

Direct Current Traction Power System Analysis in Electrical Railway Systems

Ibrahim Sengor, Yusuf Basegmez and Mugdesem Tanrioven

Abstract— Today's, urban transportation began to get more importance because of increasing rates of urbanization and the traffic problems. Therefore, railway systems have started to play a key role in urban transportation with technological development because of rapid transit, less carbon emission, low ratio between the energy consumption and transport capacity. In this study, the grid and DC traction power supply system of a subway which is the widespread urban electrical railway systems has been modeled by using MatLAB Simulink. Electrical analysis was carried out of the subway line according to the variable load and different line distance.

Keywords—traction power, railway, transportation, energy

I. Introduction

Transportation is an engineering issue that people try to find new solutions to the problems for ages. The aim of the transportation, an inevitable phenomenon in the life of countries and cities, is that to transport people from one place to another as soon as possible in the most secure, more comfortable way with least cost.

Transportation has become one of the main problems especially in crowded place. Engineers tried to solve the issue by designing an optimal system in terms of environmental pollution, cost and energy. When the all parameters took into account, railway systems have accepted a considerable way for transportation by all over the world. Subway, tram, light rail can be ordered examples for urban transportation system. These systems can be operated with 750 V, 1500 V and 3000 V DC voltage from third rail or catenary line [1].

The most significant advantages of railway systems are environmentally friendly and more passenger capacity than the others. Also railway transport has many benefits in terms of security, energy, area and noise. The only disadvantage is that being high initial capital cost. Nevertheless, rail transport systems are spreading in our country and the world day by day.

In this study, the power supply and distribution systems will be examined in electric rail transportation systems. In this context; power requirement of rail vehicles and equipment of stations and effects of electric rail vehicle on the grid will be analyzed. Moreover, simulation results obtained by using MatLAB Simulink are going to be reviewed.

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II. Structure of the Electric Railway Transportation Systems

Railway transportation systems are possible to divide into two parts as fixed systems and vehicles' systems. Fixed systems consists of stations, substations, rails, catenary or third rail and control centers. Vehicles' systems contains ventilation and lighting equipment. Railway transport systems are composed of four parts with regard to electrical way; feeders, auxiliary power systems, drive systems and protection and control systems.

A. Feeders

The Feeder system consists of third rail and catenary system. In catenary system, the energy obtained from substations is transmitted to the pantograph installed to the upper side of vehicle via overhead line. In the third rail system, the energy is transferred from third rail to the train by using current collector shoes instead of pantograph.

Power demand from substation varies according to the frequency of timetable, the total weight of the train and the quantity of track line. The amount of energy consumption depends on the train speed and the characteristics of track. The detailed analysis is necessary for decision of substation location. According to the voltage level, the probable locations of the substation is determined. According to the Railway Applications – Supply Voltage of Traction Systems standard EN 60153, DC traction systems are permissible voltage drop in values between 15-30% [2].

B. Auxiliary Power Systems

Auxiliary power systems include the heating, ventilation and air conditioner and lighting equipment. These are fed by the energy inverted from third rail or catenary to AC voltage. Fig. 1 shows details connection diagram of an auxiliary power systems.

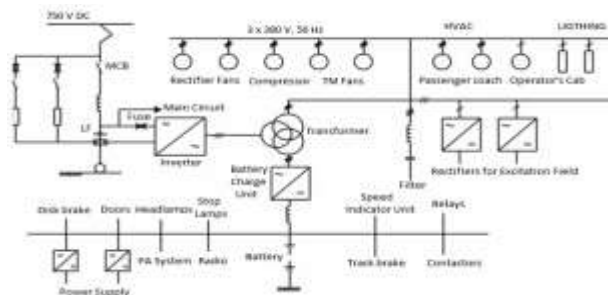


Figure 1. Auxiliary Power Systems Connection Diagram [3]

C. Drive System

The drive system is composed of many equipment such as pantograph, current collector shoes, main isolation switch, main circuit breaker, filter, excitation field, DC chopper and over voltage protector.

- Pantograph that is a part of drive system transmit the energy from catenary to electrical equipment of vehicle.
- Main isolation switch that is under power mode provides the connection between pantograph and main circuit breaker.
- Main circuit breaker has a property to disconnect between power system and power supply while there is an over current.
- Under the situation of both acceleration and electrodynamic braking, filter is activated to decrease the harmonics with inductance coil and the line capacitor.

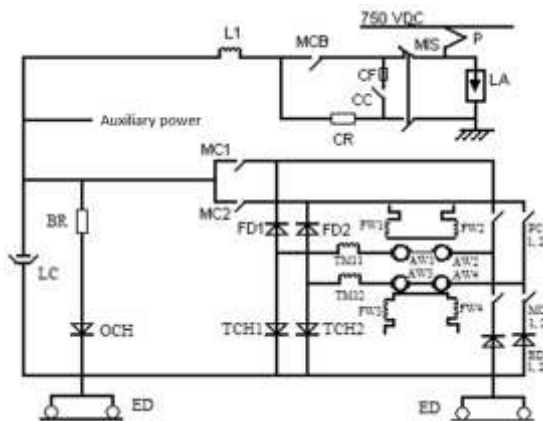


Figure 2. An Example Diagram for The Drive System [3]

DC traction motor is used as a drive motor in the subway system. Each vehicle has four DC motor and two parallel connected rectifiers. The field winding of DC motor is connected to rectifier unit. Acceleration mode is provided via the contacts of motor according to main circuit diagram. The switchgear position is open during the electrodynamic braking, is close during the acceleration. At the chopper unit, the current fluctuation is limited by inductance if there is no vehicle accelerated from opposite way. The function of braking resistor is conversion of the power to heat during the braking. [4].

D. Protection and Control systems

The protection and control system has a significant importance for power electronic circuits to provide uninterrupted and quality energy. While the critical operation situation such as over current, over voltage, short circuit situation, this system protects all equipment used in railway system [4].

III. System Design

The different voltage level is used for railway traction power systems. According to EN 50163 standard, the most common used DC traction power supply systems are shown in Table I given below.

TABLE I. DC TRACTION POWER VOLTAGE LEVELS [2]

Voltage Level	U _n (V)	U _{min1} (V)	U _{max1} (V)	U _{max2} (V)
750V DC	750	500	900	1000
1500V DC	1500	1000	1800	1950

- U_n: Nominal Voltage
- U_{min1}: Lowest Permanent Voltage
- U_{max1}: Highest Permanent Voltage
- U_{max2}: Highest Nonpermanent Voltage

The subway line has 5 station, totally 7.8 km distance and fed with 750 V DC power. The energy is provided by traction power substations that have totally 3300 kVA traction transformers in each substations.

The line is fed by third rail and the vehicles on line have 12 DC motors which are 152 kW runs with 90 % efficiency. Also, each with 72 kW, 3 auxiliary power units run with 80 % efficiency on a vehicle. Table II shows the total power for one vehicle.

TABLE II. TRACTION MOTOR POWER AND AUXILIARY POWER VALUES

The Power of Traction Motor	Auxiliary Power
1641.6 kW	172.8 kW

Each station has rectifier units and traction transformers. The output voltage of the three phase rectifiers can be obtained by using (1). The features of each uniform substations is given below in Table III used in simulations. There are two outputs; one of them is wye (Y) connected and another one is delta (Δ) connected. These secondary sides connect to the rectifiers which are parallel and 12-pulse version. DC voltage obtained from output of rectifiers feeds the third rail. The connection diagram is illustrated in Fig. 3.

$$V_R = V_{max} \times \frac{\sin \frac{\pi}{6}}{\frac{\pi}{6}} \quad (1)$$

$$V_R = \sqrt{2} \times 590 \times 0.95 = 796.7 \text{ V}$$

TABLE III. ELECTRICAL FEATURES OF A TRACTION TRANSFORMER[8]

Nominal Power	1650e3VA
Frequency	50 Hz
Primer Windings Voltage	34500 V
R ₁ , L ₁	0.72136 Ω, 0.091847 H
Secondary Windings Voltage	590 V
R ₂ , L ₂	0.00021818 Ω, 2.778e-005 H
R _m	1.8034e+005 Ω
L _m	574.04 H

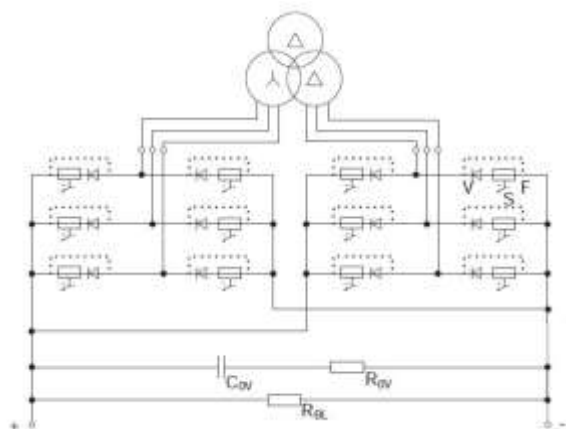


Figure 3. The Rectifier Connection Diagram [9]

The third rail was modelled as resistor R ohm per km that is 0,015 ohm/km. The distance between each station is different such as 2.25 km, 1.5 km and so on. Therefore total resistors between the station vary.

IV. System Description

The subway line which has 5 stations and 7.8 km distance was implemented by using AutoCAD to imagine the general overview of the subway system. Fig. 4 illustrates one station of the general system.



Figure 4. AutoCAD Diagram of The Subway Line

To analyze power flow and the voltage drops of the subway line; the grid, 5 stations, traction substations, tracks and the vehicles was modelled by using Matlab Simulink. General overview of the subway line in Simulink can be seen in Fig. 5.

In this simulation, traction substation is composed of two 1650 kVA traction transformers that are connected as Δ/Δ and Δ/Y . Moreover, outputs of transformers linked up with rectifiers. The traction transformers and the rectifier units are shown in Fig. 6. Two 6 pulse rectifiers connected to each other as parallel to get DC voltage for the third rail that has resistors 0.015 ohm/km value. Fig. 7 illustrates the third rail and vehicle model.

The railway vehicles were modelled as constant load and the load varies at some stations because of passengers, heating, ventilation, air conditioner and lighting load. Vehicles were moved by using breakers depend on time. Fig. 8 gives the details about the vehicles.

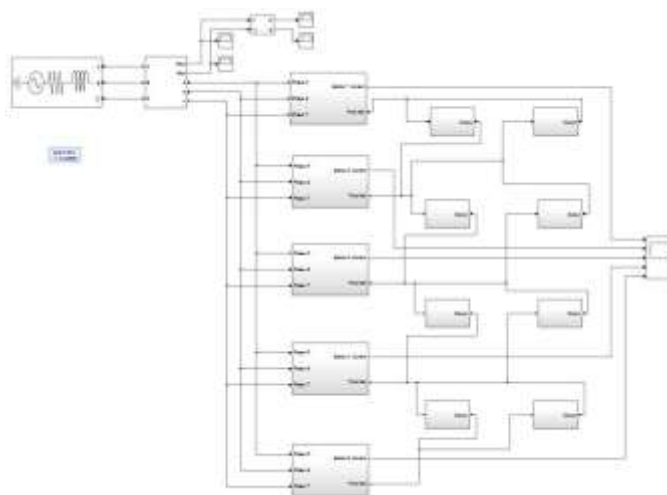


Figure 5. General Overview of The Subway System

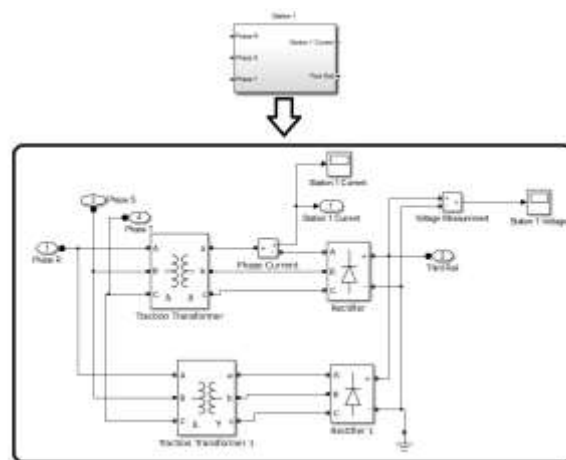


Figure 6. The Traction Transformers and The Rectifier Units

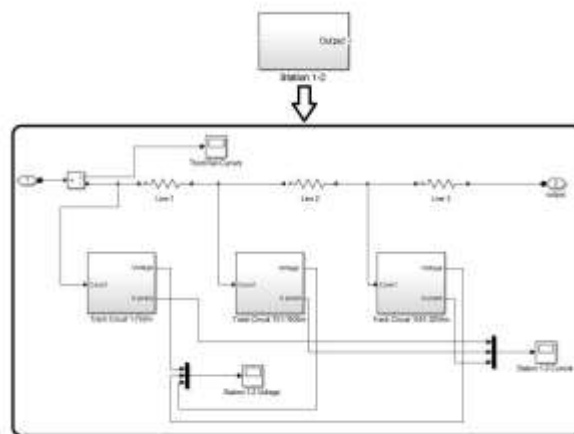


Figure 7. The Third Rail and Train Model

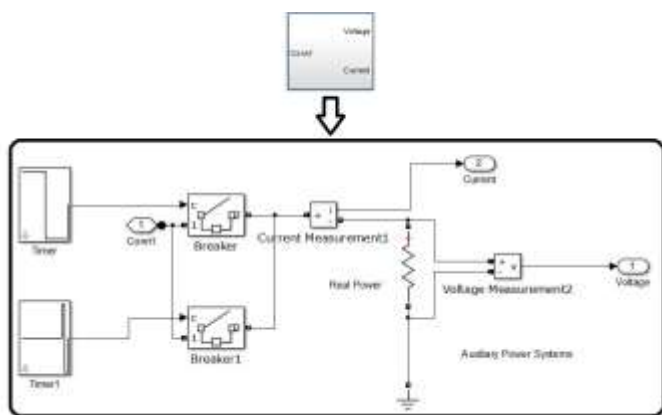


Figure 8. Dc Motor And Auxiliary Power System Model

v. Simulation Results

The simulation was operated under the different conditions for instance, while there are 2 trains or 4 trains at the same time on line, different passenger load and different distance between two stations.

There are two cases that change with number of trains. Case 1; while 2 trains are on the line, first train moves from station 1 and second one moves from station 5. Case 2; while 4 trains are on the line. In addition to case 1, third train goes from station 3 to station 1 and fourth one goes from station 3 to station 5.

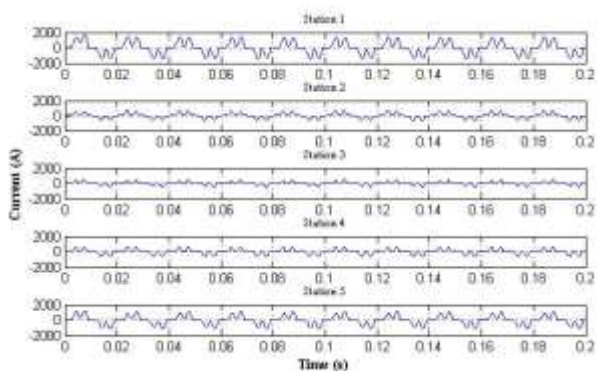


Figure 9. Drawing Current from Traction Transformers (Case 1)

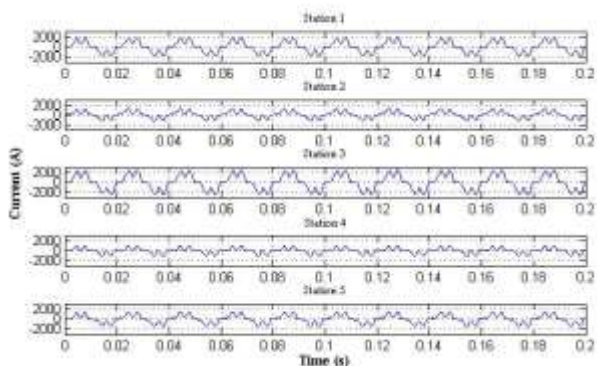


Figure 10. Drawing Current from Traction Transformers (Case 2)

Fig. 9 and Fig. 10 shows the currents drawn from the traction transformers at the stations for case 1 and case 2 on the line. There is less current needed in case 1 than case 2. Besides, trains' movement can be seen in Fig. 9 and Fig. 10.

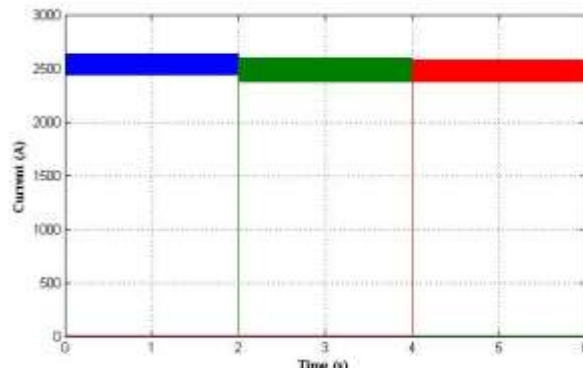


Figure 11. Current Variation for the Train Between Station 1 and 2

Fig. 11 illustrates the current variations for the train between station 1 and 2. The current drawing from the third rail was calculated analytically in (2) as 2.6 kA. The calculation result and simulation result agrees with 1 % relative error. There is a decrease for the current, as it can be seen from Figure 11, reason of that is the voltage drop on the third rail.

$$P = V \times I \quad (2)$$

$$1950 \text{ kW} = 750 \text{ V} \times I$$

$$I = 2.6 \text{ kA}$$

Requested active and reactive power from the grid also were obtained from the simulation. Demand active power can be seen in Fig. 12 for case 2. Also demand reactive power can be seen in Fig. 13 for case 2. Considering mean value of the results $\cos\phi$ is calculated for the system by using (3) and (4);

$$P = S \times \cos \phi = 2.25 \text{ MW} \quad (3)$$

$$Q = S \times \sin \phi = 0.5 \text{ MVA} \quad (4)$$

$$\phi = \tan^{-1} \frac{Q}{P} = 12.53^\circ \quad (5)$$

$$\cos \phi = 0.97 \quad (6)$$

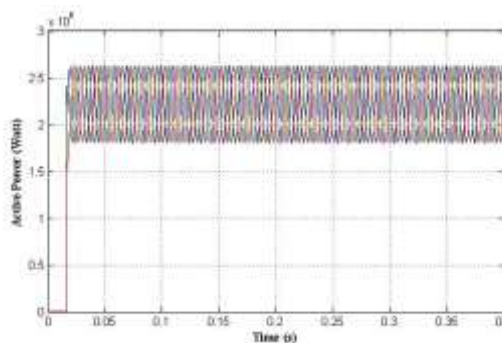


Figure 12. Active Power From The Grid (Case 2)

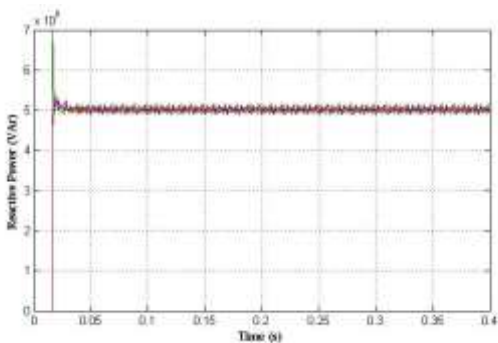


Figure 13. Reactive Power From The Grid (Case 2)

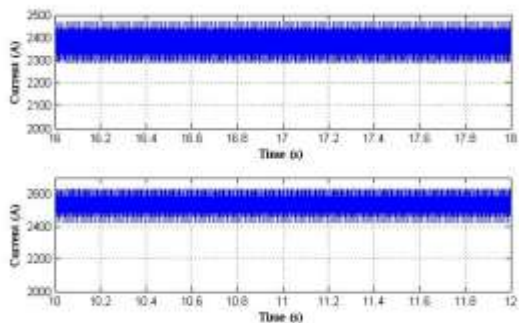


Figure 14. Different Passenger Load at Same Distance

Drawing current from the third rail while different number of passengers on a train at same distance can be seen in Fig. 14.

vi. Conclusion

In this study, electrical structure of railway is searched and then a subway line is created in MatLAB Simulink. The system response is investigated under the different scenario such as, 2 trains operation, 4 trains operation, different number of passenger and different distances between the stations. The simulation results are commented and compared with analytical calculations.

This study shows that more efficiency subway system can be installed by using simulations like that. Because there are voltage drops and losses on the third line. Both of them should be considered before built a subway line.

Next step of this station can be investigation of response of the system under different fault moments and system harmonics.

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