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Research Article

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Analysis of Electrical and Operational Effects of the Supply Voltage Specification Together With the Comparison of 750 V and 1500 V DC Option: A Case Study of A Railway Line

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Abstract Electrification system of a railway is designed with regard to some design parameters. While the electrification 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. This value needs to be kept within certain limits for the continuity of the operation. In this study, analysis of electrical and operational effects of the supply voltage specification together with the Comparison of 750 V and 1500 V DC option was researched. The minimum catenary voltage value was calculated for 750 V and 1500 V option and the results were compared for a railway line. The loss of a transformer station and the loss off two near substations that affects the vehicle traffic especially studied.

Keywords DC, electrification, power, railway, traction

1. Introduction

1500 V DC supply voltage is used for the traction force system on DC supplied railways. 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 [1-5]. The equivalent circuit model of the DC railway is presented in Figure 1.

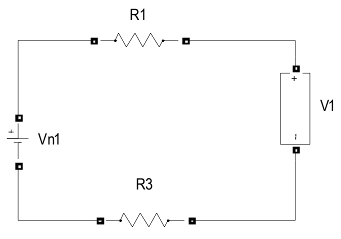

Figure 1: Equivalent circuit model of the AC railway

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 [6-10].

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

In this study, analysis of electrical and operational effects of the supply voltage specification together with the Comparison of 750 V and 1500 V DC option was researched. The minimum catenary voltage value was calculated for 750 V and 1500 V option and the results were compared for a railway line.

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 [11-12]. 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 transformator station loss depending on the trip frequency. The matlab simulation screen is given with Figure 2.Basaksehir-Kirazli metro line was studied that has 8 substations for 750 V DC and 1500 V DC.

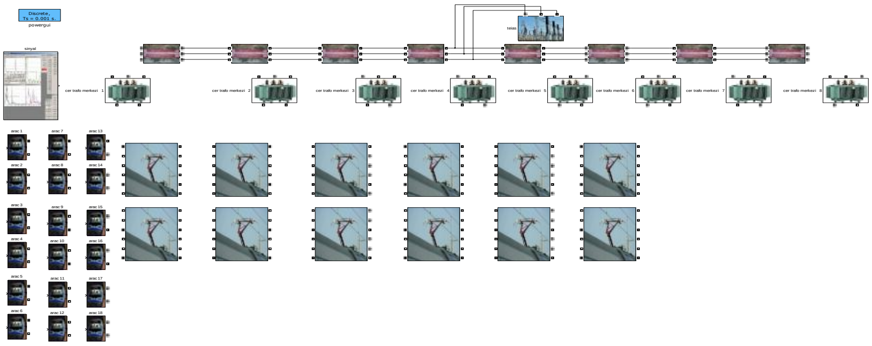

Figure 2: Matlab simulation screen

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. 750 V DC Simulation Results

Figure 3 shows the 750 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 730 V and 840 V. The lowest catenary voltage of 730V gains this value by the end of the 1th 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.

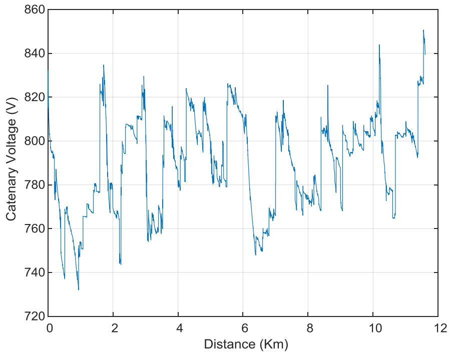

Figure 3: Minimum catenary voltage for nominal operation (750 V DC)

Figure 4 shows the 750 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 -20V and 60V. The maximum rail voltage of 60 V gains this value by the end of the 1^{st} km as seen in Figure 4. In this state there are 18 trains in the system.

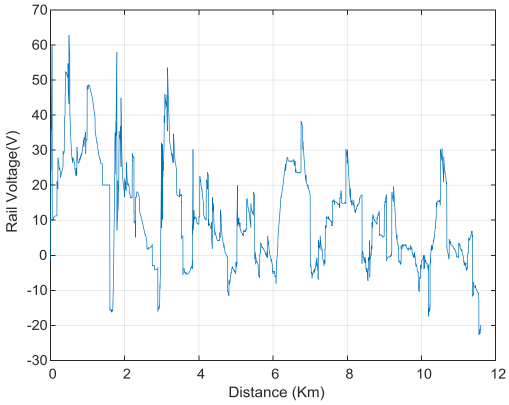

Figure 4: Maximum rail voltage for nominal operation (750 V DC)

Figure 5 shows the 750 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 660 V and 840 V. The lowest catenary voltage of 660 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.

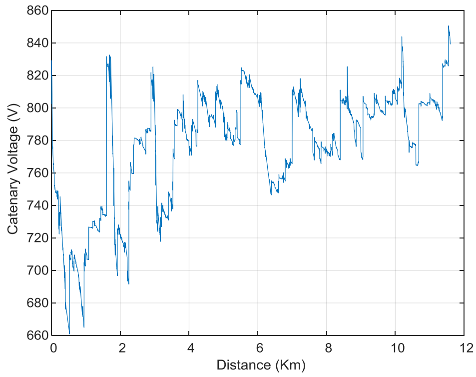

Figure 5: Minimum catenary voltage for one substation off (750 V DC)

Figure 6 shows the 750 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 -40 V and 90 V. The maximum rail voltage of 90 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.

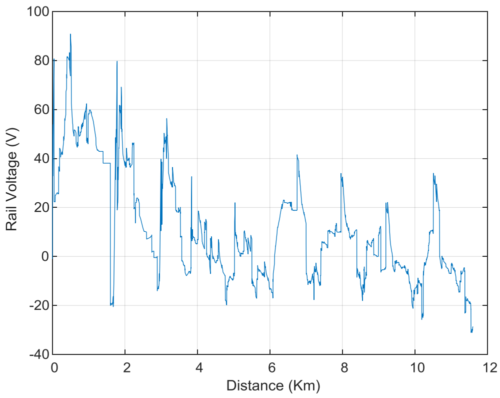

Figure 6: Maximum rail voltage for one substation off (750 V DC)

Figure 7 shows the 750 V DC simulation results of the catenary voltage at the trip frequency of 1.5 minutes and the two near substation off state. The minimum catenary voltage varies between 600 V and 840 V. The lowest catenary voltage of 600 V gains this value by the end of the 3rd 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.

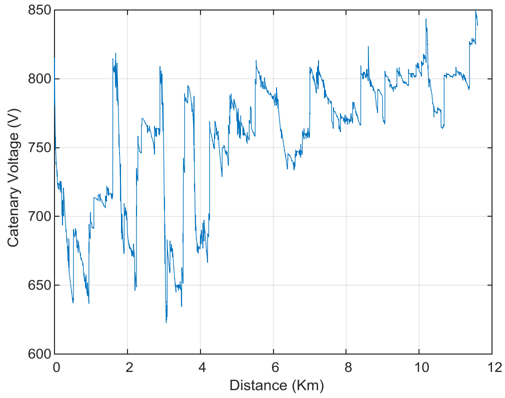

Figure 7: Minimum catenary voltage for two near substation off (750 V DC)

Figure 8 shows the 750 V DC simulation results of the rail voltage at the trip frequency of 1.5 minutes and the two near substation off state. The maximum rail voltage varies between -50 V and 90 V. The maximum rail voltage of 90 V gains this value by the end of the 3rd km as seen in Figure 8. In this state there are 18 trains in the system.

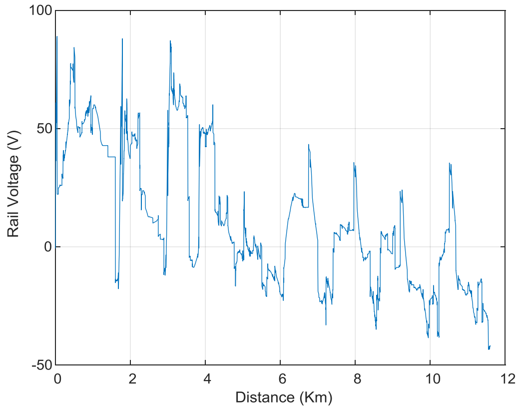

Figure 8 Maximum railvoltagefortwonearsubstationoff (750 V DC)

B. 1500 V DC Simulation Results

Figure 9 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 9. Minimum catenary voltage rises at transformer station feeding points. In this state there are 18 trains in the system.

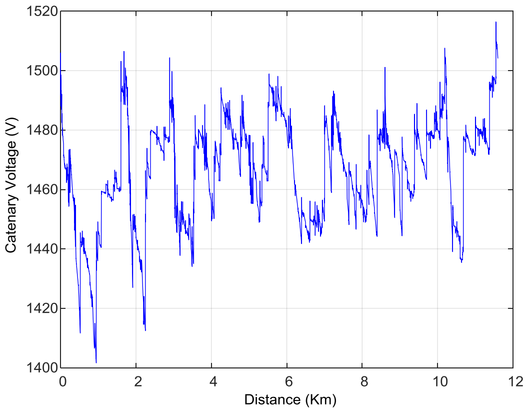

Figure 9: Minimum catenary voltage for nominal operation (1500 V DC)

Figure 10 shows the 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 10. In this state there are 18 trains in the system.

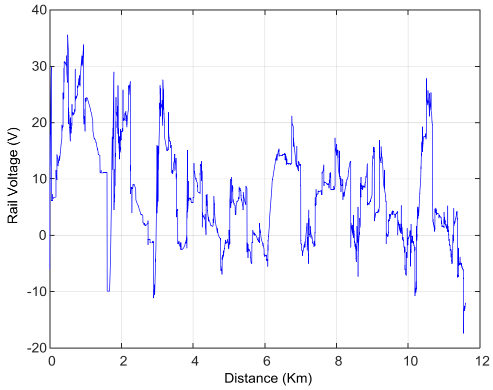

Figure 10: Maximum railvoltagefor nominal operation (1500 V DC)

Figure 11 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 11. Minimum catenary voltage rises at transformer station feeding points. In this state there are 18 trains in the system.

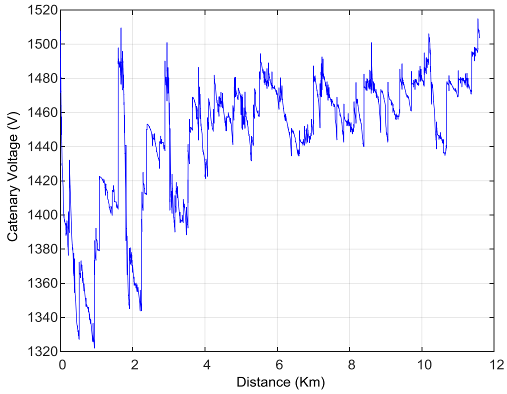

Figure 11: Minimum catenary voltage for one substation off (1500 V DC)

Figure 12 shows the 1500 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 60 V. The maximum rail voltage of 60 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.

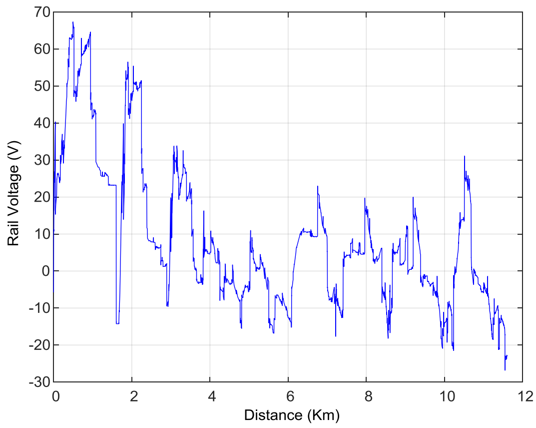

Figure 12: Maximum rail voltage for one substation off (1500 V DC)

Figure 13 shows the 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 13. Minimum catenary voltage rises at transformer station feeding points. In this state there are 18 trains in the system.

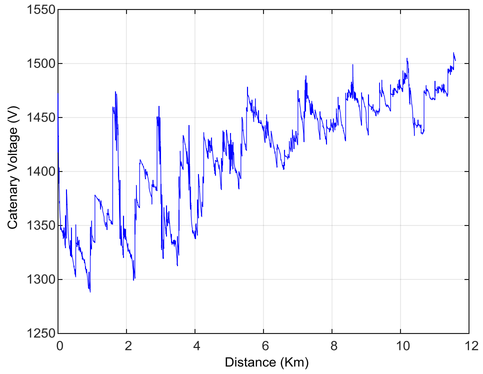

Figure 13: Minimum catenary voltage for two near substation off (1500 V DC)

Figure 14 shows the 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 14. In this state there are 18 trains in the system.

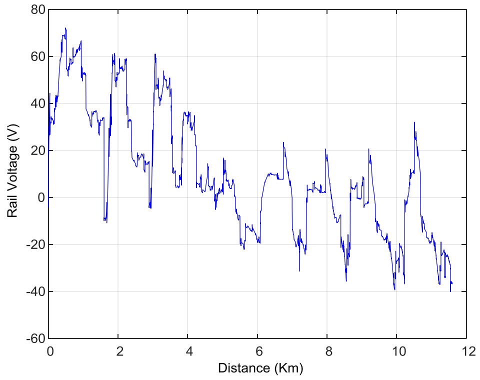

Figure 14: Maximum railvoltagefortwonearsubstationoff (1500 V DC)

C. The Comparison of the 750 V and 1500 V Simulation Results

When the 750 V DC and 1500 V DC simulation results are compared, the 750 V DC voltage values observed critical than the 1500 V DC voltage values. The results are given with table 1.

Table 1: The simulation results of 750 V and 1500 V DC Supply Voltage

Supply Voltage	**750 V DC**	**1500 V DC**
Minimum Catenary Voltage (Nominal Operation)	730 V	1400 V
Maximum Rail Voltage (Nominal Operation)	60 V	30 V
Minimum CatenaryVoltage (One Substation Off)	660 V	1320 V
Maximum Rail Voltage (One Substation Off)	90 V	60 V
Minimum Catenary Voltage (Two Substation Off)	600 V	1300 V
Maximum Rail Voltage (Two Substation Off)	90 V	60 V

4. Conclusion

In this study, the simulation of the electrification system and the traction power system of 1500 V DC feeding Basaksehir-Kirazli railway line was performed according to different operation scenarios using Matlab/Simulink. More effective operation conditions were investigated 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 750 V DC supply voltage minimum catenary voltage occurs in the state off two substation off with the 600 V. However in the 1500 V DC supply voltage minimum catenary voltage occurs in the state off two substation off with the 1300 V. These values are acceptable for the EN 50122 standards. When the 750 V DC and the 1500 V DC values are compared 750 V DC voltage values are more critical for the electrification system.

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