

Commercial Operation of Electrostatic Precipitator High Frequency Energization in Intermittent Energization Mode at Labadie Energy Center, Units 1 & 2

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Summary

Electrostatic precipitator (ESP) high frequency energization in intermittent energization mode (IE mode) is now in commercial operation at Ameren's Labadie Energy Center, Units 1 & 2.

High frequency energization provides a low-ripple secondary waveform that allows for ESP operation at higher secondary voltage and current. IE mode then superimposes corona on/off-times onto this low ripple D-C waveform. High frequency energization in IE mode provides two primary advantages:

1. It overcomes the debilitating effects of high resistivity particulate matter (PM) and is applicable when PM resistivity is mid $E+10$ ohm-cm, with the degree of effectiveness increasing as PM resistivity increases
2. Owing to frequent waveform off-times, ESP electric power consumption is reduced, and hence ESP operating cost is lower.

The ESP systems at Labadie Energy Center, Units 1 and 2 are competitively-sized and considered "SCA-efficient" ESPs. By contract, performance testing took place with two (2) of the installed PowerPlus™ sets out of service. The Unit 2 system was tested with one (1) set off-line in each ESP, while the Unit 1 system was tested under a significantly more rigorous condition: two (2) sets energizing ESP C, both located within the same cell (gas lane), were out of service during the performance test program.

The Units 1 and 2 ESP systems were individually performance tested and produced similar stack PM emissions rates. More extensive field testing and data analysis was conducted on the Unit 1 ESP system and so, for the most part, the Unit 1 test results are reported on and discussed in this paper.

Unit 1 has a PM emissions rate of 0.00904 lb/mmBtu (57.1 lb/hr) and a stack opacity of 8.1%. Fly ash resistivity was determined to be $4.5E+10$ ohm-cm by means of a modified version of the Bickelhaupt computer program. Air heater outlet/ESP inlet fly ash mass median diameter (MMD) was determined to be 5.6 microns, as measured in-situ by Anderson cascade impactors. Stack PM emissions were similarly measured and found to have a MMD of 1.3 microns. ESP fractional collection efficiencies were determined and these are listed on Table 3.

Unit 2 was tested with and without benefit of IE mode and stack PM emissions decreased from 0.0109 lb/mmBtu in DC Mode to 0.00850 lb/mmBtu in IE mode. This data determines an ESP migration velocity enhancement factor (w'/w) of 1.158 at a fly ash resistivity of $5.1E+10$ ohm-cm. A literature search failed to uncover an IE mode

enhancement factor of this magnitude associated with a fly ash resistivity of only $5.1E+10$ ohm-cm.

When operating in IE mode, the kW for each SMPS, as collected through Ameren's data acquisition software, was reduced nearly 40-50% when compared to operating in normal mode.

Description of Labadie Energy Center, Units 1 & 2

Units 1 & 2 at Ameren's Labadie Energy Center, located in Labadie, Missouri, are subcritical pulverized coal-fired units, each having a gross generating capacity of 625 MW when firing Powder River Basin (PRB) sub-bituminous coal. Figure 1 shows the overall layout of the plant; Units 1 & 2 are on the left hand side of the photograph.



Figure 1: ESP System Overview

Units 1 & 2 are dry bottom, tangentially-fired boilers installed by Combustion Engineering in 1966, and each unit has a gross heat rate of 6,300 mmBtu/hr. PRB coals are shipped in from various mines but all have low sulfur content (0.21% on average, by weight). Due to the low sulfur content of the PRB coal, Labadie Energy Center is not equipped with SO₂ scrubbing. Table 1 lists a typical ultimate coal analysis for PRB coal delivered Labadie Energy Center.

Each of Labadie Energy Center's four boilers originally discharged into dry, weighted-wire type electrostatic precipitators (ESPs A & B) arranged in a chevron flow configuration. In 1979 a new rigid-frame type dry ESP (ESP C) was retrofitted in parallel with ESPs A & B. ESP C treated approximately 35% of the total flue gas flow. This upgraded arrangement produced an ESP system PM collection efficiency that was sufficient to meet stack emissions standards in effect at that time provided that SO₃ flue gas conditioning was employed to condition the high resistivity fly ash.

Because all three ESPs were installed as stand-alone casings their inlet and outlet ductwork had an unusual geometry, as shown in Figure 1. ESPs A & B were located on the river-side of the plant, while the retrofitted ESP C was (and still is) located on the coal storage side of the plant.

Recently Southern Environmental Inc. (SEI) deployed Synergy ESP technology as an additional upgrade to limit filterable PM emissions to 0.015 lb/mmBtu and stack opacity emissions to less than 10%. In so doing this new ESP system operates without benefit of SO₃ flue gas conditioning. There are currently no gas stream additives utilized, although Ameren has made provisions for the future injection of activated carbon and Trona.

Several approaches were investigated to accomplish this more stringent PM emissions and stack opacity goals, with the following two upgrade concepts deemed most favorable:

1. A general upgrade of the A, B, and C ESPs using new high frequency power supplies, wide (16-inch) collecting plate spacing and new ESP internals, in conjunction with improvements to ESP gas flow distribution and also a possible re-biasing of flue gas flow between the three upgraded ESPs.
2. An upgrade of the C ESP by retrofitting new high frequency power supplies in conjunction with construction of a new D ESP in parallel with the upgraded C ESP. For this approach the A and B ESP's would be bypassed and retired. The D ESP was designed with NWL PowerPlus™ high frequency power supplies, 16-inch plate spacing and SEI/ELEX discharge electrodes. The C ESP was

retrofitted with NWL PowerPlus™ high frequency power supplies, but otherwise unmodified.

Enlargement of the A & B ESPs for optimum performance was deemed infeasible due to space limitations between the boiler building and ID fans. The D ESP retrofit approach was selected due to superior construction access and greater freedom to properly size a new D ESP. This arrangement is shown in Figure 2; the abandoned A & B ESPs are on the right hand side of the stack, the New D ESP is at the far left of the photograph, and the C ESP is located beneath the (as yet uninsulated) duct run connecting the outlet of the D ESP to the stack.



Figure 2: Overall Layout of ESPs A, B & D

PRB Coal Analysis

Typical coal ultimate and ash mineral analyses for the PRB coals delivered to Labadie Energy Center are detailed on Tables 1 & 2.

Ultimate Analysis (As-Received Basis)	(%)
Moisture	25.95
Ash	4.51
Sulfur	0.21
Carbon	50.67
Hydrogen	4.92
Nitrogen	0.73
Oxygen	13.01
Total	100.00

Table 1: Typical Coal Analysis

Ash Mineral Analysis	(%)
Silicon Dioxide, SiO ₂	35.27
Aluminum Oxide, Al ₂ O ₃	17.66
Titanium Dioxide, TiO ₂	1.49
Iron Oxide, Fe ₂ O ₃	6.44
Calcium Oxide, CaO	19.81
Magnesium Oxide, MgO	4.11
Potassium Oxide, K ₂ O	0.47
Sodium Oxide, Na ₂ O	1.38
Sulfur Trioxide, SO ₃	8.76
Phosphorus Pentoxide, P ₂ O ₅	0.90
Manganese Oxide, MnO ₂	4.14
Undetermined	-
Total	100.43

Table 2: Typical Ash Mineral Analysis

The PRB coal's combination of low sulfur and relatively low sodium produce fly ash resistivities between $3.9E+10$ and $5.2E+10$ ohm-cm at an operating flue gas temperature range of 300 to 360 deg F. This temperature window straddles the peak of the PM resistivity versus gas temperature's bell-shaped relationship.

ESP inlet PM loading was moderately light, ranging from 3.1 to 4.8 lb/mmBtu, which is typical of tangentially-fired boilers originally designed to fire Eastern bituminous coal but were converted to PRB coal firing.

ESP System Startup and Tuning

During ESP system startup the tenacity of this "pure" PRB fly ash demanded that special care be taken with regard to rapping cycle frequency and intensity. Also the gas flow split between the C and D ESPs was adjusted to ensure maximum performance relevant to the capability of these very differently designed ESPs.

Over a four week span, each of these parameters was fine-tuned in sequence until optimum ESP system performance was achieved. However it was noted that on hot summer days, when the flue gas temperature climbed above 340 deg F due to elevated ambient air temperature, stack opacity gradually crept up throughout the afternoon hours. Secondary voltage versus current (V-I) curves were obtained in order to evaluate the extent of back corona ionization. It was observed that hot afternoon V-I curves displayed signs of mild back corona when compared to V-I curves produced earlier in the day.

This investigation suggested that the implementation of IE mode would be of benefit. In this manner, the potential for developing back corona ionization was reduced, resulting in better and more consistent ESP performance. An additional benefit of IE mode is a reduction in ESP power consumption.

High Frequency Energization in IE Mode

High frequency energization provides a low-ripple secondary waveform that allows for ESP operation at higher secondary voltage and current. IE mode then superimposes corona on/off-times onto this low ripple D-C waveform. When operated in IE mode, high frequency energization is capable of delivering "on-times" from 0.10 to 10 milliseconds and "off- times" from 0.10 to 99 milliseconds. This favorably compares to a one half cycle (8.33 milliseconds) on-time and a full cycle (16.67 milliseconds) off-time for conventional 60 Hz power supplies. Hence high frequency energization in IE mode provides significantly greater operating flexibility when compared to conventional energization.

Figures 3A & 3B compare a NWL PowerPlus™ set operating in DC mode versus IE mode. Note that this data was not taken at Labadie Energy Center but rather at a similar installation. Figure 3A is an oscilloscope trace of DC mode operation where $kV_{avg} = 29.4$ and $kV_p = 30.7$. Figure 3B demonstrates IE mode operation with 0.30 milliseconds on-time and 3.3 milliseconds off-time, where $kV_{avg} = 26.6$ and $kV_p = 37.4$. The 21.8% increase in kV_p provides improved charging and precipitation of high resistivity particles without the onset of back corona ionization. Also, the 3.3 milliseconds off-time provides electric energy savings.

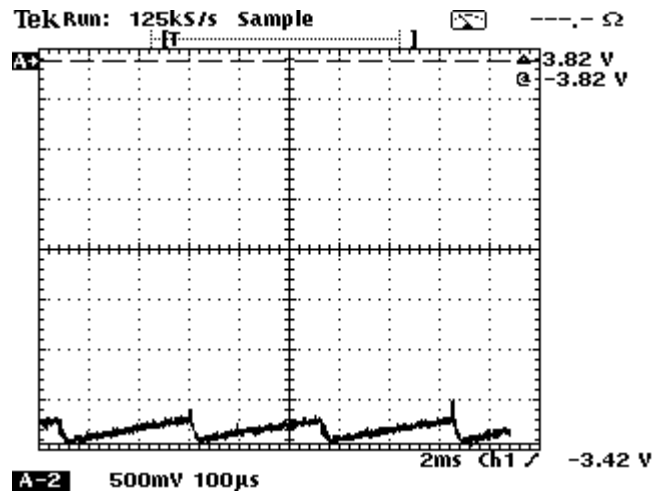


Figure 3A: DC Mode Operation (Reference 3)

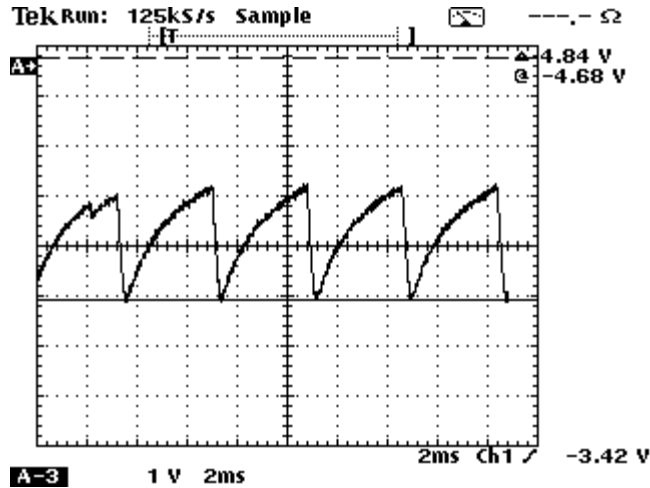
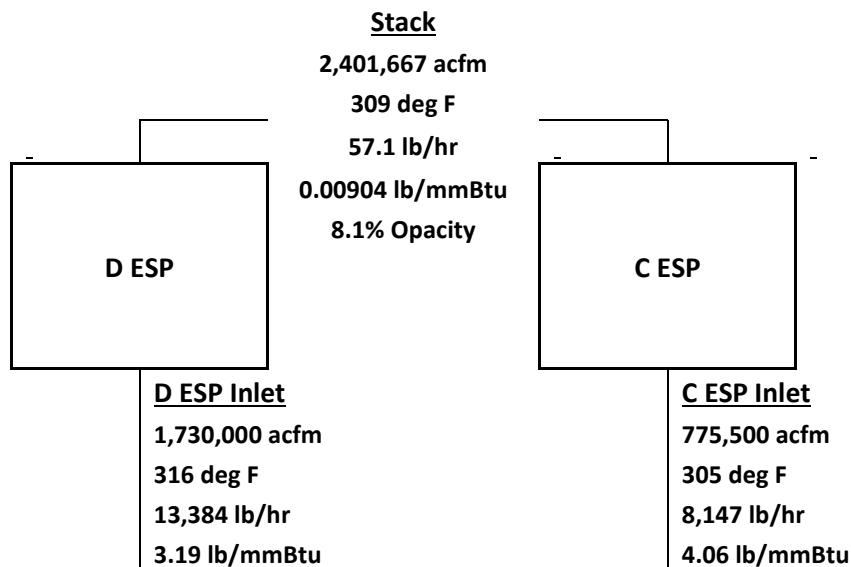


Figure 3B: IE Mode Operation (Reference 3)

High frequency energization in IE mode has provided ESP enhancement factors of 1.23 when collecting coal fly ash with resistivities greater than $1E+11$ ohm-cm.

Labadie Unit 1 Performance Test Program

The Unit 1 ESP performance test program took place on February 10-11, 2015. A total of six individual test runs were conducted and then averaged together. Each test run included PM sampling at both ESP inlet test stations (USEPA Method 17) and at the stack test station (USEPA Method 5). In-situ particle size measurements were also conducted during three of the six test runs using Anderson cascade impactors. Particle sizing measurements were conducted at the inlets to the ESPs as well as in the stack. Figure 4 summarizes PM sampling and stack opacity results at Labadie Unit 1.



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Air Heater

Figure 4: Unit 1 PM Sampling Results (6-Test Run Averages)

A total fly ash rate of 21,531 lb/hr entered the ESP system and 57.1 lb/hr was emitted, determining an overall ESP system collection efficiency of 99.735%.

The ESP system’s design performance goals were 0.015 lb/mmBtu PM emissions and 10% stack opacity, while 0.00904 lb/mmBtu emissions and 8.1% opacity was measured.

Air heater outlet/ESP inlet fly ash mass median diameter (MMD) was determined to be 5.6 microns, as measured in-situ by Anderson cascade impactors. This is typical for tangentially-fired boilers originally designed to fire Eastern bituminous coal but subsequently were converted to PRB coal firing. Stack PM emissions were similarly measured and found to have a MMD of 1.3 microns. ESP fractional collection efficiencies were determined and are listed on Table 3.

	Duck Creek	Labadie Unit 1
	70% PRB/30% Bituminous	100% PRB
	<u>ESP in DC Mode</u>	<u>ESP in IE Mode</u>
PM	99.91	99.735 (0.00904 lb/mmBtu)
PM 10	99.73	***
PM 5	***	99.54 (0.00713 lb/mmBtu)
PM 2.5	99.63	99.33 (0.00568 lb/mmBtu)
PM 1	99.37	98.68 (0.00393 lb/mmBtu)
PM 0.5	***	98.67 (0.00200 lb/mmBtu)
PM 0.25	***	98.36 (0.00182 lb/mmBtu)

Table 3: Comparison of Duck Creek and Labadie Unit 1 Fractional Efficiencies

On Table 3 Labadie Unit 1's fractional efficiency results are compared to Ameren's Duck Creek Station ESP, an SEI Synergy ESP collecting fly ash from a boiler firing a blend of 70% PRB and 30% Eastern bituminous coals (see Reference 5). While fractional efficiency values appear to compare unfavorably, these differences are solely due to the lighter, finer nature of the "pure" PRB fly ash exiting the Labadie Unit 1 boiler. Most impressive are the ultra-low PM emissions rates determined for PM1 and below.

Labadie Unit 2 Performance Test with and Without IE Mode

Unit 2 was tested with and without benefit of IE mode and stack PM emissions decreased from 0.0109 lb/mmBtu in DC Mode to 0.00850 lb/mmBtu in IE mode. This data determines an ESP migration velocity enhancement factor (w'/w) of 1.158 at a fly ash resistivity of $5.1E+10$ ohm-cm. A literature search failed to uncover an IE mode enhancement factor of this magnitude associated with a fly ash resistivity of only $5.1E+10$ ohm-cm.

Long-term Operation of ESP System

When operating in IE mode, the kW for each SMPS, as collected through Ameren's data acquisition software was reduced nearly 40-50%, when compared to operating in normal mode. The reduction in kW is attributed to the IE mode setting. For example, Labadie's set points are 2ms on and 2ms off. If the set points were changed the kW reduction would also change.

Because the IE is most effective at high flue gas temperatures, Labadie also had to install logic to turn IE on and off automatically on start-ups and shut-downs based on air heater outlet temperature and stack temperature. It is important to note that to avoid exceedances, IE mode was turned on and off in groups of four SMPSs, in lieu of changing modes all at once. However, because each start-up and shut-down can be unique, Ameren later added logic to provide the operator manual control to turn IE on and off as desired.

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