A study on results of TPS according to the optimum traction power supply system of Urban MAGLEV railway

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ABSTRACT: The main purpose of this study is to conduct correlation factor analysis in both headway time and power capacity by means of analytical approach to results of power property in terms of headway time of Urban MAGLEV from the standpoint of headway time of Urban MAGLEV on the Incheon international airport maglev railway, in the process of construction at the moment, in Korea. Railroad track, as a fundamental condition of service simulation, is set up with double track, and it is therefore that the three patterns of headway time of Urban MAGLEV on the track. TPS is performed by Urban MAGLEV operation consisted of three separated patterns in headway time on the double railroad track or the trial track. As a result of such simulation, three types of characteristics listed below were obtained.

1) The peak power capacity related to transportation demand on the trial track compared to the result given.

2) The optimum capacity of substation is determined based on the analysis.

3) The location of substations is determined based on the analysis.

The result of research performance, therefore, enables us to reflect the power supply system design for the stabilized and economized Urban MAGLEV operation

1 INTRODUCTION

After the initial study of MAGLEV train in Korea in the late 80',the proto type of MAGLEV train was developed and Korea Institute of Machinery & Material conducted its trial operation, and it have been operating with passengers on approximately 1 km routes built from national science museum in Daejeon to expo park. It has been finished in respect of its basic design and its practice design is in progress at this moment for improving the capability of railway carriage with travelers of Incheon Airport in order to continue approximately 6.1 kilometer-long trail railroad as national project at Incheon International Airport.

This system will be built as railroads of medium/slow-speed urban MAGLEV train, and results influenced by performance of the primary simulation are introduced for power supply system 's optimal design. The figure 1 below is a diagram on execution of traction power supply simulation.

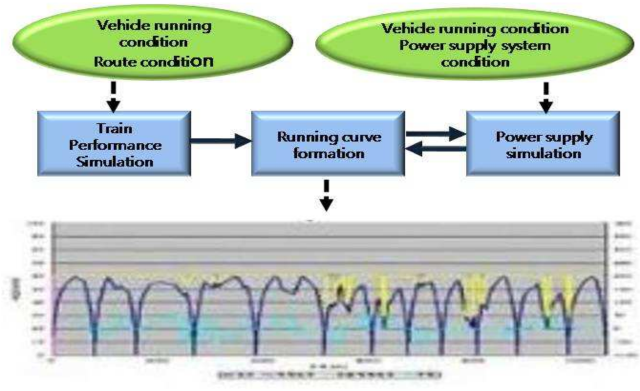


Figure 1. Diagram on execution of traction power supply simulation.

2 BASIC CONCEPTION OF TRACION POWER SUPPLY SYSTEM

Railway traction power supply system consists of substation facility, power conductor rail, train and return rail. Usually substation facilities of them can be classified into AC high voltage switchgear, rectifier transformer, rectifier, DC switchgear, inverter (or resistor bank) and SCADA system. The electrical power can be divided into traction power and station auxiliary power. The traction power circuit is usually designed into two banks for redundancy. In the DC traction power system, current from the traction power substation is delivered to the moving trains through both the positive conduct rail and negative conduct rail, and returned to the substations through the negative conduct rail.

To illustrate the power simulation of DC railway traction power network, the overall power flow scheme can be represented by each substation with transformer and rectifier, power cables, passenger stations according to train moving in Fig.2.

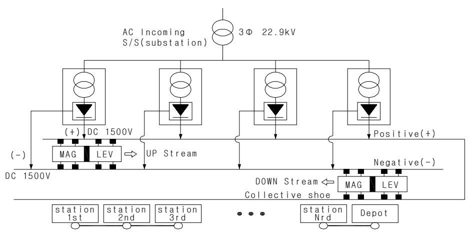
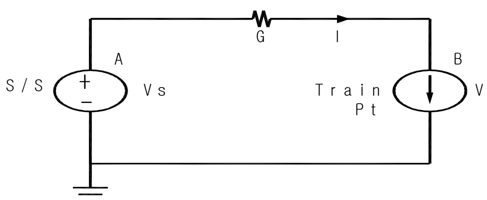


Figure 2. DC-fed traction power system.

With a train represented by a voltage source and a series conductance, a simple plain network is



shown schematically for power analysis in Fig.3. The DC voltage source, Vs, feeds a train load which draws power Pt through the conductor rail with conductance G.

It is assumed that Pt is fixed, although in reality it varies with different collector-shoe voltages and train speeds according to a series of curves which are not necessarily linear. [5, 6].

Figure 3. Simplified DC feeding circuit

3 BASIC DESIGN FOR ELECTRIC POWER SUPPLY SYSTEM

3.1. Network Analysis

The matrix equation describing the performance of a DC-traction power system in conductance form is as eq.(1)

$$[G][V] = [J] \tag{1}$$

This current source is connected between train collector-shoe node and train node at the train position. The nodal current of these nodes in the right-hand side vector [*J*] is replaced by either positive or negative train current. The solution is initiated by assuming that train voltages are all at the system-voltage level. Then, the train current is derived from the loading condition

$$I_{kt} = \frac{P_{kt}}{V}(kt = 1, 2, \ldots\ldots, kn) \tag{2}$$

where, *kt* refers to the train number and *kn* is the total number of trains in the system. The train current calculated from eq.(2) are substituted into eq.(1) to obtain a new set of train voltages. These new voltages are used in eq.(2) to recalculate train currents for a subsequence solution of eq.(1). The process will be carried out until a desired voltage tolerance is achieved. eq.(1) can be rewritten in a matrix form:

$$\begin{bmatrix} G_{11} & G_{12} & \cdots & G_{1n-1} & G_{1n} \\ G_{12} & G_{22} & \cdots & G_{1n-2} & G_{2n} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ G_{n-11} & G_{n-12} & \cdots & G_{n-1n-1} & G_{n-1n} \\ G_{n1} & G_{n2} & \cdots & G_{nn-1} & G_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_{n-1} \\ V_n \end{bmatrix} = \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_{n-1} \\ I_n \end{bmatrix} \tag{3}$$

where [*Gij*] is a conductance between node *I* and *j*, [*Vj*] is a node (substation, train, tie-post) voltage, and [*Ij*] is a node (substation, train, tie-post) current.

3.2. Simulation Algorithm

Fig. 4 shows the simulation configuration for the overall traction power system. It makes a digital train ride simulation including the entire electrical network possible. There are two steps of calculations in the simulation process. The first

one is on the train movement (TPS), the second one is on the electrical power supply network.

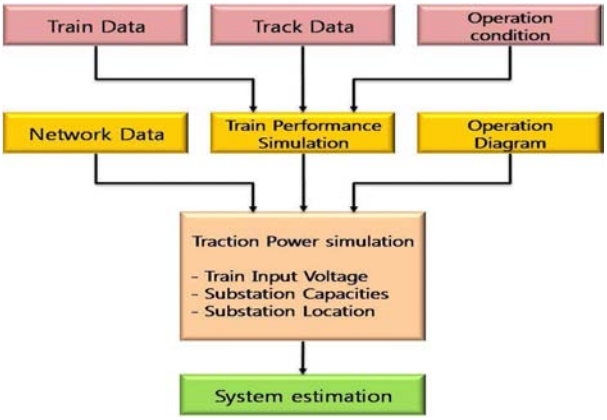


Figure 4. Traction power system simulation structure.

Fig. 5 shows the flowchart of proposed algorithm. Using eq.(2) and (3), the system basic value such as node voltage and current are estimated per every time step. The iteration stops when voltage value converges into the tolerance value.

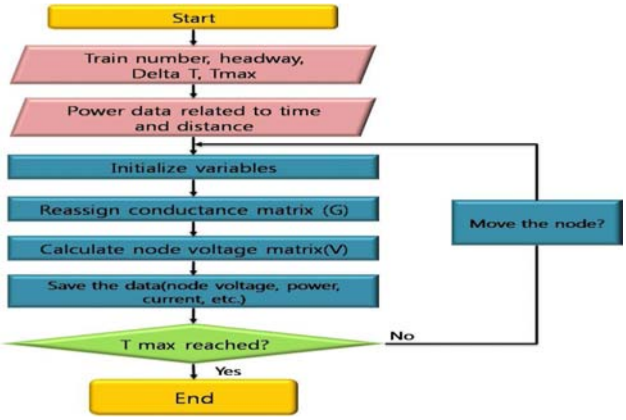


Figure 5. Simulation algorithm flowchart.

3.3. Procedures for Simulation

The proposed design procedures for the electrification system of the Urban MAGLEV line are summarized as follows.

Step 1) the most suitable position of substations are chosen from candidate group (substation, station and depot). Also, the candidates being easy to connect to power grid are more economic.

Step 2) the specialist considers voltage drop, economic performance, etc. from this candidate group and choose some cases which shall be arranged from candidates for substation position again.

Step 3) each selected case conducts power simulation to decide most suitable position and capacity.

Step 4) check the voltages at the pantograph from simulation result by considering the voltage drop to supply voltage magnitude more than smallest input voltage of VVVF inverter for traction motor. This voltage should always be in the range of 900 ~1800[V] for a nominal voltage of DC 1500[V] system.

Step 5) examine the overload requirement and peak power from simulation result. Rectifier capacity shall be required to endure 100[%] load continuously, 150[%] for 2 hours, 300[%] for 1 min. The rating of Rectifier decides by duty class 6 of IEC 146-1-1

Step 6) decide the most suitable locations of the substation and their capacities. And decide the capacity regenerative inverter if it is required.

3.4. The data of urban MAGLEV system

The data of urban MAGLEV system for simulation listed blow.

Table 1. Input Data for Simulation

Parts	Item	Unit	Remark
Running Condition (MAGLEV)	Train formation	2 Cars/train	
	Vehicle weight	56 Ton/train	28 Ton/car
	Vehicle Aux. Power	200kw/train	
	Station stop	30[sec]	
	Headway time	90[sec]	Max. time
	Cross time	30[sec]	
	Range of Voltage	900~1800[V]	
	Min Voltage	990[V]	10% Margin
	LIM (Linear Induction Motor)	16[ea]	Train formation
	Design Max speed	110km/h	
	Max acceleration	4.0[km/h/s]	
	Max deceleration	4.0[km/h/s]	
Power supply condition	Line Voltage	DC 1500[V]	
	Unload Voltage	DC 1620[V]	8% Margin
	Unload Voltage	DC 1750[V]	1 SS fault
	Inner resistance	0.03[Ω]	Substation
	Rate of Voltage range	8[%]	Substation
	Inner resistance	0.05[Ω]	Regenerative DIV
	Distortion power factor	95.5[%]	Rectifier
	Voltage drop	6[%]	Transformer
	Transformer efficiency	99[%]	
	Conductor resistance	0.02[Ω/km]	Power rail
	Cable resistance	0.0014 [Ω/km]	SS to Power rail
	Conductor current	2200[A]	Power rail
Simulation	Simulation time	3600[sec]	

Table 2. Main Facts of the Urban MALEV Line

Item	Unit	Remark
Length[m]	6,113	Except depot
Track type	Double	
Station	6	
Depot	1	
Substation	3	line:2, Depot:1

Table 3. Location of the Stations

Station	No	Location[m]
101	Station_1	28
102	Station_2	417
103	Station_3	907
104	Station_4	1383
105	Station_5	4854
106	Station_6	5883
Depot	Depot_1	6470

4 TRAIN PERFORMANCE SIMULATION RESULT

4.1 Determination of Substation site

Substation location is optimized 104 and 105 station searched through the simulation

Table 4. Case 1.(Substation Installation to 104 and 105)

Substation		nominal	1 SS fault	
			104	105
Aver. Load [kW]	104	2717.0	-	5138.5
	105	2280.o	5309.9	-
Max Load [kW]	104	4583.7	-	9021.2
	105	4018.2	9363.6	-
Min. Voltage of MAGLEV [V]		1462.5	1228.8	1359.5

Table 5. Case 2.(Substation Installation to 104 and 106)

Substation		nominal	1 SS fault	
			104	106
Aver. Load [kW]	104	2898.6	-	5141.3
	106	2101.6	5595.0	-
Max Load [kW]	104	4785.0	-	9023.4
	106	3716.9	10460.9	-
Min. Voltage of MAGLEV [V]		1474.5	1013.1	1368.9

Table 6. Comparison of case 1 and case 2

Case1	strength	○ The load shared between substations is excellent. ○ The voltage drop is relatively lower.
	weakness	○ The substation of No.105 is far from the depot.
case 2	strength	○ The substation of No.106 is close to the depot.
	weakness	○ The load shared between substations is not good relatively ○ The voltage drop is relatively higher.

4.2 Calculation of Rectifier capacity

It was assumed that rectifier capacity of each substation is equivalent to the others considering the advantage of regular maintenance and repair. Estimation of capacity took into account both the subsequent formula (1) and the formula (2) at a time.

Continuous rating>average load x 110% (1)

Continuous rating >maximum load x 110%/300% (2)

(1) Rectifier capacity of operation at the stage 1 (7 min internal)
In case of 7 minutes per hour, as seen in the table 6, the maximum load indicates 1104kw, and capacity of an individual rectifier is established as 2000kw due to rectifier capacity(more than 1104 x 1.1=1214Kw) estimating its capacity in consideration of the clearance (10%)
In the other hand, the maximum load is, from the table 6, 2297kw and it is 2297 x 110%/300%=1099KW<2000kw regarding the clearance (10%), therefore, short-term rating is qualified.

(2) Rectifier capacity of operation at the stage 2 (3 min internal)
It was assumed that an additional rectifier having an even-sized capacity with the rectifier adapted at the stage 1 was built in case of 3 minutes per hour.
In this case, we examined that the rectifier is sufficient for the condition of average load and maximum load regarding the total amount of rectifier capacity (2000kw x 2=4000kw).
In the table 7, the maximum average load is 2596Kw (2596Kw x 110% <4000kw), therefore, it satisfies Continuous rating (formula 1), and maximum load which is 6309 x 110%/300%=1099Kw is regarded as sufficient in terms of short-term (within 1 minute) rating required.

(3) Rectifier capacity of operation at the final stage (1.5 min internal)
At the final stage, we hypothesized that three rectifier having an even-sized capacity with the rectifier adapted at the stage 1 were operated in parallel.
Namely, we analyzed that it had satisfactory results under conditions of average load condition(formula 1)and maximum load condition (formula 2) when operating at the level of 1.5

minutes per hour in case of continuous rating rectifier (6000kw).

In the table 7, the maximum average load is 5310kw (5310kw x 110%=5841Kw<6000Kw), therefore, it is sufficient for the formula (1), and maximum load is 9364kw (9364 x 110%/300%=3433Kw<6000Kw) is also satisfactory for formula (2).

Table 7. Max & Min load of substation in intervals

Interval		7min			3min			1.5 min		
Running state		nominal	104 fault	105 fault	nominal	104 fault	105 fault	nominal	104 fault	105 fault
average load	104 Substation	588		1097	1356		2543	2717		5139
	105 Substation	496	1104		1137	2596		2280	5310	
maximum load	104 Substation	2000		2798	3357		5746	4584		9021
	105 Substation	1392	2997		2266	6309		4018	9364	

4.3 Design of Transformer capacity for rectifier

Transformer for rectifier (2500 KVA) is linked to a rectifier (2000kw). Thus, at the last stage (1.5 minutes per hour) where three rectifiers are built, the three transformers for rectifier (2500kVA) will be built.

Distortion Power Factor of Rectifier = 95.5%
Voltage drop by Tr leakage inductance = 6%
Transformer efficiency = 99%
Transformer capacity for rectifier> 2000Kw x 1.06/0.955 x 0.99=2243Kw.

Therefore, transformer capacity for rectifier has 2500kVA .

4.4 Examination of Regenerative energy absorb device

(1) study of regenerative energy quantity and substation absorb quantity

In case that one railway carriage runs in both-way operation, running energy and regenerative energy are considered as shown below, respectively

Running energy = 77.9[kwh]
Regenerative energy = 19.4[kwh]
Regenerative rate = 19.4/77.9 x 100%=24.9

Regenerative rate of 24.9% does not refer to 'a possibility of returning 24.9& on running energy.

Electric energy recycled from the railway carriage is primarily utilized as a supplementary power for itself

Extra energy after utilization of auxiliary power is employed as running energy for a railway carriage in operation nearby through streetcar line.

(Substation with diode rectifier make feeding in parallel, therefore, catenaries of all lines are not separated and electronically related and vehicle regenerative energy is, as a result, possible to be used in all railway carriages in operation.

Thus, at the center of our focus is the amount of regenerative energy absolved by regenerative energy absorb device of substation. Regenerative energy quantity is slight.

The reason is that supplementary power (200kw) is large.

Regenerative energy of a railway carriage is primarily consumed by the inside of itself vehicle.

At the same time, absorb quantity of regenerative energy shortens as interval time does.

The reason is that regenerative energy is consumed by the other railway carriage reversing.

The table 8 is a result of simulation at 7 minutes per hour

In the left column, it is seen as the result of the supplementary power (200kw), and in the right, it is the one of the supplementary power (30kw),

As seen in the table 8, economic efficiency of the maximum absorb regenerative energy is not significant in terms of conditioning of 58.3kwh at 7 minutes per hour.

Simply, in case that regenerative energy absorb device is obliged to be built due to a technical issue, it is calculated that building one in substation is sufficient without having two in both substation.

(2) Study of regenerative energy absorb device capacity

Form of regenerative energy absorb device is identified as the one consisting Chopper(DC-DC Converter) and Super Capacitor

This formulation is more effective than others.

Thus, capacity of DC-DC Converter and Super Capacitor is analyzed.

The capacity of DC-DC Converter is quoted in an unit of electricity, therefore, power moment value can be an account for capacity calculation, and capacitor is quoted in energy, that is an unit of kj in terms of capacity, the cumulative value during certain period of power is, at last, ground for capacity calculation.

Given that Capacitor shifts in regard of charge and discharge of electricity in turn, charge quantity demanded should be investigated in a given period of time for calculation of capacitor capability.

In the simulation of this study, it was calculated in separation of temporal cumulative values (energy): 10 sec, 20 sec, 30 sec, 40 sec, 50 sec, and 60 sec, and the maximum charge quantity demanded among them was the account for capacitor capacity calculation .

However, it could be possible to have a maximum charge quantity demanded out of the given period, there was additional 10% deviation due to cross time.

Capacity of DC-DC Converter was, as the same with the case of inverter, calculated by criterion for standard of duration for 1 minute with 300% of the rated road and for 2 hours with 150% of the rated road.

5 CONCLUSIONS

DC traction power supply system of a planed Korean Urban MAGLEV line, which is being most important in operation of Urban MAGLEV. The main conclusions in this paper are summarized as follows.

1) For the analysis and design of the system, characteristics of a train, feeding network configuration, and design method of substation arrangements have been clarified.

2) Its assessment of the system has been made using the most suitable iterative method with nodal equation at network analysis and power calculations.

3) In order to evaluate and design the system from computer simulation results, the procedure was proposed.

4) The design of DC traction power supply system for a planed Korean Urban MAGLEV line was conducted.

Therefore, most suitable locations of the substation and their capacities were determined using the result of simulation according to the proposed procedure based on the IEC and the EN50163.

TPS is performed by Urban MAGLEV operation consisted of three separated patterns in headway time on the double railroad track or the trial track. As a result of such simulation, three types of characteristics listed below were obtained.

1) The peak power capacity related to transportation demand on the trial track compared to the result given.

2) The optimum capacity of substation is determined based on the analysis.

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The result of research performance, therefore, enables us to reflect the Power Supply System design for the stabilized and economized Urban MAGLEV operation.

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