Carbon And Life Cycle Comparison Of Traditional And Flywheel Power Plants For Grid Frequency Regulation Applications[1]

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Paper:

This paper is a summary of KEMA's investigation of the potential emissions savings associated with utilizing a flywheel-based power plant for frequency regulation. The study compares the emissions of the flywheel application to that of other traditional methods or power plants. The purpose is to determine whether there is improvement in emissions achieved by utilizing the flywheel application. For the study, the flywheel application was compared to other traditional generation technologies that are currently being utilized for the purpose of frequency regulation. The emission factors examined in the study are CO_2, SO_2, and NOx.

This particular effort was part of a two-phase technology evaluation of the 20 MW Beacon Flywheel power plant. This first phase examined the Environmental impact evaluation of the flywheel system, while the second phase of the project examined the financial benefits and life-cycle cost performance of the flywheel.

Description of Frequency Regulation:

Typically, generators are used to help maintain a system grid frequency at 60Hz. In order to accomplish this, a generator's output is increased or decreased depending on the specific needs of the grid at that moment. The diagram below in Figure 1 shows when this occurs and how power-plants respond to these specific needs of the grid.

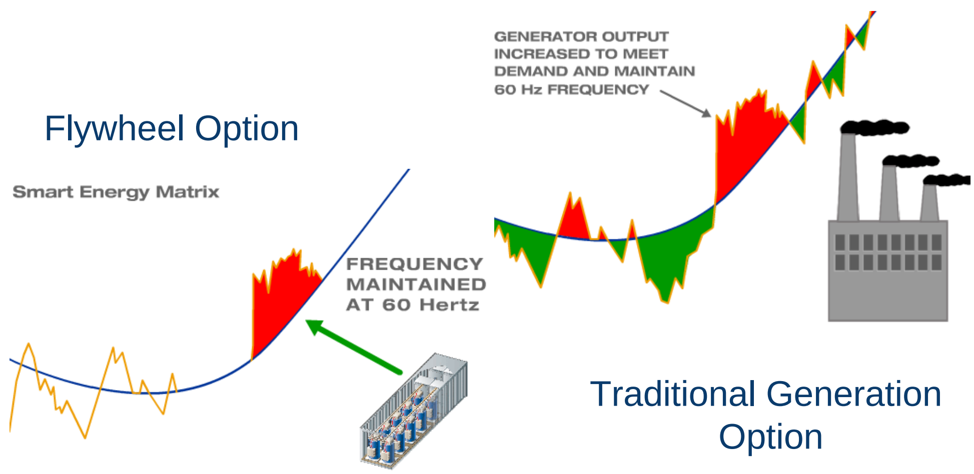

Figure 1: Principles of Frequency Regulation

The diagram also shows how the flywheel application, through its charging and discharging cycles, could also support the frequency regulation requirements.

Goals of Emission Model

The characteristics of the flywheel response time, size of the plant, and storage capability allow it to perform a fast-response frequency regulation role. With the charging and discharging capability, the flywheel can perform the same function as a power plant that typically needs to either ramp up its output or reduce its output in response to control signals. Because the flywheel power plant is capable of performing this role, KEMA

[1] Funded in part by the Energy Storage Systems Program of the U.S. Department Of Energy (DOE/ESS) through Sandia National Laboratories (SNL)

developed a model to compare the flywheel to the current methods. As stated above, this comparison examined whether there are any emission benefits gained by utilizing the flywheel in this capacity. To accomplish this task, the flywheel system was compared to three (3) different options. This first option was a coal generation plant - a 400 MW plant operating in a baseloaded mode and a 75 MW plant operating in a peaker mode. The second option was a natural gas generation plant - again a 400 MW plant operating in a baseloaded mode and a 75 MW plant operating in a peaker mode. The third option is a simple pumped hydro storage system.

The sizes of the plants for the baseload and peaker mode operation were selected to represent the typical type of power plants that are running for each of the operational modes. The baseloaded plant was selected so that the 20 MW swings represented a relatively small percentage change in the plant output. For the peaker mode operation, the size was selected to allow the unit to be able to handle the 20 MW swings without falling below a minimum threshold of operation.

Finally, in order to examine a cross function of territories, power plant data was taken from three (3) different ISO territories. These territories are PJM Territory, ISO-New England, and California ISO.

Model Premise

In order to compare the operation of the flywheel to the alternative generation and hydro technologies, the following approach was taken. For the flywheel, as the unit does not generate electricity and only absorbs power from the grid or discharges power, the emissions were calculated only on the energy that was lost in each of the cycle phases – charging, discharging, idling, and load bank. Hence, to calculate the total amount, emissions were calculated on losses during the charging cycle as well as the extra energy that is required to maintain the flywheel operation during idle periods. Though the flywheel had been confirmed to be able to respond to frequency control signals over 98% of the time, emissions for the approximately 2% additional energy was also accounted for in the calculation.

For the fossil generation plants, emissions were calculated for the incremental increases in output of fuel consumption due to the power plant responding to frequency control signals. For the baseloaded plants, as they were assumed to already be operating and supplying power to the grid, only the incremental differences in emission from altering the operation – either ramping up output or decreasing output – was accounted for when calculating the emissions. For the peaker plant, a similar methodology was utilized except that as the peaker plant was assumed to only be operating for the purpose of frequency regulation, emissions for the unit “idling” was also accounted for in addition to the incremental changes in operation.

The pumped hydro was approach in the same manner as the flywheel, were only the energy losses to operate the system were used for the emission calculations.

Emission calculations were made for one cycle, extrapolated to one day, then one year, then for the 20-year lifetime of the flywheel power plant.

With this approach, two main drivers were found to have an impact in the emissions of the fossil generation plants when compared to the flywheel. These drivers were, first, the additional inefficiencies due to responding to the frequency regulation market and, second, the fact that the flywheel would get its energy from a portfolio of generators while a plant depended specifically on its own emission profile.

<u>Plant inefficiencies due to Frequency Regulation market</u>

Our research showed that when a plant responds to frequency control signals and continually modulates its output, increased inefficiencies occur with the power plant. To determine the amount of increase, KEMA conducted web searches, interviews with State Agencies, and researched Department of Energy activity to estimate the effects on the overall efficiency of the power plant. Inputs from this process provided a range of effects between .5 and 2.5 percent. In the model, a factor of .7 % was used as the variance factor.

Generation Mix

The second driver that had an impact in the comparison was the Generation mix for each of the ISO territories that were being compared. Even though the flywheel does not generate its own electricity, power is still required to charge the plant and to maintain its rotation when the unit is not charging or discharging. This power need is drawn from Power Grids that are made up of a portfolio of generator technologies. These technologies combined to form a "grid average" emission factor for CO_2, NO_x, and SO_2.

When compared to an individual power plant, the average emission of the grid can sometimes provide an advantage of the emissions rates over a single power plant. This is seen in the case of a coal generation power plant, where the average emission factor is less than the emission factors for the coal plants.

Figure 2 below provides a chart of the percentage of generation types that make up each of the ISO territories.

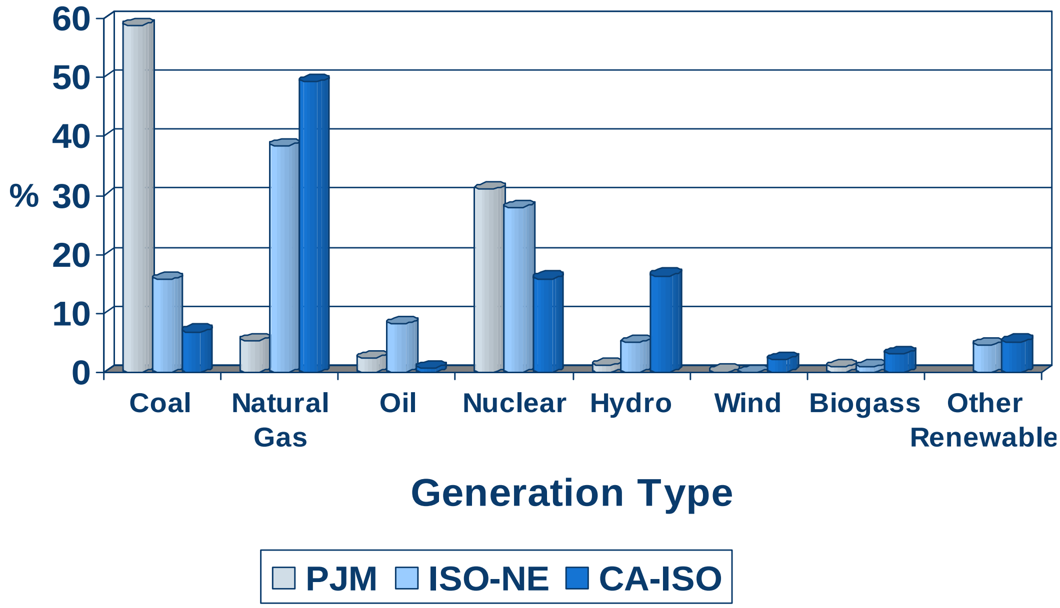

Figure 2: Generation Types for Each Territory

This information was taken from the US EPA eGrid database and the ISO territories themselves. Hence, for each of the territories, information was collected on the generation mix, the overall emission rate of the grid as a whole, and the emission rate for each of the specific technologies in the territory. When calculating emissions for flywheels and pumped hydro plants, the "average" emission rate was used to calculate the emissions for the energy utilized by the flywheel and pumped hydro plant.

Results

The conclusions of the study showed that by utilizing a flywheel power plant for frequency regulation in place of traditional power plants and commonly used Frequency Regulation methods, dramatically reduced emissions and cleaner performances can be achieved. A summary of the CO_2 emissions savings is shown in Figure 3.

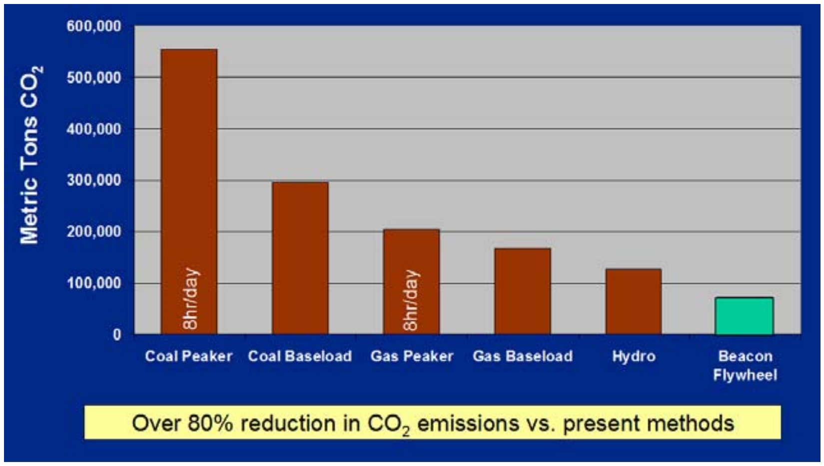

Figure 3: CO2 Emissions Summary

These savings are calculated over the 20-year life cycle of the flywheel plant. The chart shows that for CO2 emissions, the Beacon Flywheel had the greatest saving when it was compared to coal peaker power plants as well coal baseloaded power plants. For Carbon emissions, the flywheel application offered savings across all generation technology categories. For Natural Gas power plants, the savings were less than the coal plants but also significant. The benefits that were seen when compared to Hydro plants were mainly from the fact that the Flywheel operates at a slightly better efficiency than hydro plants.

The three charts below in Figure 4 shows the actual CO2 savings and saving percentage calculated for the flywheel vs. traditional technologies.

Flywheel Emission Savings Over 20-year Life: PJM					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	149,246	149,246	149,246	149,246	149,246
Alternate Gen.	308,845	616,509	194,918	224,439	202,497
Savings (Flywheel)	159,599	467,263	45,672	75,193	53,252
Percent Savings	52%	76%	23%	34%	26%

Flywheel Emission Savings Over 20-year Life: ISO-NE					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	106,697	106,697	106,697	106,697	106,697
Alternate Gen.	304,759	608,354	197,359	227,249	144,766
Savings (Flywheel)	198,062	501,657	90,662	120,552	38,070
Percent Savings	65%	82%	46%	53%	26%

Flywheel Emission Savings Over 20-year Life: CA-ISO					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	91,079	91,079	91,079	91,079	91,079
Alternate Gen.	322,009	608,354	194,534	223,997	123,577
Savings (Flywheel)	230,930	517,274	103,455	132,917	32,498
Percent Savings	72%	85%	53%	59%	26%

Figure 4: CO2 Emissions Summary

Conclusions

In summary, a detailed emission model was developed by KEMA to evaluate the emissions generated by traditional generation technologies participating in Frequency Regulation markets. The results showed highly favorable advantages for the flywheel specifically with the reduction of CO_2 across all regions. When compared to coal peaker plants and baseloaded power plants, the flywheel showed advantages of reduced emission profiles for all emission categories examined.

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