High Frequency Power Supply Operation on Hot-Side ESP

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Abstract: In recent years Switch Mode Power Supplies (SMPS) have been introduced into the utility ESP market. This paper summarizes EPRI and Southern Company funded Switch Mode Power Supply testing on Alabama Power's Plant Barry Unit 4 Hot-Side ESP. For this test program, eight Switch Mode Power Supplies were installed parallel to the existing four T/R sets.

During the test program, the ESP was operated for a time using each power supply type and emission measurements were taken. Included are ESP Outlet Loading and Size Distribution Results as well as EPA Method 5 mass emission results. Additionally, the paper includes an analysis of the ESP electrical characteristics during the operation of both types of power supplies as well as any possible conclusions.

Keywords: High Frequency, Hot Side, Power Supply

1 INTRODUCTION

1.1 High Frequency Power Supply Technology

High Frequency Power Supplies also referred to as Switch Mode Power Supplies (SMPS) have been heavily adopted into the Electrostatic Precipitator (ESP) market over the last decade. These power supplies have dramatically different characteristics than the linear transformer/rectifier (T/R) sets with SCR based controls that have been used in the industry for years. The SMPS takes a three-phase input and rectifies and filters it to a smooth intermediate voltage DC bus. They key element of the SMPS is the integrated gate bipolar transistor (IGBT) which converts this DC bus into a high frequency AC waveform. The SMPS then steps up the high frequency AC, rectifies it, and delivers high voltage DC it to the ESP.

This technology provides several distinct benefits. Since the step-up transformer operates at high frequency, up to 20,000 Hz, it can be substantially smaller and require much less cooling fluid than an equivalent 60 Hz transformer. Due to the rapid ability to turn off the IGBT, the circuit can turn on and off over 250 times faster than a linear power supply allowing for much faster control response. This method of treating the AC input voltage also creates a very small ripple in the DC voltage allowing for peak and average voltages to be nearly equivalent. Finally, the three-phase input results in a higher power factor greatly increasing the electrical efficiency of the power supply.[1]

1.2 Barry Electric Generating Plant

Plant Barry is owned and operated by Alabama Power Company, a subsidiary of Southern Company. The plant located north of Mobile, Alabama consists of five (5) pulverized coal (PC) units and two (2) gas-fired combined cycle units. Three of the PC boilers, Units 1-3, are equipped with hot-side electrostatic precipitators. These three units share a common stack which is regulated to 20% maximum opacity. As is common with hot-side ESP's, these units are prone to suffer from a time functioned degradation specifically under high dust loading accompanied by a reduction in applied power, often referred to as sodium depletion. Based on the characteristics of the SMPS and successful experience with this technology on cold-side ESP's, Southern Company in a collaborative effort with the Electric Power Research Institute (EPRI) installed SMPS's in parallel to the existing conventional transformer/rectifiers on Barry Unit 2 to assess the benefit of this technology on hot-side ESP's.

2 SMPS INSTALLATION

The Barry Unit 2 ESP consists of four (4) fields in the direction of gas flow and two (2) sections across gas flow. The collecting plates are on 11 inch spacing and the high voltage is delivered to rigid frame electrodes. The ESP has been powered by four (4) 60 Hz transformer/rectifiers with each power supply dedicated to one (1) field across both sections. The ratings of the power supplies are given in Table 1.

Due to the limited capacity of the available SMPS's, it was decided to further sectionalize the ESP for the SMPS installation as to avoid a current limiting scenario. Eight (8) 70 kV, 1000 mA NWL PowerPlus™ SMPS's were installed parallel to the existing transformer/rectifiers. Each SMPS was dedicated to one (1) field across only one (1) section. High voltage switch boxes were utilized to allow for switching between conventional T/R operation and SMPS operation. A schematic of the installed layout is given in Fig. 1.

Table 1 Conventional T/R rating

T/R SET NO.	VENDOR	MODEL NO.	V - A - kV - mA	kVA
2A thru 2D	RICO	10-10277	575 - 369 - 80p - 2500	212

Then installation was completed in late 2006 followed by several periods of operation of each type of power supply throughout 2007.

3 RESULTS

The comparative results of the operation of the SMPS and the operation of the T/R sets were analyzed with three different types of data including the electrical readings of the power supplies, EPA Method 5 test results, and Process Particle Counter particle size distribution results.

3.1 Power Supply Electrical Data

One readily accepted method of assessing ESP performance is through the analysis of the electrical output of the power supply. The correlation between precipitator performance and electrical energization is supported by fundamental precipitator theory. ESP efficiency can be

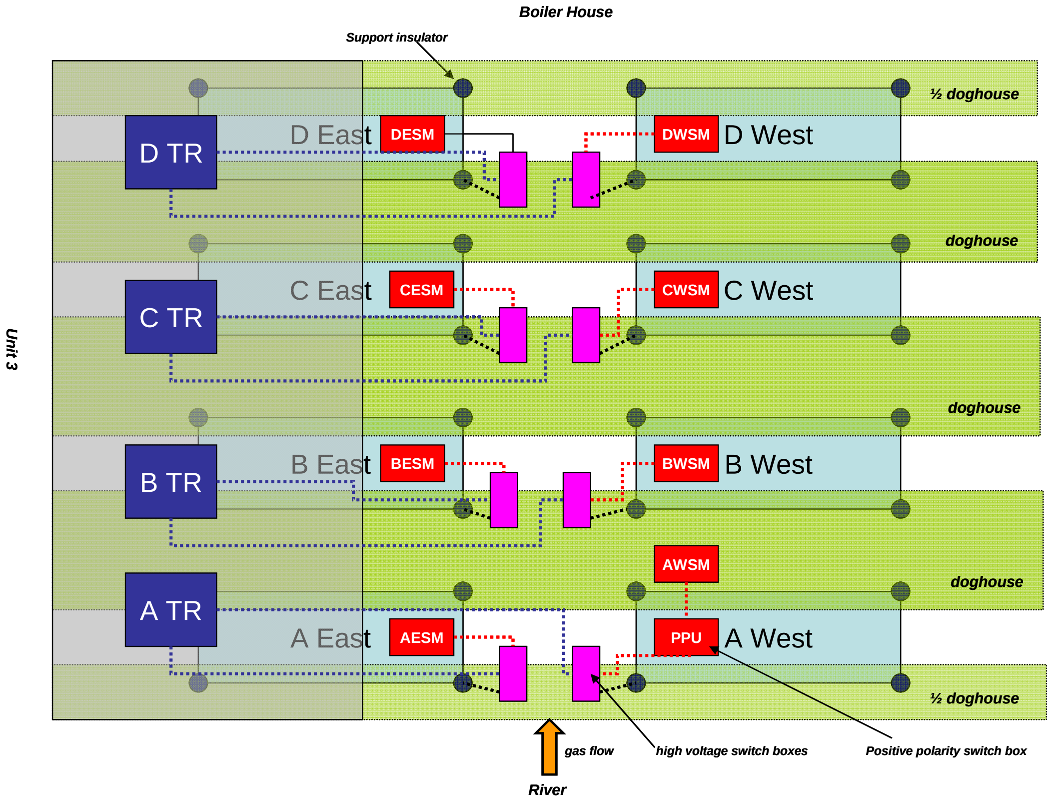

Fig. 1 Barry Unit 2 SMPS Installation Schematic

expressed in a generalized form as

$$\eta = 1 - e^{(-A/V)\omega}$$

in which A and V are the precipitator collection area and gas flow rate, and ω is the velocity of the particle in the electric field of the ESP. Furthermore, ω has been shown to be equivalent to

$$\omega = \frac{aE_0E_p}{2\pi\eta}$$

where E_0 is the discharge field strength and E_p is the collection field intensity. Finally, approximations may be made such as

$$E_0 \sim V_p$$
$$E_p \sim V_{av}$$

where V_p and V_{av} are the peak and average voltages respectively.[2] Consequently, an increase applied power to the ESP load should have a direct correlation to ESP performance.

The simplest method of applying this technique is to observe trends in the overall power applied to the ESP. Fig. 2 presents the applied power to Barry Unit 2 immediately prior to and following a switch from the Conventional T/R's to the SMPS's. The impact is unmistakable as the SMPS's provide a significant increase in power to the load. The values presented are across the load range; however, with the exception of a low load period early each morning the unit was operated a full load. These low load periods can be seen as spikes in the figure. Further analysis of the data indicates that the average power input increased 57% from the two days

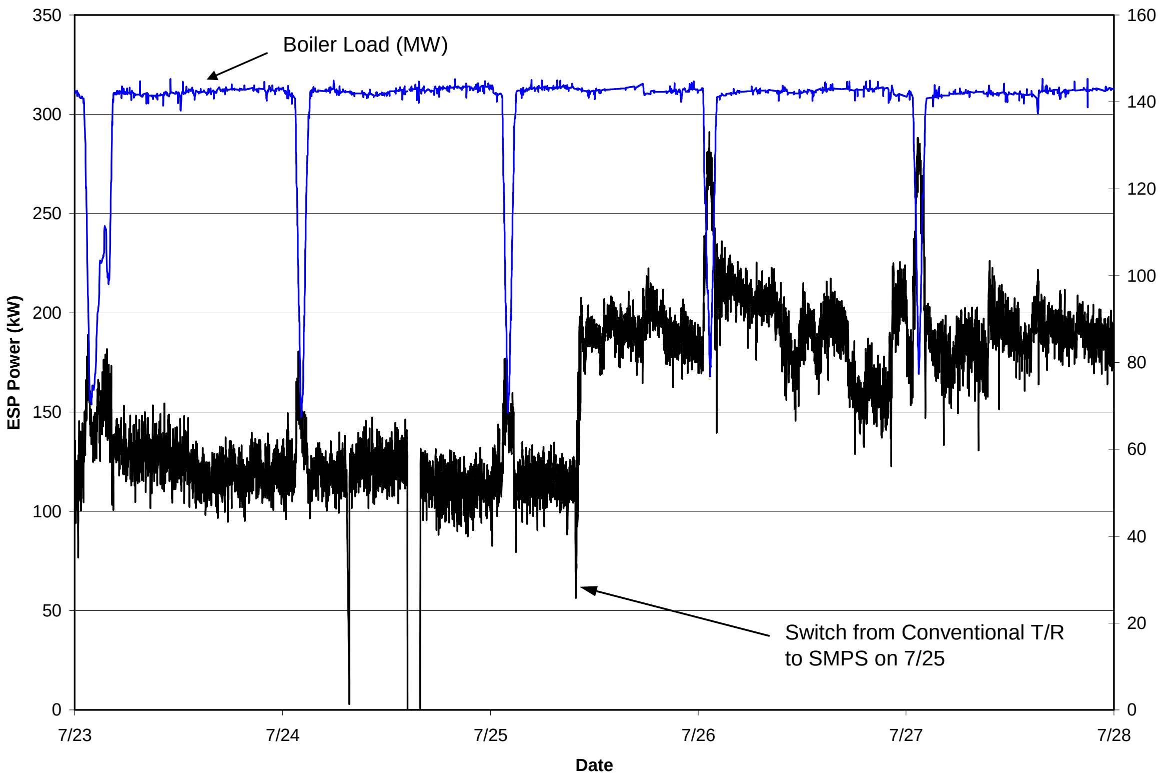

Fig. 2 Applied power to Barry Unit 2 ESP

prior to the switch to the two days following. This increase in power is most assuredly a result of the decrease in the DC voltage ripple resulting in much higher average voltages. The rapid recovery time from spark set back and the increased sectionalization are also likely contributors to the increased average power input.

Analysis of the field specific data is presented in Table 2. These values represent two day averages for the period immediately prior to and following the power supply switch.

As observed in the data, voltage and current levels increase in each of the four fields; however, the greatest increase is observed in the inlet field current levels. During operation of the conventional T/R's, these current levels were most likely suppressed by heavy ash load and high resistivity deposits, and the SMPS's seem to somewhat relieve that situation. Also observed is a appreciable decrease in the input kVA which is a noted benefit of the high frequency technology.

Table 2 Average power levels of Barry Unit 2 ESP

		Field A	Field B	Field C	Field D
T/R	Avg Voltage (kV)	34.6	37.2	31.5	26.8
	Avg Current (mA)	126.1	705.9	1367.1	1770.1
	Avg kW	4.4	26.7	43.9	47.9
	Avg KVA	18.4	69.6	125.1	152.7
SMPS	Avg Voltage (kV)	38.3	41.6	37.9	34.1
	Avg Current (mA)	187.5	1111.1	1879.6	1961.2
	Avg kW	7.6	46.8	71.2	66.8
	Avg KVA	12.4	61.4	88.0	83.2
Percent Increase	Avg Voltage (kV)	11%	12%	20%	27%
	Avg Current (mA)	49%	57%	37%	11%
	Avg kW	72%	75%	62%	40%
	Avg KVA	-32%	-12%	-30%	-45%

It is also insightful to compare the Unit 2 ESP power levels with the Unit 1 ESP power levels. The Unit 1 and 2 boilers are sister units and burn coal from the same source. The two precipitators are of identical design with the exception of the SMPS installed on Unit 2. Fig. 3 shows eight hour average power levels for both Unit 1 and Unit 2 throughout the calendar year 2007. During the first half of the year, when both Units were operating on 60 Hz T/R's, similar trends are observed. The power level peaks directly following a Unit outage when the collecting plates are clean and quickly deteriorate to a value nearly half of the peak value. It appears that both Units approach a similar steady-state value between 100 kW and 150 kW. The power levels diverge immediately when the SMPS's are put into operation on July 25, and Unit 2 maintain approximately 75 kW to 100 kW higher power consumption than Unit 1. A downward trend may be observed in the Unit 2 power levels; however, it does not approach the minimum power levels experienced with the 60 Hz T/R sets.

The analysis of the SMPS power levels clearly demonstrates that these advanced power supplies apply a significantly increased amount of power to the Barry Unit 2 Hot-Side ESP. In most cases this increase in power exceeds 50%. Based on fundamental precipitator theory, this increase in applied power should result in increased collection efficiency; however, it is uncertain whether the precipitator is operating under the ideal conditions assumed by the theory. In order to better assess the actual performance enhancement provided by the additional power two types of particle measurements were conducted.

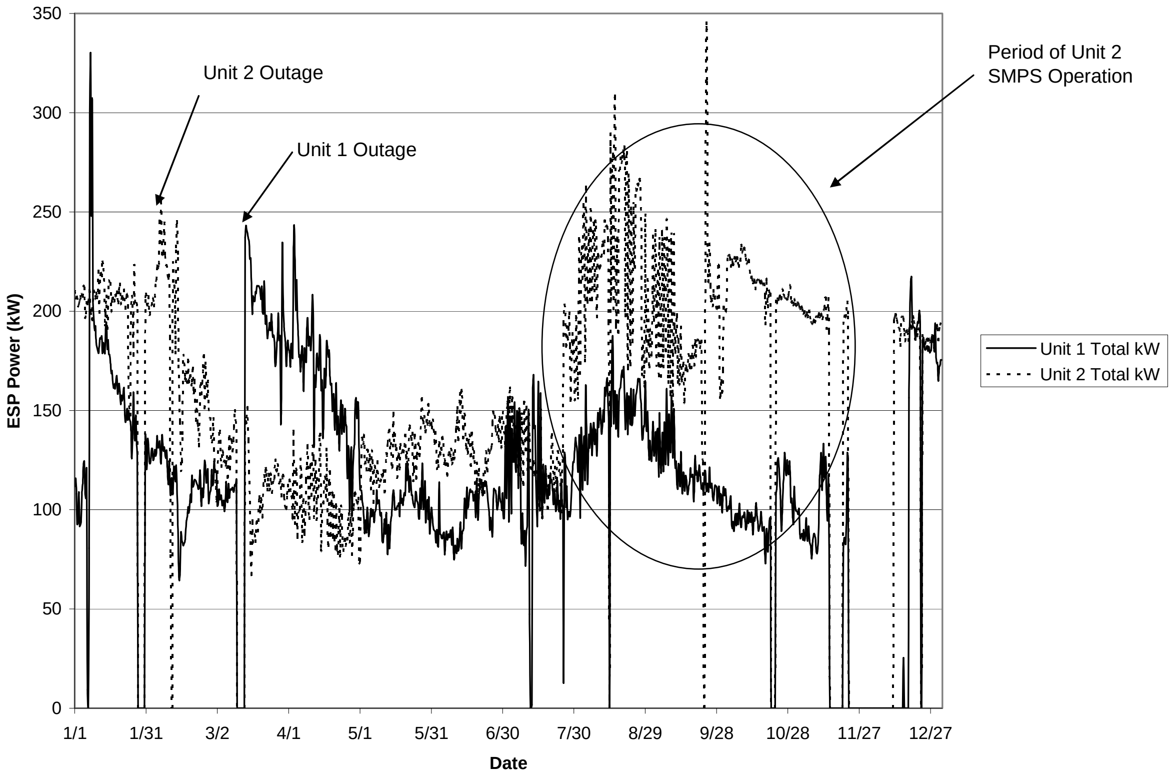

Fig. 3 Eight hour average power levels for Barry Units 1 and 2 ESP's

3.2 Process Particulate Counter Results

During the time surrounding the switch from conventional T/R's to the SMPS's, a series of Process Particulate Counter (PPC) tests were conducted to measure the outlet particle concentration and size distribution during the operation of each type of power supply. The comparative results of these parameters are shown in Table 3. As indicated, the particle concentration measurement was 28% lower for the period of operation with the SMPS's as compared to the operation of the traditional T/R's. The particle mass mean diameter; however, remained essentially unchanged.

Table 3 Particulate Concentration and Mass Mean Diameter at Unit 2 ESP Outlet with Conventional and Switch Mode T/R Sets

	Conventional T/R Sets	Switch Mode T/R Sets
Average Concentration [mg/m^3]	17.6	12.7
Particle Dm(50) [μm]	24.2	25.3

While this data does seem to indicate an appreciable increase in collection efficiency, it must be noted that the measurement of average concentration is somewhat suspect due to the nature of the particulate spiking. Fig. 4 represents the data from one of the sampling intervals taken during the operation of the traditional T/R sets. As seen in the figure, the baseline particulate concentration is much less than the average concentration while the spikes are up to ten times greater than the average. This indicates that the average values are driven by the magnitude and duration of the spikes caused by the rapping sequence. Due to the limitations in sampling time, it is reasonable to suggest that the difference in average concentration measured could be more an affect of the number and position of rapping spikes captured during a test sequence than the performance of the power supplies themselves. A closer examination of the baseline concentration alone does not yield the magnitude of performance enhancement suggested by the average values.

3.3 Particulate Mass Measurements

In order to further quantify the affects of the SMPS's on collection efficiency, triplicate runs of abbreviated Method 5 mass measurements were made on July 24 and July 27. The results of these tests are provided in Table 4 and 5 respectively. The test on July 24 was conducted with conventional T/R sets in service and resulted in an average collection efficiency of 99.571%. The test on July 27 was conducted with SMPS's in service and resulted in an average collection efficiency of 99.59%. While this indicates no difference in collection efficiency between the two types of power supplies, it may be meaningful to note that the inlet loading was 30% higher for the test conducted with SMPS operation. This additional dust load may have had some impact on the results.

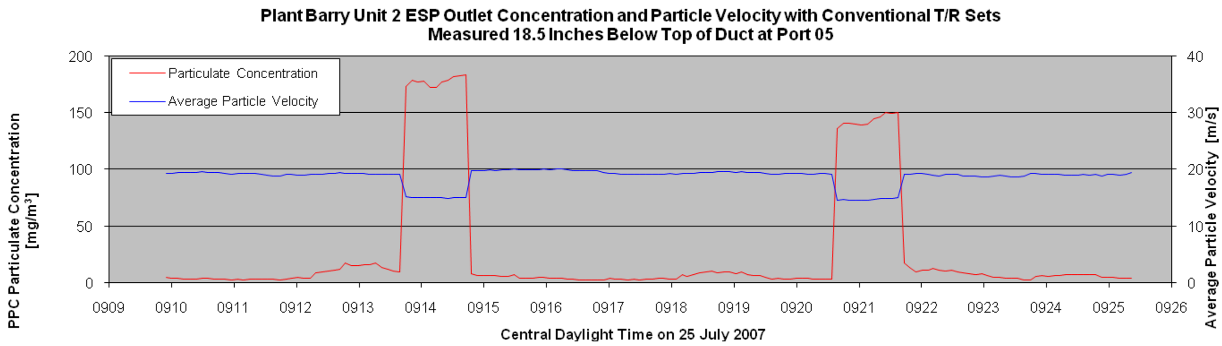

Fig. 4 Sample PPC test interval.

Table 4 Method 5 results for conventional T/R operation.

	Inlet Run 1	Inlet Run 2	Inlet Run 3	Inlet Avg	Outlet Run 1	Outlet Run 2	Outlet Run 3	Outlet Avg
Particulate Concentration (Grains per ACF)	1.0456	0.7518	1.0647	0.954	0.0039	0.0037	0.0053	0.004
Particulate Emission Rate (Pounds per Hour)	5369.9	3902.6	5592.6	4955	21.6	21	29.8	24.2
Particulate Emission Rate (Pounds per Mbtu)					0.016	0.015	0.021	0.017
Efficiency					**99.651**	**99.532**	**99.531**	**99.571**

Table 5 Method 5 results for SMPS operation.

	Inlet Run 1	Inlet Run 2	Inlet Run 3	Inlet Avg	Outlet Run 1	Outlet Run 2	Outlet Run 3	Outlet Avg
Particulate Concentration (Grains per ACF)	1.253	1.2392	1.2368	1.243	0.0076	0.0039	0.0041	0.005
Particulate Emission Rate (Pounds per Hour)	6281.1	6352.2	6268.3	6300.6	43	21.1	22.9	29
Particulate Emission Rate (Pounds per Mbtu)					0.032	0.016	0.016	0.021
Efficiency					**99.405**	**99.691**	**99.675**	**99.59**

3.4 Future Investigations

It is reasonable to question why such an increase in applied power would not lead to a conclusive performance enhancement. The most likely scenario is that the hot-side ESP is operating in a non-ideal condition where not all of the applied power is "useful". Common to hot-side ESP's is the build up of a fine layer of high resistivity ash on the surface of the collecting plate that does not dislodge with normal rapping. Depending on the magnitude of the resistivity, the layer will either cause premature sparking or under high current flow may enter a region of electrical breakdown where positive ions are formed resulting in a phenomenon referred to as back corona. In this scenario, current flow may be present at higher than normal levels but may not be beneficial to ESP performance. Two approaches to remedy this possible solution are proposed for the Barry Unit 2 ESP. The first approach to be investigated will be reverse polarity rapping which is intended to break the surface charge that helps attach the ash layer to the plate. The second is Intermittent Energization which attempts to limit the current flow while maintaining sufficient voltage levels. The design characteristics of the High Frequency Power Supplies lend themselves to these possible solutions more so than conventional T/R's. The ongoing attempt is to assure that the maximum amount of "useful" power is applied to the ESP using the advanced technology now available in ESP power supplies.

4 CONCLUSIONS

It is evident by the findings of this test program that the High Frequency Power Supplies significantly increase the power applied to the subject hot-side ESP relative to conventional 60 Hz transformer/rectifiers. Short term power levels increased 57% when operation was switched from conventional T/R's to SMPS's. This power increase ranged from over 70% in the inlet fields to 40% in the outlet fields. The power levels of the SMPS do appear to decay over time; however, not to the extent that a sister unit operating on conventional T/R's experienced.

While traditional theory suggests that an increase in applied power should positively correlate to collection performance, the performance measurements applied during this program are inconclusive. The Process Particulate Counter yielded a 28% decrease in outlet particle concentration for the SMPS operation relative to the conventional T/R's; however, the measurement was dominated by rapping spikes which were not consistently captured by each sampling period. The particulate mass measurement indicated a constant efficiency across both types of power supplies. During the period of sampling for the SMPS's, there appeared to be an increase of inlet mass loading which may have affected the comparative results.

The ESP demonstrates performance characteristics common the effects of sodium depletion. This phenomenon may explain the lack of distinct performance enhancement associated with the increased power levels. The high frequency power supply technology may be utilized in future investigations to mitigate this problem. Intermittent Energization will be investigated in order to limit the current that may contribute to back corona and polarity reversal will be investigated to enhance collection surface cleaning to limit the ash layer resistivity.

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