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Research Article

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Calculation of the Effects of the Traction Force Curve to the Catenary Voltage with a Comparison of Two Different Curve Levels in a Railway Line

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Abstract Rail system traction power system is designed with regard to some design parameters. In the Traction power design the traction force curve of the vehicle is critical. 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 the effects of the traction force curve to the catenary voltage with a comparison of two different curve levels was researched. The minimum catenary voltage value was calculated for two option and the results were compared for a railway line. Electrical analysis for nominal operation and the loss of a transformer station that affects the vehicle traffic explained.

Keywords AC, electrification, power, railway, traction

1. Introduction

In AC railways 25 kV AC supply voltage is used for the traction power system. In 25 kV AC systems the supply voltage that the traction force uses is acquired through an interconnected network which has 154 kV three phase voltage. Two transformers of 154 kV / 25 kV are present in the substations and the transformers can operate as back-up [1-3]. The equivalent circuit model of the AC railway is presented in Figure 1.

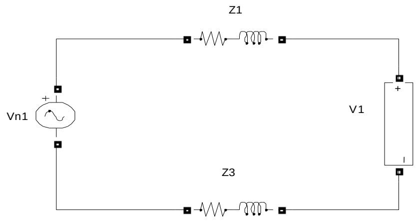

Figure 1: Equivalent circuit model of the AC railway

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 Z1 and Z3. Z1 and Z3 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 20-40 MVA. The power consumption is important for the electrical system analysis [4-8].

$$V_1 = V_{n1} - I_{vehicle} \times Z_1 - I_{vehicle} \times Z_3 \qquad (1)$$

In this study, the effects of the traction force curve to the catenary voltage with a comparison of two different curve levels was researched. The minimum catenary voltage value was calculated for high level and low level traction force curve option and the results were compared for a railway line. Electrical traction power simulation is done for 25 kV AC supply voltage.

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 [9-11]. 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. Afyon-Manisa railway line was studied.

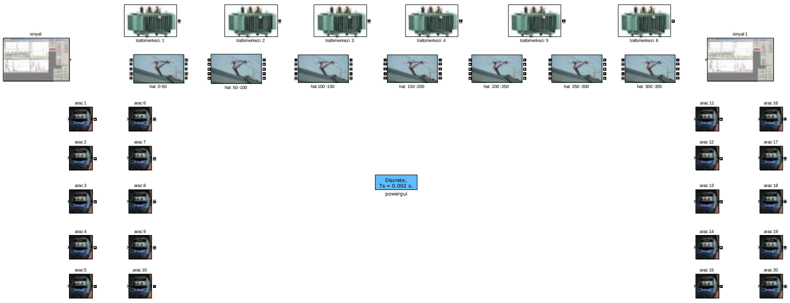

Figure 2: *Matlab simulation screen*

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. This problem affects the vehicle traffic. The state of losing a transformer station is studied especially through simulation before the process of construction. In this study 25 minutes and 50 minutes headway frequency is researched. Traction curve of two options simulated depending on operational parameters.

A. High Level Traction Curve AC Simulation Results

Figure 3 shows the 25 V AC simulation results of the catenary voltage at the trip frequency of 25 minutes and the nominal operation state. The minimum catenary voltage varies between 20.7kV and 25kV. The lowest catenary voltage of 20.7 V gains this value by the end of the 60th km as seen in Figure 3. Minimum catenary voltage rises at transformer station feeding points. In this state there are 20 trains in the system.

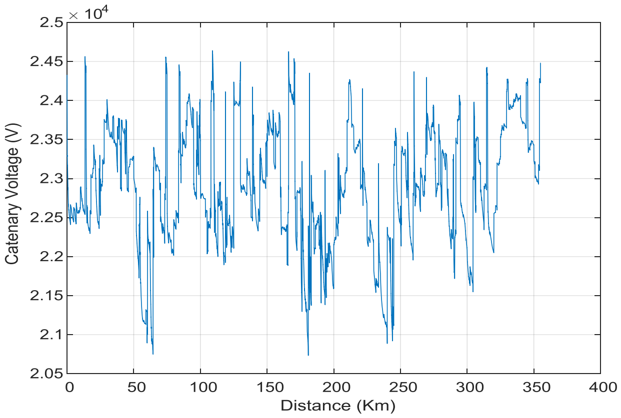

Figure 3: Minimum catenary voltage for nominal operation (25 Minutes Headway)

Figure 4 shows the 25 V AC simulation results of the catenary voltage at the trip frequency of 50 minutes and the nominal operation state. The minimum catenary voltage varies between 21.5kV and 25kV. The lowest catenary voltage of 21.5kV gains this value by the end of the 60th km as seen in Figure 3. Minimum catenary voltage rises at transformer station feeding points. In this state there are 10 trains in the system.

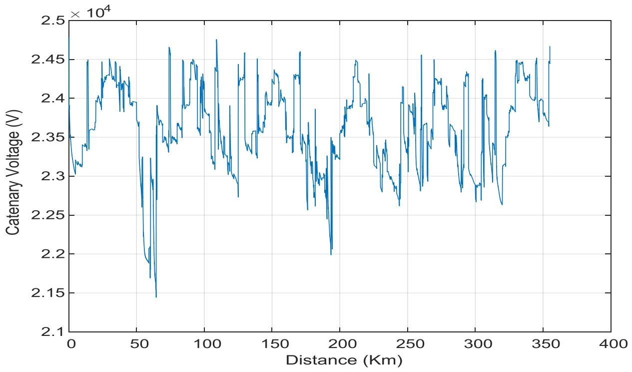

Figure 4: Minimum catenaryvoltagefor nominal operation (50 Minutes Headway)

Figure 5 shows the 25 V AC simulation results of the catenary voltage at the trip frequency of 25 minutes and the first substation is off state. The minimum catenary voltage varies between 12kV and 25kV. The lowest catenary voltage of 12kV gains this value by the end of the 25th km as seen in Figure 5. Minimum catenary voltage rises at transformer station feeding points. In this state there are 20 trains in the system.

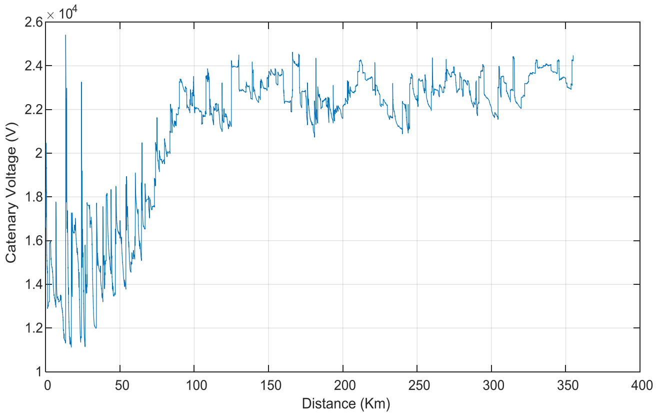

Figure 5: Minimum catenary voltage foronesubstationoff (25Minutes Headway)

Figure 6 shows the 25 V AC simulation results of the catenary voltage at the trip frequency of 50 minutes and the first substation is off state. The minimum catenary voltage varies between 18.4kV and 25kV. The lowest catenary voltage of 18.4kV gains this value by the end of the 5th km as seen in Figure 6. Minimum catenary voltage rises at transformer station feeding points. In this state there are 10 trains in the system.

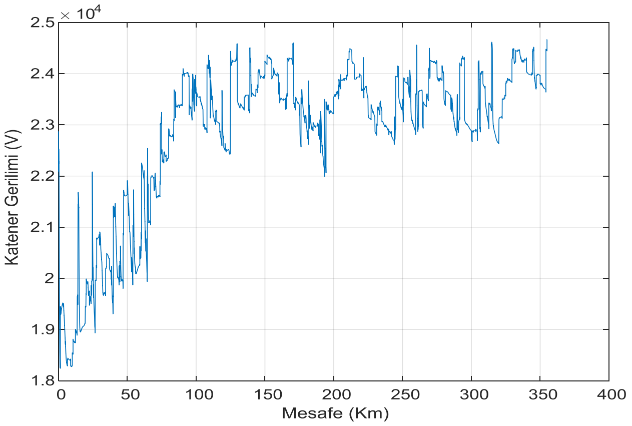

Figure 6: Minimum catenaryvoltageforonesubstationoff (50 Minutes Headway)

Figure 7 shows the 25 V AC simulation results of the catenary voltage at the trip frequency of 25 minutes and the second substation is off state. The minimum catenary voltage varies between 16kV and 25kV. The lowest catenary voltage of 16kV gains this value by the end of the 60th km as seen in Figure 7. Minimum catenary voltage rises at transformer station feeding points. In this state there are 20 trains in the system.

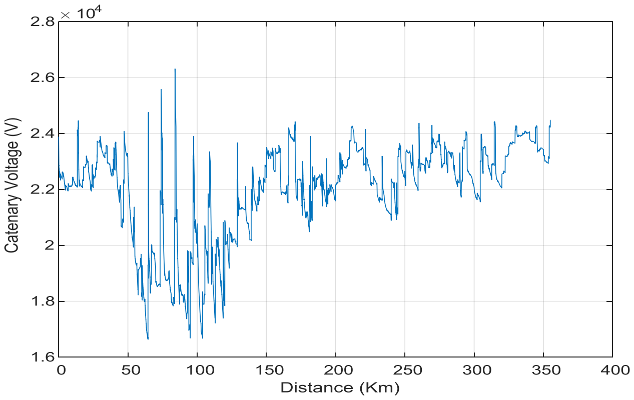

Figure 7: Minimum catenary voltage for second off (25 Minutes Headway)

Figure 8 shows the 25 V AC simulation results of the catenary voltage at the trip frequency of 50 minutes and the second substation is off state. The minimum catenary voltage varies between 20kV and 25kV. The lowest catenary voltage of 20kV gains this value by the end of the 100th km as seen in Figure 8. Minimum catenary voltage rises at transformer station feeding points. In this state there are 10 trains in the system.

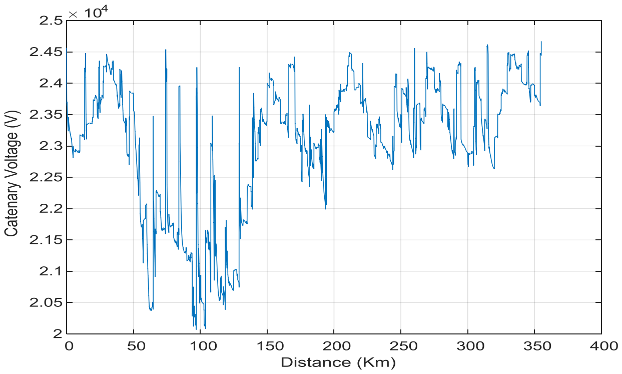

Figure 8: Minimum catenary voltage for second substation off (50 Minutes Headway)

B. Low Level Traction Curve AC Simulation Results

Figure 9 shows the 25 V AC simulation results of the catenary voltage at the trip frequency of 25 minutes and the nominal operation state. The minimum catenary voltage varies between 21.8kV and 25kV. The lowest catenary voltage of 21.8kV gains this value by the end of the 60th km as seen in Figure 9. Minimum catenary voltage rises at transformer station feeding points. In this state there are 20 trains in the system.

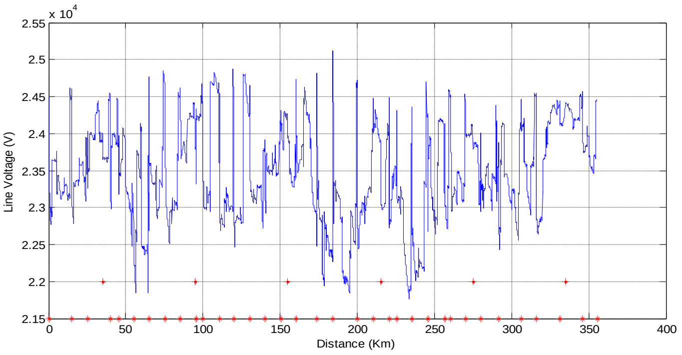

Figure 9: Minimum catenary voltage for nominal operation (25Minutes Headway)

Figure 10 shows the 25 V AC simulation results of the catenary voltage at the trip frequency of 50 minutes and the nominal operation state. The minimum catenary voltage varies between 22.1kV and 25kV. The lowest catenary voltage of 22.1kV gains this value by the end of the 200th km as seen in Figure 10. Minimum catenary voltage rises at transformer station feeding points. In this state there are 10 trains in the system.

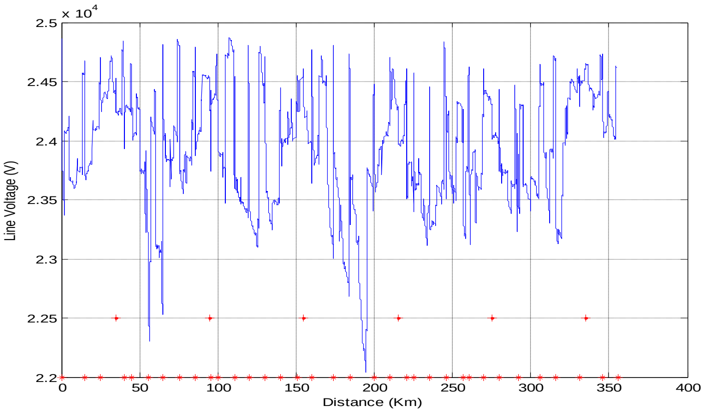

Figure 10: Minimum catenaryvoltagefor nominal operation (50 Minutes Headway)

Figure 11 shows the 25 V AC simulation results of the catenary voltage at the trip frequency of 25 minutes and the first substation is off state. The minimum catenary voltage varies between 14kV and 25kV. The lowest catenary voltage of 14kV gains this value by the end of the 10th km as seen in Figure 11. Minimum catenary voltage rises at transformer station feeding points. In this state there are 20 trains in the system.

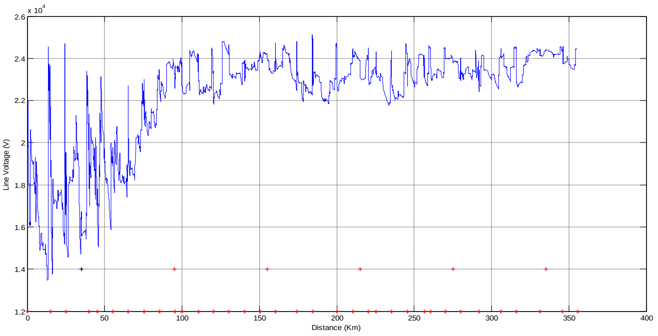

Figure 11: Minimum catenary voltage for first substation off (25Minutes Headway)

Figure 12 shows the 25 V AC simulation results of the catenary voltage at the trip frequency of 50 minutes and the first substation is off state. The minimum catenary voltage varies between 19.5kV and 25kV. The lowest catenary voltage of 19.5kV gains this value by the end of the 10th km as seen in Figure 12. Minimum catenary voltage rises at transformer station feeding points. In this state there are 10 trains in the system.

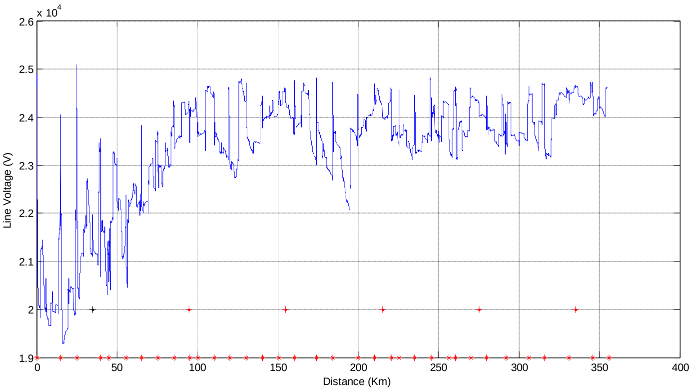

Figure 12: Minimum catenary voltage for first substation off (50 Minutes Headway)

Figure 13 shows the 25 V AC simulation results of the catenary voltage at the trip frequency of 25 minutes and the second substation is off state. The minimum catenary voltage varies between 18kV and 25kV. The lowest catenary voltage of 18kV gains this value by the end of the 100th km as seen in Figure 13. Minimum catenary voltage rises at transformer station feeding points. In this state there are 20 trains in the system.

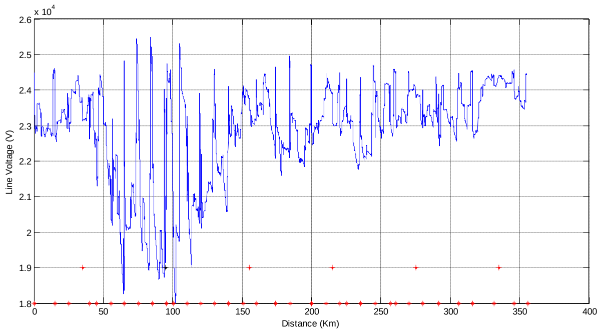

Figure 13: Minimum catenary voltage for second substation off (25Minute sHeadway)

Figure 14 shows the 25 V AC simulation results of the catenary voltage at the trip frequency of 50 minutes and the second substation is off state. The minimum catenary voltage varies between 20.5kV and 25kV. The lowest catenary voltage of 20.5kV gains this value by the end of the 10th km as seen in Figure 14. Minimum catenary voltage rises at transformer station feeding points. In this state there are 10 trains in the system.

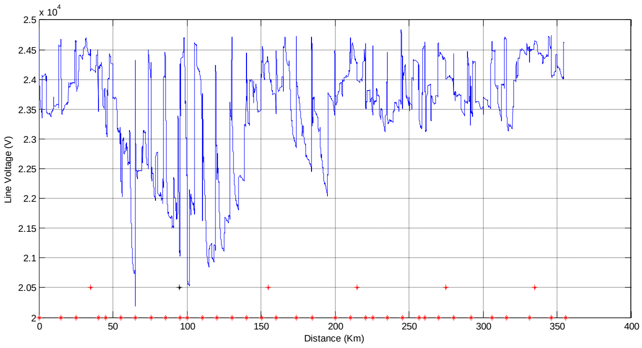

Figure 14: Minimum catenary voltage for second substation off (50 Minutes Headway)

C. The Comparison of the Different Traction Curve Level Simulation Results

When the high level and low level traction curve simulation results are compared, in the high level state voltage critical values observed lower than the low level state voltage values. The results are given with table 1.

Table 1: The simulation results of Different Traction Curve Levels

Traction Curve Level	High Level	Low Level
Minimum Catenary Voltage (Nominal Operation with 25 Minutes Headway)	20.7 kV	21.8 kV
Minimum Catenary Voltage (Nominal Operationwith 50 Minutes Headway)	21.5 kV	22.1 kV
Minimum Catenary Voltage (First Substation Off with 25Minutes Headway)	12 kV	14 kV
Minimum Catenary Voltage (First Substation Offwith 50 Minutes Headway)	18.4 kV	19.5 kV
Minimum CatenaryVoltage (Second Substation Offwith 25Minutes Headway)	16 kV	18 kV
Minimum CatenaryVoltage (Second Substation Off with 50 Minutes Headway)	20 kV	20.5kV

Conclusions

The simulation of the electrification system and the traction power system of 25kV AC feeding Afyon-Manisa 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 curves. The situations that occur under different operation conditions are summarized in Table 1. In the high level traction curve state minimum catenary voltage occurs in the state off second substation off with the 12kV. However in the low level state minimum catenary voltage occurs in the state off second substation off with the 14kV. These values are critical for the EN 50122 standards. When high level traction curve and low level traction curve values are compared high level voltage values are more critical for the electrification system. Therefore Traction curve characteristics are important for the traction power system design.

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