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SAVING MONEY EVERY DAY: LA METRO SUBWAY WAYSIDE ENERGY STORAGE SUBSTATION

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ABSTRACT

The Los Angeles County Metropolitan Transportation Authority (LA METRO) subway provides service with up to six-car trains at up to 65 mph at five minute headways on weekdays. To reduce energy usage, LA METRO implemented a flywheel-based Wayside Energy Storage Substation (WESS), which reduces energy usage by capturing and reusing braking energy generated by trains when they decelerate and brake approaching the passenger station. The LA METRO WESS has a 2 MW, 15 second capacity, or 8.33 kWh, and can charge and discharge with a 1.5 minute cycle rate. WESS has been in daily full operation since August 2014. WESS has saved 10 to 18% of the traction power energy at the Westlake TPSS, every day.

ABOUT WESS

The Los Angeles County Metropolitan Transportation Authority (LA METRO) heavy rail Red Line and Purple Line subways provide service with up to six-car trains at up to 65 mph at five minute headways on weekdays, connecting downtown Los Angeles to North Hollywood and the Mid-Wilshire Corridor. To reduce Red Line and Purple Line energy usage, LA METRO implemented a flywheel-based Wayside Energy Storage Substation (WESS) at the traction power substation (TPSS) at the Westlake / MacArthur Park station. The Federal Transit Administration (FTA) funded the project under the American Recovery and Reinvestment Act (ARRA) TIGGER program. WESS has been in daily operation since August 2014.

WESS captures and reuses energy released by trains as they brake for stations and curves. When a LA METRO subway train decelerates and brakes, the train can regeneratively brake converting its kinetic energy into electrical energy. Without WESS, a braking train can return

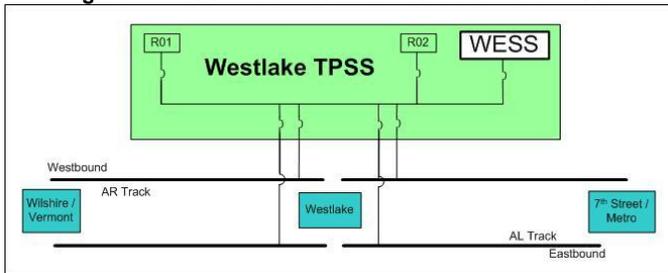
its energy to the third rail to power other trains, only to the extent other nearby trains are receptive, that is, drawing power close enough to the regenerating (regen) train. With WESS, when a train brakes near the WESS TPSS, if no other train can accept this regenerated energy, WESS captures and stores the regen energy. WESS then returns the captured energy to the next train that needs it. WESS cooperates with and augments natural train-to-train regeneration, and only captures regenerative energy that load trains can't accept. By recycling train braking energy that would otherwise be wasted as heat in the braking resistors, WESS reduces the TPSS energy usage and peak power demand, reducing LA METRO's utility bill and provides benefits, external to LA METRO, to the environment and utility infrastructure.

VYCON provided the high-speed, high cycle rate flywheel equipment, ELCON Associates designed the equipment installation into the TPSS, and Turner Engineering Corporation designed and built the WESS controller. VYCON flywheels provide high storage capacity, low losses, a high charge and discharge power rating, and high cycle life, well matched to train accelerating and decelerating profiles and service.

The LA METRO WESS has an installed capacity of 2 MW for 15 s, or 8.33 kWh, and can be expanded to 6 MW for 15 s, or 25 kWh. The project analyzed WESS predicted energy savings at Westlake TPSS to determine the preferred WESS capacity. The analysis showed WESS energy savings increase linearly with WESS capacity of up to 4 MW. With a WESS capacity of 6 MW, energy savings increase significantly compared 4 MW, but slightly less than linearly. Also, the cost of a 6 MW WESS is not 3x compared to a 2 MW WESS, since engineering, cables, controls, circuit breakers, preparation costs, and installation costs are not

directly related to WESS rating. A 6 MW WESS was the preferred size considering energy and power savings, but available funding limited the WESS installation to 2 MW. WESS is connected in parallel with the TPSS, as shown in Figure 1.

Figure 1: WESS in the Westlake/MacArthur Park TPSS



The 2 MW WESS consists of 4 flywheel modules (FWMs), each of which contains 4 flywheels units (FWUs). Each FWU has a 125 kW, 15 s capacity. The 16 FWUs are connected in parallel and are commanded to charge and discharge in sync. WESS can turn individual FWUs off or on independently, and runs with any number of FWUs active.

In normal operation, the FWUs run between 10,000 rpm with zero available energy to 20,000 rpm with maximum available energy. A FWU cannot provide energy when its speed is at or below 10,000 rpm, and cannot store any more energy when it is at its maximum speed of 20,000 rpm. The FWUs require minimal periodic inspection or maintenance, and have a 20 year lifetime at the maximum charge/discharge cycle rate.

ENERGY SAVINGS

WESS continuously monitors the Westlake/MacArthur Park TPSS voltage, feeder breaker currents, and the locations of trains near the Westlake/MacArthur Park Station. WESS uses the value and trend of voltage, currents, and train locations to control its operation, monitor energy savings, monitor train energy usage and to adapt as needed for optimal energy savings. WESS monitors, records, and reports energy savings as a continuous real time function.

Every day, WESS saves 1.3 to 1.7 MWh, with an average of 1.5 MWh or 12 % energy saved. Energy saved is per equation 1.

$$\% \text{ Energy Saved} = \frac{\text{Energy Saved}}{\text{Energy Saved} + \text{Energy Provided by Rectifiers}} \quad \text{Eqn. 1}$$

Metro subway service runs 20 hours a day with a sustained peak hour headway of 5 minutes. Through the middle of the day, Metro runs trains on 6 minute headways with headways of 10 to 20 minutes off peak in the early and late hours. Weekend headways are 5 to 20 minutes. Trains vary in size, either 4 or 6 cars per consist. During weekdays WESS saves an average of 1.6 MWh per day and during the weekends an average of 1.5 MWh per day.

Figure 2 summarizes the WESS weekly savings by train schedule.

Figure 2: LA METRO WESS Weekly Savings

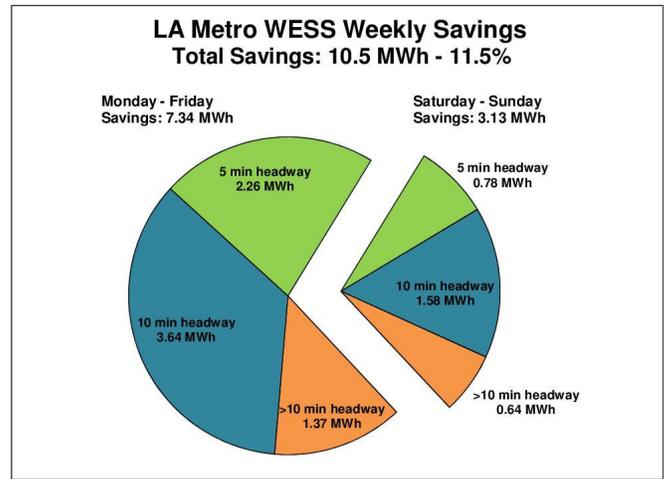
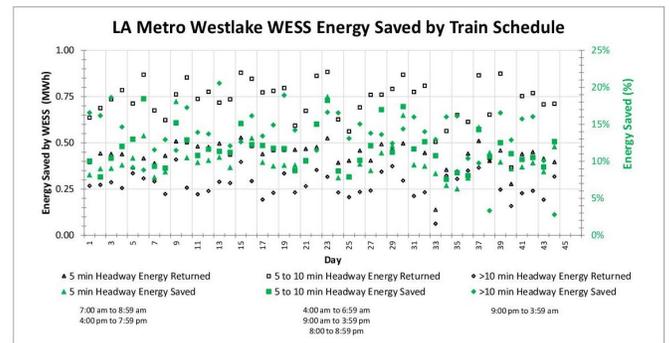


Figure 3 shows the WESS Energy Saved by scheduled train headway.

Figure 3: LA METRO Westlake WESS Energy Saved by Train Schedule



During the 5 minute headway intervals, WESS saves an average of 0.45 MWh per day or 10% energy saved. This close headway has the most trains per hour and trains are close together on the line, so there is significant natural train-to-train regeneration. The extent of train-to-train regeneration at a specific station depends on the train sequence. In a synchronized train sequence, a regeneration train decelerates into a station at the same time a load train accelerates out of the station. This synchronized sequence maximizes train-to-train regeneration so less braking energy is available for WESS capture. WESS makes sustained 7 % energy saved while the close headway sync condition persists.

When the train sequence is not synchronized at the WESS station, two trains enter a station at nearly the same time and leave the station at nearly the same time. These conditions minimize natural train-to-train regeneration and maximize the braking energy available for WESS capture. WESS makes sustained 20% energy saved while the close headway asynchronous condition persists.

At Metro, the train sequence varies, and is sometimes stably synchronized, sometimes stably asynchronous, and sometimes

varying. WESS handles all these conditions and cooperates with regenerative and load trains as they come.

During 5 to 10 minute headway intervals, WESS makes the greatest savings, 0.73 MWh per day or 11% energy saved. With 5 to 10 minute headways, the number of trains per hour remains fairly high, and trains are further apart so less natural train-to-train regeneration occurs. As a result, WESS has many cycles with significant energy capture.

During intervals with 10 to 20 minute headway, trains are further apart, so there is little train-to-train regeneration and WESS has the highest percentage energy saved, 14% energy saved. WESS typically captures all the regenerative energy from a train and returns the energy to the same train as it leaves the station. However, with these long headways, there are fewer trains per hour so WESS saves the least total energy, 0.27 MWh per day.

ENERGY SAVINGS BY UTILITY SCHEDULE

The power utility daily billing segments are high peak, low peak and base, with high, medium, and lower energy and power costs in the three segments. The LA METRO train schedule headway segments and the power utility daily billing segments do not align by time of day. For example, the power utility high peak daily segment, when energy costs the most, spans the LA METRO 5 to 10 minute headway and the 5 minute headway segments.

For cost savings analysis, this analysis groups the energy savings to align with the three power utility daily segments. Table 1 shows the energy usage and energy saved during each segment. WESS saves the most energy during the base segment, 0.7 MWh or 12 %, because the base segment makes up most of the day and powers the most trains.

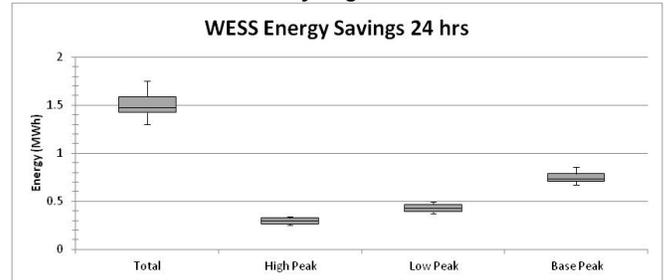
Figure 4 shows daily variations in the WESS energy savings, grouped by power utility billing segment. The base segment has the highest day-to-day fluctuations because the base segment includes the morning 5 minute peak headway period when energy savings are more variable.

Table 1: Average Daily WESS Savings by Power Utility Daily Segment

Average Daily WESS Energy Savings by Power Utility Daily Segment				
	Total (MWh)	High Peak (MWh)	Low Peak (MWh)	Base (MWh)
WESS Energy Returned ¹	1.5	0.3	0.4	0.7
Rectifier Energy ¹	11.5	2.6	3.5	5.7
Total Energy to Trains ¹	13.0	2.9	3.9	6.4
% Energy Saved ¹	11%	10%	11%	12%
Energy Usage prior to WESS including Aux ²	16.2	2.4	3.5	10.3

Note: [1] Calculated from WESS measurements
[2] Calculated from Power Utility bills

Figure 4: LA Metro Westlake WESS Energy Saved by Power Utility Daily Segment



POWER SAVINGS BY UTILITY SCHEDULE

For the utility supplying power to the Metro subway, power demand is the average power used in a 15 minute interval, and peak power demand is the highest average power use in any 15 minute interval. WESS reduces the utility energy use, which in turn lowers the average power and the peak power demand.

Table 2 compares the peak power demand with and without WESS. WESS reduces the peak power demand by about 350 kW in each of the three utility power billing segments.

Table 2: WESS Peak Power Savings by Power Utility Billing Schedule

WESS Peak Power Savings by Power Utility Daily Segment			
	High Peak (kW)	Low Peak (kW)	Base (kW)
Peak Power Demand with WESS ¹	915	965	1070
Peak Power Demand without WESS ²	1260	1305	1455

Note: [1] Calculated from WESS measurements
[2] TPSS peak power demand calculated from Power Utility bills

PREDICTED UTILITY COST SAVINGS

The analysis estimates WESS savings using the Table 1 energy savings data and the Table 2 power savings. The two relevant components of the monthly power utility bill for predicting cost savings are energy usage in kWh and peak power demand in kW. The billing rates of the utility supplying WESS vary for energy and power use in the base, low peak, and high peak segment of the day and in the high and low seasons of the year. The prices increase during high season and peak segment and decrease during low season and non-peak segments.

Figure 5 shows the estimated WESS cost savings for one year. The analysis estimates WESS will save at least \$99,000 per year at the Westlake/MacArthur Park TPSS. 52% of the yearly savings due to energy savings and 48% due to peak power demand savings. High season accounts for 39% of the total savings in just 3 months of the year.

The predicted cost savings assumes traction power energy usage is consistent throughout the year and that the highest peak power demand with WESS active applies for the daily high peak, low peak, and base segments. Using the same peak power demand with WESS for all three daily segments is

conservative in that it estimates lower savings than using three different average powers for the three segments.

The WESS energy, peak power demand and cost savings only apply to the Westlake/MacArthur Park TPSS. Installing additional VYCON flywheel based WESS on the LA METRO rail system will increase the overall LA METRO savings.

As in any application of a new technology into a mission-critical public service like the LA METRO subway, the first WESS deployment entailed high development and integration costs, covering considerations including system performance parameters, operating considerations, system interfaces, operating safety, electromagnetic compatibility, and manuals

and training adapted to the LA METRO environment. Fortunately for LA METRO, the FTA funding provided the means to resolve these issues and make a successful installation, commissioning, and entry into service. As WESS units are installed in more LA METRO TPSSs, production scale will reduce capital and deployment costs. At a suitable level of deployment, a WESS could cost about \$1m, and achieve a 10 year return on investment, even without any improvement in energy savings, peak power reduction, or an increase in the cost of power.

Future enhancements for WESS can include an increase WESS capacity at the Westlake TPSS and expansion of WESS to more TPSSs.

Figure 5: WESS Yearly Predicted Savings

