Emissions Comparison for a 20 MW Flywheel-based Frequency Regulation Power Plant

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Emissions Comparison for a 20 MW Flywheel-based Frequency Regulation Power Plant

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EXECUTIVE SUMMARY

KEMA Inc. was commissioned by Beacon Power to evaluate various performance aspects of the Beacon Power 20 MW flywheel-based frequency regulation power plant, including its emissions characteristics. To support the emissions evaluation, a detailed model was created to compare the emissions of CO_2, SO_2 and NO_x for a Beacon Power flywheel plant versus three types of commercially available power generation technologies used in the market to perform frequency regulation ancillary services.

The comparison of generation technologies included a typical coal-fired power plant, natural gas combustion turbine, and pumped storage hydro system. Emissions from the coal and natural gas-fired generation technologies result directly from their operation because they burn fossil fuels. In contrast, emissions for the flywheel and pumped hydro energy storage systems occur indirectly because they use some electricity from the grid to compensate for energy losses during operation.

The mix of power generation technologies and average system heat rates for fossil-based power generation systems varies across regions in the United States. To obtain a regionally adjusted emissions comparison, system data specific to three Independent System Operator (ISO) regions were examined: PJM (Mid-Atlantic), California ISO (CAISO), and ISO New England (ISO-NE). Data for each of these ISOs was extracted from the Department of Energy (DOE) Energy Information Administration (EIA) and Environmental Protection Agency (EPA) eGRID databases. Model calculations assumed typical heat rate and efficiency data for each type of generation.

For coal and natural gas-fired generation, KEMA's research found that frequency regulation results in increased fuel consumption on the order of 0.5 to 1.5%.[1] This finding is supported from estimates made by a U.S. DOE National Lab, information obtained from ISOs, and from a European study that evaluated electricity producers to determine whether power plants providing frequency regulation had an increase in fuel consumption and maintenance requirements. This effect was reflected in the model.

Based on the above data, model analysis showed that flywheel-based frequency regulation can be expected to produce significantly less CO_2 for all three regions and all of the generation technologies, as well as less NO_x and SO_2 emissions for all technologies in the CAISO region. The flywheel system resulted in slightly higher indirect emissions of NO_x and SO_2 in PJM and ISO-NE for gas-fired generation. This is because PJM and ISO-NE's generation mix includes coal-fired plants, and make-up electricity used by the flywheel and hydro systems reflects higher NO_x and SO_2 emissions from electricity

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[1] A 0.7% increase in fuel consumption due to frequency regulation was assumed in the model for this study.

generated in those areas. This effect was greatest in PJM because it has proportionally more coal-fired plants than ISO-NE.

When the flywheel system was compared against "peaker" plants for the same fossil generation technologies, the emissions advantages of the flywheel system were even greater. Model results for each of the ISO territories are summarized in Table 1, Table 2, and Table 3 on the following pages.

Table 1: Emissions Comparison for PJM

Flywheel Emission Savings in Tons, Over 20-year Life: PJM					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	107,902	107,902	107,902	107,902	107,902
Alternate Gen.	331,879	626,477	172,680	187,822	175,189
Savings (Flywheel)	223,978	518,576	64,779	79,920	67,287
Percent Savings	67%	83%	38%	43%	38%
SO2					
Flywheel	694	694	694	694	694
Alternate Gen.	2,152	5,172	0	0	1,127
Savings (Flywheel)	1,458	4,478	-694	-694	433
Percent Savings	68%	87%	n/a	n/a	38%
NOx					
Flywheel	227	227	227	227	227
Alternate Gen.	770	1,850	149	208	369
Savings (Flywheel)	542	1,623	-78	-19	142
Percent Savings	70%	88%	-52%	-9%	38%

Table 2: Emissions Comparisons for CAISO

Flywheel Emission Savings in Tons, Over 20-year Life: CA-ISO					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	67,791	67,791	67,791	67,791	67,791
Alternate Gen.	326,119	625,571	205,939	223,997	110,066
Savings (Flywheel)	258,327	557,780	138,148	156,206	42,275
Percent Savings	79%	89%	67%	70%	38%
SO2					
Flywheel	17	17	17	17	17
Alternate Gen.	1,232	2,961	0	0	27
Savings (Flywheel)	1,216	2,944	-17	-17	11
Percent Savings	99%	99%	n/a	n/a	39%
NOx					
Flywheel	55	55	55	55	55
Alternate Gen.	734	1,765	148	206	89
Savings (Flywheel)	680	1,710	93	151	34
Percent Savings	93%	97%	63%	73%	38%

Table 3: Emissions Comparisons for ISO-NE

Flywheel Emission Savings in Tons, Over 20-year Life: NE-ISO					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	88,483	88,483	88,483	88,483	88,483
Alternate Gen.	331,399	625,571	182,351	198,341	143,661
Savings (Flywheel)	242,916	537,088	93,868	109,858	55,178
Percent Savings	73%	86%	51%	55%	38%
SO2					
Flywheel	373	373	373	373	373
Alternate Gen.	1,984	4,769	0	0	605
Savings (Flywheel)	1,611	4,396	-373	-373	232
Percent Savings	81%	92%	n/a	n/a	38%
NOx					
Flywheel	148	148	148	148	148
Alternate Gen.	360	810	146	203	240
Savings (Flywheel)	212	662	-2	55	92
Percent Savings	59%	82%	-1%	27%	38%

The emissions estimates under the scenarios listed above show highly favorable comparisons for the flywheel across all generation technologies.

The remaining sections of the report provide the assumptions that were used in the modeling as well as further insights and analysis.

A full summary of the emission comparisons is provided in Section 4.3 of this report. The final data was based on the operation of a “typical” power plant for each of the categories. Analysis using known heat rates for a specific generating plant performing regulation would improve the accuracy of model comparisons relative to that specific plant.

1. Introduction

Beacon has requested that KEMA perform a two-phased technology evaluation of a 20 MW flywheel technology contrasting flywheel-based frequency regulation with conventional fossil, hydro and lead acid solutions with respect to:

Phase I: Environmental impact evaluation of the flywheel system with other commercially utilized frequency regulation technologies, bidding into the ancillary services market.

Phase II: Benefits of fast response to grid frequency regulation management, updated life-cycle environmental impacts and cost-performance analysis of the flywheel.

This report addresses Phase I, evaluating the environmental impact of the flywheel, compared to other existing commercially available technologies for frequency regulation as an ancillary service.

2. Scope of Work and Workplan

2.1 Technologies

KEMA evaluated the following technologies for frequency regulation at three locations. One in the CAISO service area, one in the PJM service area and one in the ISO New England service area:

a) Beacon Flywheel (Nominal power at 20MW plant)

b) Conventional coal-fired fossil generating plants (Base Load and Peaker units)

c) Conventional gas-fired fossil generating plants (Base Load and Peaker units)

d) Pumped Hydro Storage

2.2 Environmental Impact Evaluation

The Beacon flywheel is evaluated against other generation for the purpose of frequency regulation based on emissions and includes the following:

a) Impact of the operation of the storage system to the environment - Quantified in tons of CO_2, NO_x, and SO_2.

b) Assumptions are provided to Beacon and collectively accepted before the analysis commences.

c) As part of the assignment an environmental evaluation tool was developed by KEMA. This tool is proprietary and is only for internal Beacon Power use.

d) The deliverable for the Phase I task is this report on the possible emissions savings.

3. Assumptions and Approach

3.1 General Assumptions Emissions Calculations

For coal and natural gas, a simplified approach was used to characterize whether plant efficiencies at altering loads have a large impact on actual emissions output. For coal and natural gas, emissions can vary depending on other factors. For coal, it can depend on the type of coal and firing conditions, while natural gas has efficiency variances around not only loading but also temperature factors. Hence, for the analysis, the following simplified assumptions were used:

(i) Comparisons of the natural gas and coal plant emissions were made against units that did not have emission reduction equipment in the case of NO_2 and SO_2.

(ii) For coal and natural gas base loaded plants, cycles were conducted around a 95% capacity factor with up and down ramping of +/- 5% of capacity. Cycling can be adjusted to occur around another factor by adjusting the Heat Rate factors for each of the charging and discharging inputs per the worksheet heat rate vs. capacity output table.

(iii) ISO related “System-wide” emission outputs were used in calculating the emissions from the flywheel and hydro pumped storage options associated with the losses. This data was taken from EPA eGRID [1] and DOE EIA [2] databases. System-wide ISO emissions do take emission control technology into account.

(iv) Coal emission factors are typically calculated based on loads of 80% or greater. Although the emissions generated at a given heat rate or efficiency are influenced by additional factors related to fuel type, the actual plant output has a more significant impact on the overall emissions which allows the use of the simple calculation.

(v) Because the data was taken for one cycle and extrapolated over an entire year for the base load configurations, the focus of the model is on operations during that single cycle.

(vi) For coal and natural gas-fired generation, KEMA's research found that frequency regulation results in increased fuel consumption on the order of 0.5 to 1.5%. For this study 0.7% is used as the increased fuel consumption. This finding is supported from estimates made by a U.S. DOE National Lab, information obtained from ISOs, and from a European study [9, 10] that evaluated electricity producers to determine whether power plants providing frequency regulation had an increase in fuel consumption and maintenance requirements. This effect was reflected in the model.

3.2 Flywheel Charging and Discharging Cycles

For frequency regulation, the first general assumptions that were used were the number of cycles that occurred for each day. A cycle was defined as 15 minute ramp up or charging period, a 15 minute ramp down or discharging period, and 30 minutes of maintaining steady state or normal operations. For a complete day, 24 cycles were examined. The model uses a build-up approach that focuses on a single cycle, then extrapolates that data into a single day, a single year, and finally to a 20-year lifetime. Partial charges and discharge cycles were not considered.

3.3 Flywheel Operation

For the flywheel to operate in frequency regulation mode, four separate modes of operation were taken into account. These include: ramp-up (charging), ramp down (discharging), steady state period where the voltage level is being maintained in the flywheel, and an accommodation for the percentage of time when the flywheel system is unavailable for frequency regulation because it has run out of energy. KEMA utilized Beacon data for this percentage. In the scale power test unit in California, Beacon determined the flywheel was available 98.3% of the time for frequency regulation. Hence, a factor of 1.7% was used to account for the percent of time that the unit was unavailable. The emissions are created during these operating scenarios by the Flywheel using power from the grid to make up for the estimated 10% load losses on ramp up and ramp down, 1% energy required to maintain the flywheel, and the remaining unavailability utilization factor.

These idling losses (1%) of the flywheel can be absorbed from the grid or they can be compensated with renewable energy resources (solar or wind plant). In these calculations all flywheel losses are compensated by the generation mix of the specific ISO. Emissions rates used in these calculations use standard area fossil emission factors and "system" average heat rates and reflect the generation mix of the ISO region.

It was estimated that the flywheel system plant is able to provide only regulation during the availability period (assumed 98.3%) and that the overall charge - discharge efficiency of the flywheel is assumed at 80% (10% for ramp-up and 10% for ramp-down).

3.4 Coal-fired Plant Operation

The coal-fired plant emission data is calculated under two scenarios:

a) The first scenario is a base-load operation. Under this scenario, the coal plant is deemed to be a large power plant (400MW), base-loaded, and participating in a steady energy market. Hence, as the plant is considered to be already on-line, the emissions calculations above normal operations only occur when the plant is asked to increased its output (ramp-up) or decrease its output (ramp-down).

Summarizing:

i. A large power plant was used (400 MW) to represent a base-loaded coal plant that would be supplying wholesale energy to the market.

ii. Plant size was selected in order to allow a plant that could supply 20 MW around its rated 95 % capacity.

iii. Heat rates were used from a "general" coal plant as referenced in the DOE and EPA data without emissions reduction equipment. General estimates of heat rate fluctuations off the 100% operation were obtained through an estimated heat rate curve.

iv. A cycle was determined by a ramp-up, increasing output to the grid, and ramp-down decreasing output of the power plant.

b) A second operating scenario is in "peaker" operation. Under this scenario, the emissions of the coal plant are estimated in a "peaker" operating mode. In a "peaker" operating mode the plant is only operating to participate in the frequency regulation market. In this case, the ramp up and ramp down emissions are calculated, as well as idling emissions, where the emissions for the output while idling are compared against the same output that would have been produced by a plant running at full rated capacity. Data for typical emission rates were taken from the EPA eGRID [1] and DOE EIA [2] databases on ISO emission factors. It is assumed that these plants operate only for a limited time during the day and year.

Summarizing:

i. The power plant operates for a limited number of hours per day (typically 6-12 hours per day). In this calculation 8 hours was used.

ii. A size of 75 MW plant size was assumed in order to allow power plant output to swing from + 20 MW to – 20 MW around an idling situation.

iii. Model assumes plant is in idling model of operation to respond to frequency regulation, emissions for idling condition (supplying power to market) is counted towards emission. Amount of emissions is calculated by comparing the emissions of the idling power plant to that of a power plant providing the equivalent amount of output (MW) while operating at is full rated capacity. The emission of the plant operated at full capacity is used as a plant would otherwise be supplying that power and output to the grid (100% base loaded operation).

iv. Ramp up and ramp down cycles are measured against output swings around the idling capacity of 50%.

v. For peaking plants, a decrease in output of plant has a more dominant effect on the results than the rising heat rate. Ramp-down cycles act as an offset to the ramp-up cycle.

vi. Fuel content for CO_2, SO_2, and NO_x were based on coal power generation data from EPA eGRID [1] and DOE EIA [2] databases for the specific regions examined. (PJM, NE ISO, CA ISO).

3.5 Natural Gas Fired Combustion Turbines

Like the coal-fired power plants, the natural gas turbines are operated in the same modes of operation – Base-load and "Peaker" operation as discussed above in the Coal Section 3.4. Heat rate data from a typical Natural Gas fired plant was utilized for the study. As the emission factors for the NG plants are lower than for coal, estimated emissions were correspondingly less than those produced by coal-fired plants. Lifetime emissions savings for a flywheel regulation plant replacing a base-load natural gas-fired plant were calculated to be 38% for CO_2.

The analysis showed the flywheel to have greater emission than the natural gas plant for SO_2 and NO_x. These differences are accounted from the fact the flywheel creates its emissions indirectly from an average of all generation sources on the system. These system averages were taken from EPA eGRID [1] and DOE EIA [2] databases. This is the main driver to the Natural Gas Power Plant producing less NO_x and SO_2 emissions versus the flywheel-based system.

KEMA believes that a significant amount of frequency regulation is conducted with natural gas combustion turbines. Operation of the base loaded and peaker power plants were similar to the coal units. The main differences between the two technologies are in the size of the efficiency fluctuations and a higher minimum load level used for gas generation compared to coal. The analysis only varied heat rate based on partial loading. Natural gas turbine efficiencies are also typically subject to variations such as temperature. However, for this analysis, only efficiency fluctuations were included.

3.6 Hydro Pump Storage

Pump-storage scenarios were similar to the flywheel scenario insofar as like the flywheel regulation, hydro regulation does not produce emissions directly. The indirect emissions that were calculated were based on the inefficiencies of the system and the extra energy that is required to make up for the losses. The losses associated with ramping up and ramping down are larger than that of the flywheel since the efficiency of a hydro pump storage facility is lower. Thus the overall emissions for hydro pump storage are greater than those for the flywheel. It was estimated that a pump hydro plant is able to provide regulation 100% of time. The overall charge - discharge efficiency of the hydro system was estimated at 70%.

3.7 Assumptions on ISO Generation Mix

The mix of power generation technologies and average system heat rates for fossil-based power generation systems varies across regions in the United States. To obtain a regionally adjusted emissions comparison, system data specific to three Independent System Operator (ISO) regions were examined: PJM (Mid-Atlantic), California ISO (CAISO), and ISO New England (ISO-NE). The year 2000 data in the EPA eGRID [1] and DOE EIA [2] databases were used to assume the different generation mixes in the different ISOs investigated. Model calculations assumed typical heat rate and efficiency data for each type of generation.

The flywheel emissions were compared to the emissions of the generators that are currently actively bidding into the frequency regulation ancillary services market. These are mainly Natural Gas, Coal and Oil power plants. A summary of the year 2000 generation mixes for each of the ISO territories used in the analysis is shown below in table 4.

Table 4: Assumed Generation Mix in Different ISOs

Territory	Fuel Type	Fuel Mix (%)
	Coal Power Plant	45.1%
	Natural Gas	8.8%
PJM	Oil	2.8%
	Nuclear	40.0%
	Hydro	1.2%
	Wind	0.0%
	Non-Hydro Renew	1.3%
	Other	0.7%
	Coal Power Plant	16.8%
	Natural Gas	20.9%
ISO-NE	Oil	16.0%
	Nuclear	29.7%
	Hydro	8.2%
	Wind	0.0%
	Non-Hydro Renew	6.9%
	Other	1.5%
	Coal Power Plant	6.52%
	Natural Gas	45.0%
CA ISO	Oil	1.41%
	Nuclear	17.6%
	Hydro	17.6%
	Wind	2%
	Non-Hydro Renew	9.7%
	Other	0.5%

4. Developed Emissions Evaluation Tool

4.1 Description of Emission Tool

To support the evaluation, a detailed model was developed to compare the emissions of CO_2, SO_2 and NO_x for one of Beacon Power's planned 20 MW flywheel plants versus the three major types of conventional power generation technologies used today to perform frequency regulation. A spreadsheet based tool has been developed as part of this phase of the project. The tool has variable inputs on the different assumptions, discussed above. These inputs are used to calculate the emissions comparison per ISO region.

4.2 Variable Inputs to Emission Tool

An example of the different variable inputs is shown in the Table below. The input variables are shown for the flywheel. Similar input tabs are used for the different generator types.

Table 5: Variable Input Page for Flywheel

Variables		
Max Cycles per day	**24**	cycles
Size	20,000	kW
Heat Rate(PJM)	10,128	btu/kWh
Charge/Discharge Time	0.25	hr
One-way Power Electronic losses	**10%**	Percentage
Percentage Regulation Compliance	**98.3%**	Percentage
No load losses	**1%**	Percentage
Plant Losses	**2%**	Percentage
Cycle Time with No Load	**0.5**	hr
Solar System Providing No Load Power Toggle	**No**	

4.3 Output of Emission Comparison Tool

Table 6 is a summary of the emissions data obtained from modeling the operation of the Beacon Power flywheels against the other options for frequency regulation - a base-loaded coal plant, a "peaker" coal plant, base-loaded natural gas plant, a "peaker" gas plant and hydro pump storage are compared with the flywheel emissions output.

Comparison	CO_2				SO_2				NOx			
	Per Cycle	Per Day	Per Year (tons)	Per Lifetime (tons)	Per Cycle	Per Day	Per Year (tons)	Per Lifetime (tons)	Per Cycle	Per Day	Per Year (tons)	Per Lifetime (tons)
PJM	lbs		tons		lbs		tons		lbs		tons	
Fly Wheel	1,232	29,562	5,395	107,902	8	190	35	694	3	62	11	227
Coal Baseload	3,789	90,926	16,594	331,879	25	590	108	2,152	9	211	38	770
Coal Peaker	3,876	171,638	31,324	626,477	25	1,417	259	5,172	9	507	92	1,850
Natural Gas Baseload	1,971	47,310	8,634	172,680	0	0	0	0	2	41	7	149
Natural Gas Peaker	994	51,458	9,391	187,822	0	0	0	0	1	57	10	208
Pump Storage	2,000	47,997	8,759	175,189	13	309	56	1,127	4	101	18	369
ISO NE	lbs		tons		lbs		tons		lbs		tons	
Fly Wheel	1,010	24,242	4,424	88,483	4	102	19	373	2	41	7	148
Coal Baseload	3,783	90,794	16,570	331,399	23	544	99	1,984	4	99	18	360
Coal Peaker	3,870	171,389	31,279	625,571	23	1,306	238	4,769	2	222	41	810
Natural Gas Baseload	2,082	49,959	9,118	182,351	0	0	0	0	2	40	7	146
Natural Gas Peaker	1,050	54,340	9,917	198,341	0	0	0	0	1	56	10	203
Pump Storage	1,640	39,359	7,183	143,661	7	166	30	605	3	66	12	240
CA ISO	lbs		tons		lbs		tons		lbs		tons	
Fly Wheel	774	18,573	3,390	67,791	0	7	1	17	1	15	3	55
Coal Baseload	3,723	89,348	16,306	326,119	14	338	62	1,232	8	201	37	734
Coal Peaker	3,808	168,658	30,780	615,603	14	811	148	2,961	9	484	88	1,765
Natural Gas Baseload	2,351	56,422	10,297	205,939	0	0	0	0	2	40	7	148
Natural Gas Peaker	1,186	61,369	11,200	223,997	0	0	0	0	1	56	10	206
Pump Storage	1,256	30,155	5,503	110,066	0	7	1	27	1	24	4	89

Table 6: Comparison of Emissions Output Data

These evaluation results are also summarized for each of the ISO territories in Table 7, Table 8, and Table 9 for the 20 year life cycle of the application.

Table 7: Emissions Comparison for PJM

Flywheel Emission Savings in Tons, Over 20-year Life: PJM					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	107,902	107,902	107,902	107,902	107,902
Alternate Gen.	331,879	626,477	172,680	187,822	175,189
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Percent Savings	67%	83%	38%	43%	38%
SO2					
Flywheel	694	694	694	694	694
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NOx					
Flywheel	227	227	227	227	227
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Percent Savings	70%	88%	-52%	-9%	38%

Table 8: Emissions Comparisons for CAISO

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CO2					
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Alternate Gen.	326,119	625,571	205,939	223,997	110,066
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Percent Savings	79%	89%	67%	70%	38%
SO2					
Flywheel	17	17	17	17	17
Alternate Gen.	1,232	2,961	0	0	27
Savings (Flywheel)	1,216	2,944	-17	-17	11
Percent Savings	99%	99%	n/a	n/a	39%
NOx					
Flywheel	55	55	55	55	55
Alternate Gen.	734	1,765	148	206	89
Savings (Flywheel)	680	1,710	93	151	34
Percent Savings	93%	97%	63%	73%	38%

Table 9: Emissions Comparisons for ISO-NE

Flywheel Emission Savings in Tons, Over 20-year Life: NE-ISO					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	88,483	88,483	88,483	88,483	88,483
Alternate Gen.	331,399	625,571	182,351	198,341	143,661
Savings (Flywheel)	242,916	537,088	93,868	109,858	55,178
Percent Savings	73%	86%	51%	55%	38%
SO2					
Flywheel	373	373	373	373	373
Alternate Gen.	1,984	4,769	0	0	605
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Percent Savings	81%	92%	n/a	n/a	38%
NOx					
Flywheel	148	148	148	148	148
Alternate Gen.	360	810	146	203	240
Savings (Flywheel)	212	662	-2	55	92
Percent Savings	59%	82%	-1%	27%	38%

4.4 Discussions of the Emission Comparison Results

The emissions comparisons estimates showed highly favorable results for the flywheel for CO_2. The developed model and analysis shows that the flywheel-based frequency regulation can be expected to create significantly less CO_2 for all of the generation technologies in every region, as well as less NO_x emissions for all technologies in the CAISO region.

Lifetime CO_2 savings for a flywheel-based regulation plant displacing a coal-fired plant in the PJM Interconnect area were estimated to be 223,978 tons for a base loaded coal plant and 518,576 tons for a peaker coal plant. This translates to projected reductions of 67% and 83%, respectively. In the NE ISO region, CO_2 reduction versus base loaded and peaker coal plants were projected to be 73% and 86%, respectively.

Lifetime CO_2 savings for a flywheel-based regulation plant displacing a base loaded natural gas-fired plant in California were estimated to be 138,148 tons, while CO_2 savings for a peaker gas plant were 156,206 tons. This translates to a projected savings of 67% and 70% in CO_2 emissions, respectively.

Lifetime CO_2 savings for a flywheel-based regulation plant displacing a pumped hydro plant were 38% in all three regions.

The flywheel system resulted in slightly higher indirect emissions of NO_x and SO_2 in PJM and ISO-NE for gas-fired generation. This is because PJM and ISO-NE's generation mix includes coal-fired plants as well as the low SO_2emissions from Natural Gas power plants. The make-up electricity used by the flywheel and hydro systems reflects higher NO_x and SO_2 emissions from electricity generated in those areas.

5. Conclusions

In this report, KEMA compared the emissions from different frequency regulation generator technologies that actively participate in the ancillary services market, with the equivalent emissions associated with a 20 MW flywheel. A detailed model was developed to compare the emissions of CO_2, SO_2 and NO_x for a Beacon Power flywheel plant versus three types of commercially available power generation technologies used in the market to perform frequency regulation ancillary services.

The generation technologies compared included a typical coal-fired power plant, natural gas combustion turbine, and pumped storage hydro system. Emissions from the coal and natural gas-fired generation technologies result directly from their operation because they burn fossil fuels. In contrast, emissions for the flywheel and pumped hydro energy storage systems occur indirectly because they use some electricity from the grid to compensate for energy losses during operation.

The mix of power generation technologies and average system heat rates for fossil-based power generation systems varies across regions in the United States. To obtain a regionally adjusted emissions comparison, system data specific to three Independent System Operator (ISO) regions were examined: PJM (Mid-Atlantic), California ISO (CAISO), and ISO New England (ISO-NE). Data for each of these ISOs was extracted from the DOE EIA, and EPA eGrid databases. Model calculations assumed typical heat rate and efficiency data for each type of generation.

For coal and natural gas-fired generation, KEMA's research found that frequency regulation results in increased fuel consumption on the order of 0.5 to 1.5%. In this study 0.7% increased fuel consumption is used.

Based on the above data, model analysis showed that flywheel-based frequency regulation can be expected to produce significantly less CO_2 for all three regions and all of the generation technologies, as well as less NO_x and SO_2 emissions for all technologies in the CAISO region. The flywheel system resulted in slightly higher indirect emissions of NO_x and SO_2 in PJM and NE ISO for gas-fired generation. This effect was greatest in PJM because it has proportionally more coal-fired plants than ISO-NE.

When the flywheel system was compared against "peaker" plants for the same fossil generation technologies, the emissions advantages of the flywheel system were even greater.

6. Recommendations

- All the data of this study was based on publicly available data from DOE, EPA and the different ISO sites. Some of the data may be dated in terms of the generation mix and generating efficiencies and heat rates. These results should be validated with direct ISO involvement in a future study.

- The assumed generation data is of a generic plant. It is thus limited in the details of specific frequency regulation plant efficiencies under different operating scenarios. It is proposed that a more in-depth analysis is performed based on specific coal or gas-fired generators. This should be done to calculate the specific emission savings that the flywheel installation can achieve at a specific installation in a certain ISO region.

- The frequency regulation control signal from a specific ISO could not be integrated into the current simplistic model. When a specific site is selected for frequency regulation, it is recommended to use specific generation data and integrate the relevant ISO frequency regulation control signal. This will be valuable to investigate the impact of partial discharge cycles on the lifetime emissions savings of the flywheel system compared to other generation technologies.

- The flywheel system has a much faster dynamic response compared to other frequency regulation generation technologies. The faster response or ramp-rate of the flywheel system may provide better frequency regulation results compared to conventional generation units. For comparison this improved performance could not be evaluated and needs to be investigated further.

7. References

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