

## Field Tests of DC 1500 V Stationary Energy Storage System

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### Abstract

The ESS(energy storage system, here after) for a DC 1500V was developed in 2009. A ESS was installed on the track of Daejeon HRT in 2010. The advantage of the ESS is that it can save the energy and plus stable the catenary voltage. This paper presents the energy saved by the ESS in Daedong substation. When the ESS is on/off, the field tests are performed.

**Keywords :** Energy storage system, Saving energy rate, EDLC, Urban transit system

### 1. Introduction

The Korean government announced a plan to cut greenhouse gas emissions by 21-30 percent by 2020, as part of the “Business as Usual” (BAU) campaign. The government plans to reduce carbon emissions from the transportation sector by 33-37 percent by 2020. The government is also pushing ahead with the development of eco-friendly transportation systems such as those that use recycled energy. Therefore, urban transit companies should consider incorporating energy storage systems as a means of saving energy. Due to the recent environmental protection trend, which enforces more strict energy savings, every transportation system should reduce energy consumption to the absolute minimum. High-efficiency operation systems, energy saving methods, and CO<sub>2</sub> emissions have become vital issues in the railway system, as well as other major public transportation systems [1].

The Korean electric railway system is used to transport several million commuters on a daily basis. There are distinct characteristics to this system, owing to the fact that the vehicles are being driven by electricity, such as variations in displacement and power. Notably, the vehicles generate regenerative power on braking but some of this power, which cannot be supplied to the other accelerating vehicles, is being wasted; it is being dissipated as heat at

present [2-4]. Since the vehicles in suburban railway systems repeatedly accelerate and brake, it is obvious that the utilization of some ESS would aid in saving energy and considerably improve the energy efficiency of the electric railway system. The ESS is considered to be one of the useful devices for energy storing and recycling [5,6].

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### 2. Energy Storage System

The system saves energy by efficiently using regenerated energy. Regenerated energy is recycled amongst vehicles by mean of charge and discharge corresponding to powering and braking of electric vehicle operations. Fig. 1 shows how the ESS stores the energy generated during braking, and discharges it again when a vehicle accelerates. The ESS stores excess energy caused by braking

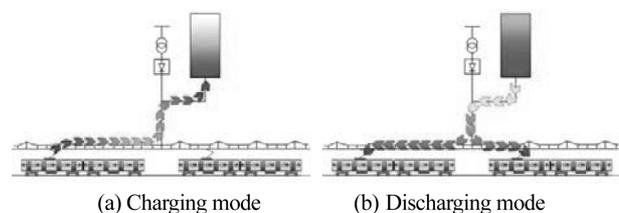


Fig. 1 Charging and discharging mode

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Fig. 2 Developing and installing process



Fig. 3 Daejeon HRT line

vehicles. The powering vehicle receives traction power from a substation and the ESS. Excess energy is distributed amongst powering and braking vehicles [7,8].

### 3. Test Plan

The ESS was installed on 2010.8.28. We measured the regenerative energy and reviewed to put it in Daedong substation. Development and installation of the ESS are shown in Fig. 2.

#### 3.1 Substation

A ESS is installed on the track of Daejeon HRT in Korea. The ESS is tested in Daedong substation. Fig. 3 shows the system configuration.

The power system in the railway substation converts AC 22.9 kV to DC 1500 V. The power system having 12-pulse forward diode rectifiers injects DC power into the catenary as shown in Fig. 4.

#### 3.2 Vehicle

The 4-car Vehicles run on the Daejeon line. Vehicle's

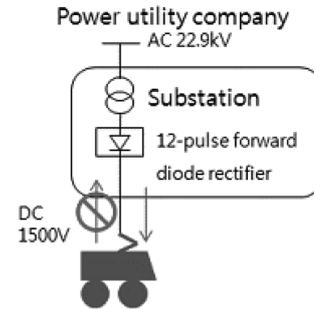


Fig. 4 Daejeon HRT railway system

Table 1. Vehicle's characteristics

	Characteristics
Vehicle	4-car
Tare weight	16 ton/car
Voltage	DC 1500 V
Maximum Speed	80 km/h
Service acceleration rate	3.0 km/h/s
Service deceleration rate	3.5 km/h/s
Jerk	Below 0.8 m/s <sup>3</sup>
Motor Power	1680 kW(210 kW x 8 motors)
SIV	120 kVA

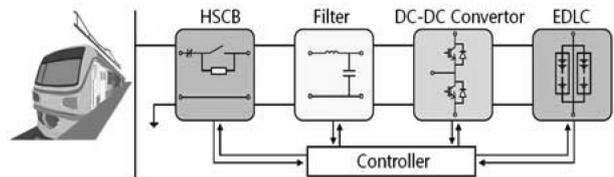


Fig. 5 The Configuration of the ESS

characteristics are shown in Table 1.

#### 3.3 Track

Daejeon Metropolitan Rapid Transit Corporation operates a 20.5 km-long single line from Banseok Station to Panam Station. Trains are normally composed of four cars with a regenerating brake system. The headway during rush-hour is 5 min. The headway during off-peak hours is 10 min.

#### 3.4 ESS configuration and specification

Fig. 5 shows the ESS configuration. The system can be connected either directly to the traction power supply system or the busbar in the substation by means of the connection unit, which comprises the disconnector, the DC high-speed circuit-breaker and the precharging unit.

The connection between the connection unit and the

**Table 2.** The specification of the ESS

Technical Data		
Configuration	Size	1.83 m(H)
		1.2 m(W)
		1.3 m(D)
EDLC	Elec. Characteristic	Max. volt
		1,166 [V]
		Max. Amp
		200 A x 8(parallel)
		Capacity
		55 [F]
		Total Energy
		37.39 [MJ]
Chopper Feeder Volt	Charging Volt	1,680 [V]
	Discharging Volt	1,620 [V]
DC high-speed circuit -breaker	Rated Volt.	1,500 [V]
	Rated Amp	1,200 [A]
	Breaking Amp.	1,400A~1,800 [A]
Discharging resistance	Resistance	10 [ $\Omega$ ]
	Max. Amp	110 [A]

actual storage unit is made by the standard vehicle converter, which functions as a step-up/step-down converter. The chopper system has a bi-directional function. It works as a chopper to decrease voltage when it charges up the EDLCs (Electric double-layer capacitors) as media and to increase voltage when it discharges them.

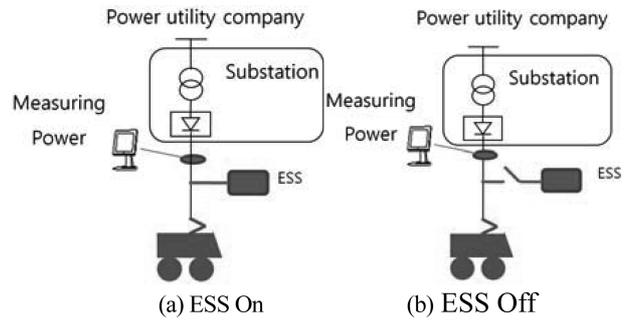
The group of the EDLCs consists of 192 modules, with 8 molecules connected in a parallel configuration, and 24 groups in a series. The maximum voltage per module is 48.6V, and the capacity is 165F. The specification of the ESS is shown in Table 2.

#### 4. Measuring Consumptive and Regenerative Energy

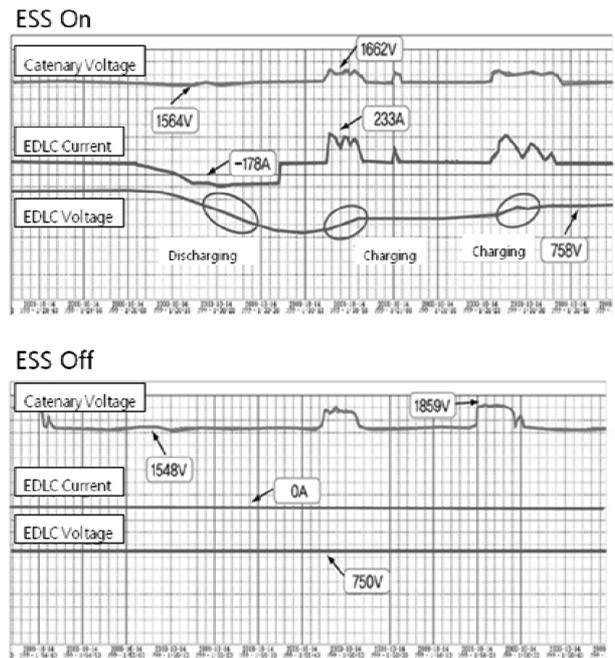
The vehicles run on the track. When the ESS is on/off, the consumed energy is measured in Daedong substation as shown in Fig. 6. When the ESS is on/off, the ESS charges the regenerative energy.

##### 4.1 Process

- (1) Preliminary inspection
  - (a) the DCPT and CTs are installed in feeders to measure the consumption energy.
  - (b) the vehicles run on the line
- (2) ESS: On
  - (a) Turning the ESS on.
  - (b) Measuring consumption power, feeder voltage and temperatures of heat-pipe and boost reactor in Dae-



**Fig. 6** Measurement of energy saving



**Fig. 7** Charging / discharging wave form

- (c) Calculating consumption power by the measured data.
- (3) ESS: Off
  - (a) Turning the ESS off.
  - (b) Measuring consumption power, feeder voltage and temperatures of heat-pipe and boost reactor in Daedong substation.
  - (c) Calculating consumption power by the measured data.

#### 5. Results

Fig. 7 shows charging/discharging wave forms of the installed ESS. The EDLC voltage falls at the time of powering, but the catenary voltage doesn't fall a lot. So it is expected that the voltage drop of the railway vehicle may be deterred by the discharge of EDLCs. On the other hand,

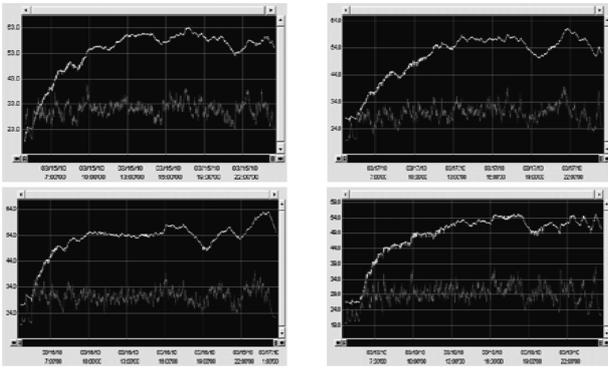


Fig. 8 Temperature test

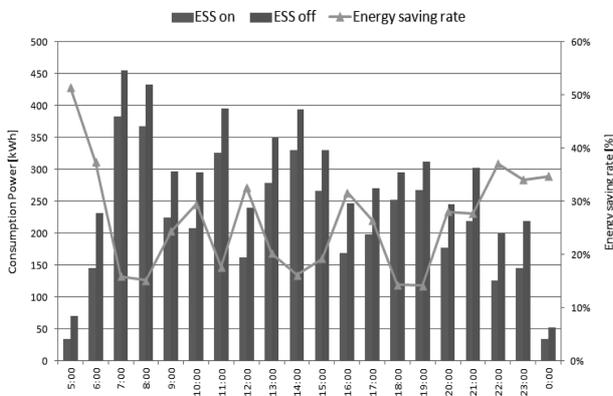


Fig. 9 Consumption power in Daedong substation

the catenary voltage doesn't rise at the time of regeneration. The ESS continues charging and discharging in this manner because the ESS voltage reverts to the maximum through one charge/discharge pattern.

Before the ESS is installed in Daedong substation, the voltage is fluctuated from 1548 V to 1859 V. The voltage is fluctuated within  $\pm 19\%$ . After the ESS is installed in Daedong substation, the voltage is very stable. The voltage is fluctuated within  $\pm 6\%$  from 1564 V to 1662 V.

Temperature tests are shown in Fig. 6. Temperature of Heat-pipe does not go over 40°C. The protective operation temperature is set 80°C. Boost reactor also does not go over 65°C. The protective operation temperature is set 170°C.

The tests were officially performed by KIER (Korea Institute of Energy Research) in 2010. The vehicles run and consumption power data are recorded in Daedong substation when the ESS is on/off. The detail data of consumption power in Daedong substation are shown in Fig. 9 and Table 3.

The summary results are shown in Table 4. As the test results, when the ESS is on, the consumption power is 4313.85 kWh. When the ESS is off, the consumption power is 5633.57 kWh. Therefore, the energy saving rate

Table 3. Energy saving rate

Time		ESS on	ESS off	Energy saving rate
Start	End	[kWh]	[kWh]	[%]
4:30	5:00	0.00	0.00	0.00
5:00	6:00	34.11	70.23	51.43
6:00	7:00	145.19	231.78	37.36
7:00	8:00	383.28	455.58	15.87
8:00	9:00	367.54	433.11	15.14
9:00	10:00	224.78	297.26	24.38
10:00	11:00	208.14	295.04	29.46
11:00	12:00	326.11	395.76	17.60
12:00	13:00	161.75	240.04	32.62
13:00	14:00	279.03	349.70	20.21
14:00	15:00	330.55	394.19	16.14
15:00	16:00	266.46	329.69	19.18
16:00	17:00	168.61	246.66	31.64
17:00	18:00	198.65	269.79	26.37
18:00	19:00	252.85	294.89	14.26
19:00	20:00	267.53	311.45	14.10
20:00	21:00	176.51	245.34	28.05
21:00	22:00	218.40	302.00	27.68
22:00	23:00	125.55	199.34	37.02
23:00	0:00	144.69	219.44	34.06
0:00	0:30	34.14	52.29	34.70
total		4313.85	5633.57	23.43

Table 4. Vehicle's characteristics

	Consumption power[kWh]		Energy Saving Rate[%]
	ESS : On	ESS : Off	
Mena value of Measured data	4313.85	5633.57	23.4%

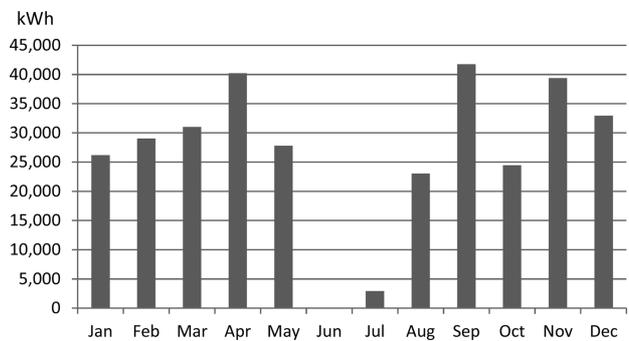


Fig. 10 Saved energy for 10 months

is 23.4%.

Since 2010, the ESS saved energy, 318,762 kWh(about

50 Million Won). The ESS was checked Contactors, chopper stack, fans, etc. for and overhaul in June and July.

#### 4. Conclusion

The energy storage system for a DC 1500 V electrified railway was developed. An energy storage system was built for the DC 1500 V and verification tests were conducted in cooperation with the Daejeon Metropolitan Rapid Transit Corporation. We carried out charge/discharge tests with the 1500 V ESS to verify its ability to contribute to a stable power supply for DC electrified railways.

Before the ESS is installed, the fluctuation of voltage is within  $\pm 19\%$ . After the ESS is installed in Daedong substation, the voltage is very stable within  $\pm 6\%$  from 1564 V to 1662 V. Temperature tests are under limited value.

When the ESS is on/off, the energy saving rate is tested. When the ESS is on, the consumption power is 4313.85 kWh. When the ESS is off, the consumption power is 5633.57 kWh. Therefore, the energy saving rate is 23.4%. Since 2010, the ESS saved energy, 318,762 kWh (about 50 Million Won). Therefore, the ESS is considered to be one of the useful devices for energy storing and recycling.

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