A STUDY FOR DC 1500V RAILROAD SYSTEM AND DEVELOPMENT OF RAILROAD SYSTEM MODELING USING PSCAD/EMTDC

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ABSTRACT
This paper is for modeling on 1500V DC electric railroad system. Electric railroad system has special characteristics with other electric system. One of the special characteristics is that the railroad system has electric vehicle loads which are power-varying and location-varying with time. Because of this load characteristic, the electric railroad system modeling which reflect its own characteristics on EMTDC simulation could not be achieved. However, to reflect load characteristic on EMTDC, this paper suggests electric railroad system modeling by using Train Performance Simulator (TPS) that was developed in Korea Railroad Research Institute. A TPS program has various kinds of input data, such as operation condition, vehicle condition, and power system condition. By these data, TPS calculates mechanical power consumption and location, especially it decide electric power consumption on the basis of the fact that consumed electric and mechanical power are equal. Moreover, on this paper, movement of vehicle is reflected on EMTDC simulation as variation of feeder impedance. Also, an electric vehicle load is modeled as time-varying constant power load model.

KEY WORDS
Electric railroad system, Railroad system modeling, PSCAD/EMTDC

1. Introduction
Because of the increment of distribution volume following highly grown-industrialization and the overpopulation on a big city, difficult conditions of traffic are embossed. Moreover, caused by a steep increment of an automobile, land route traffic reached limits and solicitude for environmental problems, such as atmospheric contamination by exhaust gases and din pollution, are getting higher. However, on conditions that durable investments for social overhead capital are not enough and traffic and environmental problems are become one of the most urgent problems in our society, electric railroad systems which has much benefit such as environmental-friendliness, efficiency for fuel, safety, rapidness, and convenience, are presented as an optimal alternative-solutions for present traffic problems. In according to these trends, electric railroad diffusions get spread, electrifications for main railroad lines gets accomplished, and a demand for electric energy as a main power source of electric railroad is increasing rapidly. Increments of electric railroad operations cause prime cost curtailment by reducing transportation cost through energy efficiency enlargement and solution proposal for environmental problem through environment-friendliness. However, several problems such as inductive interference on communication line and harmonic current injection, are occurred. Based on the common characteristics of these problems, fundamental solutions are needed by railroad system standardization. On this paper, as one of the fundamental solutions by railroad system standardization, simulation modules for DC supplying railroad system are proposed. Two types of railroad substation modules, fixed and variable line impedance modules, and railroad vehicle module are constructed by PSCAD/EMTDC.

2. DC railroad system
In Korea, DC railroad system takes electric power from 22.9kV or 154kV bus bar in AC power system. Especially, DC railroad includes rectifier in DC railroad substation. Substations are installed per 4–10km by considering voltage drop on feeder. The DC railroad system is constructed on Fig. 1. Comparing with AC type electric railroad system, DC type electric railroad has many advantages on various aspects, especially on underground railroad. Its main characteristic can be expressed by ‘low voltage and high current’. In Korea because A DC system uses 1.5kV
rectified from 22.9kV AC electricity, the DC system current goes up high, 2kA[1].
Because of it uses DC voltage and low level voltage, the DC system have no induced interference phenomena and short insulating distance gap. Especially, the insulating distance gap is important for underground railroad, because it determines how large the tunnel is. In other words, short insulating distance gap of the DC railroad system save expenses for constructing underground railroad.

3. Modeling for DC railroad system

Modeling for two types of DC substation, variable feeder, and railroad vehicle in DC railroad system has performed by PSCAD/EMTDC.

3.1 Substation

DC railroad system has two types of substation. One has diode rectifier and the other has thyristor rectifier. The objective of these substations is to supply 1.5kV DC voltage to DC railroad system.
A DC railroad substation is to rectify 1.5kV DC voltage. In Korea, a diode type rectifier substation is applied on the railroad where is connected to 22.9kV AC power system and a thyristor type is for 154kV AC system. Actually, thyristor type substations are applied on Pusan railroad system in Korea. That is, Pusan railroad system is connected to 154kV AC systems. Because 154kV AC systems have high reliability for power supplying and Pusan area has a lot of typhoon damage every year, Pusan railroad system has connected to 154kV AC systems.
A diode type substation receives electric power from 22.9kV AC power systems. AC 22.9kV is lowered to 380V by substation transformer. The substation transformer is three phase-three winding type. Two secondary winding voltages are inputs for 12-pulse rectifier. By these process, substation supply electric power by 1.5kV DC voltage.
A thyristor type has almost similar processes. However, AC voltage is 154kV and it can vary output DC voltage because the 12-pulse bridge rectifier is composed of 12 thiristors. It can adjust DC output voltage against AC voltage variance or faults[2].
of feeder and rail is 0.0205 Ohm/km and 0.00765 Ohm/km. On case study of this paper, these values are used. The object of variable line constant model is to see voltage drop on feeder by railroad vehicle moving. Feeder voltage drop effect to maintain the vehicle voltage 1.5kV and it can make the vehicle voltage lower than 900V that is the standard limit.

3.3 Railroad vehicle

On an actual state, the railroad vehicle has very complicated structure that is composed of induction motor, inverter and many controllers. To make model actual railroad vehicle is hard and make simulation takes long time. Therefore, railroad vehicle is simplified on this paper. The vehicle modeling is presented by constant load model[3]. Vehicle load model on Fig. 5 has two parts. Fig. 5(a) is for reading consumed power calculated by TPS, and Fig. 5(b) is the constant load model that express railroad vehicle.

4. Train performance simulator

TPS was developed by Korea Railroad Research Institute(KRRI). It calculates consumed electric power for vehicle driving and location of vehicle.

4.1 TPS

TPS needs three kinds of input data classes which are about driving condition, vehicle condition and electric system condition. The driving condition includes departure time, departure station, arriving station, distance between two stations, driving mode, standard driving mode, a standard driving curve, a gradient and the curvature radius of the rail. The vehicle condition includes velocity-traction curve, velocity-breaking curve, kind of vehicle, the number of vehicle, rating voltage of vehicle, motor efficiency, inverter efficiency, gear box efficiency, etc. And the electric system condition includes substation data, location, capacity, receiving-end voltage, voltage variance rate, supplying voltage, and line constant. Fig. 6 shows the standard operation curve. Railroad vehicles repeat the simple pattern that is acceleration-inertial driving-breaking-stop. Vehicles generate reverse and resuscitation current. And by getting acceleration or breaking force from the current component, vehicles determine next driving state and velocity. Therefore, vehicles have one of the states on Fig. 6. That is, they determine location by their velocity and choose driving mode by standard operation curve after determining velocity and location.

As seen above calculation algorithm, TPS calculate the vehicle’s location per second. It can calculate the location by integral acceleration by time. Consumed power is calculated by mechanical analysis method. Mechanically, the energy to make the vehicle drive can be calculated by product acceleration and mass of the vehicle.

4.2 Electric power consumption

TPS calculates consumed power of vehicle by calculating mechanical force and energy. To get consumed power output data, it needs standard operation curve, a gradient and curvature radius of rail, velocity-acceleration curve, velocity-breaking curve, vehicle data, motor efficiency, inverter efficiency. By these data, TPS calculate the mechanical power and make output data by assumption that mechanical power is equal to electrical power. Fig. 7 illustrates consumed power calculated by TPS while railroad vehicle drives between Apgujung and Sin-sa stations. The vehicle departs Apgujung station at 0.0sec, arrives Sin-sa station 17.5sec, and departs Sin-sa station at 20.0sec.

4.3 Location of vehicles

TPS calculates location of vehicle from substation. The location of vehicle is important because it means impedance between vehicle and substation and the line impedance induces voltage drop on feeder. Especially, because DC railroad system has low voltage and high current characteristic, voltage drop on feeder is high. Because of voltage drop on feeder, standard voltage of vehicle driving can be lowered under standard limit, 900V. Fig. 8 illustrates vehicle location calculated by TPS while railroad vehicle drives between Apgujung and Sin-sa stations. The line constant increase proportionally.
However, feeder voltage drop is not proportional with the curve on Fig. 8. On case study, feeder voltage drop is illustrated.

Fig. 7. Power consumption curve of vehicle

Fig. 8. Location of vehicle from the substation

5. Case studies

To see the voltage on railroad system, test system was constructed as illustrated on Fig. 9. This case study is to verify whether substation bus voltage and vehicle voltage is higher than standard limits, 1.1kV and 900V each. Especially in case of vehicles, if the voltage is lower than 900V, because of the inverter operation voltage, vehicles cannot operate[4].

The simulation conditions which are the standard operation pattern on Korea railroad system are 4km distance between substations, 52.5km/h average velocity of vehicle, 4min time intervals between vehicles driving, 175sec moving time from Apgujung to Sin-sa, and 25sec standing time on Sin-sa station. Resistance per kilometer of feeder and rail is 0.0205Ohm/km and 0.00765Ohm/km each. And the location data and power consumption data of vehicle is from TPS simulation.

A thyristor type rectifier substation is not considered on this paper because its substation voltage can be maintained near 1.5kV by adjusting thyristor firing angle. As the case study is to see variance of substation and vehicle voltage, thyristor substation simulation is useless on this paper.

Also, on case study, time scale is reduced by ten times. Actually, applied TPS output data is for vehicle which operates for 200sec. However, 200sec is too long to perform EMTDC simulation by 100usec time step.

On this simulation, substation bus voltage, vehicle voltage, and feeder voltage drop are measured. On Fig. 9, test system is illustrated. The test system has three DC railroad substation and 8 railroad vehicles. 4 vehicles are for up-line and the others are for down-line. Each two vehicles have 4min time intervals. To perform case simulation, location of vehicle is reflected on simulation by using Fig. 8 location data. Also, Fig. 7 power consumption curve is used for consumed power of vehicle. Fig. 10 illustrates 3 substations voltage while railroad vehicles are moving. By vehicle’s moving, because the burdens of each substation for railroad load are different, substation voltage variance aspects appears on Fig. 10. Fig. 11 illustrates 4 vehicles voltage. Fig. 11 shows the difference of each vehicles voltage because of the differences that initial distance from substation, driving mode of each vehicles.

The graphs on Fig. 10 and 11 have initial rising state that is due to EMTDC initial characteristic. Power source on test system should be set rise time that cannot be set zero. And rectifier operation takes more time to be steady-state. Therefore, minimum and maximum voltages are calculated between 1.0sec and 11.0sec. The ripples on graphs are generated by transient analysis on EMTDC. Because a railroad vehicle modeling is performed by using constant power load model, EMTDC perceives value variation on consumed power transient state.

Fig. 9. Test system for case studies
On Table 1, minimum, maximum and standard limit voltages are indicated. No substations and vehicles are lower than standard limit voltage.

Fig. 12 and 13 illustrate voltage drop on feeders. As seen Fig. 12 and 13, because impedance increases, voltage drop increases when vehicle goes far from substation. In this simulation, maximum voltage drop indicates 54V nearly on Fig. 13. On standard operation, voltage drop is not enough high to make vehicle voltage lower limit voltage, 900V. However, in the cases of shorter vehicle time interval, more rapid operation, longer distance between substations, or substation failure, each substation need to supply higher current and feeder voltage drop goes up to high.

### Table 1

<table>
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<th>( V_{\text{max}} ) (V)</th>
<th>( V_{\text{limit}} ) (V)</th>
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</table>

### 6. Conclusion

To apply characteristics of railroad system on EMTDC simulation, variable feeder impedance model and railroad vehicle model are developed. By using developed models, test system is constructed and simulation is performed.
The input data on EMTDC simulation is from TPS, and TPS simulation input data is from real railroad system Apgujung-Sinsa section. TPS location output data is transformed to feeder impedance data. By applying impedance and consumed data, railroad on standard operation is simulated.

The stable operation criteria are that each substations and vehicles voltage should be higher than standard limit voltage, 1,100V and 900V. Through case studies, 3 substations and 4 vehicles voltage are measured and indicated minimum and maximum voltage. Under standard operating condition, it is verified that railroad system is not out of limit.

The main object of this developed DC railroad simulator is 'verification' before system construction or operating schedule preparation. By this simulator, we can determine the distance between substation, two vehicles time interval, the number of vehicles between substations, etc. Moreover, the simulator helps the research on DC railroad system activated.

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References