



A Case Study of a Subway Line For the Electrical Properties of the Supply Voltage Selection with the Comparison of 1500 V and 3000 V DC Simulation Results

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Abstract Traction system in electrification system of a railway is designed with regard to some design parameters. While the traction system is designed, the minimum voltage rating required by the traction force in the course of operation needs to be provided. The maximum value of the voltage drop occurring on the line determined by the distance of traction power centers. Voltage drop should be kept within certain limits for the continuity of the operation. In this study, analysis of electrical effects of the supply voltage specification together with the Comparison of 1500 V and 3000 V DC option was researched. The minimum catenary voltage value was calculated for 1500 V and 3000 V option and the results were compared for a subway line. Electrical analysis for the loss of a transformer station and the loss off two near substations that affects the vehicle traffic explained.

Keywords DC, electrification, power, railway, traction

1. Introduction

1500 V DC and 3000 V DC supply voltage is used for the traction force system on DC supplied railways. In 1500 V DC systems the supply voltage that the traction force uses is acquired through an interconnected network which has 34.5 kV phase to phase voltage. Two transformers of 34.5 kV / 1.2 kV are present in the substations and the transformers can operate as back-up [1-3]. The equivalent circuit model of the DC railway is presented in Figure 1.

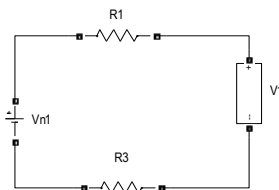


Figure 1: Equivalent circuit model of the DC railway

The equation regarding the supplying status from a single substation is given with Equation (1). The resistance values of the feeder cables were also added to R1 and R3. R1 and R3 values change in accordance with the distance depending on the location of the vehicle. V1 is the voltage of the vehicle, Vn1 indicates the nominal supply voltage, Ivehicle indicates the vehicle current. The maximum traction force of the vehicles in the railway vehicles with a high power consumption can increase to 20 MVA. The power consumption is important for the electrical system analysis [4-7].

$$V_1 = V_{n1} - I_{vehicle} \times R_1 - I_{vehicle} \times R_3 \quad (1)$$



In this study, analysis of electrical and operational effects of the supply voltage specification together with the Comparison of 1500 V and 3000 V DC option was researched. The minimum catenary voltage value was calculated for 1500 V and 3000 V option and the results were compared for a railway line. Electrical traction power simulation is done for 1500 V DC and 3000 V DC supply voltages.

2. Material and Method

The model of the railway power system consists of certain steps. These are obtaining certain data based on the equivalent circuit design, vehicle model, transformer station model and vehicle operation [8-10]. The vehicle model is quite critical for the system analysis in simulation. In the literature there are railway power flow studies and electrification system simulations. However, in this study, a dynamic model is created with a new algorithm for the vehicle acceleration mode, permanent speed mode, and braking mode. With this algorithm vehicle movement is modeled dynamically and simultaneously depending on environmental effects and vehicle load characteristics. Vehicle speed profile is created simultaneously. In this way real vehicle characteristics are obtained and the simulation performance is increased. The electrification system analysis is done for the transformer station loss depending on the trip frequency. The matlab simulation screen is given with Figure 2. Basakşehir-Kirazlı metro line was studied that has 8 substations for 1500 V DC and 3000 V DC.

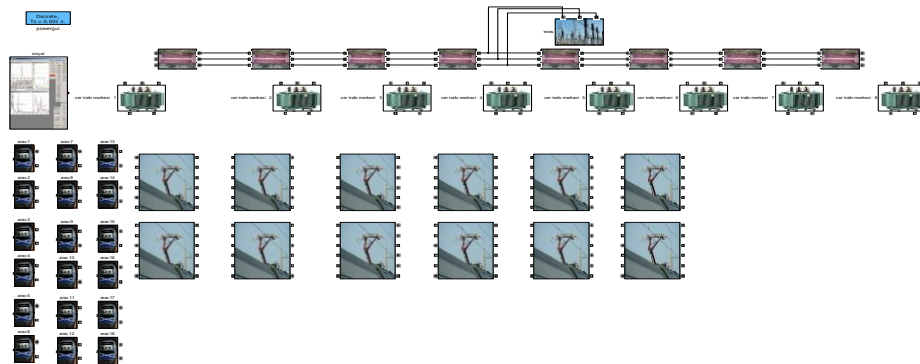


Figure 2: Matlab simulation screen

3. Findings

Certain problems can be encountered in the electrification system during the vehicle traffic in the enterprise. The most critical among these is the loss of a transformer station and the loss off two near substations. This problem affects the vehicle traffic. The state of losing a transformer station and the loss off two near substations is studied especially through simulation before the process of construction.

A. 1500 V DC Simulation Results

Figure 3 shows the 1500 V DC simulation results of the catenary voltage at the trip frequency of 1.5 minutes and the nominal operation state. The minimum catenary voltage varies between 1400 V and 1500 V. The lowest catenary voltage of 1400 V gains this value by the end of the 1st km as seen in Figure 3. Minimum catenary voltage rises at transformer station feeding points. In this state there are 18 trains in the system.

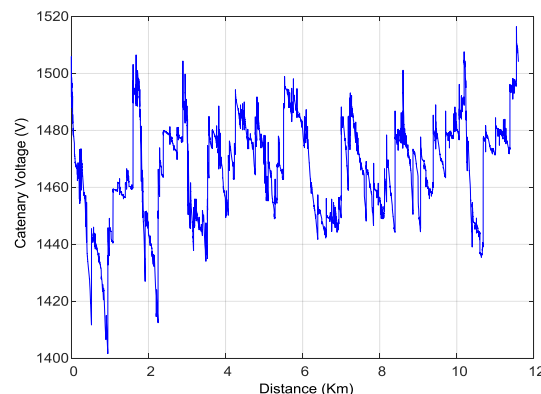


Figure 3: Minimum catenary voltage for nominal operation (1500 V DC)



Figure 4 shows the 1500 V DC simulation results of the rail voltage at the trip frequency of 1.5 minutes and the nominal operation state. The maximum rail voltage varies between -20 V and 30 V. The maximum rail voltage of 30 V gains this value by the end of the 1st km as seen in Figure 4. In this state there are 18 trains in the system.

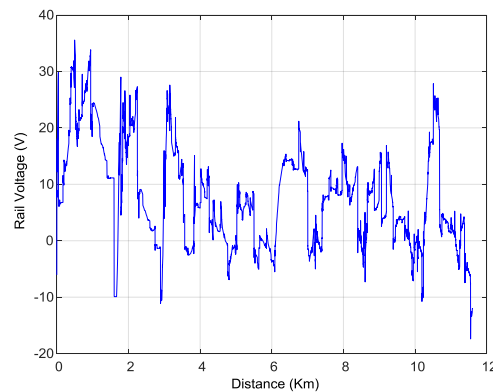


Figure 4: Maximum rail voltage for nominal operation (1500 V DC)

Figure 5 shows the 1500 V DC simulation results of the catenary voltage at the trip frequency of 1.5 minutes and the one substation off state. The minimum catenary voltage varies between 1320 V and 1500 V. The lowest catenary voltage of 1320 V gains this value by the end of the 1st km as seen in Figure 5. Minimum catenary voltage rises at transformer station feeding points. In this state there are 18 trains in the system.

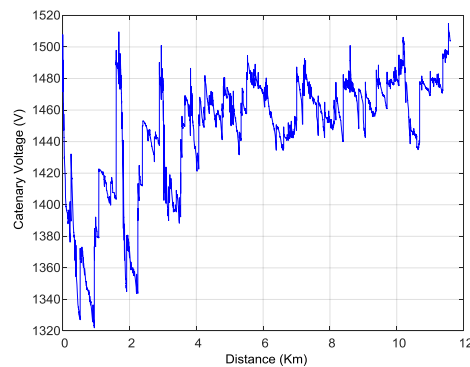


Figure 5: Minimum catenary voltage for one substation off (1500 V DC)

Figure 6 shows the 1500 V DC simulation results of the rail voltage at the trip frequency of 1.5 minutes and the one substation off state. The maximum rail voltage varies between -30 V and 60 V. The maximum rail voltage of 60 V gains this value by the end of the 1st km as seen in Figure 6. In this state there are 18 trains in the system.

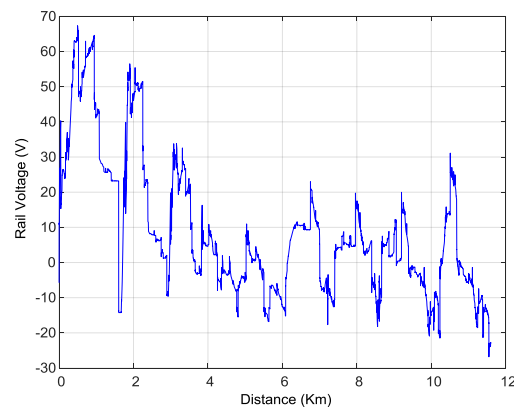


Figure 6: Maximum rail voltage for one substation off (1500 V DC)



Figure 7 shows the 1500 V DC simulation results of the catenary voltage at the trip frequency of 1.5 minutes and the two substation off state. The minimum catenary voltage varies between 1300 V and 1500 V. The lowest catenary voltage of 1300 V gains this value by the end of the 1st km as seen in Figure 7. Minimum catenary voltage rises at transformer station feeding points. In this state there are 18 trains in the system.

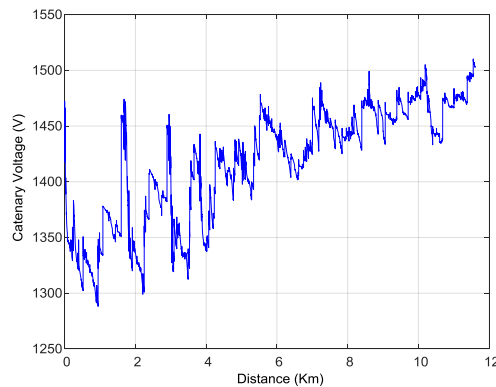


Figure 7: Minimum catenary voltage for two near substation off (1500 V DC)

Figure 8 shows the 1500 V DC simulation results of the rail voltage at the trip frequency of 1.5 minutes and the two substation off state. The maximum rail voltage varies between -40 V and 60 V. The maximum rail voltage of 60 V gains this value by the end of the 1st km as seen in Figure 8. In this state there are 18 trains in the system.

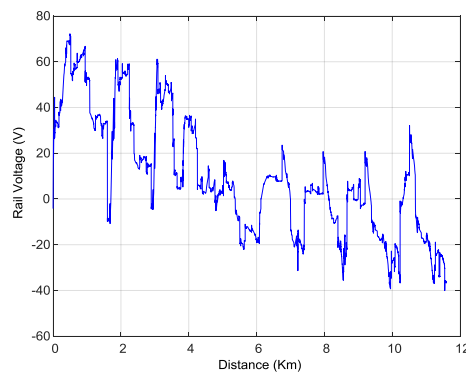


Figure 8: Maximum rail voltage for two near substation off (1500 V DC)

B. 3000 V DC Simulation Results

Figure 9 shows the 3000 V DC simulation results of the catenary voltage at the trip frequency of 1.5 minutes and the nominal operation state. The minimum catenary voltage varies between 3220 V and 3350 V. The lowest catenary voltage of 3220 V gains this value by the end of the 1st km as seen in Figure 9. Minimum catenary voltage rises at transformer station feeding points. In this state there are 18 trains in the system.

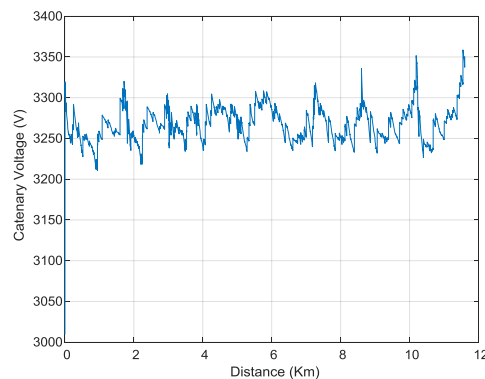


Figure 9: Minimum catenary voltage for nominal operation (1500 V DC)



Figure 10 shows the 3000 V DC simulation results of the rail voltage at the trip frequency of 1.5 minutes and the nominal operation state. The maximum rail voltage varies between -20 V and 35 V. The maximum rail voltage of 35 V gains this value by the end of the 11th km as seen in Figure 10. In this state there are 18 trains in the system.

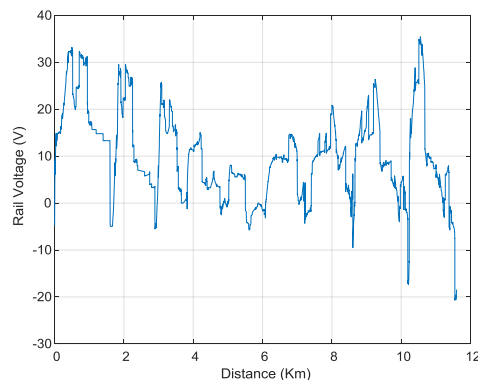


Figure 10: Maximum railvoltagefor nominal operation (1500 V DC)

Figure 11 shows the 3000 V DC simulation results of the catenary voltage at the trip frequency of 1.5 minutes and the one substation off state. The minimum catenary voltage varies between 3140 V and 3350 V. The lowest catenary voltage of 3140 V gains this value by the end of the 1st km as seen in Figure 11. Minimum catenary voltage rises at transformer station feeding points. In this state there are 18 trains in the system.

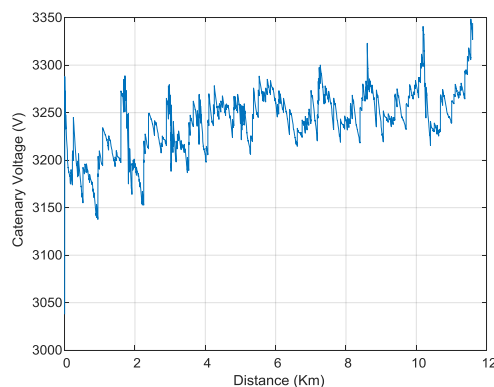


Figure 11: Minimum catenary voltage for one substation off (1500 V DC)

Figure 12 shows the 3000 V DC simulation results of the rail voltage at the trip frequency of 1.5 minutes and the one substation offstate. The maximum rail voltage varies between -30 V and 50 V. The maximum rail voltage of 50 V gains this value by the end of the 1st km as seen in Figure 12. In this state there are 18 trains in the system.

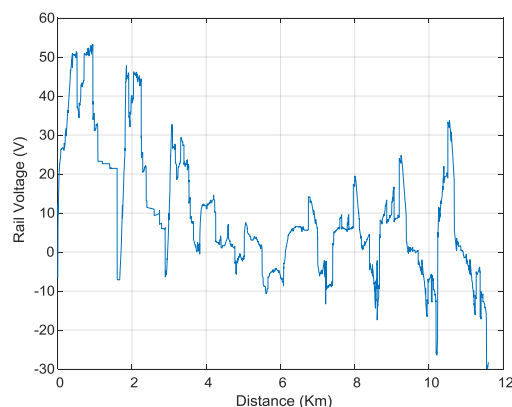


Figure 12: Maximum rail voltage for one substation off (1500 V DC)



Figure 13 shows the 3000 V DC simulation results of the catenary voltage at the trip frequency of 1.5 minutes and the two substation off state. The minimum catenary voltage varies between 3050 V and 3330 V. The lowest catenary voltage of 3050 V gains this value by the end of the 1st km as seen in Figure 13. Minimum catenary voltage rises at transformer station feeding points. In this state there are 18 trains in the system.

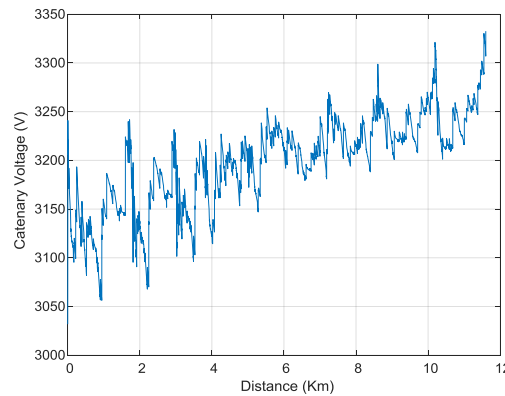


Figure 13: Minimum catenary voltage for two near substation off (1500 V DC)

Figure 14 shows the 3000 V DC simulation results of the rail voltage at the trip frequency of 1.5 minutes and the two substation off state. The maximum rail voltage varies between -40 V and 70 V. The maximum rail voltage of 70 V gains this value by the end of the 1st km as seen in Figure 14. In this state there are 18 trains in the system.

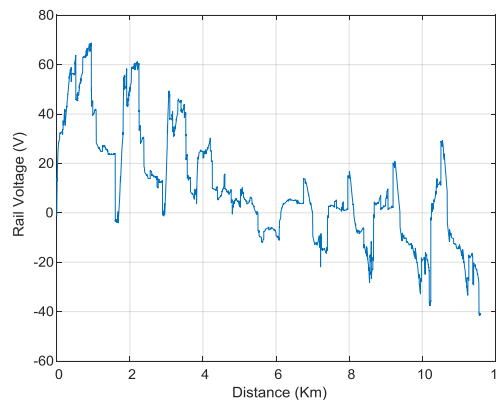


Figure 14: Maximum railvoltage for two near substation off (1500 V DC)

C. The Comparison of the 1500 V and 3000 V Simulation Results

When the 1500 V DC and 3000 V DC simulation results are compared, the 1500 V DC voltage critical values observed lower than the 3000 V DC voltage values. The results are given with table 1.

Table 1: The simulation results of 1500 V and 3000 V DC Supply Voltage

Supply Voltage	1500 V DC	3000 V DC
Minimum Catenary Voltage (Nominal Operation)	1400 V	3220 V
Maximum Rail Voltage (Nominal Operation)	30 V	35 V
Minimum Catenary Voltage (One Substation Off)	1320 V	3140 V
Maximum Rail Voltage (One Substation Off)	60 V	50 V
Minimum Catenary Voltage (Two Substation Off)	1300 V	3050 V
Maximum Rail Voltage (Two Substation Off)	60 V	70 V



4. Conclusions

The simulation of the electrification system and the traction power system of 1500 V DC feeding Basakşehir-Kirazlı railway line was performed according to different operation scenarios using Matlab/Simulink explained in this study. Better operation conditions were researched depending on the traction supply voltage standard and minimum catenary voltage. The situations that occur under different operation conditions are summarized in Table 1. In the 1500 V DC supply voltage minimum catenary voltage occurs in the state off two substation off with the 1300 V. However in the 3000 V DC supply voltage minimum catenary voltage occurs in the state off two substation off with the 3050 V. These values are acceptable for the EN 50122 standards. When the 1500 V DC and the 3000 V DC values are compared 1500 V DC voltage values are more critical for the electrification system.

References

- [1]. Huh JS, Shin HS, Moon WS, Kang BW, Kim JC. Study on voltage unbalance improvement using SFCL in power feed network with electric railway system. *IEEE Transactions on Applied Superconductivity* 2013; 3: 3601004.
- [2]. Ghassemi A, Fazel SS, Maghsoud I, Farshad S. Comprehensive study on the power rating of a railway power conditioner using thyristor switched capacitor. *IET Electrical Systems in Transportation* 2014; 4: 97-106.
- [3]. Raimondo G, Ladoux P, Lowinsky A, Caron H, Marino P. Reactive power compensation in railways based on AC boost choppers. *IET Electrical Systems in Transportation* 2012; 2: 169-177.
- [4]. Aodsup K, Kulworawanichpong T. Effect of train headway on voltage collapses in high-speed AC railways. In: *APPEEC 2012 Power and Energy Engineering Conference*; 27-29 March 2012; Shanghai, China. New York, USA: IEEE. pp. 1-4.
- [5]. Baseri MAA, Nezhad MN, Sandidzadeh MA. Compensating procedures for power quality amplification of AC electrified railway systems using FACTS. In: *PEDSTC 2011 Power Electronics Drive Systems and Technologies Conference*; 16-17 February 2011; Tehran, Iran. New York, USA: IEEE. pp. 518-521.
- [6]. Brenna M, Foadelli F. The compatibility between DC and AC supply of the Italian railway system. In: *Power and Energy Society General Meeting*; 24-29 July 2011; San Diego, USA. New York, USA: IEEE. pp. 1-7.
- [7]. Abrahamsson L, Kjellqvist T, Ostlund S. High-voltage DC-feeder solution for electric railways. *IET Power Electronics* 2012; 5: 1776 - 1784.
- [8]. Raygani SV, Tahavorgar A, Fazel SS, Moaveni B. Load flow analysis and future development study for an AC electric railway. *IET Electrical Systems in Transportation* 2012; 2: 139-147.
- [9]. Goodman CJ, Chymera M. Modelling and simulation. In: *REIS 2013 Railway Electrification Infrastructure and Systems Conference*; 3-6 June 2013; London, England. New York, USA: IEEE. pp. 16-25.
- [10]. Ladoux P, Raimondo G, Caron H, Marino P. Chopper-Controlled steinmetz circuit for voltage balancing in railway substations. *IEEE Transactions on Power Electronics* 2013; 28: 5813-5822.

