A Study on Braking Energy Pattern on Tilting Train

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ABSTRACT: Korean-style tilting train (TTX), dubbed "Hanbit 200" which was developed by Korea Railroad Research Institute (KRRI) has been in trial operation on Honam, Jonngang, Choongbuk and Taebaek line. In this study, the voltage supplied to TTX in trial operation was monitored and analyzed to identify the voltage condition supplied by the existing railroad. To directly measure the voltage supplied to TTX, PT was installed at the bottom of TTX pantograph for monitoring the primary voltage of the transformer, and for accurate measuring, surrounding environment and conditions were recorded and the analysis of stringing voltage using CBEMA curve was conducted. As a result, some of the section on Honam, Jonngang and Taebaek line were supplied 110[%] pf rated voltage (25[kV]) for more than 200[s] frequently exceeding 110[%] Taebaek line appeared to have had the installed voltage in worst condition. The analyzed data is expected to be helpful in stabilizing the power system and power conversion system of TTX which will run Jonngang and Taebaek line.

1 INTRODUCTION

Electric railway has been increasingly adopted in advanced nations for its environment-friendly features and high energy efficiency, indicating the electrification rate of 49% in France, 53% in germany and 77% in Sweden. In line with such a trend, Korea established a long-term railroad network scheme for the 21st century and developed the high-tech Korean-style tilting train (TTX), dubbed "Hanbit 200" to replace the deteriorated Saemaeul train. The Korean-style tilting train (TTX), "Hanbit 200" is the electric car incorporating tilting system which enables to run the curve without reducing the speed while existing train reduces the speed by 20~30%.
"Hanbit 200" will be running Jonngang and Taebaek line where high-sped rail hast yet to be installed. Before starting operation, "Hanbit 200" has been in test operation on Honam, Jonngang, Choongbuk and Taebaek line, and the study to secure the further safety has been in process now. The study was intended to monitor the voltage supplied to "Hanbit 200" from the existing railroad to ensure the power supplied by Honam, Jonngang, Choongbuk and Taebaek line will be compatible with the design of "Hanbit 200"

Electric railway car is subject to movable load. Rated load of "Hanbit 200" is 4[MW] However as a result of measuring the electric energy on Joongang line during test operation, it's 1.94[MW] in coasting driving mode and 2.36[MW] in power driving mode and the maximum was 4[MW], which indicated fluctuated load with changeable voltage. Should low voltage or overvoltage be supplied due to voltage variance, it would possibly cause a great stress and trouble to the car which may lead to the serious accident.

Table 1 Regulation of voltage and technical specification

Classification	Description	
Regulation of voltage	19 ~ 27.5[kV]	
Technical specification	23.5 ~ 27.5[kV]	Car power 100[%]
	19 ~ 23.5[kV]	Proportional
Hanbit 200	17.5 ~ 30[kV]	Car power 100[%]
	Other range	Protection device starts operating
Toshiba Inverter specification	19 ~ 30[kV]	Car power 100[%]
	Other range	Protection device starts operating

Thus, regulation of the voltage shall be set 19~27.5[kV] and the car shall be manufactured to be compatible with this range. So the specification of "Hanbit 200" defines as Table 1. "Hanbit 200" was also manufactured according to the Table 1 to cope with the extreme voltage variance and Toshiba-manufactured inverter was also manufactured to cope with such voltage regulation. In fact, manufacture specification is stricter than this specification.

There are many ways of evaluating the voltage quality and in this study, a Computer Business Equipment Manufacturer Association Curve (CBEMA) curve which enable to evaluate the momentary voltage drop (sag) or momentary voltage rise (swell) was adopted. CBEMA curve was used as the tool to indicate the resistance against the voltage disturbance and then has been used currently in indicating the data for evaluation of the system against the voltage variance.

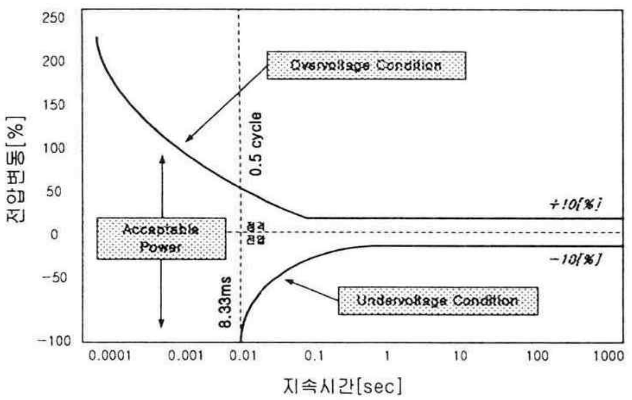

Fig 1 CBEMA curve

Fig 1. shows the CBEMA curve. It comprises the two curves and the territory inside two curves indicated the allowable voltage territory which has nothing to do with equipment operation, which is indicated as duration time and voltage scale. Should it be out of this territory, it causes overvoltage or low voltage.

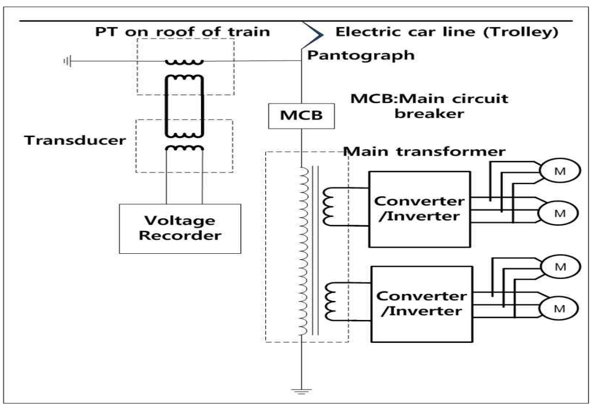

Fig 2. Measurement point of service voltage

To directly measure the voltage supplied to the electric car, PT was installed at the bottom of pantograph of "Hanbit 200" and the primary voltage of main transformer was monitored. Fluke's FLUKE 1760 was used as the record to measure the voltage at 0/2[s] interval.

Table 2 The sections of voltage measurement

Line	Section	Distance	Open year
Honam	Iksan ~ Songjeongri (round trip)	68.8[km]	04.04.01
Jungang	Youngju ~ Wonju	110.6[km]	87.12.30
Choongbuk	Bongyang ~ Ohgeunjang	89.5[km]	05.03.30
Taebaek	Yeonha ~ Jecheon	109.0[km]	74.06.20

The routes where the Hanbit 200" is in test operation are Honam, Jungang, Choongbuk and Taebaek line. In this study, as indicated in Table 2, service voltage at the section of "Hanbit 200" was measured. AC25[kC] and AT (auto transformer) were applied over entire section. Among the sections, Honam line is part of KTX route where the traffic is frequent, while Moogunghwa and Saemaeul run Choongbuk line less than 83 trips and Jungang and Taebaek line, which are categorized into the industrial line accommodate 46 trips a day.

2 POWER PATTEN OF TILTING TRAIN

2.1 Analysis of operation characteristicsof electric railway

Brakes is appled, during train operation, depending on train speed, slope, curve and operator's operation pattern and the braking force required is demand braking force. With regard to demand braking force, electrical braking force is determined depending on service voltage and surrounding condition and intimate interface with mechanical braking system is needed, Because of noise, steel dust generated by friction with brake pad and increase in maintenance cost, the railroad operators demand the electric railway car manufacturers that the mechanical braking be minimized.

Though the role of electric braking has been on the rise, the maximum allowable voltage is limited to 28[kV] by substation for the safety. So, to maintain more than 90% of regenerative braking during operation, many efforts such as the resistor to consume the regenerative braking energy have been made. In this study, the characteristics of electric braking and mechanical braking in response to braking demand were reviewed. Regenerative braking is known to be 30 ~ 40% but it varies depending on railway. Thus, demand braking force and electric braking force were monitored from the tilting train running on Honam, Joongang and Choongbuk line and evaluated by line.

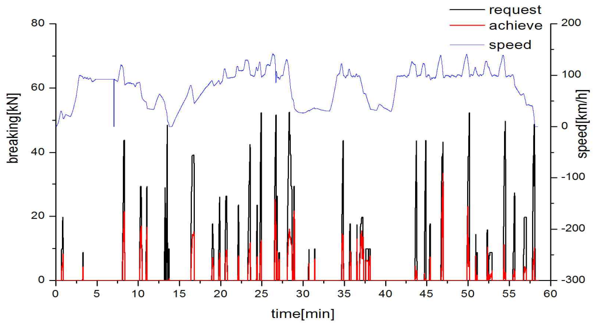

Fig 3. Braking characteristic on Honam line

Honam line has extended route and the max speed is 160km/h which is the highest among existing lines. To maintain such speed, high propulsion and braking force are needed. Fig 3 shows the demand braking force and regenerative braking force on Honam line. Generally, demand braking force per time is higher than other lines and the same to regenerative braking force, which means regenerative energy could be accommodated at favorable condition because of high substation capacity and frequent train operation.

2.2 *Analysis of braking energy distribution characteristic of electric train*

Fig 4 ~ [Fig 3-50] show the braking energy needed for braking on Honam, Joongang and Chungbuk line. It's the braking energy needed for the train per brake and to reduce the speed by mechanical braking and electric braking. Demand braking energy on Honam line was 14[MJ] which was dependent on train speed and quick braking as aforementioned.

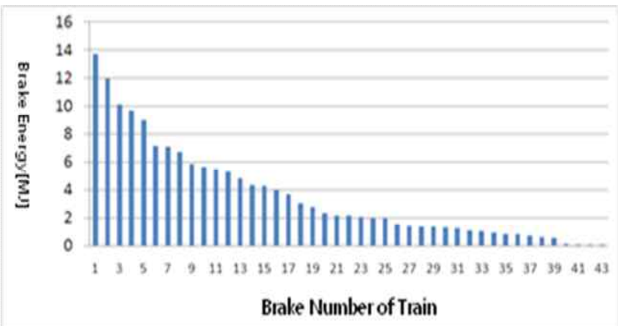

Fig 4. Distribution of braking energy (Honam line)

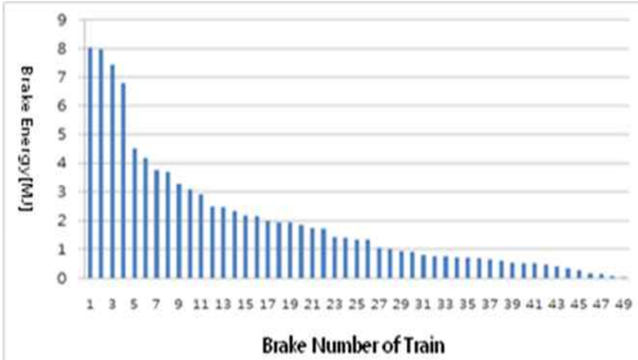

Fig 5. Distribution of braking energy (Joongang line)

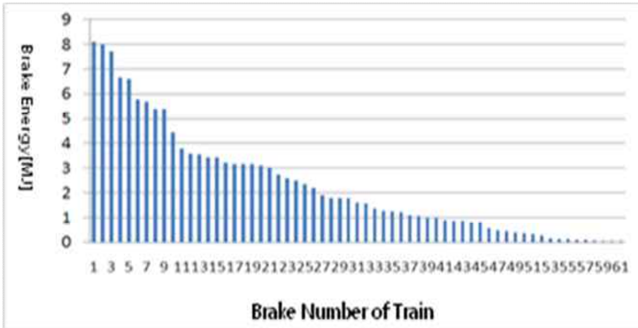

Fig 6. Distribution of braking energy (Choongbuk line)

When it comes to Joongang and Choongbuk line, maximum braking energy was 8[MJ], indicating a slower speed than Honam line and in general, a considerable amount of braking was required on Hinam line. On Honam line, braking energy was distributed on 6[MJ] or less, while Joongang and Choongbuk line were 4[MJ] or less.

3 CONCLUSIONS

With regard to the electric power quality in electric railway system, the damage was occurred by various causes including malfunction of the on-board equipment, inductive disturbance of communication cable, power loss by resonance of high harmonics, damage of weak electric equipment, malfunction of protective relay and increased loss by deteriorated power quality and so on. The power quality problems is also attributable to using various types of railroad vehicles from old model motor car using diode rectifier to KTX using semi-bridge rectifier, motorized car using PWM control inverter or VVVF control. Despite of high harmonics with various orders, electric braking using regenerative braking has been adopted, which causes deteriorated electric power quality and the negative effect on high

harmonics and voltage fluctuation, leading to increasing malfunction. Thus, the range of higher harmonics and voltage fluctuation are strictly limited by domestic electric facility standard or IEC standard. In addition, the study in an effort to enhance the electric power quality has been underway.
The efforts to evaluate the electric power quality of the electric vehicle system in operation as well as to seek the measure to improve the quality have been made. For the electric railway under construction, it's requested to minimize the higher harmonics and voltage regulation by applying comprehensive operation conditions.
A greater part of the problems with the high harmonics was caused by increase in high harmonic ratio by propulsion and braking which are repeated during train operation. In a bid to deal with such problems, characteristics of electric power were evaluated by operation mode so as to carry out the study on regenerative energy pattern by regenerative braking. Regenerative energy is transmitted to regenerative isolation or resistance for consumption when the car is not in operation.
It's necessary to implement the further study by conducting the test of regenerative energy pattern system for evaluating the performance continuously as well as verifying the reliability and safety of the proposed system.

4 REFERENCES

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