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LA METRO RED LINE WAYSIDE ENERGY STORAGE SUBSTATION REVENUE SERVICE REGENERATIVE ENERGY SAVING RESULTS

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ABSTRACT

The Los Angeles County Metropolitan Transportation Authority (LA Metro) Red Line (MRL) provides heavy rail subway service with six-car trains at up to 65 mph, connecting downtown to the San Fernando Valley with weekday headways down to five minutes. MRL trains have either DC chopper propulsion or AC propulsion. Revenue service measurements at the busy Westlake/MacArthur Park station show that natural regeneration from braking trains to accelerating trains recoups 34% of the energy provided by nearby braking trains. The remaining 66% of the braking train energy is a candidate for capture and reuse.

To capture and reuse this energy, Metro contracted with VYCON Inc. to design, supply, and integrate a flywheel Wayside Energy Storage Substation (WESS). WESS will capture and reuse train braking energy at the MRL Westlake traction power substation, located at the Westlake/MacArthur Park station. The project, funded by a grant from the Federal Transit Administration through its Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program under the American Recovery and Reinvestment Act (ARRA), is being cooperatively performed by Metro and VYCON. The initial WESS deployment is of a 2 MW rated system with a 15 s charge / discharge time, and an 8.33 kWh energy capacity. The WESS design allows easy expansion to a 6 MW rating. This paper presents results from initial MRL tests to measure regenerative energy savings which occur during revenue service operations, before installing the WESS.

LA WESS PROJECT

The Los Angeles County Metropolitan Transportation Authority (LA Metro) Red Line (MRL) provides heavy rail subway service with six-car trains at up to 65 mph, connecting downtown to the San Fernando Valley, with a branch to the west along Wilshire Boulevard (the Purple Line). On weekdays, the lines have 10 min headway on each branch, and five min headway on the downtown Los Angeles trunk section. MRL trains have either DC chopper propulsion or AC propulsion.

When a MRL train brakes into a passenger station, or when it brakes at curve speed reductions between stations, it can convert train kinetic energy into regenerated electric energy which can flow on the third rail and power another nearby accelerating train. If there is no train accelerating nearby to accept this regenerative energy, the energy is dissipated by resistors on the braking train.

The Westlake / MacArthur Park passenger station is on the trunk section, with 5 min headway weekday service. Revenue service measurements at Westlake/MacArthur show that natural regeneration from braking trains to accelerating trains recoups 34% of the total possible energy which braking trains can provide. The remaining 66% of the braking train energy is a candidate for capture and reuse.

The U.S. Federal Transportation Administration (FTA) provided a grant to LA Metro to apply energy storage to reduce rail transit energy use. The FTA provided the grant through its Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program under the American Recovery and

Reinvestment Act (ARRA). Metro expects to benefit from reduced electricity costs both from energy savings and from reduction of peak power demands.

To capture and reuse the possible 66% of regenerated energy, Metro contracted with VYCON Inc. to design, supply, and integrate a flywheel Wayside Energy Storage Substation (WESS). LA Metro installed the WESS at the MRL Westlake traction power substation, located at the Westlake/MacArthur station. LA Metro and VYCON cooperatively performed the WESS project.

Transit agencies in the US and around the world are testing flywheel, battery, and supercapacitor energy storage systems. Sacramento Regional Transit District has two WESS projects: batteries for voltage support and supercapacitors for regenerative braking. New York City Transit tested flywheels for voltage support and is testing batteries for regenerative braking energy capture. The Washington Metropolitan Area Transit Authority and Southeastern Pennsylvania Transportation Authority are testing batteries for regenerative braking energy capture [1].

LA Metro chose flywheels over batteries and supercapacitors because flywheels have superior cycle lifetime, fast and equal charge and discharge rate, and suitability for harsh conditions. Compared to batteries and supercapacitors, flywheels require less maintenance because they use magnetic levitation system rather than mechanical bearings. Batteries have a higher energy density and quick discharge rate, but have a slower charge rate and have a limited cycle lifetime. The slow charge rate would decrease the efficiency of WESS capturing regenerative energy and require periodic inspection for leakage, cracks, capacity, and corrosion. Battery performance degrades with age and cycle use, while flywheel performance does not degrade with age and use. Supercapacitors have a faster charge and discharge rate than flywheels, but also have a capacity and limited lifetime. When supercapacitors fail, they emit toxic gases that can be dangerous for transit agency employees and passengers, so precautions must be taken when using supercapacitors to contain the potential toxic gases.

With WESS, when a MRL train brakes and no other nearby train can accept regenerated power, WESS absorbs the regenerated energy and stores it until it can be used by another train. The regenerative energy flows from the train via the third rail to the traction power substation (TPSS) where WESS captures and stores it. WESS then provides the stored regenerated train energy via the third rail to the same train or another train when it accelerates. WESS can also be commanded to provide line voltage support, at times or places where that is useful.

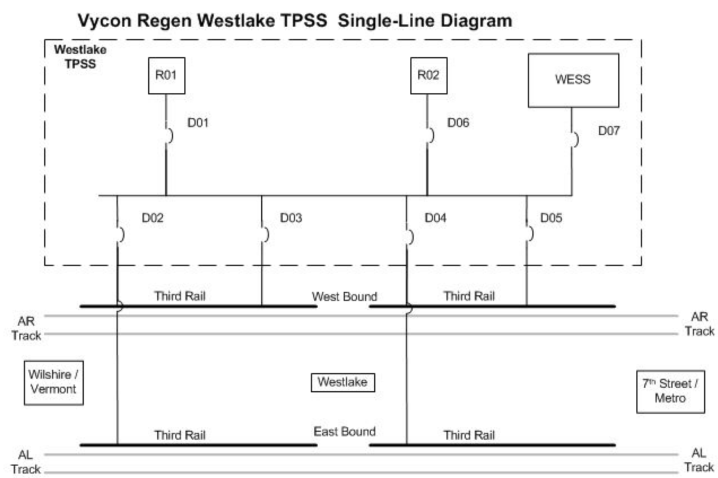
The downtown terminal at Union Station serves the Red Line, which runs west to the Wilshire/Vermont station and then north where it terminates in North Hollywood, and the Purple Line, which branches west at the Wilshire/Vermont station along Wilshire Boulevard to Western Ave. The Purple Line will extend west, to Westwood, with plans for a further extension west to Santa Monica. The Westlake/MacArthur station where WESS is installed is on the trunk section serving both the Red and Purple lines. The weekday headway on the trunk section is 5 min, and LA Metro plans increased future service with trunk headway down to 2 min. MRL is presently served by two fleets of electric multiple unit heavy railcars. The original fleet uses DC chopper propulsion and the second uses AC inverter propulsion. LA Metro plans to refurbish the first fleet with AC propulsion and acquire additional AC propulsion cars, eliminating the DC chopper propulsion.

The initial WESS deployment is of a 2 MW rated system with a 15 s charge / discharge time, and an 8.33 kWh capacity. The flywheels can make a full charge and discharge cycle every 1.25 min, repeatedly and continuously. The initial WESS consists of four Flywheel Modules (FWM), each rated at 500 kW, 2.08 kWh. Each FWM consists of 4 individual Flywheels Units (FWUs). The WESS can be expanded to 6 MW, 25 kWh by adding 8 more FWMs, totaling 12 FWMs, or 48 FWUs. The FWMs have a 20 yr minimum service life.

WESS AT WESTLAKE

Figure 1 shows the Westlake TPSS single line diagram. The Westlake TPSS is a dual 2.5 MW conventional rectifier power station. The DC bus at Westlake is fed by two circuit breakers (CB) D01 and D06, from two rectifiers R01 and R02. The DC bus supplies four track feeder CBs, D02 – D05, which feed the east and west sections of the eastbound (AL) and westbound (AR) tracks. The third rail sections are separated by bridging gaps at the entrance to and non-bridging gaps at the exit from each passenger station. Figure 2 shows the WESS single line diagram.

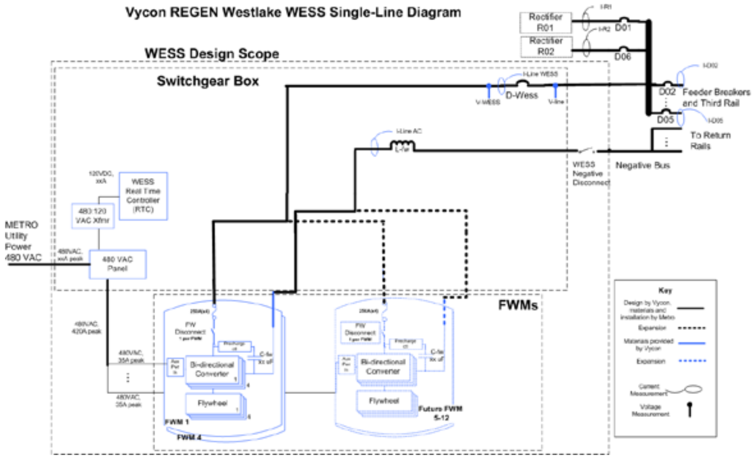
Figure 1



WESS is installed in the Westlake TPSS and is connected to the existing TPSS DC bus by a new CB D07. A key-interlocked negative disconnect allows WESS to be fully isolated from the TPSS and traction power system for service. The WESS CB D07 provides remote and local control and overcurrent and fault protection.

WESS ensures adequate electromagnetic interference (EMI) protection for the MRL track circuits with an EMI filter consisting of a line inductor, and the link capacitors in each FWU. WESS auxiliary power is supplied from a separate 480 VAC service.

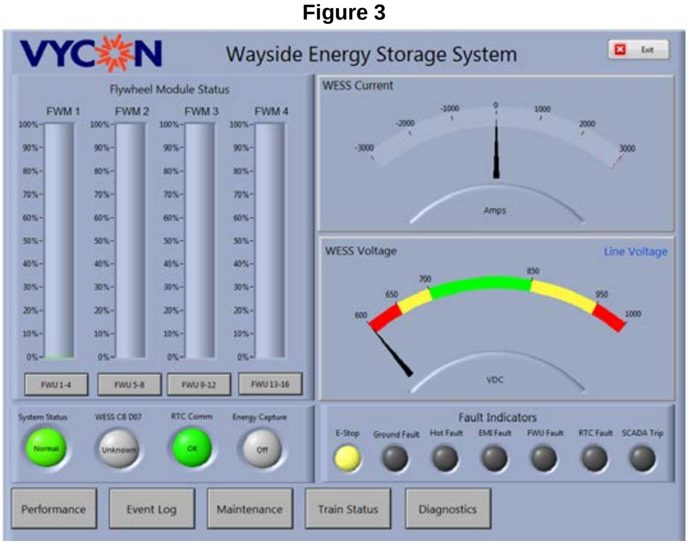
Figure 2



The FWMs are controlled by the WESS Real Time Controller (RTC). The RTC provides control, monitoring, and logging of WESS. The RTC watches for train braking events then commands the FWMs to charge and watches for accelerating events then commands the FWMs to discharge. The RTC consists of a rugged industrial processor, analog and digital input and outputs, network communications, and a touch panel display for user interface.

Figure 3 shows the RTC main display of WESS performance and status. The RTC monitors the FWMs, the third rail Feeder Breakers, TPSS Rectifiers, and DC Switchgear. The RTC uses the local inputs to measure traction power conditions and power use at Westlake. The RTC also performs WESS safety control functions, including transient protection command to FWMs.

Figure 3



The RTC is connected to each FWUs by Ethernet. The RTC provides a command packet and receives a status packet to and from each FWU at a 10 Hz rate. RTC commands to FWUs include mode control, and control of the charge or discharge power level. FWU status to RTC includes FWU state, status, and fault information.

RTC analog inputs measure current in each Westlake CB as well as bus voltage. The RTC receives commands from MRL SCADA, and provides status to the SCADA. The RTC controls and monitors the WESS D07 CB, as permitted by the operating mode and SCADA command.

The RTC processes, displays, and logs FWU data and data measured from connected sensors. The RTC reports on WESS operation, energy saving, and performance for monitoring WESS real-time and long-term performance. The RTC securely communicates over Ethernet and internet to any authorized connected terminal, providing complete authorized remote access to WESS data and control information.

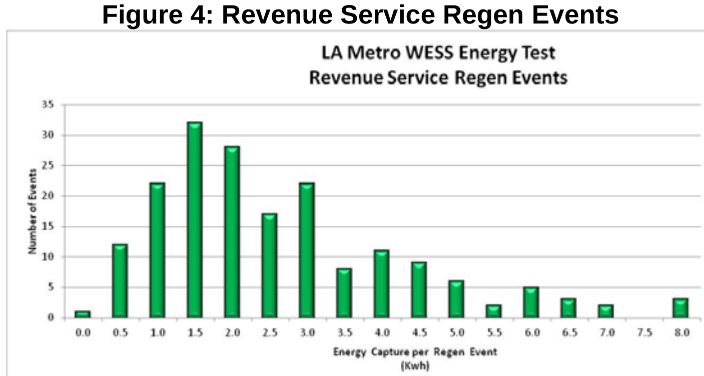
For EMI protection, the RTC uses an AC current sensing loop in an EMI Detector (EMID) function, to check specific frequencies of the WESS current to protect the MRL track circuits. The EMID continuously monitors WESS conducted emissions on the WESS main circuit connected to the Westlake TPSS DC bus, across the MRL automatic train control track signaling frequency range. If the EMI levels exceed acceptable levels, the RTC will command each WESS FWU to stop sinking or sourcing current, command each FWU to open its line contactor, and open the WESS DC circuit breaker.

PRE-WESS ENERGY MEASUREMENTS AT WESTLAKE

To quantify the energy and power used by MRL trains before WESS implementation and the potential energy that can be recovered during braking, VYCON and LA Metro measured Westlake TPSS power use. The project monitored the rectifier and feeder CB currents and voltage during normal revenue service and during non-revenue tests.

The revenue service tests covered peak rush-hour and off-peak activity, with a total of 184 regen events and 507 kWh of regen energy. During this time, only three train-to-train 8 kWh regen events occurred, where conditions and timing allowed near maximum high energy transfer. All other events had lower regen energy transfer. The average regen event captured 2.8 kWh, with a possibility of at least 8 kWh. Figure 4 is a histogram of regen events at each energy level.

Figure 4: Revenue Service Regen Events



Run time: 5.1 hrs. Regen events: 184.
Total regen energy: 507 kWh.
Max regen event: 8 kWh. Min regen event: 0.3 kWh

Considering a possible 8 kWh energy transfer per train braking event, analysis of the 184 regen events indicate that about 34% of the available regen energy is presently captured by the normal interaction of trains entering and leaving the Westlake station during peak and off-peak periods. This implies the remaining 66% of regen energy is potentially available to be captured, stored, and reused by WESS.

Non-revenue service tests used two test trains to manage train braking and acceleration timing to maximize regenerated energy transfer. The runs were arranged so that one train accelerated (Load Train) while the other train braked (Regen train). Figure 5 shows a regen event where an AC propulsion train was the Regen Train braking from 50 mph, and a DC Chopper propulsion train was the Load Train. This event recovered 7 kWh.

Figure 6 shows the post-measurement analysis of test run 129-08, a peak hour test. Figure 6 shows numbers highlighted for measured and calculated data:

1. AR and AL Regen Power (kW): These results are calculated from the Regen current of AR and AL tracks and TPSS DC Voltage.

2. Track Current for ARe, ARw and ALe, ALw tracks (DC A): Four feeders from the Westlake TPSS connect to the four track segments. Positive current on the graph is power to the train, and negative current is power coming from a train, typically from a Regen Train.

3. Substation Voltage (V DC): Nominal value is 800 Vdc.

4. Westlake Substation Rectifier Current for D01, D06 (A DC): Positive current indicates Westlake TPSS sourcing. Zero current indicates power is being supplied from other sources including regen events and adjacent TPSS.

5. AR, AL and total Regen Energy (Wh): These results are calculated from regen power and time.

ACKNOWLEDGMENTS

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REFERENCES

[1] C. Lamontagne, Advanced Wayside Energy Storage System for Rail Transit. Transit IDEA Project 66, April 2013. Transportation Research Board, Washington DC.

Figure 5 Measured 7 kWh Regen Event.

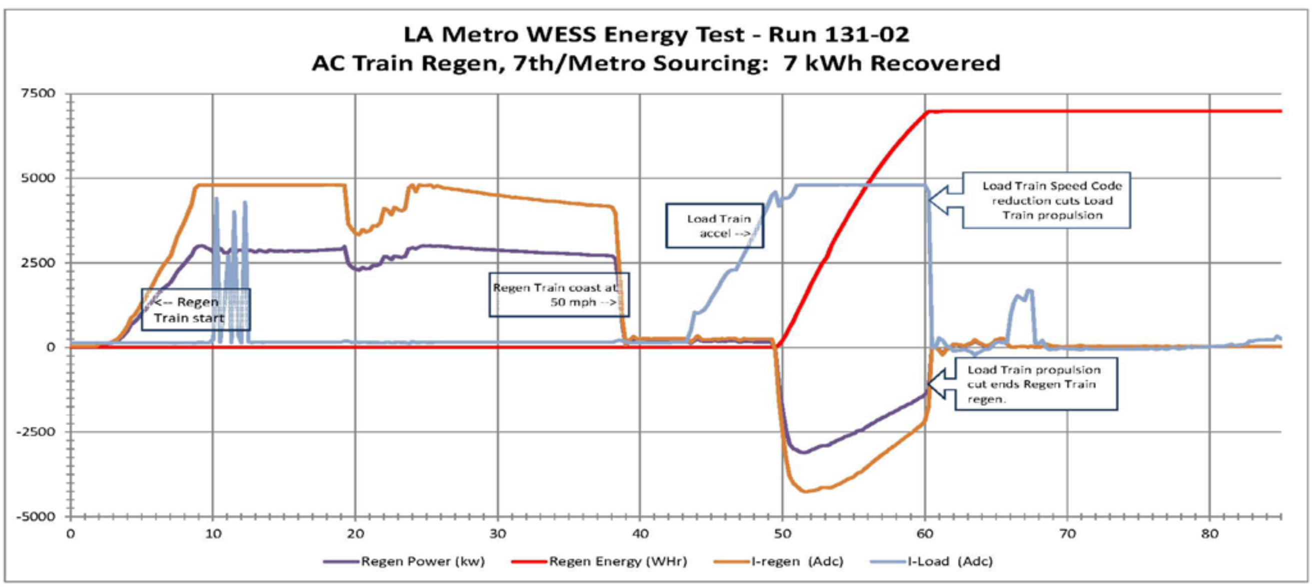
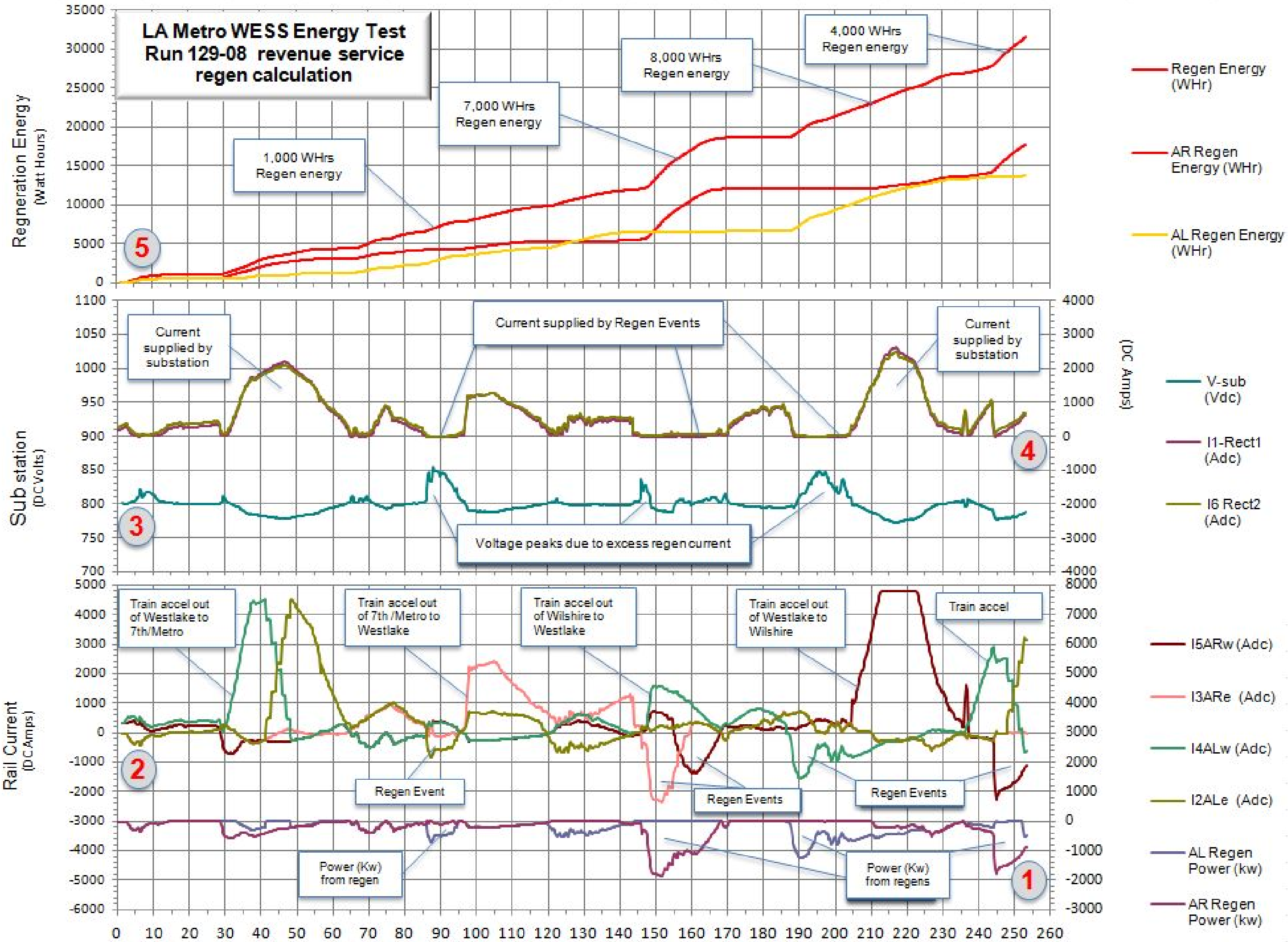


Figure 6



LA Metro WESS Energy Test
Run 129-08 revenue service
regen calculation
1,000 WHrs Regen energy
7,000 WHrs Regen energy
8,000 WHrs Regen energy
4,000 WHrs Regen energy
Regeneration Energy (Watt Hours)
Regen Energy (WHr)
AR Regen Energy (WHr)
AL Regen Energy (WHr)
Current supplied by substation
Current supplied by Regen Events
Current supplied by substation
Voltage peaks due to excess regen current
Sub station (DC Volts)
(DC Amps)
V-sub (Vdc)
I1-Rect1 (Adc)
I6 Rect2 (Adc)
Train accel out of Westlake to 7th/Metro
Train accel out of 7th /Metro to Westlake
Train accel out of Wilshire to Westlake
Train accel out of Westlake to Wilshire
Train accel
Regen Event
Regen Events
Regen Events
Power (Kw) from regen
Power (Kw) from regens
Rail Current (DC Amps)
I5ARw (Adc)
I3ARe (Adc)
I4ALw (Adc)
I2ALe (Adc)
AL Regen Power (kw)
AR Regen Power (kw)