminary studies play a significant role in project feasibility assessments, informing the selection of modern, sustainable technologies that will ensure efficient future operation [12]–[15]. Moreover, this research contributes positively to the academic and research environment in educational institutions and supports consulting activities for governmental bodies and project investors. In this study, we focus on modeling the power supply system for high-speed railways, specifically evaluating appropriate transformer technologies for traction substations to mitigate their impact on the external power grid. The research was conducted using MATLAB Simulink, a robust simulation platform, to visualize the power traction substation system. This approach supports more effective subsequent research, instruction, and learning related to traction power systems [16]–[18].

2. Transformer schematic diagram of traction substation

In the railway electrification system, a 25 kV/50 Hz configuration is commonly employed for long-distance, high-capacity, and high-speed railway lines or systems with a large carrying capacity [9], [16]. The traction power supply for the high-speed railway system is provided by the highest-capacity power system, primarily from the national transmission grid. Each traction power station is supplied from two separate sources to ensure a reliable and flexible power supply. At every traction substation, a minimum of two traction transformers are installed, one in operation and the other on standby. These transformers are responsible for converting the

incoming three-phase high-voltage supply (typically ranging from 110 kV to 500 kV) into a single-phase output at the rated voltage level of 25 kV (or 27.5 kV). The traction power transformers are connected to the high-voltage source on the primary side, while the secondary (low-voltage) side supplies 25 kV power to the railway system. This power is delivered to the trains through remote monitoring and control cabinets via the Supervisory Control and Data Acquisition system [13], [14]. In railway electrification systems, traction substations (TSS) typically employ various transformer configurations, such as single-phase, star-missing/delta-open (V/V) [18]–[20], Star/Delta-1,11 [21], Scott [13], [14], Le Blanc, Modified Woodbridge, and Roof-Delta [22], [23]. These different transformer configurations have varying impacts on the power grid, investment efficiency, and long-term system operation [24].

In the above diagrams, the V/V transformer diagram is widely used in many countries, particularly in China's high-speed railway [18] – [20]. In contrast, the Scott, Modified-Woodbridge, and Roof Delta configurations are commonly applied in Japan, with the Roof Delta being the most recent technology, introduced in 2007 to overcome the limitations of previous transformer types [22], [23]. In this study, we focus on simulating two diagrams of V/V and Roof Delta transformers.

Symbols and assumptions:

U_A , U_B , and U_C are three-phase primary high voltage;

AX, BY, and CZ are primary windings; the beginning of the phases is A, B, and C; the end of the phases is X, Y, and Z;

ax, by, and cz are secondary windings; the beginning of the phase is a, b, and c; the end of the phase is x, y, and z;

n_1 and n_2 are the numbers of primary and secondary windings;

$k_T = \frac{n_1}{n_2}$ is the transformer factor;

U_L and U_R are left and right phase voltages;

I_{tr} is the traction current of train;

RS is a rail and return current system;

OCS is an overhead contact line system;

F is a feeder line system;

$\dot{I}_A$, $\dot{I}_B$ and $\dot{I}_C$ are respectively the currents of phase A, phase B, and phase C on the primary side of the power supply at the PCC;

$\dot{I}_L$ and $\dot{I}_R$ are traction currents on the left and right phases of TSS;

$\dot{I}_{rs-L}$ and $\dot{I}_{rs-R}$ are return currents on the left and right phase TSS;

$\dot{U}_{L(ttr.i)}$ and $\dot{U}_{R(ttr.i)}$ are the potential voltages between the contact wire and the rail at the contact position by the train's pantograph on the left and right phases of the TSS.

2.1. Transformer schematic diagram

In each TSS, transformers are responsible for converting voltage from the high-voltage transmission system to a 25 kV single-phase voltage for the railway. The high-voltage side operates at a voltage level ranging from 110 kV to 500 kV. The secondary side may be configured either as a 1x25 kV (direct system) or a +25 kV system with AT installed along the line. Each traction substation supplies power to feeder lines: one on the right side and one on the left side of the substation. These are referred to as the right-phase voltage ($\dot{U}_{R(ttr.i)}$) and the left-phase voltage ($\dot{U}_{L(ttr.i)}$), respectively. Power is transmitted through two sets of rails—the outgoing and returning rails, which run in opposite directions. When a train operates within the power supply section of a traction substation, electrical current is drawn from either the right-phase, the left-phase, or both phases simultaneously. Since the power supply system is based on a three-phase network while the railway load operates on a single-phase basis, this results in a three-phase imbalance at the common connection point. The degree of imbalance depends on the operational frequency of train services and the specific transformer configuration used at each traction substation. This paper investigates two typical transformer configurations: the V/V connected transformer, illustrated in Figure 1, and the Roof-Delta transformer, shown in Figure 2.

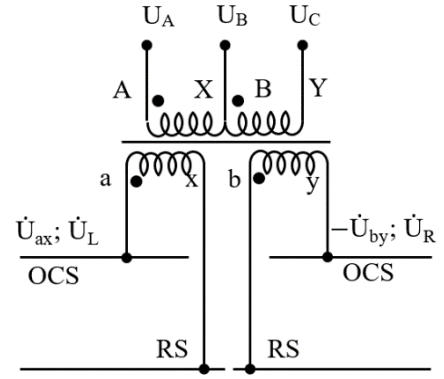


Figure 1. V/V transformer connection diagram.

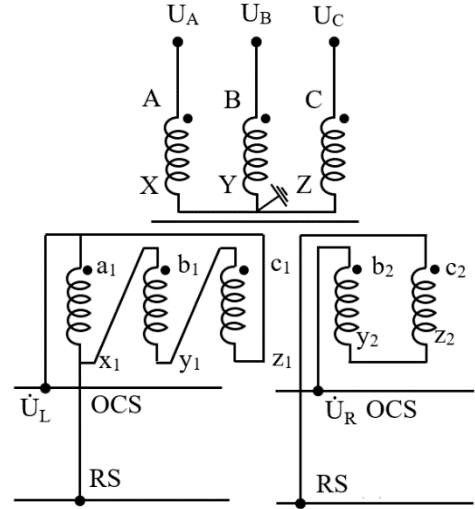


Figure 2. Roof - Delta transformer connection diagram.

The voltage and current relationships for each transformer configuration are described as follows [18], [20], [22]–[24]:

$$\begin{cases} \dot{U}_{L(V)} = \frac{1}{k_T} \cdot \dot{U}_{AB} \\ \dot{U}_{R(V)} = -\frac{1}{k_T} \cdot \dot{U}_{BC} \end{cases} \quad (1)$$

$$\begin{cases} \dot{I}_{A(V)} = \frac{1}{k_T} \cdot \sum_{l=1}^n \dot{I}_{L(l)} \\ \dot{I}_{B(V)} = -\frac{1}{k_T} \cdot (\sum_{l=1}^n \dot{I}_{L(l)} + \sum_{k=1}^m \dot{I}_{R(k)}) \\ \dot{I}_{C(V)} = \frac{1}{k_T} \cdot \sum_{k=1}^m \dot{I}_{R(k)} \end{cases} \quad (2)$$

And, for Roof - Delta transformer diagram [22]–[24]:

$$\begin{cases} \dot{U}_{L(RD)} = \frac{1}{k_T} \cdot \dot{U}_A \\ \dot{U}_{R(RD)} = \frac{1}{k_T} \cdot \frac{1}{\sqrt{3}} \cdot (\dot{U}_B - \dot{U}_C) \end{cases} \quad (3)$$

$$\begin{cases} I_{A(RD)} = \frac{1}{k_T} \cdot \frac{2}{3} \cdot \sum_{l=1}^n I_{L(l)} \\ I_{B(RD)} = -\frac{1}{k_T} \cdot \left(\frac{1}{3} \cdot \sum_{l=1}^n I_{L(l)} - \frac{1}{\sqrt{3}} \cdot \sum_{k=1}^m I_{R(k)} \right) \\ I_{C(RD)} = -\frac{1}{k_T} \cdot \left(\frac{1}{3} \cdot \sum_{l=1}^n I_{L(l)} + \frac{1}{\sqrt{3}} \cdot \sum_{k=1}^m I_{R(k)} \right) \end{cases} \quad (4)$$

Finally, as a measure of unbalance, the unbalance factor k_2 is commonly taken; it is the ratio of the negative- and/or zero-sequence component to the positive-sequence component of current (k_{2i}) of any phase is written as follows [18] – [19], [24]:

$$k_{2i.ttr(i)} = \frac{\left(I_{A(ttr.i)} \cdot \left(e^{\frac{2}{3}\pi} \right)^2 I_{B(ttr.i)} + e^{\frac{2}{3}\pi} I_{C(ttr.i)} \right)}{\left(I_{A(ttr.i)} \cdot e^{\frac{2}{3}\pi} I_{B(ttr.i)} + \left(e^{\frac{2}{3}\pi} \right)^2 I_{C(ttr.i)} \right)} \quad (5)$$

According to standards applicable to AC electric railway traffic, such as EN-50160, IEC 61000-2-12, ER-P29, and IEC-34-1, three-phase unbalance voltage or unbalance current of the equipment connected at the point of common coupling (PCC) due to a single-phase rail load must be satisfactory standard IEEE 1159-2019 and EN 50388:2012.

2.2. System parameters and simulation Matlab diagram

The system and load simulation parameters are presented in Table 1.

Table 1. Traction system simulation input parameters [18], [19], [24], [25].

	Parameters systems	Symbol	Value (Unit)
Power system	Nominal phase-to-phase voltage (rms)	U_0	220 kV
	Base voltage phase to phase (rms)	U_0	220 kV
	Short-circuit impedance ratio	X/R	45
	3-phase short-circuit level at base voltage	S_{cc}	1000 MVA
	Nominal voltage (rms)	U_1	220 kV
	Nominal voltage traction (rms)	U_n	25.0 kV
Traction power substation	Nominal secondary (rms)	U_2	27.5 kV (10%)
	Nominal secondary (rms)	U_2	30.0 kV (20%)
	Nominal power	S_n	60 MVA; 90 MVA
	Short – circuit impedance	S_{ccttr}	5%; 10%
	Number of phases connection		3/2
Traction system	Overload the durability of rated current	300%	2 minutes
	Direct feeding system		Yes
	Section post	DSP	30 km
	Distance of TPS	DTPS	60 km
	Impedances per unit length	Z_{ocs}	0.044 +j0.318 Ω /km
Train load	Nominal train power	P_{tr1}	16 MW
	Nominal train power 2	P_{tr2}	15 MW
	Power factor	$\cos\varphi$	0.95 ÷ 1.0

The TSS system is modeled and simulated using MATLAB Simulink, by effectively addresses key simulation requirements. It allows intuitive model construction using functional block diagrams, provides a wide variety of predefined components, and supports flexible design configurations. The platform also enables convenient input and modification of simulation

parameters. Moreover, the simulation outputs are rich in both graphical and numerical formats, making it well-suited for diverse analysis and evaluation objectives. The an overall system overview shown in Figure 3 and subsystem structure (open blocks) illustrated in Figures 4, 5, and 6.

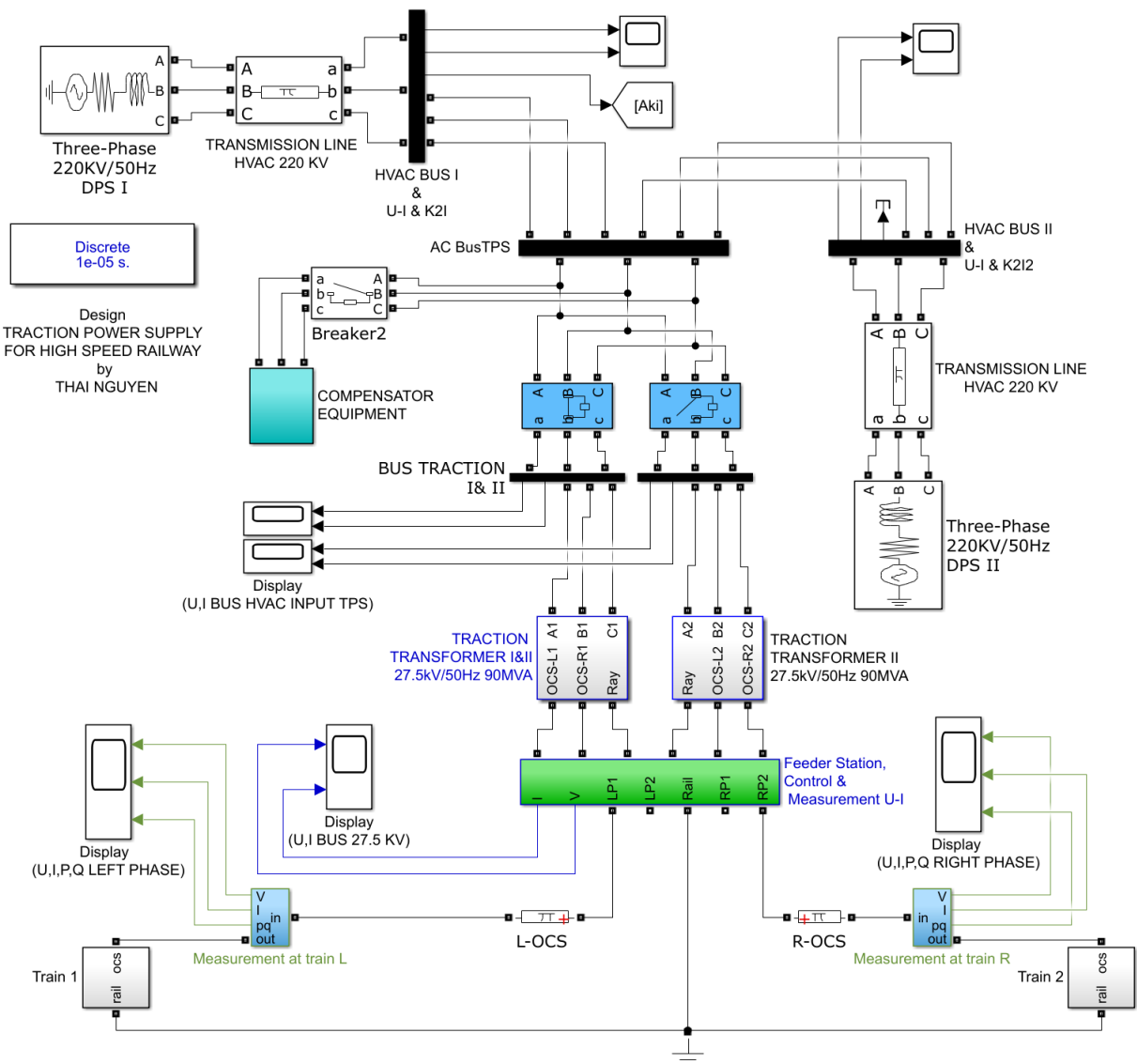


Figure 3. Matlab Simulink simulation of traction power supply system for High-speed railway.

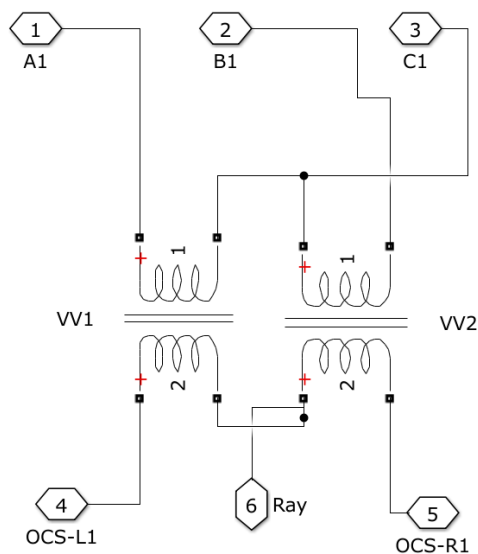


Figure 4. Matlab Simulink V/V transformer simulation.

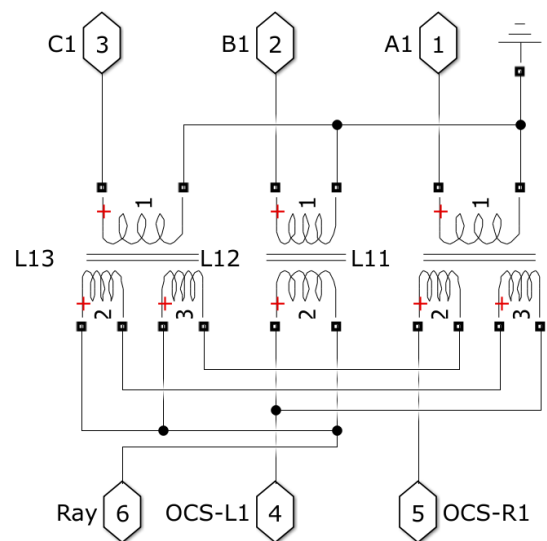


Figure 5. Matlab Simulink Roof – Delta transformer simulation

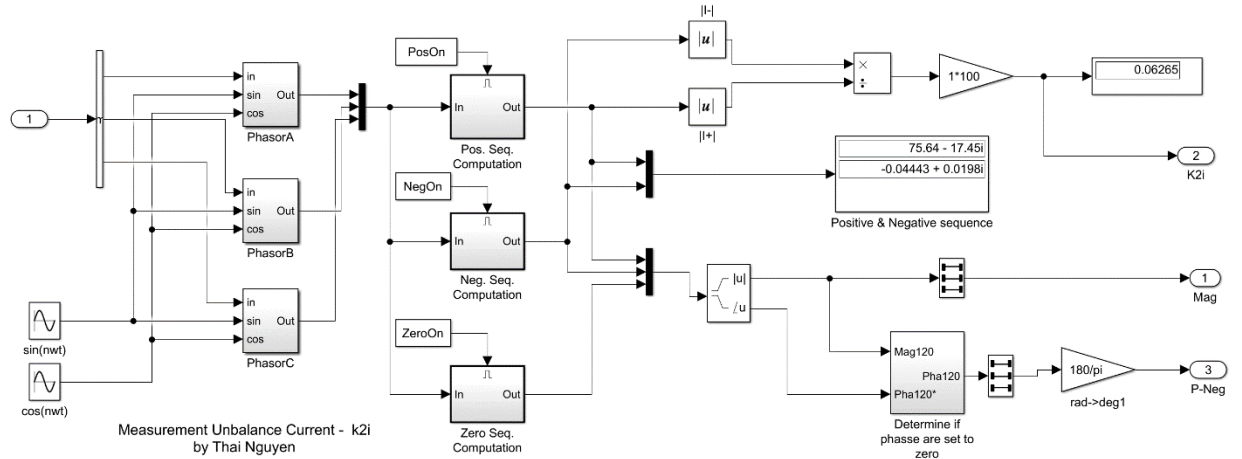


Figure 6. Matlab Simulink simulation of a three-phase current asymmetry measurement block.

In the connection diagrams of the V/V transformer (Figure 3) and the Root-Delta transformer (Figure 4), MATLAB Simulink software was used to model them. In these diagrams, primary side inputs A1 (1), B1 (2), and C1 (3) are connected to the high voltage source corresponding to phases A, B, and C, respectively. The second side outputs OCL-L (4) and OCL-R (6) are connected to left and right phase contact lines, while rail (5) is connected to return line and running rail; and primary side transformer windings are labeled as 1; secondary windings are labeled as 2 and 3. In figure 6, the schematic diagram of the three-phase current asymmetry measurement functional blocks has been constructed from the library of functional elements and the mathematical equations established as required from the theory described in section 2.1.

3. Results and discussion

The simulation results of the input supply from a 220 kV/60Hz (or 50Hz) HVAC transmission grid system (rms base phase-to-phase voltage) are shown in Figure 7. Under no-load conditions, the voltage and current waveforms are completely balanced.

Figure 8 shows the simulation results of the transformer's secondary voltage under no-load conditions. The nominal RMS voltage level is 27.5 kV, corresponding to a peak instantaneous voltage of 38.89 kV. The waveforms illustrate the left-phase voltage (UL) and right-phase voltage (UR), with the top plot representing the V/V transformer configuration and the bottom plot representing the Roof-Delta transformer.

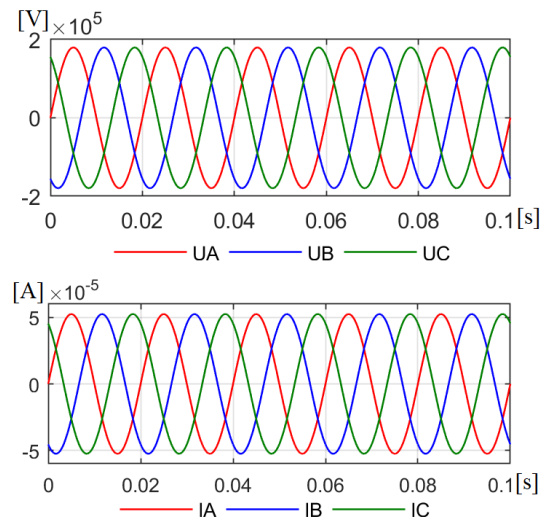


Figure 7. HVAC primary side no-load voltage (top) and current (bottom) waveforms.

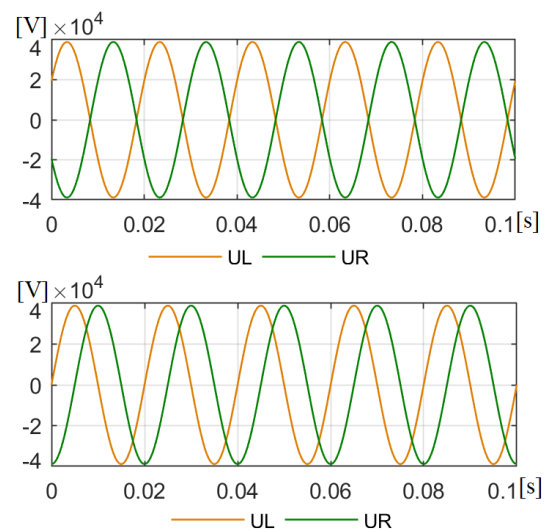


Figure 8. Standard 27.5 kV voltage waveforms of the secondary side of the V/V transformer (top) and Roof-Delta (bottom).

Figure 9 illustrates the simulation results for the case of equal load applied to both phases, each rated at 16 MW with a power factor of 1.0. The voltage (top), current (middle), and power (bottom) waveforms are shown for two train positions: one located 3 km from the source on the left-phase line with a V/V transformer (left image), and the other located 15 km from the source on the right-phase line with a Roof-Delta transformer (right image). The simulation results indicate that the voltage values measured at the first train and second trains are 35.12 kV at peak value or root-mean-square (rms) value is 24.84 kV and 29.84 kV at peak value (rms value is 21.04 kV) on the uniform impedance contact network system, the peak current value is 822.81 A for both trains the same, the power values measured at the survey point are 12.1 MW and 7.64 MVar for the first train and 10.28 MW and 6.4 MVar for the second train.

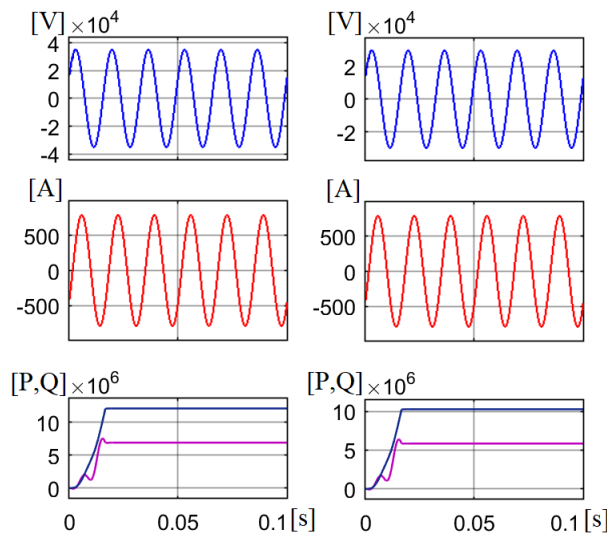


Figure 9. Measurement results at any position on the overhead contact line system.

Case 1: Consider the case where the train's load on both the left and right phases is equal ($P_L = P_R = 16$ MW) and the power factor is equal (1.0). The simulation results are shown in Figure 10, with the V/V connection on the left and the Roof-Delta connection on the right. The top plots show the current waveforms on the left and right phases of each transformer, while the bottom plots display the three-phase current waveforms at the PCC on the primary side.

The simulation results also show that when the load currents on both left and right phases are equal (822.81 A), for the V/V transformer diagram, the load currents on the left and right phases are 180° degrees apart. The peak values of the three-phase current on the primary side in the order of phases IA, IB, and IC are 178.15 A, 0.00 A, and 178.15 A, respectively. The current on phases A and phase C are 180° apart, while phase B is 0° . For the Roof - Delta diagram, the load currents on the left and right phases are 90° apart. The peak values of the three-phase current on the primary side in the order of phases IA, IB, and IC are all equal at 118.77 A, indicating a balanced condition. The phase angles of currents A, B, and C are equally spaced at 120° , in the positive sequence starting from phase A at 0° . At this time, the rms values of the positive (I_+) and negative (I_-) sequence currents on the V/V diagram are 72.73 A and 72.73 A, respectively, resulting in a three-phase current unbalance coefficient of 100%. In contrast, for the Roof - Delta diagram, the rms values of the positive and negative sequence currents are 83.9782 A and 0.000 A, respectively, yielding a three-phase current unbalance coefficient of 0.00 % at the PCC.

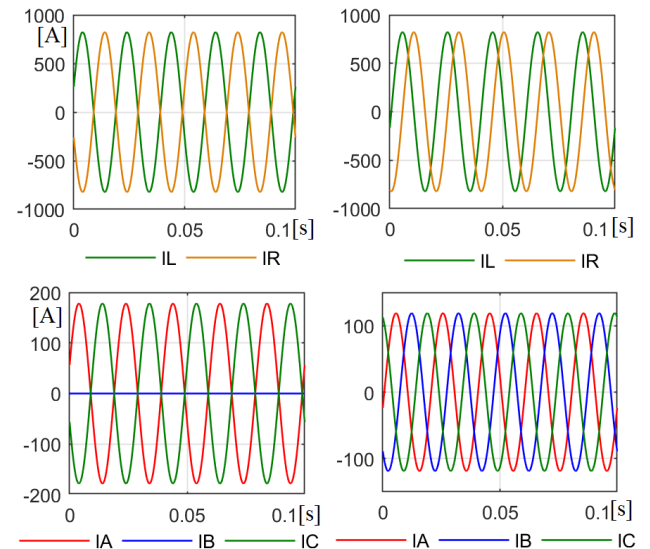


Figure 10. Measurement results of load current and three-phase source current on the primary side at the PCC in Case 1.

Case 2: In this scenario, the load on both phases is assumed to be balanced; however, due to operational variations, the power factors of individual trains may differ slightly. For modern trains, this difference is minimal, typically between 0.99 and 0.98 (less than 1%). The simulation results of the three-phase

current waveforms on the primary side of the V/V transformer (left) and the Roof-Delta transformer (right) are shown in Figure 11. The simulation results are as follows, for the V/V transformer, the rms values of the three-phase current in the positive order A, B, and C are 125.97 A, 25.19 A, and 125.97 respectively. The corresponding phase angles are 18.52° , 114.26° and -150° . At this time, the rms values of the positive order current and the negative order current are 59.77 A and 84.96 A, respectively. As a result, the three-phase current asymmetry coefficient is 142.15 %. For the Roof - Delta transformer, the three-phase primary current values of phases A, B, and C are $83.98\angle -11.48^\circ$ A, $81.81\angle -128.93^\circ$ A, and $86.08\angle 111.03^\circ$, respectively. The positive and negative sequence current rms values are 83.94 A and 2.47 A. As a result, the three-phase current unsymmetry factor at the PCC for the Roof-Delta transformer is 2.94 %.

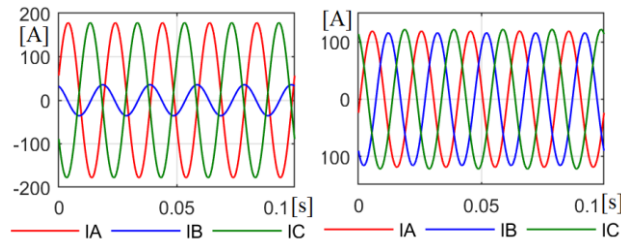


Figure 11. Measurement results of the three-phase source current on the primary side at the PCC in Case 2.

Case 3, in this case, the train load is similar to case 2, but considering the influence of the railway conditions on the overall load, the load imbalance between the two phases is 10%, the waveform results of the load current (top figure) and the three-phase source current on the primary side (bottom figure) of the connection diagram of the V/V transformer (left) and Roof - Delta (right) are as shown in Figure 12.

The simulation results of the traction load current on the left phase and the right phase have instantaneous values for the V/V transformer and Roof - Delta respectively as $IL = 551.68 + 184.82i$; $IR = -506.13 - 203.36i$; $IL = 570.18 - 115.78i$ and $IR = -76.946 - 540.00i$. The results of the three-phase secondary currents (IA, IB, IC) of the V/V transformer diagram and the Roof - Delta diagram are respectively: $IA = 119.44 + 40.02i$; $IB = -9.86 + 4.01i$; $IC = -31.53 + 75.85i$; and $IA = 82.29 - 16.71i$; $IB = -50.76 - 59.14i$; $IC = -31.53 + 75.85i$. The positive and

negative sequence current results for the V/V diagram are $I+ = 45.85 + 48.79i$ and $I- = 73.59 - 8.77i$ and the three-phase current unsymmetry factor at PCC in this case is 110.69%; similarly for the Roof - Delta transformer, $I+ = 80.12 - 13.91i$, $I- = 2.18 - 2.80i$ and the unsymmetry factor is 4.36%.

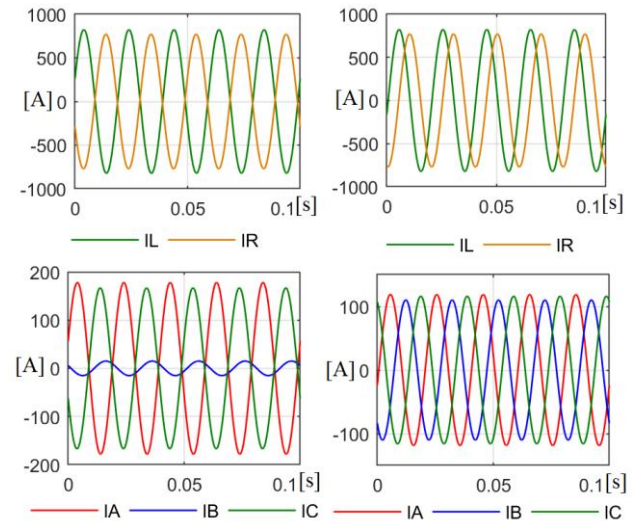


Figure 12. Measurement results of load current and three-phase source current on the primary side at the PCC in Case 3.

The simulation results of the proposed traction power supply system for high-speed railway loads demonstrate the following:

(i) Based on the transformer diagram and the system's operating scenarios under the high-speed railway load characteristics. In the case of using the V/V transformer diagram, the three-phase current asymmetry coefficient at PCC is consistently 100% when the loads on both phases are equal, while for the Roof - Delta diagram, this asymmetry index is 0.00%. In the case of two-phase loads with different power factors, the V/V diagram causes asymmetry at PCC of 142% (greater than 3%), whereas for the Roof-Delta transformer, it is 2.94%, which is below 3% compared to the allowable standard according to IEEE 1159-2019 and EN 50388:2012. In the scenario where the two phases have different power and factor, the V/V diagram still causes asymmetry greater than 100% (110%), while the Roof-Delta transformer results in a much smaller asymmetry of 4.36%. Although this exceeds the 3% standard, it remains approximately 90.32 times lower than that of the V/V configuration.

(ii) The analysis of current asymmetry caused by different traction transformer configurations shows

that the Roof-Delta transformer is more effective in limiting three-phase current unbalance at the PCC.

(iii) Since the unbalance factor remains lower in all loading conditions, the required compensation for unbalance is also reduced. This results in several indirect advantages for the Roof-Delta transformer scheme.

(iv) In addition, a fundamental advantage of the Roof-Delta transformer over all existing traction transformer configurations is that its high-voltage primary side includes a grounded neutral, unlike other schemes, which typically lack this feature.

In summary, the research and analysis results presented above highlight the effectiveness of the simulation approach using MATLAB Simulink, as well as the notable advantages of the Roof-Delta transformer. This configuration represents a modern technological solution that is currently being implemented in new system designs and used to replace outdated transformers on Shinkansen high-speed railway lines in Japan, a country recognized as a global leader in high-speed rail development. These findings also serve as a technical proposal for selecting an appropriate traction power supply system for Vietnam's future high-speed railway projects.

4. Conclusion

The article presents a study on traction power supply technology for modern high-speed railways and serves as a technical proposal for Vietnam's future high-speed railway development. The chosen research approach provides an effective pathway for accessing advanced technologies in a cost-efficient manner, while also encouraging the growth of the domestic research community in fields traditionally dominated by technologically advanced countries. The simulation results validate the suitability of the proposed transformer configurations for the evolving needs of global high-speed railway systems. Building on these findings, future research will focus on calculating the power requirements and designing an appropriate traction power supply system tailored to Vietnam's high-speed railway development plan.

Contributions of authors in this article

Thai Nguyen: Methodology, Data management, Formal analysis, Investigation, Validation, Visualization, Grant acquisition, Feedback on peer review, Writing – original manuscript. **Huong Van Dong:** Data compilation, Data analysis, Investigation, Verification, Writing – original manuscript. **Chuyen Van Dinh:** Investigation, Verification, and Overall Checking.

Declaration of competing interest and dedication to copyright

The authors declare the absence of any potential conflicts of interest from this study and affirm that the paper has not been previously published.

References

- [1] Y. Suyama, "50 Years of Tokaido Shinkansen History," *Japan Railway & Transport Review*, vol. 64, pp. 18–27, 2014.
- [2] I. Watson, "High-speed railway," *Encyclopedia*, vol. 1, no. 3, pp. 665–688, 2021.
- [3] A. Smirnov, E. Smolokurov, and Y. Fir, "Features of the development of high speed railway communications," *Transp. Res. Procedia*, vol. 61, pp. 139–146, 2022, doi: 10.1016/j.trpro.2022.01.023.
- [4] L. Mindur, Z. Zamiar, and M. Mindur, "High-speed trains in Japan in the years 2002–2020," *Combustion Engines*, vol. 1999, no. 4, pp. 88–96, 2024.
- [5] Y.-P. Chang, "Optimal harmonic filters design of the Taiwan high speed rail traction system of distributor generation system with specially connected transformers," *Int. J. Electr. Power Energy Syst.*, vol. 62, pp. 80–89, 2014, doi: 10.1016/j.ijepes.2014.02.014.
- [6] J.-P. Arduin and J. Ni, "French TGV network development," *Japan Railway & Transport Review*, vol. 40, no. 3, pp. 22–28, 2005.
- [7] R. Palacin *et al.*, "High speed rail trends, technologies and operational patterns: A comparison of established and emerging networks," *Transport Problems*, vol. 9, pp. 123–129, 2014.
- [8] A. Schmutzler, "The hidden benefits of high-speed rail," *Nature Climate Change*, vol. 11, no. 11, pp. 902–903, 2021.
- [9] G. Lu *et al.*, "Refining arrival headway for high-speed trains approaching a large railway station: A speed profile intervention approach," *Railway Eng. Sci.*, pp. 1–25, 2025.
- [10] International Union of Railways, "High-Speed around the world - Historical, geographical, and technological development," UIC Passenger Department, France, 2023.

- [11] TEDI, TRICC and TEDIS Consulting Joint Venture, "Pre-feature study report North-South high-speed railway project," Vietnam, 2024.
- [12] K. Takagi, M. Takagi, H. Hayashiya, and Y. Iwafune, "Proposal and effect evaluation of RPC application with energy storage system for regenerative energy utilization of high speed railway," *J. Int. Council Electr. Eng.*, vol. 7, no. 1, pp. 227–232, 2017, doi: 10.1080/22348972.2017.1347988.
- [13] K. Morito, "Substation facilities for Japan Railway Construction, Transport and Technology Agency for Kyushu Shinkansen West Kyushu Route (between Takeo-Onsen and Nagasaki)," *Meiden Review*, ser. no. 185, no. 2, pp. 10–16, 2022.
- [14] Y. Kurasawa, "Japan's railway technologies serving on overseas railways," *Japan Railway & Transport Review*, no. 61, Mar. 2013.
- [15] S. Sone, "Comparison of the technologies of the Japanese Shinkansen and Chinese high-speed railways," in *China's High-Speed Rail Technology: An International Perspective*, 2018, pp. 67–87.
- [16] D. D. Van and T. Nguyen, "An in-depth investigation of innovative electric traction power supply systems for mass rapid transit," *Eng. Technol. Appl. Sci. Res.*, vol. 13, no. 6, pp. 12245–12252, 2023, doi: 10.48084/etasr.6447.
- [17] C. Ding, Y. Guo, H. You, and H. Zhang, "Optimization of algorithm for solving railroad power conditioner compensation power reference value and system power quality analysis based on optimal compensation model," *Energies*, vol. 16, no. 20, p. 7073, 2023, doi: 10.3390/en16207073.
- [18] A. C. Ras, R. Bouzerara, and H. Bouzeria, "An adaptive controller for power quality control in high speed railway with electric locomotives with asynchronous traction motors," *Electr. Eng. Electromechanics*, no. 2, pp. 23–30, 2024, doi: 10.20998/2074-272X.2024.2.04.
- [19] C.-H. Chen and S.-C. Huang, "Using special transformer wiring to improve the three-phase unbalance rate of railway system," *J. Low Freq. Noise Vib. Active Control*, vol. 42, no. 4, pp. 1786–1802, 2023, doi: 10.1177/14613484231181447.
- [20] L. Chen *et al.*, "Modelling and control of a novel AT-fed co-phase traction power supply system for electrified railway," *Int. J. Electr. Power Energy Syst.*, vol. 125, p. 106405, 2021, doi: 10.1016/j.ijepes.2020.106405.
- [21] Y. A. Chernov, N. Yu. Dmitrieva, and O. Yu. Kokorina, "Power supply system with three-phase transformers for HSR," *World Transp. Transp.*, vol. 15, no. 1, pp. 48–62, 2017, doi: 10.30932/1992-3252-2017-15-1-5.
- [22] H. Morimoto, T. Uzuka, A. Horiguchi, and T. Akita, "New type of feeding transformer for AC railway traction system," in *Proc. 2009 Int. Conf. Power Electron. Drive Syst. (PEDS)*, Taipei, Taiwan, 2009, pp. 800–805, doi: 10.1109/PEDS.2009.5385659.
- [23] Y. Ogawa and S. Shinada, "Technology development of a roof-delta connection transformer," *Meiden Review*, ser. no. 156, no. 3, pp. 15–20, 2012.
- [24] X. H. Le, T. Nguyen, and D. D. Van, "The impact of high-speed railway traction power substation technology affecting the power quality: Plan for high-speed railway in Vietnam," *Int. Rev. Electr. Eng.*, vol. 20, no. 2, 2025.
- [25] S. Wang *et al.*, "Ground fault identification and location of autotransformer traction network for high-speed railway based on multi-terminals synchronous measure information," *IET Gener. Transm. Distrib.*, vol. 17, no. 24, pp. 5458–5472, 2023.