BATTERY POWER SYSTEM
FOR TRACKSIDE ENERGY STORGE

Final Report

Prepared for

THE NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY

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Agreement # 11043

October 2010

NOTICE

Abstract and Key Words

Abstract:

This energy wayside storage project was installed and tested by Kawasaki Rail Car, Inc. (KRC) and Kawasaki Heavy Industries, Ltd. (KHI) using it's Gigacell Battery technology. It tested the Nickel Metal Hydride (Ni-MH) Battery Power System (BPS) by storing the regenerative braking energy of the transit subway vehicles through the electrified third rail. The BPS then supplied this stored energy to the system to provide voltage stabilization, demand reduction and energy efficiency during the starting, acceleration and running of the trains in commercial service.

The Test Program was sponsored by the New York State Energy Research and Development Authority (NYSERDA) and was performed with the cooperation and support of New York City Transit (NYCT).

The tests demonstrated the following:

1) The BPS stabilized the dramatic fluctuations in the third rail line voltage.

2) The BPS efficiently captured the regenerated braking energy and used this energy as needed. This reduced the contract energy requirements and therefore CO_2 emissions.

3) The peak demand requirement can be reduced.

4) The BPS started a 10-car train from a complete standstill and operated it for a full round trip on the test track while all its lights and auxiliary equipment were "ON". It proved that up to 17 10-car trains could be moved to the next station during an emergency power outage condition.

5) The BPS was easily installed by direct connection to the third rail line voltage without any electronic controls and had no measured EMI impact.

The tests met or exceeded the Project Objectives.

Key Words:

1) Wayside storage
2) Nickel Metal Hydride Battery
3) Battery power system
4) Regenerative braking
5) Third rail
6) Voltage stabilization
7) Demand power
8) Contract power
9) Peak demand
10) Emergency power
11) EMI
12) Kawasaki
13) New York State Energy Research and Development Authority
14) New York City Transit
15) NYSERDA
16) NYCT
17) KHI
18) KRC

Kawasaki

New York City Transit

Battery Power System (BPS) Verification Test Report

DELIVERY	ORDER NO. R1H2358-50	KAWASAKI HEAVY INDUSTRIES, LTD.
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	DATE October 29, 2010	Document No. GSE-100045

(36 SHEETS COVER Inc.)

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1. Summary

The Test Program was sponsored by the New York State Energy Research and Development Authority (NYSERDA) and was performed with the cooperation and support of the New York City Transit (NYCT).

The Test Report details the results of the Verification Test of the Kawasaki BPS conducted on the NYCT Property. This energy wayside storage project was installed and tested by Kawasaki Rail Car, Inc. (KRC) and Kawasaki Heavy Industries, Ltd. (KHI) using it's Gigacell Battery technology. It tested the Nickel Metal Hydride (Ni-MH) Battery Power System (BPS) by storing the regenerative braking energy of the transit subway vehicles through the electrified third rail. The BPS then supplied this stored energy to the system to provide voltage stabilization, demand reduction, energy efficiency during the starting, acceleration and running of the trains in commercial service and emergency power during power outages.

The tests demonstrated the following:

1) The BPS stabilized the dramatic fluctuations in the third rail line voltage. It was demonstrated that the voltage fluctuations were reduced by 50% during both controlled full throttle acceleration and operational peak power testing.

2) The BPS efficiently captured the train regenerated braking energy and used this energy as needed. The tests proved that the BPS enables the amount of regenerative energy to at least double and that it is capable of efficiently capturing at least 70% of this regenerated energy. This reduces the contract energy requirements and therefore CO_2 emissions.

3) The BPS started a 10-car train from a complete standstill and operated it for a full round trip on the test track while all its lights and auxiliary equipment were “ON”. The test proved that up to 17, 10-car trains could be moved to the next station during an emergency power outage condition.

4) The BPS was easily installed by direct connection to the third rail without any electronic controls and had no measured EMI impact.

5) The peak demand requirement can be reduced. This parameter was not intended as a part of the verification test but the tests did show that the peak demand was reduced. However, the location of these tests at Far Rockaway

was not in the area of the expansive NYCT system where the peak demand occurred, which was in Manhattan, and therefore the demonstrated peak reduction occurred slightly before the measured time of peak demand in the entire system.

Kawasaki is confident that these Verification Test Results prove that the benefits of the Kawasaki BPS to the NYCT and other Transit Authorities and Railroads around the World.

Kawasaki Heavy Industries, Ltd. and Kawasaki Rail Car, Inc. wishes to extend its sincere gratitude to the New York City Transit (NYCT) for the full and complete cooperation it provided during this verification test of the Kawasaki BPS, which began on February 16, 2010. We also wish to extend our appreciation and thanks to the New York State Energy Research and Development Authority (NYSERDA) for the monetary assistance and guidance it provided.

2. Test Location

The following shows where this verification test was conducted. As can be seen from the map and the satellite photo in Fig. 2-1 and 2-2, the Far Rockaway test track is located in a remote area near the JFK International Airport. Fig. 2-3 and Fig. 2-4 show the interior of the “BPS House”, the existing structure that housed BPS related equipment. Another building housing the circuit breakers, shown in Fig. 2-5 is located near the BPS House.

Fig. 2-1　Test Location (Source: NYCT Map)

Fig. 2-2　Satellite Photograph (Source: Google Maps)

Fig. 2-3　BPS House Interior

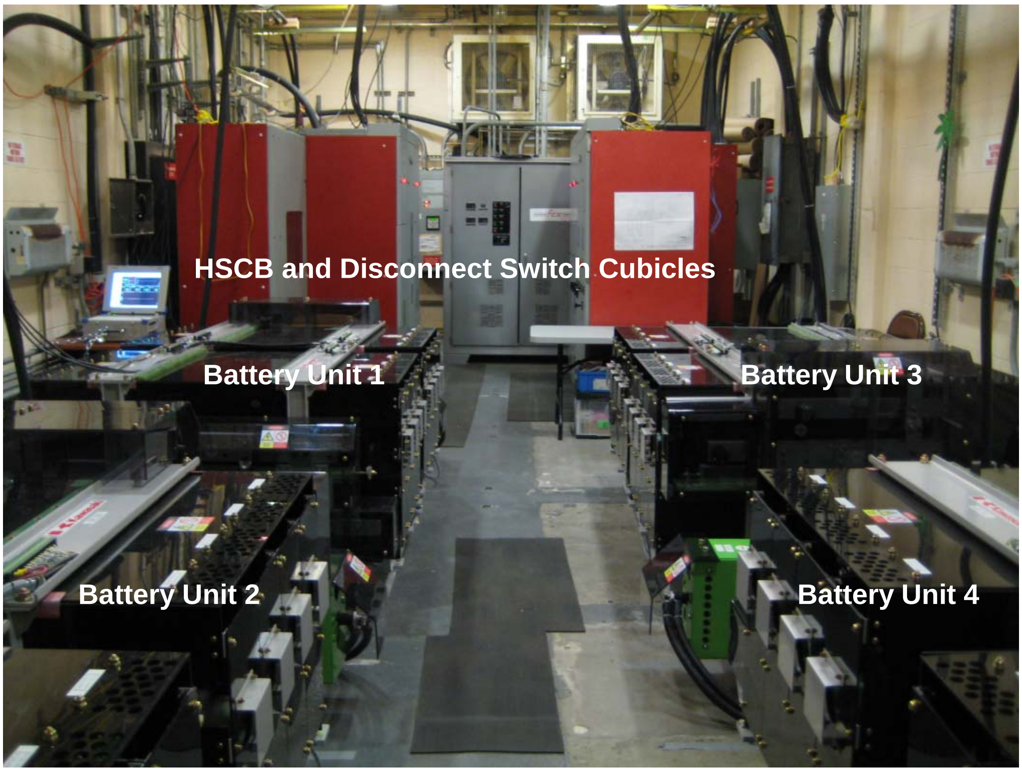


Fig. 2-4　Battery Units and Switchgear Lineup in BPS House

Fig. 2-5 Interior of Circuit Breaker House

Fig. 2-6 Circuit Breaker "Flywheel 72" for BPS

Fig. 2-7 and Fig. 2-8 show a general layout of the Third rail and the distances to the adjacent substations, which are supplying power to the Test Track and to the Service line.

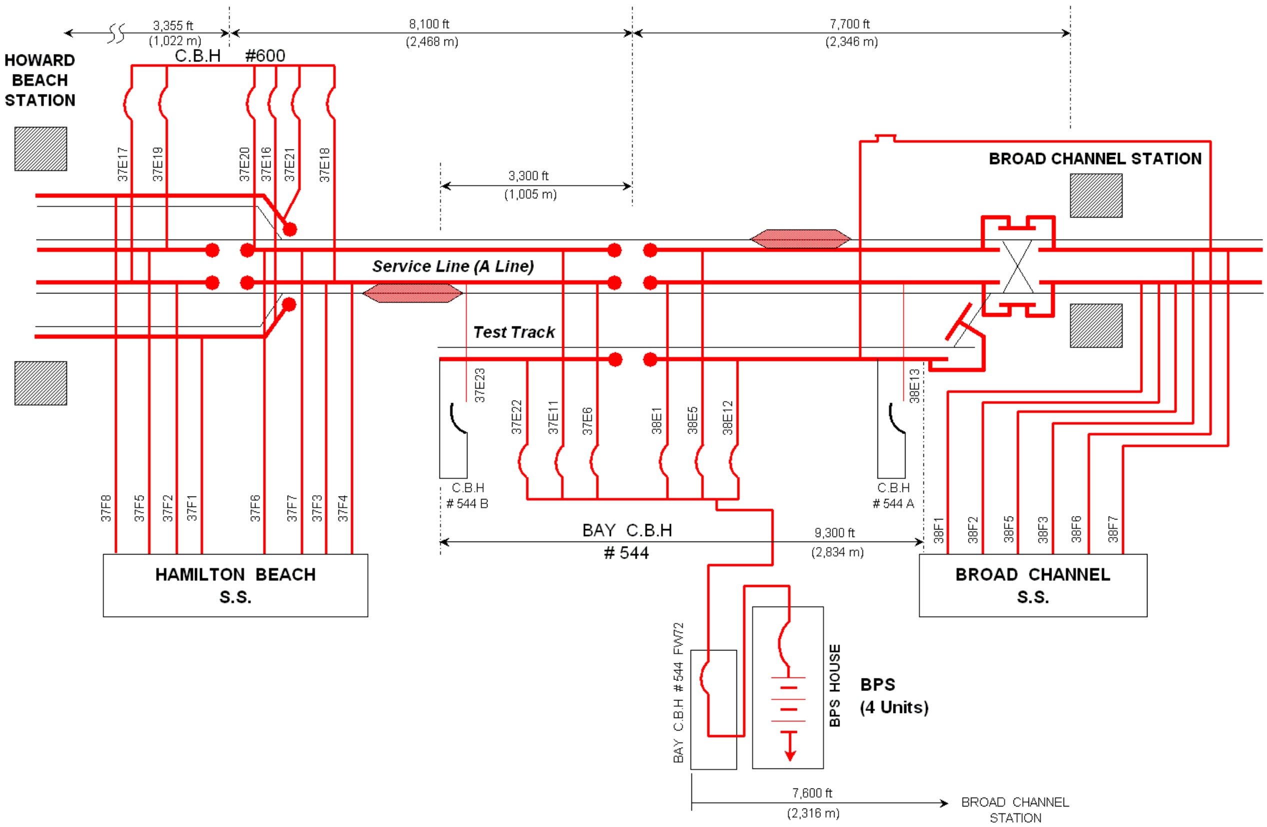


Fig. 2-7 Third Rail Diagram

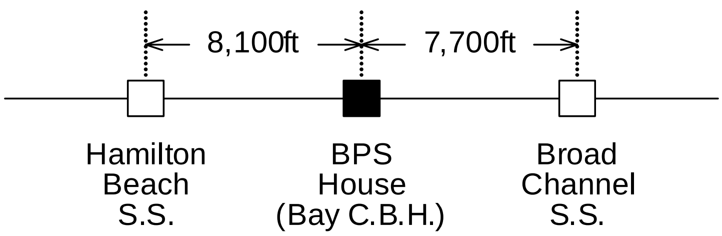


Fig. 2-8 BPS and Substations Location

3. BPS System Configuration

The Figure 3-1 shows the overall configuration of the Kawasaki BPS. As can be seen from the Configuration Diagram, that there is no “Control System” involved with the BPS and thus no EMI being produced by this system. Kawasaki wants to point out that this is one of the decided advantages of the Kawasaki BPS. The BPS configuration consists of the battery units connected in parallel and the entire battery bank is connected directly to the NYCT Traction Power System with high speed circuit breakers(HSCBs) providing protection on both the positive and negative sides. In the event of an abnormality, the BPS will be disconnected from the Authority’s Traction Power System by the HSCBs (both on Positive and Negative sides) and thus allow the Authority’s Traction Power System to continue to function. It may also be noted that manual disconnect switches are also provided to isolate the BPS from the Traction Power System, if necessary.

The condition of the BPS is monitored by the Battery Monitoring System (BMS). (Refer to Fig. 3-4 and 3-5, Page 10.) As its name implies, the BMS continuously monitors key performance characteristics of the BPS, such as internal temperature and pressure of each battery. In the unlikely event of a severe abnormality, the BMS automatically disconnects the BPS from the traction power system by opening the HSCBs.

The intrinsic safety of the Nickel Metal Hydride (Ni-MH) technology and the BMS work together to create an extremely safe and stable wayside energy storage system.

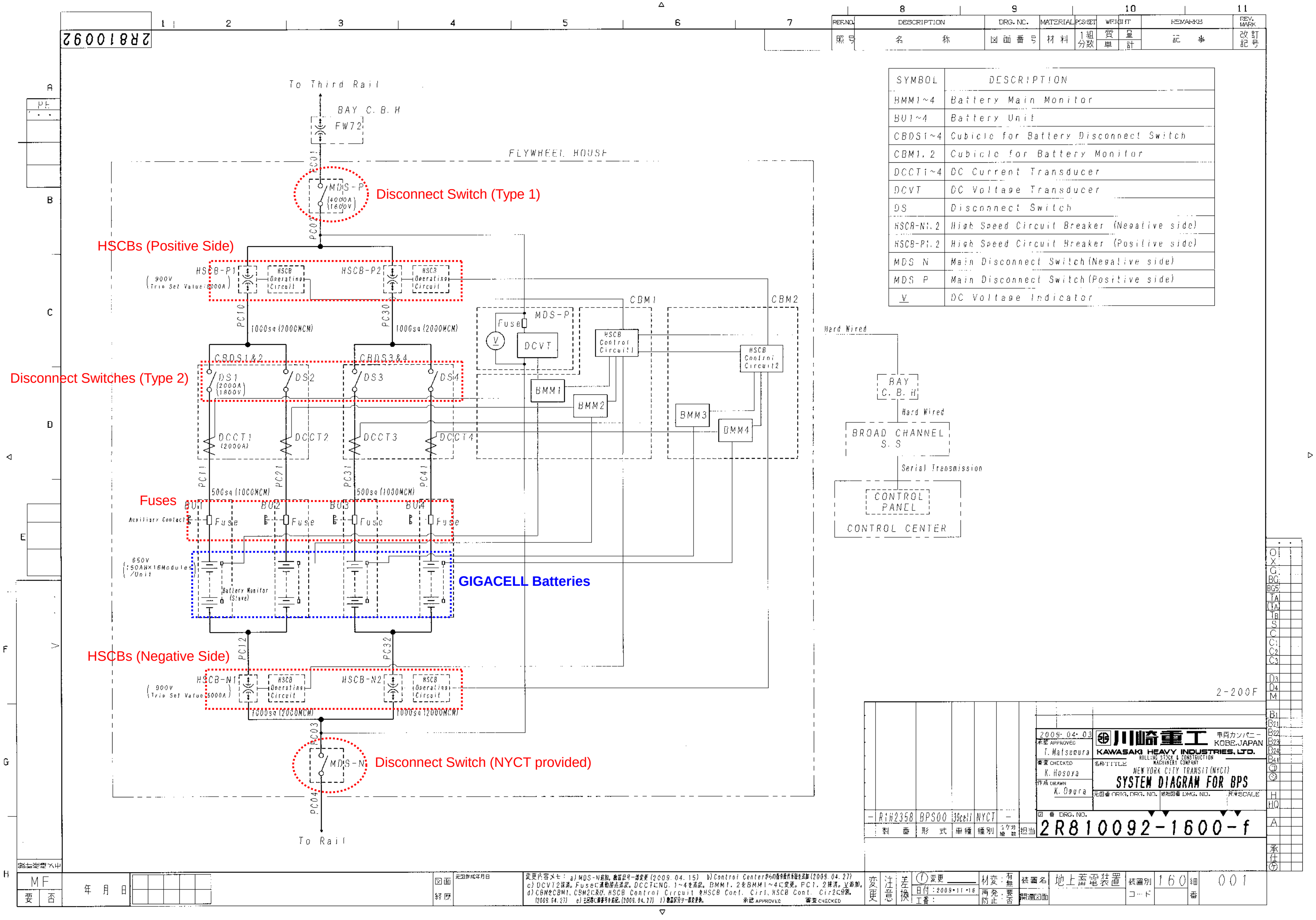


Fig. 3-1 BPS System Diagram

3-1. BPS Specification

The battery specifications and photographs of the BPS installation are provided below.

Table 3-1 Battery Specification

Battery Voltage:	670 V
Battery Capacity:	600 Ah
Energy Capacity:	402 kWh
Parallel Number of Battery Unit:	4 Units
Series Number of Battery Module:	16+1/3* Modules
Internal Resistance:	25 mΩ

* 1/3 module is one-third of a module (9 cells) provided to achieve the suitable voltage setting.

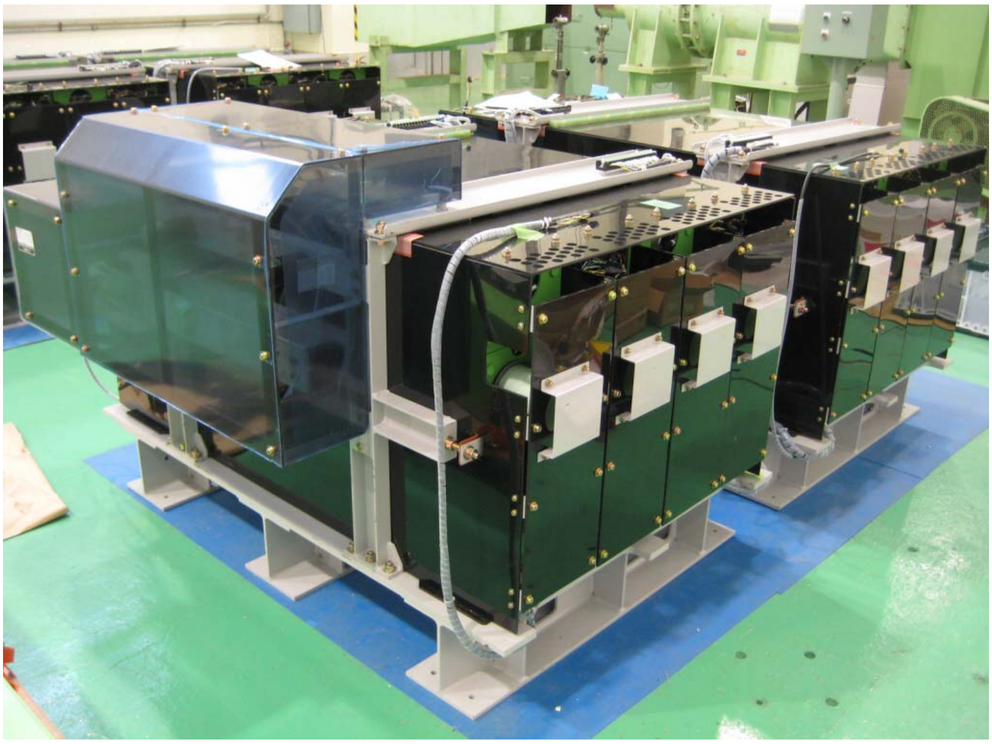


Fig. 3-2 Battery Unit

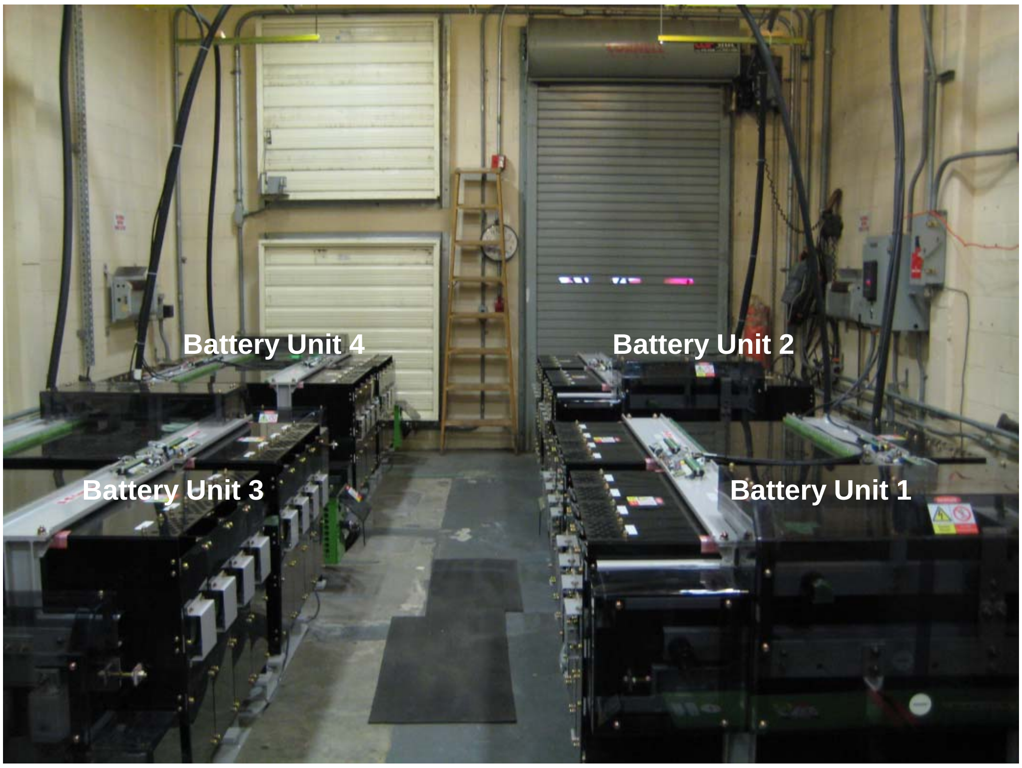


Fig. 3-3　Battery Units at BPS House

3-2. Battery Monitoring System

The follow are photographs of the Battery Monitoring System (BMS) installation.

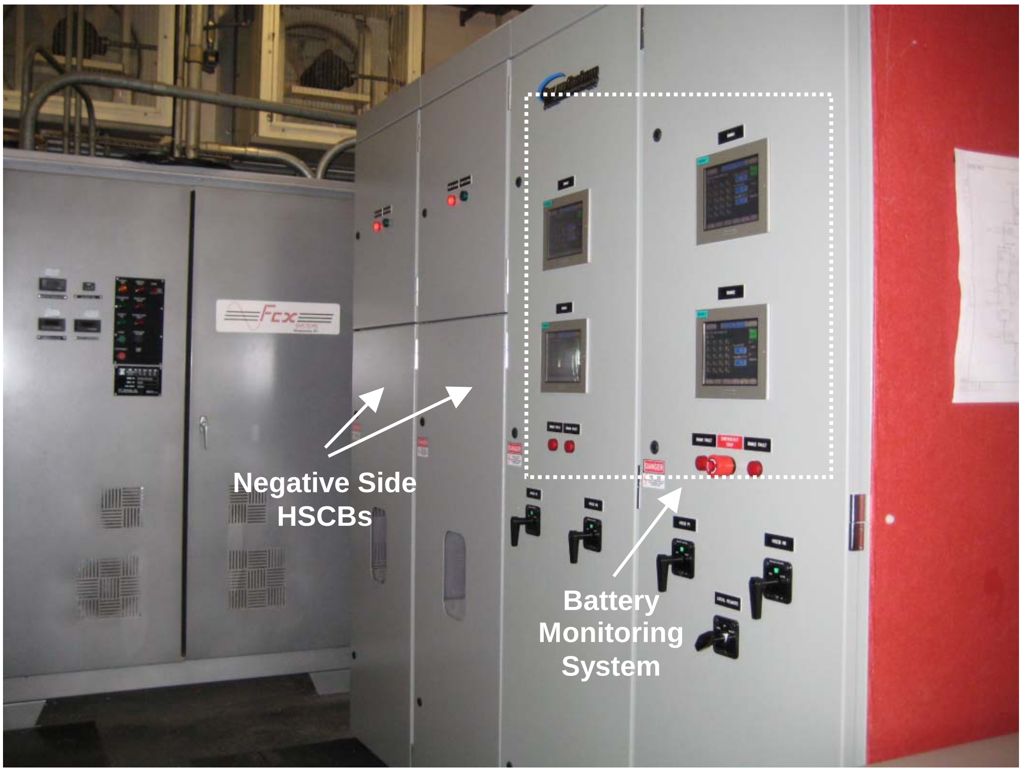


Fig. 3-4 Battery Monitoring System (BMS)

Fig. 3-5 BMS Main Monitor Screen

3-3. High Speed Circuit Breakers (HSCB) and Disconnect Switches

The follow are photographs of the power isolation and protective equipment installation.

Fig. 3-6 HSCB and Disconnect Switch Cubicles

Fig. 3-7 HSCB Exterior

Table 3-2　HSCB Specification

Symbol (In Drawing):	HSCB-P1, HSCB-P2, HSCB-N1, HSCB-N2
Rated Voltage:	900 V DC
Rated Current:	2600 A
Short Circuit Breaking Capacity:	125 kA / 100 ms
Over Current Setting:	6 kA
Control Voltage:	110 V DC
Auxiliary Contacts:	5a+5b

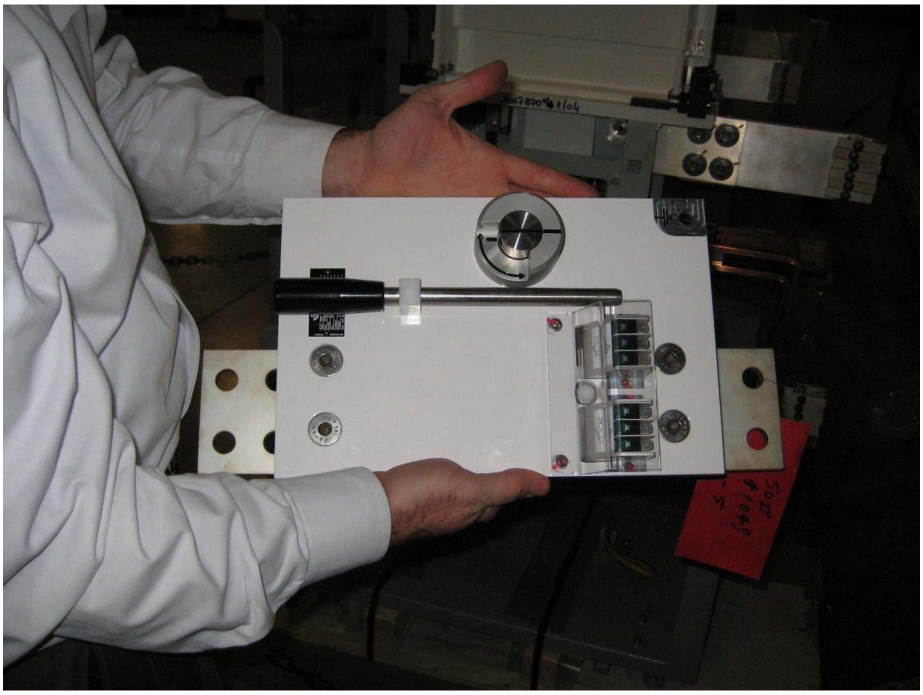


Fig. 3-8　Disconnect Switch (Type 1) Exterior

Table 3-3　Disconnect Switch Specification (Type 1)

Symbol:	MDS-P
Rated Voltage:	1800 V DC
Rated Current:	4000 A
Operation:	Manual
Number of Pole:	1

Table 3-4 Disconnect Switch Specification (Type 2)

Symbol:	DS1, DS2, DS3, DS4
Rated Voltage:	1800 V DC
Rated Current:	2000 A
Operation:	Manual
Number of Pole:	1

Table 3-5 Negative Return Disconnect Switch MDS-N

Symbol:	MDS-N
Rated Voltage:	750 V DC
Rated Current:	3000 A
Operation:	Manual
Number of Pole:	1

3-4. Fuses

Fig. 3-9 is a photograph of the fuses, which provide battery unit short circuit protection. As mentioned earlier, the HSCB provides protection between the main power line and the BPS.

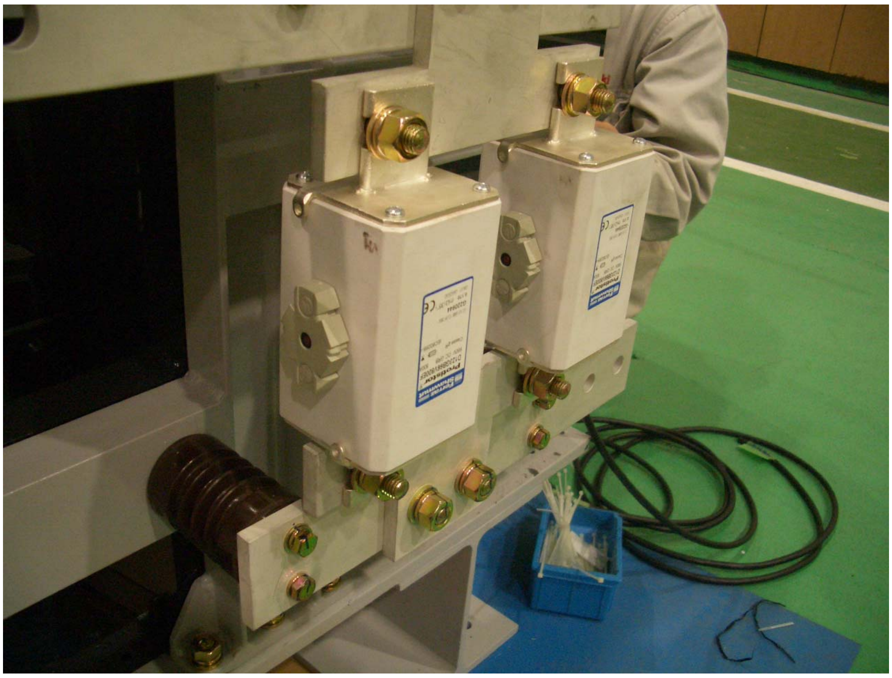


Fig.3-9　Battery Unit Fuse

Table 3-6　Battery Unit Fuse Specification

Symbol:	Fuse1, Fuse2, Fuse3, Fuse4
Rated Voltage:	750 V DC
Rated Current:	800 A

4. Test Train Specifications

The trains used during the test have the following characteristics.

Table 4-1 Test Train Specification

Train Type:	R160
Train Configuration:	10 Car Train
Estimated Gross Weight:	835,930 Lbs (379.17 tons)
Brake Type:	Regenerative
Regeneration Voltage Limit:	690V DC
AC & Lighting Status:	On
Power Supply:	625V DC, Nominal
Power Supply Method:	Third Rail

Fig. 4-1 R160 Test Train

5. Test Environment

The environmental conditions were as follows.

Table 5-1 Test Environmental Conditions

Weather:	Wet
Temperature at Start / End of Test:	32 ^{o}F (0 ^{o}C) / 32 ^{o}F (0 ^{o}C)
Humidity at Start / End of Test:	45% / 45%

6. Testing and Results

6-1. Voltage Drop caused by R160 Test Train Operation & BPS Effected Improvements

1) Objective

To evaluate the effect of BPS on the Voltage Profile.

2) Test Procedure

In Test Case 1, the test train (R160) was started and accelerated without the BPS connected and the voltage drop was measured at the third rail. In Test Case 2, the test train was operated with the BPS connected and the voltage drop was measured at the third rail.

3) Test Condition

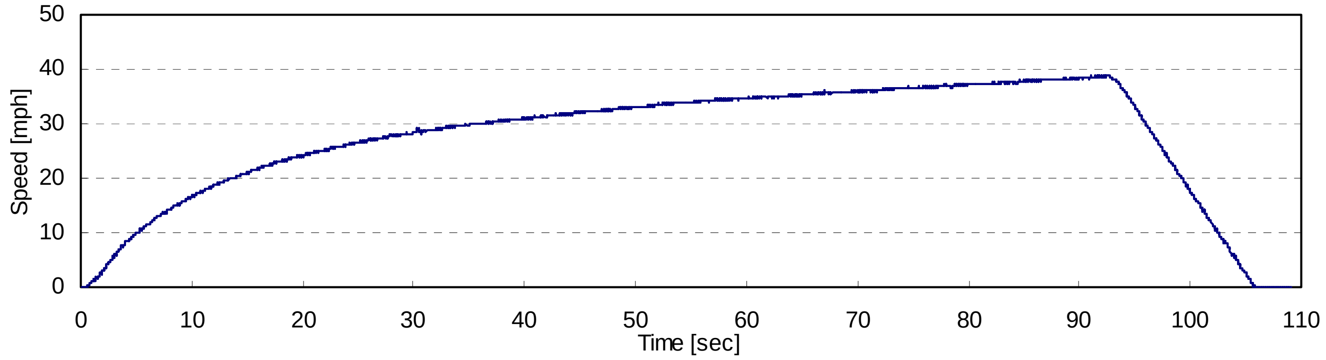
The test track traction power supply was completely isolated from the revenue track traction power.

4) Test Results

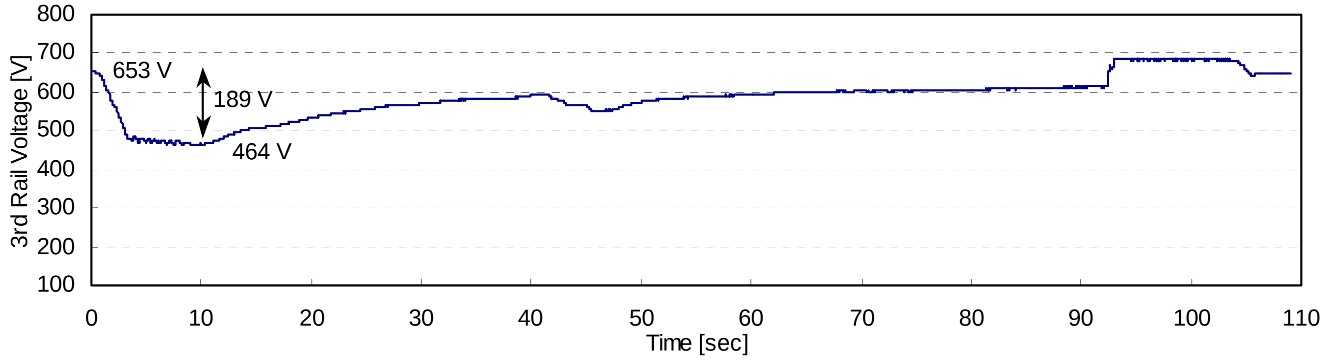
Table 6-1 and Fig. 6-1 and Fig. 6-2 show that this objective was achieved. When the train was accelerated when no BPS was connected, the third rail voltage dropped by 28.9 %. With the BPS connected, the drop was only 17.2 %.

Table 6-1 Power Line Voltage and Voltage Drop

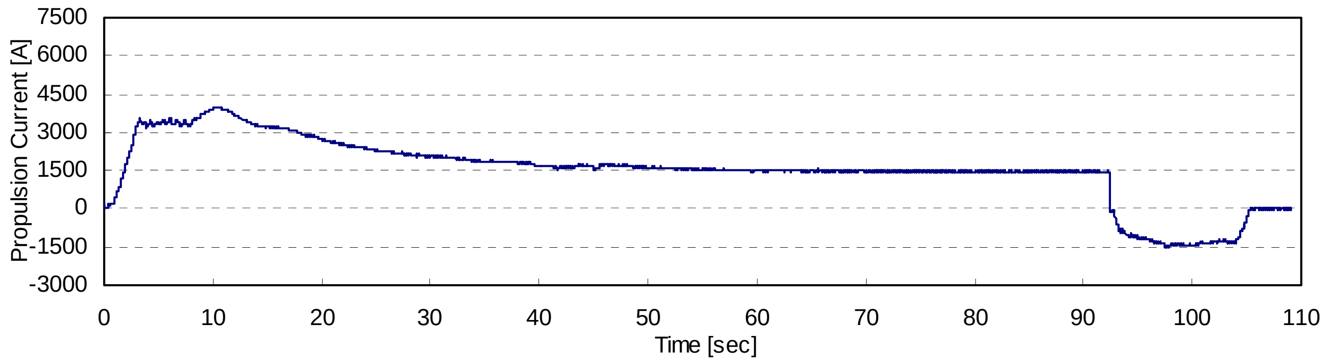
Test Case	Conditions	Power Line Voltage When Train Accelerated at Full Throttle (At starting / Lowered to) [V]	Voltage Drop [V]
1	No BPS connected (Ref. Fig. 6-1)	653 / 464	189
2	BPS connected (Ref. Fig. 6-2)	644 / 533	111



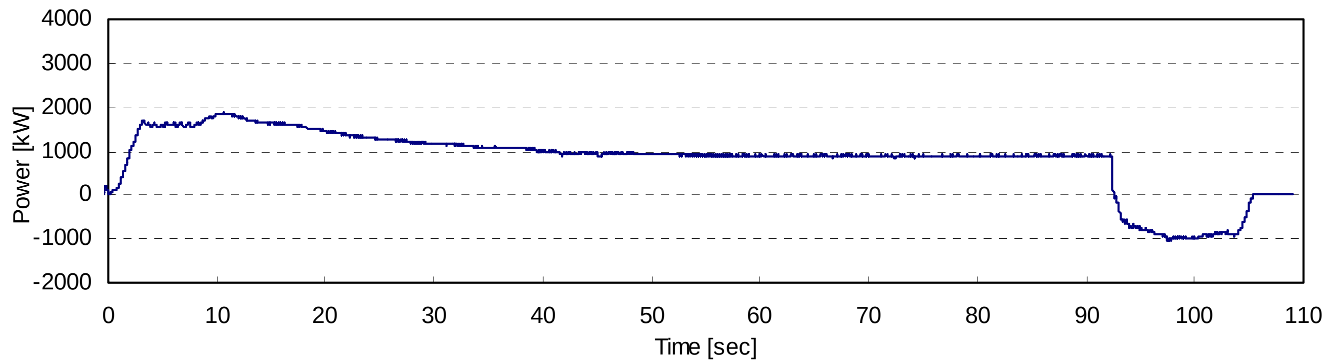
(a) Speed



(b) Voltage

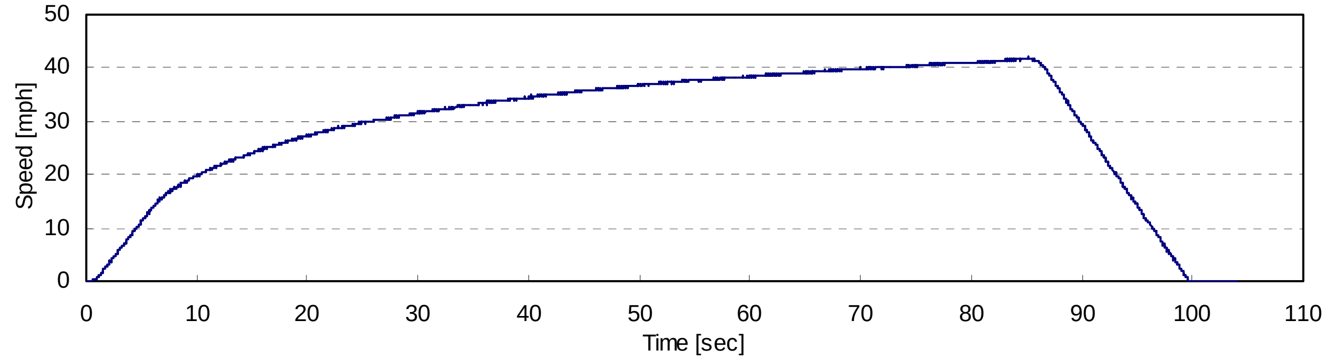


(c) Current

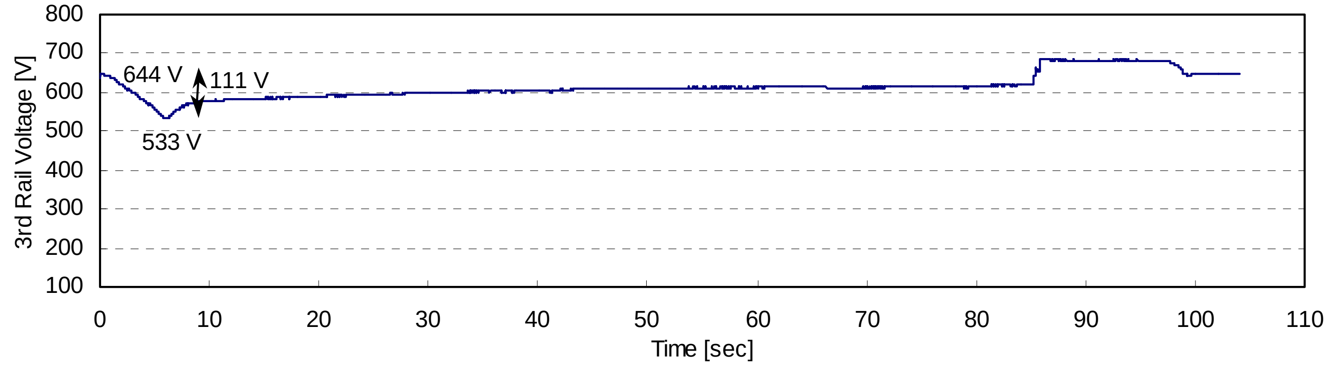


(d) Power

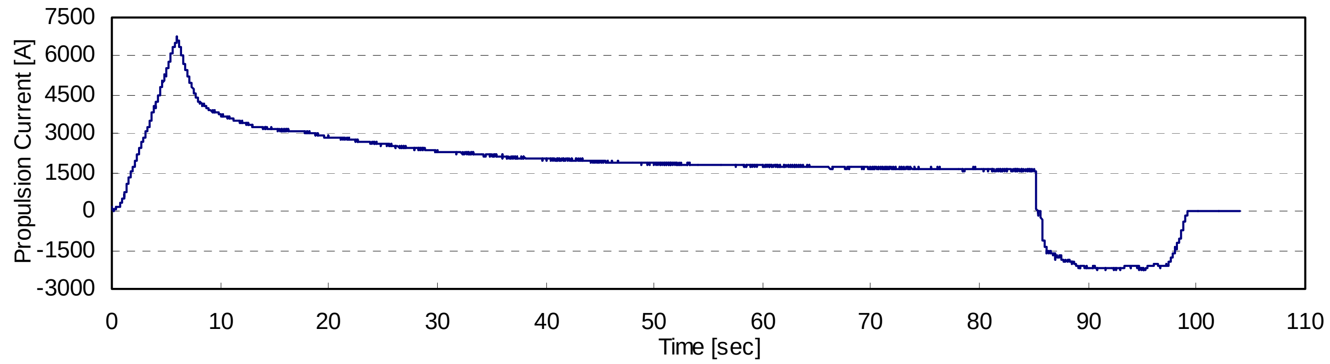
Fig. 6-1 R160 Test Result [Condition: No BPS connected]



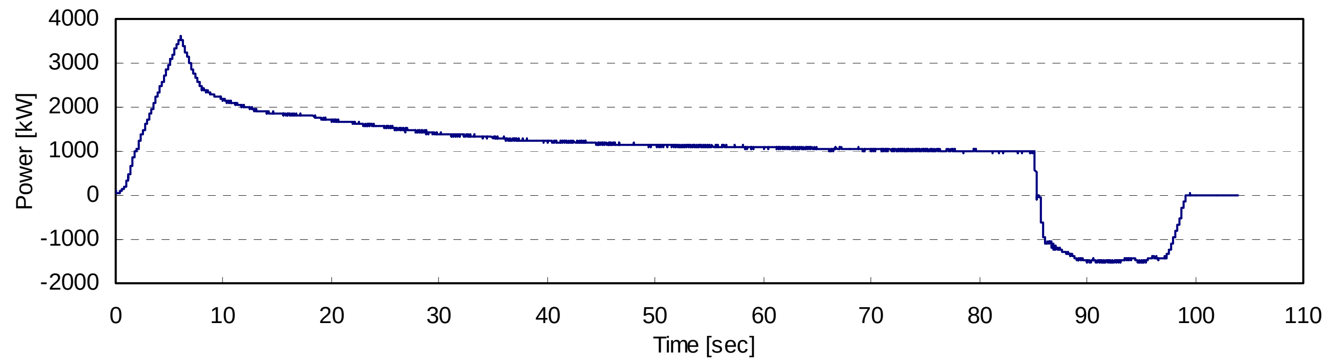
(a) Speed



(b) Voltage



(c) Current



(d) Power

Fig. 6-2 R160 Test Result [Condition: BPS connected]

6-2. Verify Regenerative Energy Enhancement and Utilization by R160 Test Train

1) Objective

To verify the following effects of BPS:

a) Enhancement of regenerative energy performance of the vehicle

b) Determine the energy generated by the regenerative braking during train operation at all speeds and the energy captured by the BPS

c) Storage of energy by the BPS and its supplemental uses as necessary

2) Test Procedure

The test train was operated without the BPS connected and the amount of regenerative energy was measured. Subsequently, the test train was operated with the BPS connected and the amount of regenerative energy was measured.

3) Test Condition

One test train run with power supplied from the Hamilton Beach S.S, Broad Channel S.S and BPS. The power line is connected the revenue service line.

4) Test Results

Table 6-2 and Fig. 6-3 to Fig. 6-4 show that the objective was achieved.

Table 6-2 Regenerative Energy and Absorbed Regenerative Energy

Test Case	Conditions	Regenerative Energy Generated by Test Train [kWh]	Regenerative Energy Absorbed by BPS [kWh]
3	No BPS connected (Ref. Fig. 6-3)	1.34	--
4	BPS connected (Ref. Fig. 6-4)	2.94	2.10

Increased Regenerated Energy (Refer to Fig. 6-5);

a) 2.94 kWh / 1.34 kWh = 2.19

Therefore, 2.19 times more regenerative energy was generated by the train with BPS.

b) 2.10 kWh / 2.94 kWh x 100 = 71.4 [%]

Therefore, 71.4 % of the regenerative energy was stored by the BPS.

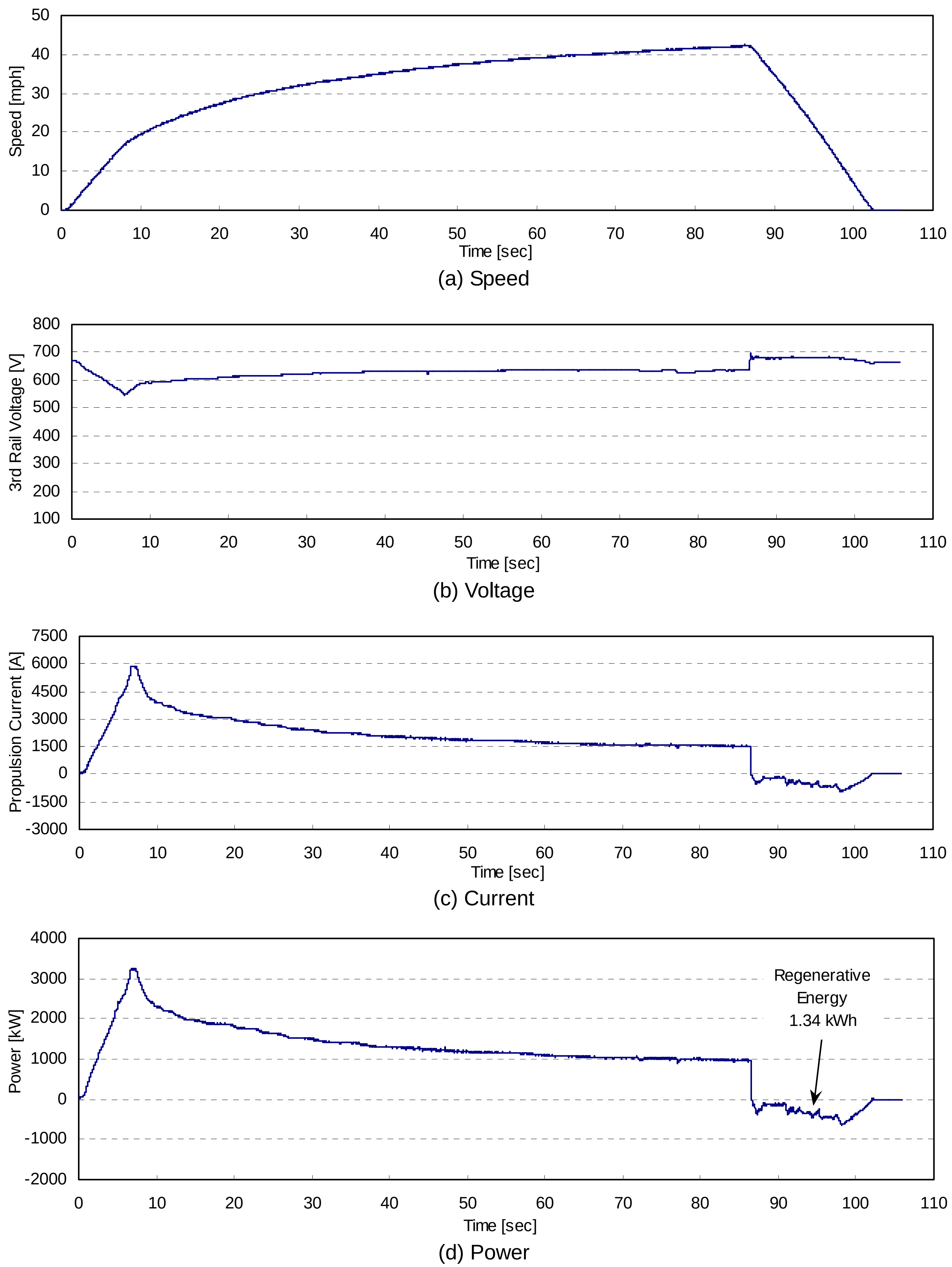


Fig. 6-3 R160 Regenerative Energy From the Test Train [Condition: No BPS connected]

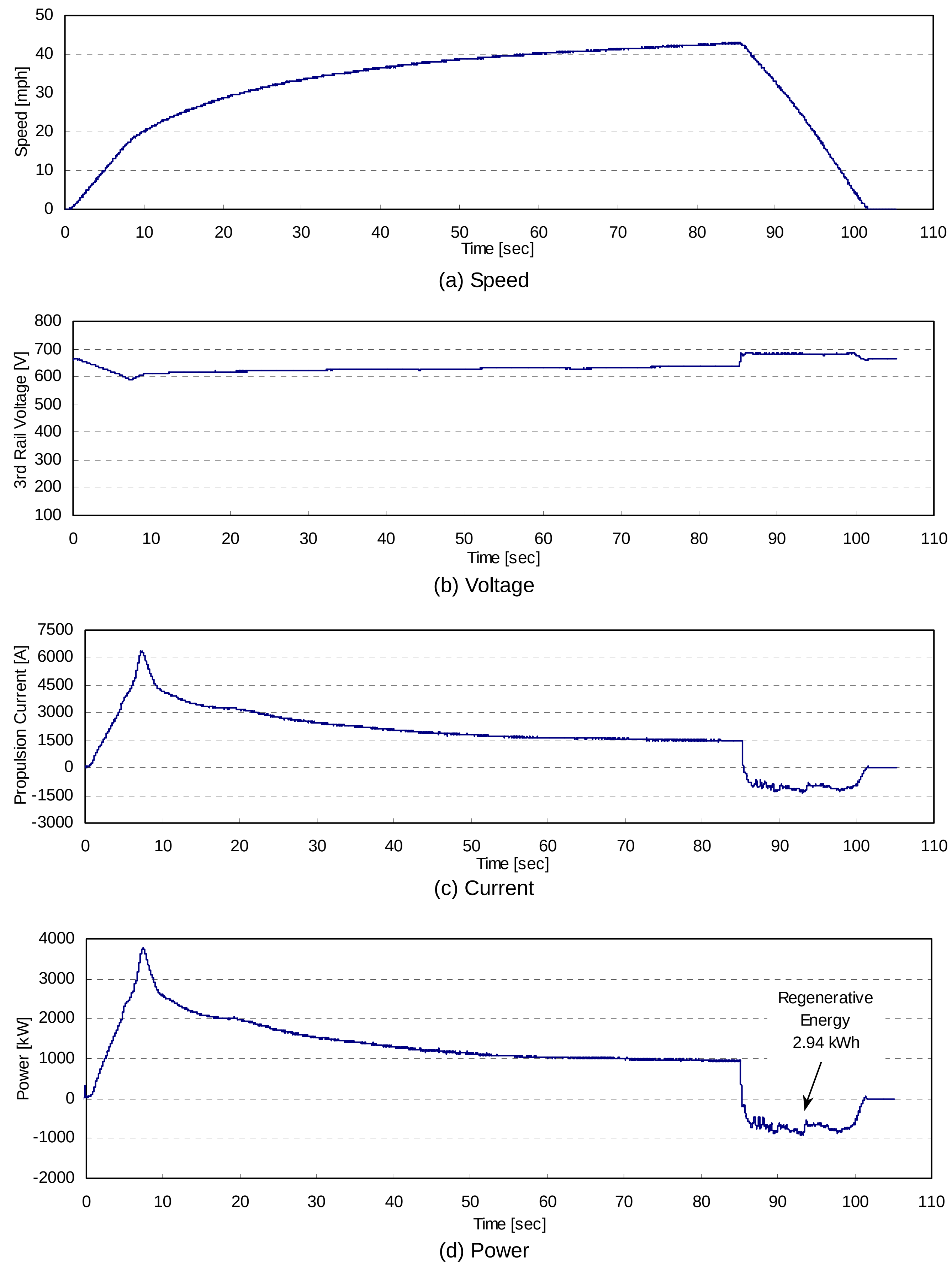


Fig. 6-4 R160 Regenerative Energy From the Test Train [Condition: BPS connected]

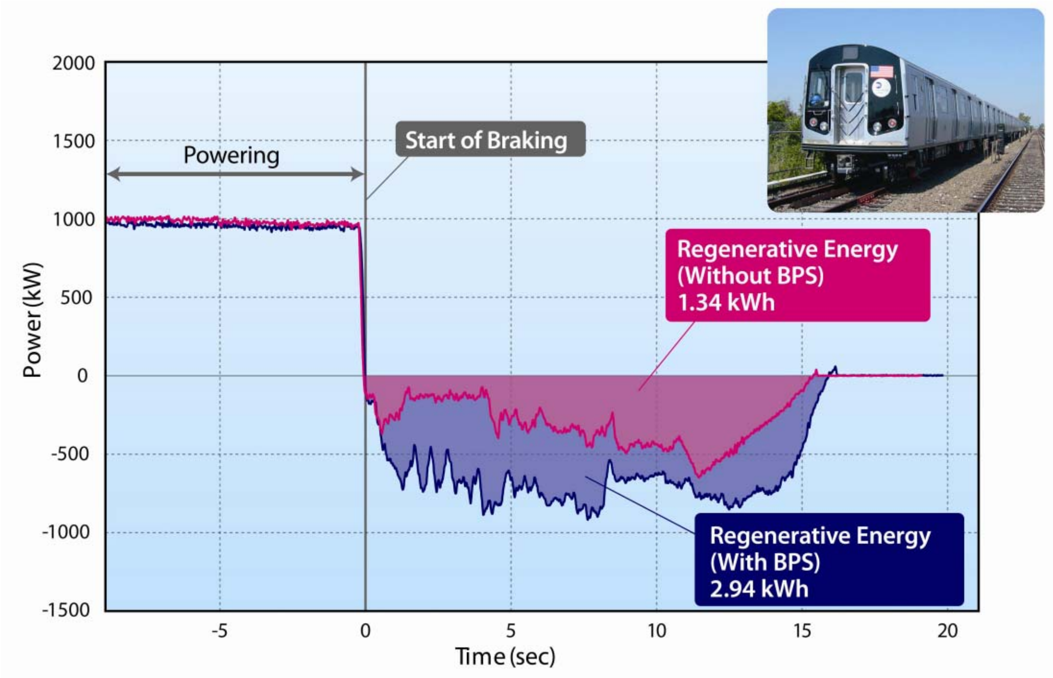


Fig. 6-5　Comparison of Regenerative Energy (Without BPS vs. With BPS)

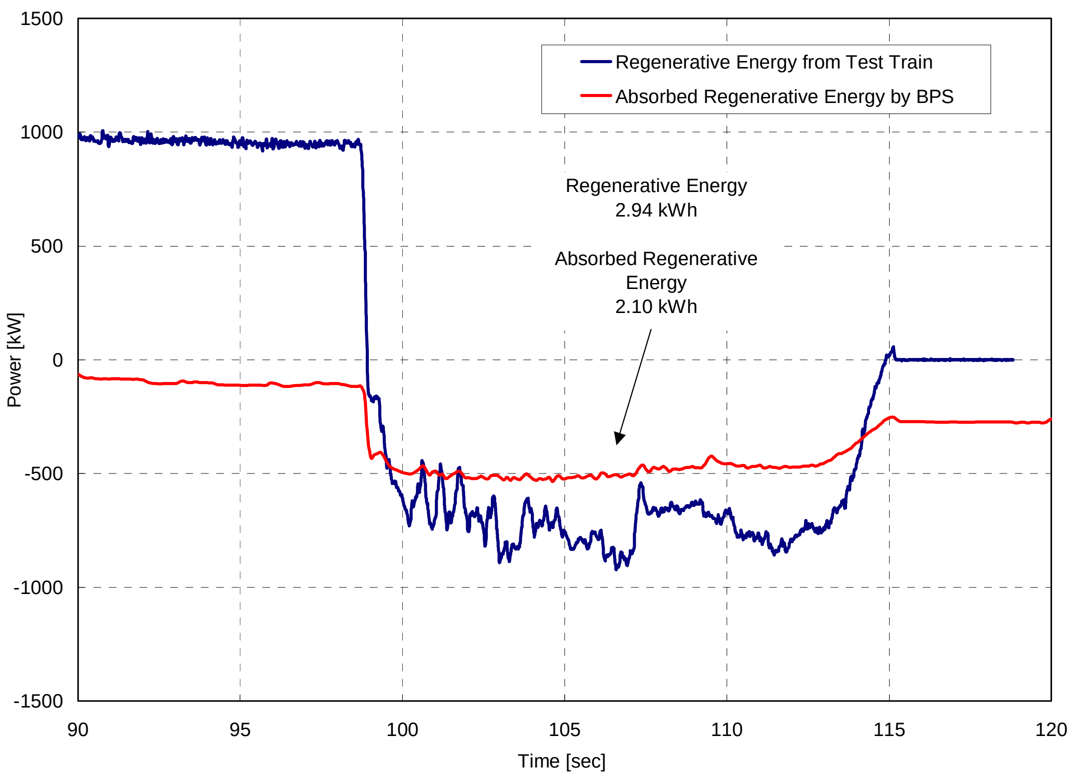


Fig. 6-6　Regenerative Energy From the Test Train and Absorbed Regenerative Energy by BPS

6-3. Verify Third Rail Voltage Stabilization when R160 Accelerated at Full Throttle

1) Objective

To verify that the BPS provides supplemental power that enables the Third Rail voltage to be stabilized when train is accelerated at full throttle.

2) Test Procedure

The test train was accelerated at full throttle without the BPS connected and the amount of voltage drop was measured. These measurements were repeated with the BPS connected. Subsequently, the test train accelerated at full throttle with the BPS connected and the amount of voltage drop was measured.

3) Test Condition

One test train run with power supplied from the Hamilton Beach S.S, Broad Channel S.S and BPS. The power line is connected the revenue service line.

4) Test Results

Table 6-3 and Fig. 6-7 and Fig. 6-8 show that this objective was achieved. When the train was accelerated when no BPS was connected, the third rail voltage dropped by 17.5 %. With the BPS connected, the drop was only 9.4 % with the BPS providing current that approached the peak current of 2,900 A during the train acceleration.

Table 6-3 Power Line Voltage and Voltage Drop

Test Case	Conditions	Power Line Voltage When Train Accelerated at Full Throttle (At starting / Lowered to) [V]	Voltage Drop [V]
3	No BPS connected (Ref. Fig. 6-7)	673 / 555	118
4	BPS connected (Ref. Chart 6-8)	671 / 608	63

5) Test Results

The power line voltage was stabilized by 55V (118 - 63 = 55) with the BPS connected and the train was accelerated at full throttle. Moreover, the ripple voltage waveform became smoother after the BPS was connected.

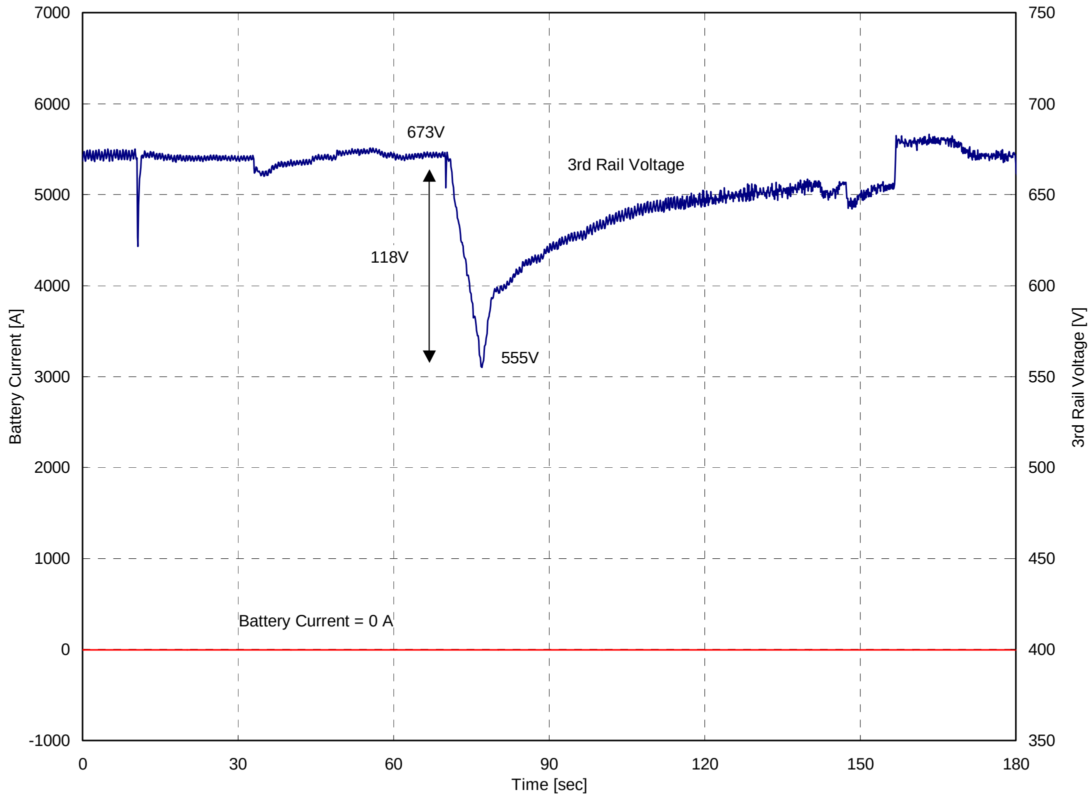


Fig. 6-7 Third Rail Voltage When Train Accelerated at Full Throttle [Condition: No BPS]

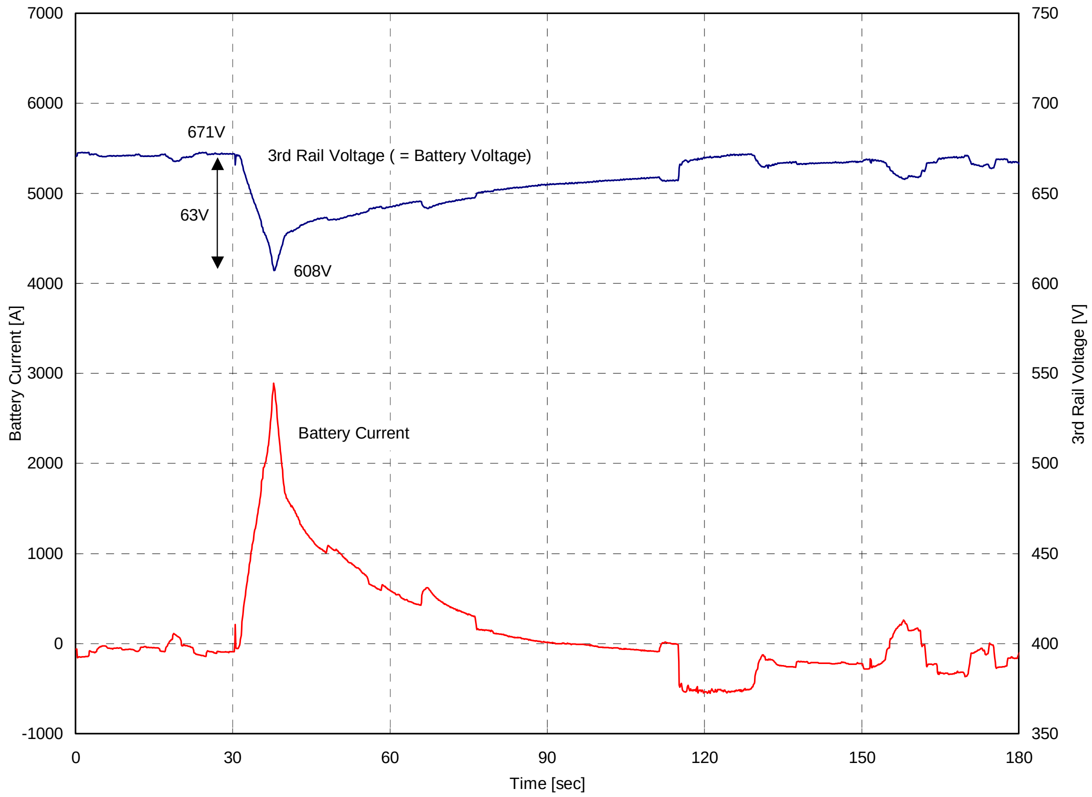


Fig. 6-8 Third Rail Voltage Voltage When Train Accelerated at Full Throttle [Condition: BPS Connected]

6-4. Verify Third Rail Voltage Stabilization at Service Line (A-Line)

1) Objective

To verify that the BPS provides supplemental power that enables the Third Rail voltage to be stabilized during times of peak power demand.

2) Test Procedure

The average and maximum voltages at the two adjacent substations were measured without the BPS connected. These measurements were repeated with the BPS connected. The peak-to-peak differences were then calculated as shown in the Table 6-4.

3) Test Results

Table 6-4 and Fig. 6-9 and Fig. 6-10 show that the objectives were achieved.

Table 6-4 Measured Voltage and Peak to Peak Difference

Test Case	Conditions	Average Voltage at Broad Channel S.S. [V]	Average Voltage at Hamilton Beach S.S. [V]	Measured Voltage (Highest /Lowest)	Peak-to-Peak Difference	Remarks
5	No BPS Connected	707 (Ref. note 1)	674	707V / 585V at C.B.H	122V	Ref. Fig.6-9
6	BPS Connected	666	668	679V / 615V at BPS (Ref. Note)	64V	Ref. Fig.6-10

Note

The value represented above was recorded prior to the adjustment of taps at the Broad Channel Substation. The reason the line voltage was adjusted to approximately 665V was to allow the R160 trains to provide regenerative braking energy.

4) Conclusion

The Third Rail voltage was stabilized by the connection of the BPS. The peak-to-peak voltage was reduced by 58V. (122 - 64 = 58)

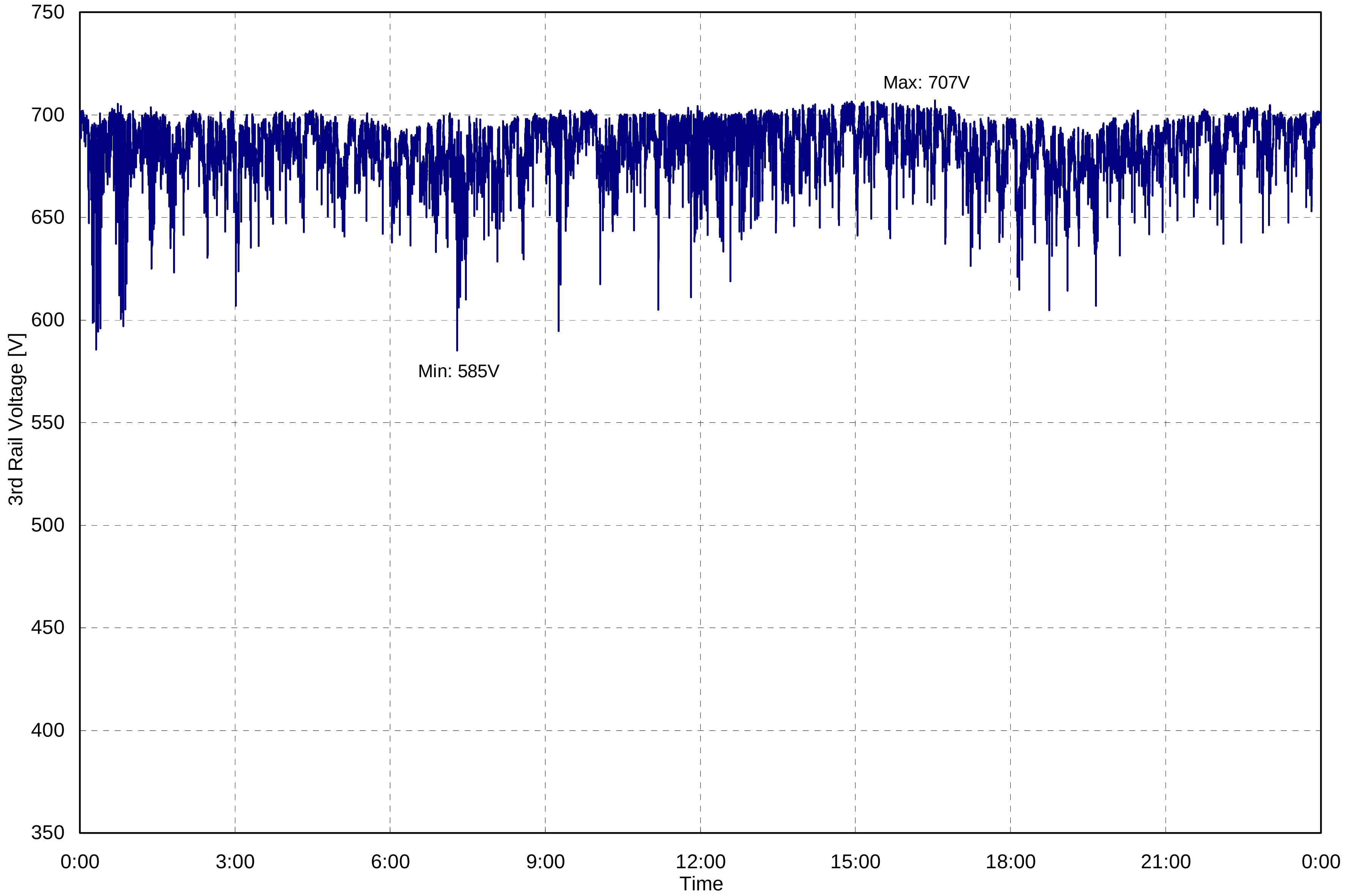


Fig. 6-9　Third Rail Voltage [Condition: No BPS]　(Measured on 2/11/2010, 0:00-24:00)

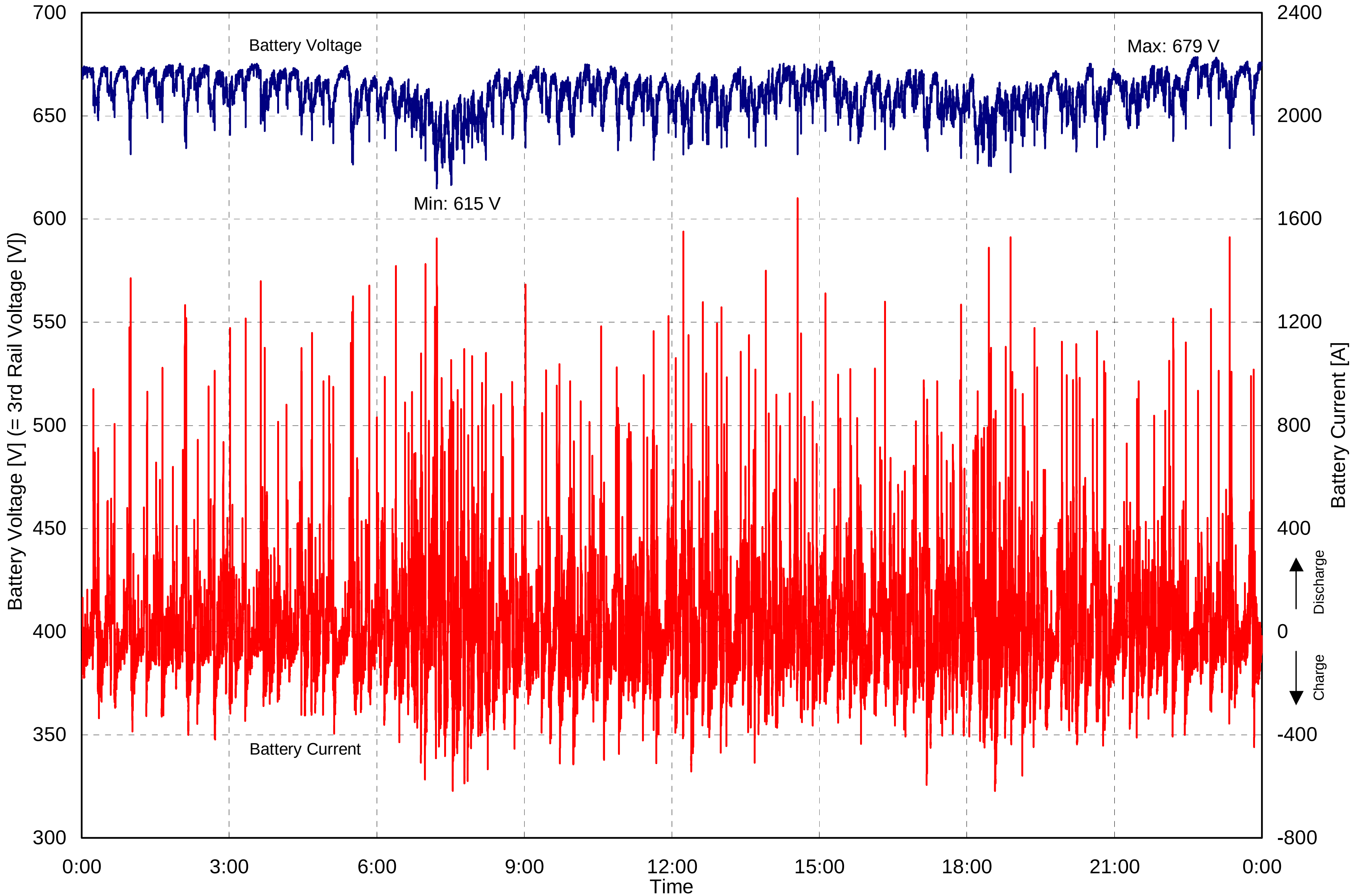


Fig. 6-10 Battery Voltage and Current [Condition: BPS Connected] (Measured on 2/17/2010, 0:00-24:00)

6-5. Verify the Use of BPS as an Emergency Power Source

1) Objective

To verify that the BPS alone can provide sufficient power to operate a single train when there is no power being supplied by the substation and to calculate the total theoretical number of trains that could be moved by BPS alone.

2) Test Procedure

The third rail was isolated from the substation power sources and the only source of power was the BPS. Test was conducted with all the auxiliary equipment such as lighting and air-conditioning on. The maximum train speed was approximately 10mph.

3) Test Results

The BPS alone powered the train as indicated in Table 6-5. This data was used to calculate the theoretical number of trains that could be moved during an emergency power outage. Fig.6-11(a) shows the speed and distance traveled by the train. Fig.6-11(b) shows the power consumption of the train during the emergency run test.

As can be seen, during powering the maximum power consumption is approximately 800 kW.

Fig.6-12 shows the discharge of the BPS during the emergency run test. The starting point appears to be approximately 300 A. This is caused by the constant load of auxiliary power equipment. During powering, battery current discharge exceeds 1,600 A for the acceleration to maintain 10 mph speed. And the battery voltage momentarily drops to about 600 V.

Table 6-5　BPS for an Emergency Power Source

Tested Line (measured date)	Run Distance, Round Trip	Consumed SOC [%] (Outbound)	Consumed SOC [%] (Inbound)	Consumed Total SOC [%] (Round Trip)
At the Test Track (Ref. Fig. 6-11)	4,100 x 2 = 8,200 ft (1.25 x 2 = 2.5 km)	5.5	6.4	11.9
At the Service Line	1,500 x 2 = 3,000 ft (0.46 x 2 = 0.92 km)	2.8	3.5	6.3

Conditions:

a) State of Charge (SOC) was 100% when power failure occurs was 0 % fully discharged.

b) Trains stopped in between stations.

(Estimated average distance to the next station is 4,000ft / train.)

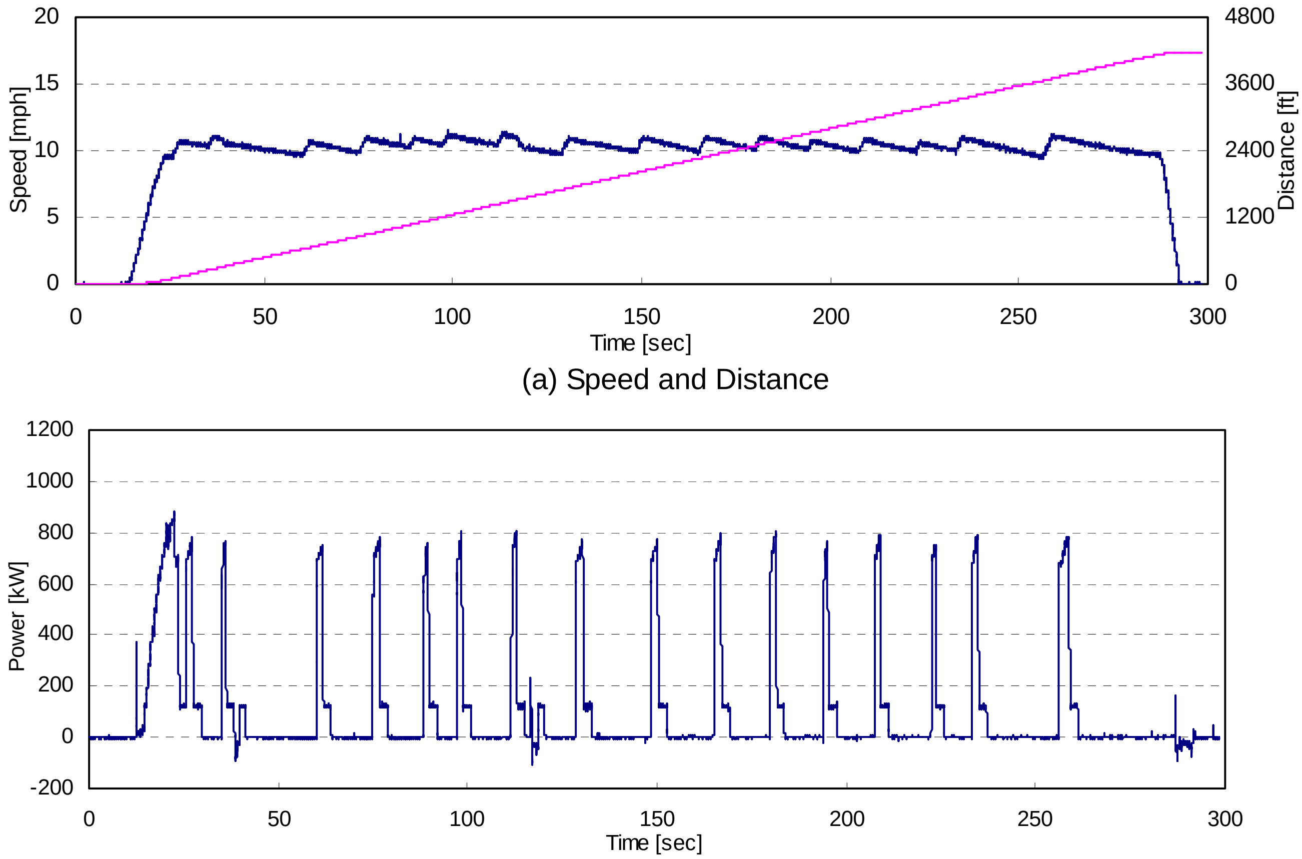
c) Trains run at a maximum speed of 10mph with all the auxiliary equipment ON.

4) Conclusions

Calculation of the number of trains that BPS can move:

1. Percentage of battery power (% of battery charge) required for moving single train
   = (11.9% / 8,200ft) / 4,000ft = 5.8% per 4,000 ft
2. Number of trains that can be moved 4,000 ft with fully charged battery
   = 100% / 5.8% = 17 trains

The BPS alone is capable of moving 17 trains to the next station.



(a) Speed and Distance

(b) Power

Fig. 6-11 R160 Test Train Runs with only BPS Power Supply

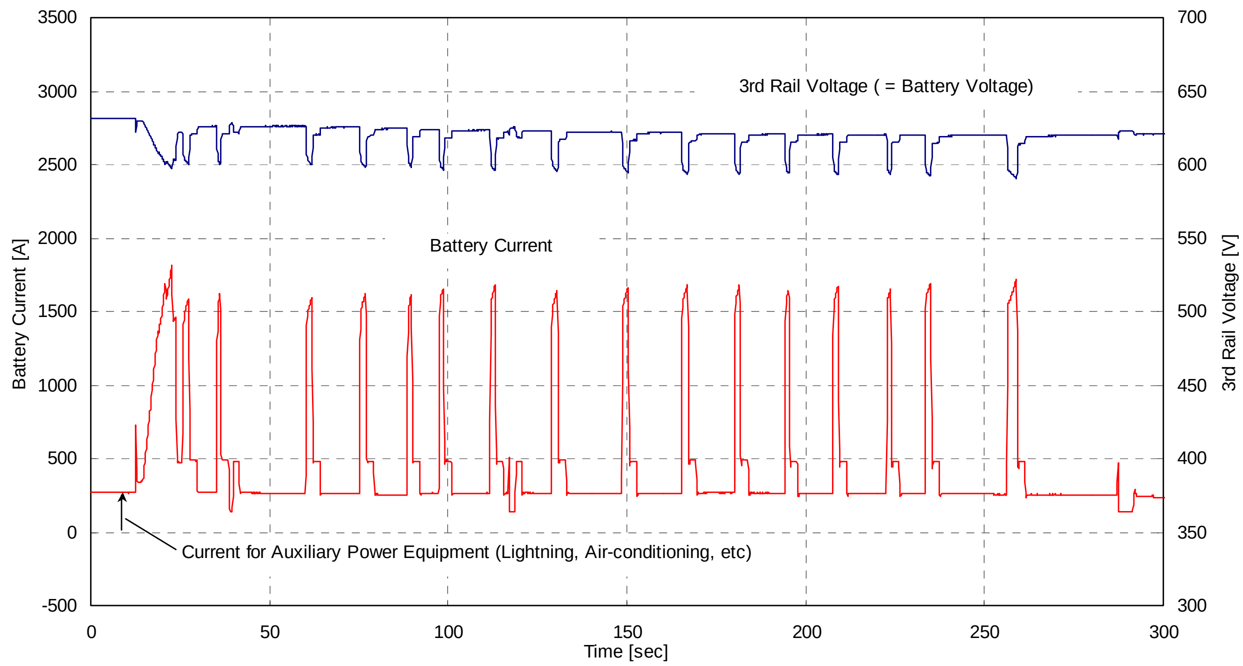


Fig. 6-12 BPS Voltage and Current during Test Track Emergency Run Test

6-6. BPS Charge / Discharge Characteristics at Time of Peak Demand

1) Objective

To verify the performance characteristics of the BPS at the time of peak demand.

2) Test Results

NYCT identified March 1, 2010 from 8:00 AM to 8:30 AM as the time that the peak demand occurred in the NYCT system.

From the data collected at the BPS site and the substations, the peak power demand on March 1 at the site occurred between 7:00 AM and 7:30 AM. The location of the BPS site is far away from Manhattan, therefore it can be assumed that the peak hour occurs about 1 hour prior to the peak power demand in the system.

From the waveforms between 7:00AM and 7:30AM shown in Fig. 6-13, the third rail voltage is sometimes less than 650V DC. When this occurs, the BPS has more opportunity to discharge and provide power to the system. It can be seen that there was 18.4 kW more energy discharged than charged during this time period.

Table 6-5 BPS Output (Discharge) Power and Input (Charge) Power

Time	BPS Output (Discharge) Power [kW]	BPS Input (Charge) Power [kW]	Difference [kW] (Output-Input)
7:00 – 7:30 AM	73.0	54.6	18.4

*Power [kW] = kWh (30 minutes) / 0.5 hour

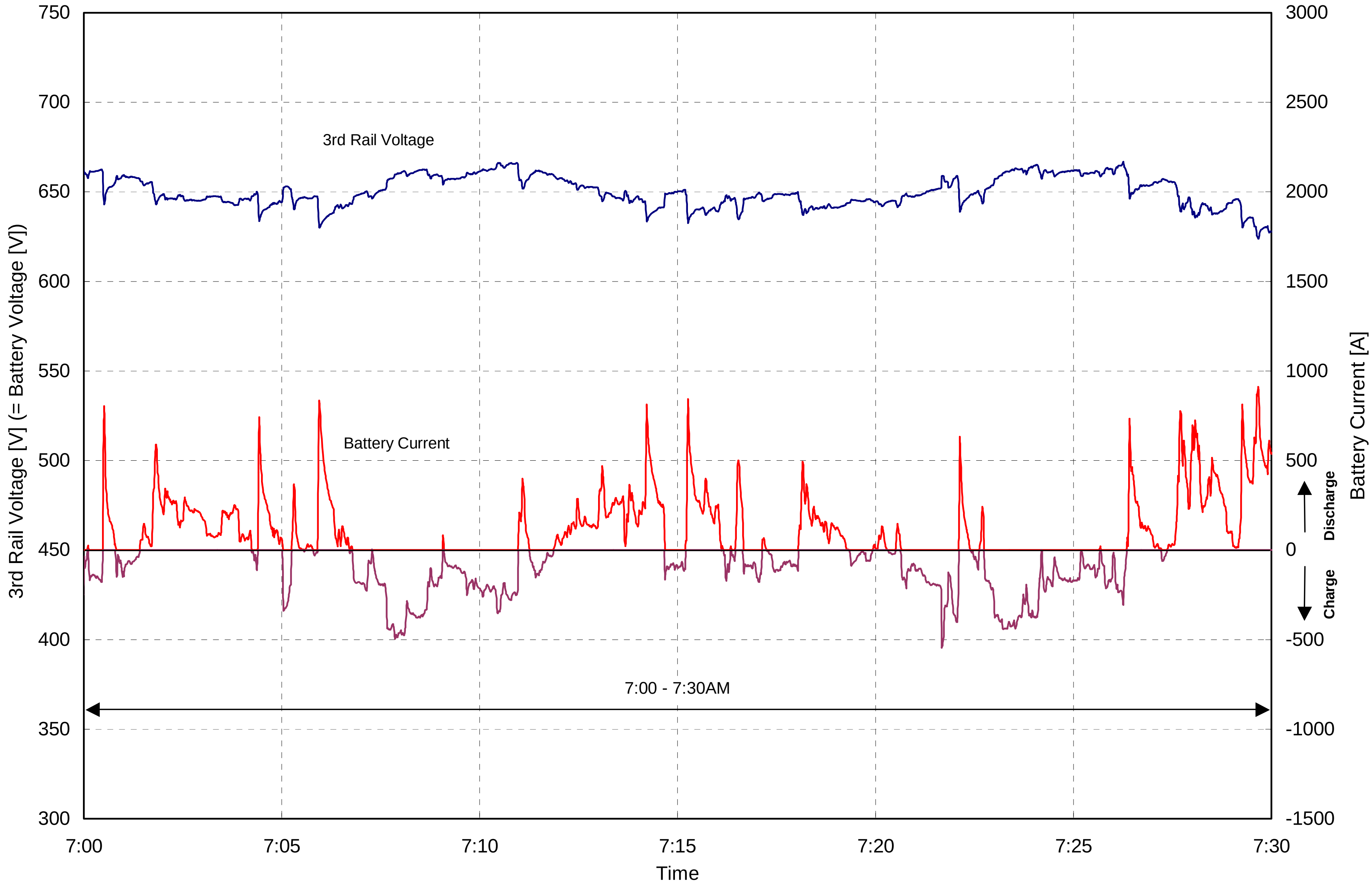


Fig. 6-13 Third Rail Voltage and Battery Current waveforms (Measured on 3/1/2010 7:00 – 7:30 AM)

3) Conclusions

It is important to remember that the data shown in the graph above was obtained under conditions that were not optimal for the BPS. In this test, the BPS was located at the BPS House between the Hamilton Beach and Broad Channel S.S. on a line that operates cars without regenerative braking. However, as shown above, the BPS performed as anticipated. It quickly charged and discharged, and at times of peak demand it had a larger discharge than charge to compensate for the drop in line voltage.

Based on the collected data, it is clear that the BPS can provide supplemental power during times of peak power demand.

6-7. EMI Test Results

1) Objective

To determine if there is any EMI impact due to the BPS.

2) Test Results

NYCT measured the EMI levels at the site and did not observe any impact when the BPS was operating.

7. Summary of Project Objectives

Test Objectives in NYSERDA Proposal	Test Descriptions and Goals	Test Results
1) Maintain line voltage of higher than 600 VDC when nominal voltage is 650 VDC. (Actual: 625 VDC)	To verify the BPS provides supplemental power that enables the 3rd rail voltage to be stabilized when the train is accelerated at full throttle. (One test train.)	1) Without BPS, the 3rd rail voltage changed from 673 V to 555 V. The voltage drop is 118 V. 2) With BPS, the 3rd rail voltage changed from 671 V to 608 V. The voltage drop is 63 V. 3) Therefore, the 3rd rail voltage was stabilized by 55 V with the BPS connected when the train was accelerated at full throttle. Moreover, the ripple voltage waveform became smoother after the BPS was connected.
	To verify that the BPS provides supplemental power that enables the 3rd rail voltage to be stabilized during peak power demands. (A-Line revenue service.)	1) Without BPS, the 3rd rail voltage changed from 707 V to 585 V. The voltage drop is 122 V. 2) With BPS, the 3rd rail voltage changed from 679 V to 615 V. The voltage drop is 64 V. 3) Therefore, the 3rd rail voltage was stabilized by 58 V.

2) Reuse 50% of the regenerative braking energy as the power supplied via the BPS. 3) Utilize regenerative braking power from all speed ranges, include low- and high-speed operations.	To verify that the BPS enhances the creation of regenerative energy, captures the energy created by the regenerative braking during train operation at all speeds, stores it and provides it for supplemental use as necessary.	1) Without the BPS connected, the regenerative energy from the train is 1.34 kWh. 2) With the BPS connected, the regenerative energy from the train is 2.94 kWh which is 2.19 times more energy. 3) With the BPS connected the regenerative energy stored by the BPS is 2.10 kWh, therefore 71.4 % of the regenerative energy was stored by the BPS.
4) Power trains by BPS alone to demonstrate evacuation during a power outage. (Trains to travel at a maximum of 10 mph [about 15 km/h] with lights and AC operating using only the power supplied by the BPS.)	To verify that the BPS alone can provide sufficient power to operate a single train when there is no power being supplied by the substation and to calculate the total theoretical number of trains that could be moved by BPS alone with all auxiliary equipment such as lighting and air conditioning on, at a maximum train speed of approximately 10 mph.	1) The train was run on the test track for a round trip distance of 8200 ft and used 5.5 % of the BPS Charge. 2) The train was run on the Service Line for a round trip distance of 3,000 ft and used 2.8% of the BPS charge. 3) Therefore, based on the next station distance of 4,000 ft a fully charged BPS alone can move 17 10-car trains to the next station.
5) Verify that BPS emits no EMI. [Additional Item]	To verify that the BPS did not create any EMI issues.	NYCT measured the EMI levels at the site and did not observe any impact when the BPS was operating.

8. Conclusions

The tests successfully demonstrated the following:

1) The BPS stabilized the dramatic fluctuations in the third rail line voltage.

2) The BPS efficiently captured the regenerated braking energy and used this energy as needed. This reduced the contract energy requirements and therefore CO_2 emissions.

3) It was demonstrated that the peak demand can be reduced.

4) The BPS started a 10-car train from a complete standstill and operated it for a full round trip on the test track while all its lights and auxiliary equipment were "ON". It proved that up to 17 10-car trains could be moved to the next station during an emergency power outage condition.

5) The BPS was easily installed by direct connection to the third rail line voltage without any electronic controls and had no measured EMI impact.

In summary, the tests met or exceeded the Project Objectives and were therefore deemed highly successful.