A Study for DC 1500V Railroad System Modeling Using EMTDC

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Abstract - This paper is about modeling on 1500V DC electric railroad system. Electric railroad systems have peculiar characteristics against other electric system. The characteristics are that the railroad systems have electric vehicle loads which are power-varying and location-varying with time. Because of this load characteristic, the electric railroad system modeling which reflects 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 TPS (Train Performance Simulator) 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.

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.[1] 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 an harmonic current injection, are occurred. Based on the common characteristics of these problems, fundamental solutions are needed by railroad system standardization.

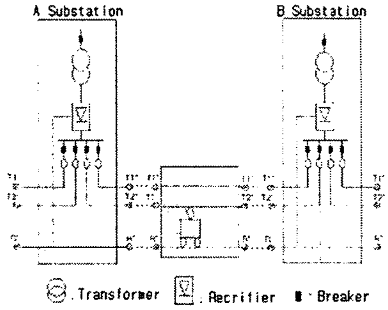
On this paper, as one of the fundamental solutions by railroad system standardization, simulation modules for DC supplying railroad system are proposed. Two types of railroad substation modules, fixed and variable line impedance modules, and railroad vehicle module are constructed by PSCAD/EMTDC.

2. DC Railroad System

In Korea, DC railroad systems take electric power from 22.9 [kV] or 154 [kV] bus bar in AC power system. Especially, DC railroad includes rectifier in DC railroad substation. Substations are installed per 4~10 [km] 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 systems have many advantages on various aspects, especially on underground railway. Its main characteristics can be expressed by 'low voltage and high current'. In Korea because DC systems uses 1.5 [kV] rectified from 22.9 [kV] AC electricity, the DC system current goes up high, 2 [kA].[2]

Because they use 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 railway, 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 railway.

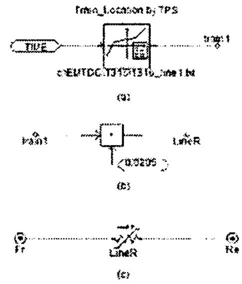


<Fig 1> DC Railroad system

3. Modeling for DC Railroad System

3.1 Catenary Model

Because an electric railroad has characteristic that is movable with time, it is hard to perform EMTDC simulation for a long time. In this paper, the effect of the location-varying characteristic is expressed on EMTDC simulation by using impedance variation.



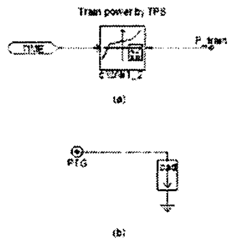
<Fig 2> Catenary model

As seen on fig 2, a line impedance module developed on this paper has three parts. (a) is for location data reading, (b) is for impedance calculation, and (c) is the variable resistance. The value, 0.0205 means resistance per kilometer on fig 2 (b). Actually, resistances of feeder and rail are 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 effects to maintain the vehicle voltage 1.5 [kV] and it can make the vehicle voltage lower than 900 [V] that is the standard limit.

3.2 Vehicle Model

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]



<Fig 3> Vehicle model

Vehicle load model on fig 3 has two parts. (a) is for reading consumed power calculated by TPS, and (b) is the constant load model that express railroad vehicle.[4][5]

3.3 TPS data

3.3.1 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, and so on. By these data, TPS calculate the mechanical power and make output data by assumption that mechanical power is equal to electrical power.

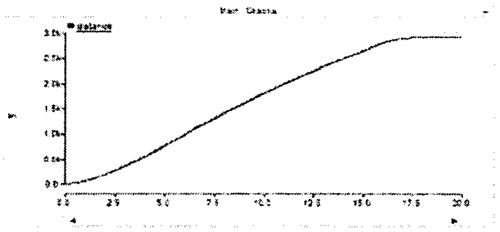
Fig 4 illustrates consumed power calculated by TPS while railroad vehicle drives between Apgujung and Sin-sa stations. The vehicle departs Apgujung station at 0.0 [sec], arrives Sin-sa station at 17.5 [sec], and departs Sin-sa station at 20.0 [sec].

<Fig 4> Vehicle model

3.3.2 Location of vehicle

TPS calculates location of vehicle from substation. The location of vehicle is important because it decides 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, vehicle voltage can be lowered under standard limit, 900 [V].

Fig 5 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 5. On case study, feeder voltage drop is simulated.

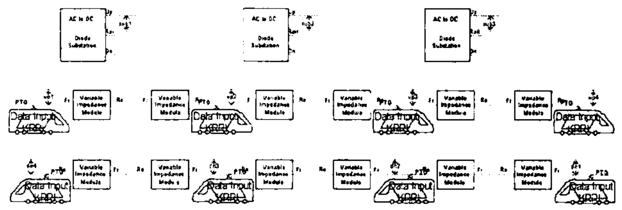


<Fig 5> Location from the substation

4. Case study

To see the voltage on railroad system, test system was constructed as illustrated on fig 6. This case study is to verify whether substation bus voltage and vehicle voltage is higher than standard limits, 1.1 [kV] and 900 [V] each. Especially in case of vehicles, if the voltage is lower than 900 [V], because of the inverter operation voltage, vehicles cannot operate.[6]

The simulation conditions which are the standard operation pattern on Korea railroad system are 4 [km] distance between substations, 52.5 [km/h] average velocity of vehicle, 4 [min] time intervals between vehicles driving, 175 [sec] moving time from Apgujung to Sin-sa, and 25 [sec] standing time on Sin-sa station. Resistance per kilometer of feeder and rail is 0.0205 [Ohm/km] and 0.00765 [Ohm/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 1.5 [kV] 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 200 [sec]. However, 200 [sec] is too long to perform EMTDC simulation by 100 [usec] time step. On this simulation, substation bus voltage, vehicle voltage, and feeder voltage drop are measured.



<Fig 6> Test system

On fig 6, 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 4 [min] time intervals. To perform case simulation, location of vehicle is reflected on simulation by using fig 5 location data. Also, fig 4 power consumption curve is used for consumed power of vehicle.

On table 1, minimum, maximum and standard limit voltages are indicated. No substations and vehicles are lower than standard limit voltage.

<Table 1> Simulation results

	Min. voltage	Max. voltage	Limit voltage
Substation 1	1481.6 [V]	1495.4 [V]	1100 [V]
Substation 2	1473.6 [V]	1499.5 [V]	1100 [V]
Substation 3	1473.6 [V]	1489.6 [V]	1100 [V]
Vehicle 1	1440.7 [V]	1467.9 [V]	900 [V]
Vehicle 2	1430.8 [V]	1453.2 [V]	900 [V]
Vehicle 3	1398.7 [V]	1491.4 [V]	900 [V]
Vehicle 4	1351.6 [V]	1499.6 [V]	900 [V]

The voltage drop on feeder is simulated. By varying the location and power of vehicle, the voltage drop on feeder is changed. On case study, the maximum voltage drop is presented 45[V] at 9.8[sec].

5. Conclusions

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 between 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.

Stable operation criteria is that each substations and vehicles voltage should be higher than standard limit voltage, 1100 and 900 [V]. Through case simulation, 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 advanced researches on DC railroad system activated.

[참 고 문 헌]

[1] "The report for railroad system standardization," Korea Railroad Research Institute, Eu-wang, Kyung-ki, Korea.

[2] Hansang Lee, Changmu Lee, Hanmin Lee, Gilsoo Jang "Analysis of Power Supplying Characteristic Following Load Pattern Using EMTDC and Proposal for Optimal Operation," The Korean Institute of Electric Engineering, Summer meeting, Korea, 2004.

[3] Stephan J. Chapman, "Electric Machinery Fundamentals," 3rd Edition, McGraw -Hill, 1999

[4] "Power Systems computer Aided Design," HVDC Research Center

[5] "Transient Analysis for PSCAD Power System Simulation," EMTDC User's Guide, HVDC Research Center

[6] E. Acha, V. G. Agelidis, O. Anaya-Lara, T. J. E. Miller, "Electric Machinery Fundamentals," Newnes, 2002