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Taking the Mystery out of Choosing Electrostatic Precipitator (ESP) Power Supplies for MATS PM Control

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ABSTRACT

Many coal-fired power plants will upgrade their aging electrostatic precipitators (ESPs) to meet the particulate matter (PM) emissions requirements established by the Mercury and Air Toxics Standards (MATS) established by the U.S. Environmental Protection Agency (EPA). Many of those upgrades will likely entail the replacement of existing conventional power supplies [transformer rectifier (TR) sets].

While the conventional single-phase power supplies have been the norm for more than 60 years, in large part due to a stellar reliability record, new types have been introduced into the marketplace. The high frequency switch mode power supply (SMPS) was launched in the 1990s. During its early stages, the SMPS was plagued with a high rate of failure which has improved, but has not achieved the reliability of single-phase. An even newer introduction, especially popular in Europe, is the 3-phase rectified power supply, which inherited many of the reliability benefits of its single-phase predecessor. Not much has been reported on the development and performance of the 3-phase low frequency power supply.

In this paper, the results of ESP power supply modeling and laboratory testing will be presented for multiple types of precipitator power supplies. In addition, the results of field testing of a single-phase and a low frequency 3-phase power supply are presented. This paper highlights the key features, advantages, and disadvantages of each device, with the intent to help the end user in the technology selection process. Several factors that affect this decision will be discussed, including the amount of ripple in the secondary voltage waveform, increased power in the precipitator field, harmonic distortion, equipment size, weight and footprint, cost, and reliability.

The results imply that low ripple power supplies hold a distinct advantage over the conventional single-phase power supply because of their ability to apply more power to the precipitator field. The results further indicate that the 3-phase power supply (a low frequency design) has an advantage over other types of low ripple power supplies because of its higher reliability and lower cost, albeit in a larger, heavier package.

INTRODUCTION

To meet particulate matter (PM) requirements of the Mercury and Air Toxics Standards (MATS), stack emissions of filterable particulate must be controlled below a level of 0.03 lb/mm Btu. This new requirement is likely to demand improved performance from existing ESPs. In addition, there are tougher demands on maintainability of this lower emissions requirement. Not only are the emissions to be reduced, they must remain low for longer periods of time.

One of the fundamental means to improve the performance of an existing ESP is to boost its corona power. The relationship between specific corona power (watts/1000 acfm) and collection efficiency has been well researched[1-3]. So, while optimization efforts to increase efficiency (e.g., a simple re-build of the ESP or adding additional plate area through increased height or additional fields) almost always entail a replacement of the existing power supplies, additional questions arise: what type of power supply can boost the corona power output, and how to manage the new challenges of higher availability when switching power supplies. A study was conducted to evaluate the key features, advantages and disadvantages, of each type of power supply.

BRIEF HISTORY OF ESP POWER SUPPLIES

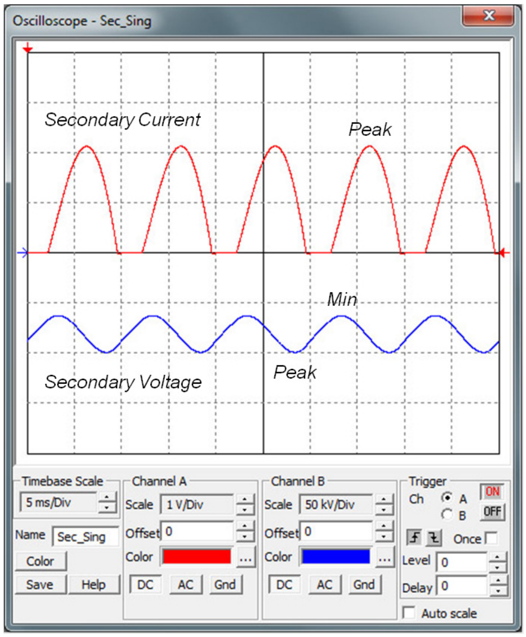
ESP power supplies have come a long way from the early days of a separate high voltage transformer and a mechanical rectifier which energized the high voltage electrodes in the ESP. The mechanical rectifier used a four-pole synchronous motor driving four pairs of discharge brushes. The synchronous contact of the brushes provided a pulsating unidirectional current.

Those early power supplies did not have an automatic voltage control, which was first patented in 1952.[4] To control ESP voltage, a manually operated switchboard was utilized with multiple taps on the primary side of the high voltage transformer. In the 1950s, mechanical rectifiers were replaced by selenium rectifiers, integral with the transformer. In the mid-1960s, silicon diodes replaced the selenium rectifiers. These diodes were more compact, had a lower forward resistance, and did not age.[5]

Analog automatic voltage controls and silicon controlled rectifiers (SCRs) were the standard for many years. The advent of microprocessors resulted in patented control algorithms,[6-8] more precise control of the power applied to the precipitator, and software integration with other plant systems.

All of these advances were limited since the single-phase precipitator power supply has a voltage waveform with a significant amount of ripple as shown in Figure 1.

Figure 1. Single-Phase Precipitator Power Supply Voltage and Current



Timebase Scale
5 ms/Div
Name Sec_Sing

Channel A
Scale 1 V/Div
Offset 0
Color 🟥

Channel B
Scale 50 kV/Div
Offset 0
Color 🟦

Trigger
Ch ● A ○ B
Once ☐
Level 0
Delay 0
☐ Auto scale

The ripple reduces how much power can be applied to the precipitator field. There is a practical limit to how much voltage can be applied to a precipitator field due to sparking, and sparking occurs at the peak of the secondary voltage waveform. The resultant average voltage is always lower than the peak voltage by about 20%. Manufacturers recognized if this waveform could be changed by making the average voltage equal to the peak voltage, significantly more power could be applied to the precipitator field. Many novel approaches have been tried to accomplish this, including placing a filter on the output of the single-phase precipitator power supply to remove the ripple.[9,10]

Today, in addition to the single-phase precipitator power supply with its rippled voltage waveform, a variety of low ripple power supply options is available. Each of these removes the ripple from the secondary voltage waveform and provides a low peak-to-average-voltage ratio. The earliest among these was the high frequency switch mode. It was designed to provide increased power to the precipitator field while having less size and weight, symmetrical 3-phase load, and higher power factor, all with high reliability.

In actual practice, however, the reliability has been less than anticipated (with a record that is much less impressive than the single-phase precipitator power supply). In addition, there have been grounding and shielding issues coupled with high input and output harmonic distortion.

Based on these experiences, and the many choices available in precipitator power supplies, B&W conducted an internal study utilizing power supply electrical models, laboratory and field testing to compare different power supply types. Since it had been reported that the Europeans were successfully utilizing low frequency 3-phase precipitator power supplies to achieve a low ripple voltage waveform, this type of power supply was also evaluated. The outcome of the study indicated potential benefits of the low frequency 3-phase precipitator power supply, which led to the development of a low frequency 3-phase precipitator power supply and field testing for further verification.

MODELING PRECIPITATOR POWER SUPPLIES

Accurately comparing precipitator power supplies presents unique challenges. Precipitator power supplies cannot be installed on the exact same precipitator field at the exact same time and experience the exact same conditions. In addition, in an operating plant, it is unreasonable to expect that the precipitator power supply will experience every possible upset condition. This results in equipment that does not get fully tested and requires product enhancement and development to be conducted in the field, often at great inconvenience and expense to the plant owner. Thus, we decided to begin our research process by using electrical modeling of typical power supplies used on ESPs.

For this project, an independent electrical model was created for each type of precipitator power supply. Once an accurate software model was created, each precipitator power supply was operated under a large number of operating conditions and the results evaluated. In addition to electrical performance, modeling software is useful for analyzing other areas including component heating (which is helpful in predicting reliability).

The greatest efficiency and best operation will be achieved if the precipitator power supply is properly matched to the precipitator load. For example, it is better to size a power supply to operate at 70 to 100% of its rating rather than 10 to 30% of its rating. It is therefore important to understand the electrical nature of the precipitator load. In its most simplified version, the precipitator load can be shown as a capacitor in parallel with a resistor.

The precipitator field has a capacitive characteristic. The basic construction of a capacitor is two conductors separated by a dielectric or insulator. The ESP collecting plates form one conductor, while the discharge electrodes form the other; the gas path between them forms the dielectric. Because the properties of the dielectric are affected by the gas that is being treated, a unique capacitor is created. A reasonable estimate (which has been used by us and by others) of the value of this capacitor for a properly matched and sized power supply is approximately 10 nf per milliamp of power supply. For a 1000 milliamp power supply this would be approximately 0.1 µf.

There are several fundamental properties of capacitors that are important to our understanding of the precipitator power supply. Ideal capacitors do not dissipate energy but store it in the form of an electric field. Therefore, even if the power supply would have a high ripple output, once the power supply is connected to the precipitator, its capacitive characteristic filters or reduces the ripple in the output voltage waveform. This is very important and explains why very low ripple in the output voltage waveform can be achieved even with low frequency power supplies.

The load resistor on the power supply dissipates energy. A reasonable estimate (which has been used by us and by others) of the value of this resistor for a properly matched and sized power supply can be found by dividing the average voltage rating of the power supply by the average milliamp rating. For example, a precipitator power supply rated at 80 kV and 1000 milliamps would yield a value of 80 KΩ for the load resistor. This indicates that for maximum power transfer, the precipitator power supply in this example should be matched to an 80 KΩ load.

In actual practice, the precipitator load of our example would rarely be exactly 80 KΩ and can vary over a significant range. If the precipitator power supply is not experiencing sparking and the actual load is less than 80 KΩ, then the precipitator power supply will operate at a current limit. If the precipitator power supply is not experiencing sparking and the actual load is more than 80 KΩ, then the precipitator power supply will operate at a voltage limit. The precipitator power supply should therefore accommodate a broad load range. Unfortunately, some high frequency designs have a turn-down limitation (typically 10%). This means the power supply cannot operate below this turn-down rating. This has been a problem in some applications that have a significant load swing or during start-up of the ESP.

The results of the model study are shown in Table 1; these results will be examined in detail later in this paper. The data indicated very good performance of the low frequency 3-phase precipitator power supply to produce a low ripple voltage waveform. These encouraging results led to the development and field testing of a low frequency 3-phase precipitator power supply that was based on its single-phase predecessor.

Table 1. Precipitator Power Supply Modeling Results

Precipitator Power Supply Characteristics[1]

			AC Line Input		DC Voltage and Current Output					Sparking	
Power Supply	Low Ripple Output	Frequency	Power Factor	Total Harmonic Distortion (Input)	Ripple in Output Voltage[2]	Peak to Average Voltage Ratio	Ripple in Output Current[2]	Peak to Average Current Ratio	Total Harmonic Distortion (Output)[3]	Maximum Time to Spark Quench	Energy Delivered to Spark by Power Supply[4]
Single-Phase	No	Low	0.566	21.40%	11.80%	1.235	72.59%	2.132	0.97%	8.33×10^{-3} seconds	7.8×10^{-3} Joules < .1% of Total Spark Energy
Single Phase with External Filter[5]	Yes	Low	0.580	18.15%	2.39%	1.036	68.19%	1.883	0.75%	8.33×10^{-3} seconds	22.05×10^{-3} Joules < .1% of Total Spark Energy
Switch Mode - Phase Controlled	Yes	Medium	0.917	29.61%	1.68%	1.033	71.64%	2.281	40.21%	1.25×10^{-3} seconds	$\approx 8.53 \times 10^{-3}$ Joules < .1% of Total Spark Energy
Switch Mode - Amplitude Controlled	Yes	Medium	0.917	29.43%	1.35%	1.032	58.69%	2.050	44.25%	1.25×10^{-3} seconds	$\approx 4.17 \times 10^{-3}$ Joules < .1% of Total Spark Energy
Switch Mode - Frequency Controlled	Yes	High	0.926	35.17%	0.11%	1.002	122.55%	3.324	132.34%	30×10^{-6} seconds	55.7×10^{-6} Joules < .1% of Total Spark Energy
Switch Mode - Phase Controlled	Yes	High	0.914	36.25%	0.02%	1.000	48.57%	1.589	69.07%	60×10^{-6} seconds	70.9×10^{-6} Joules < .1% of Total Spark Energy
3-Phase	Yes	Low	0.826	13.01%	0.57%	1.009	10.45%	1.126	1.78%	5.55×10^{-3} seconds	5.7×10^{-3} Joules < .1% of Total Spark Energy
Perfect Power Supply[6]	Yes		1.000	0.00%	0.00%	1.000	0.00%	1.000	0.00%	0.00 seconds	0.00 Joules

[1] Modeled for power supply rated at 80 KV, 1000 mA, field capacitor 0.1 µF, field resistor 80KΩ.

[2] Percent Ripple (RMS of Ripple/Average Output)

[3] Harmonic frequency content above 1000 Hz

[4] Total spark energy = 320 Joules

[5] External filter .37 µf capacitor, 335Ω resistor

[6] Theoretical ideal data

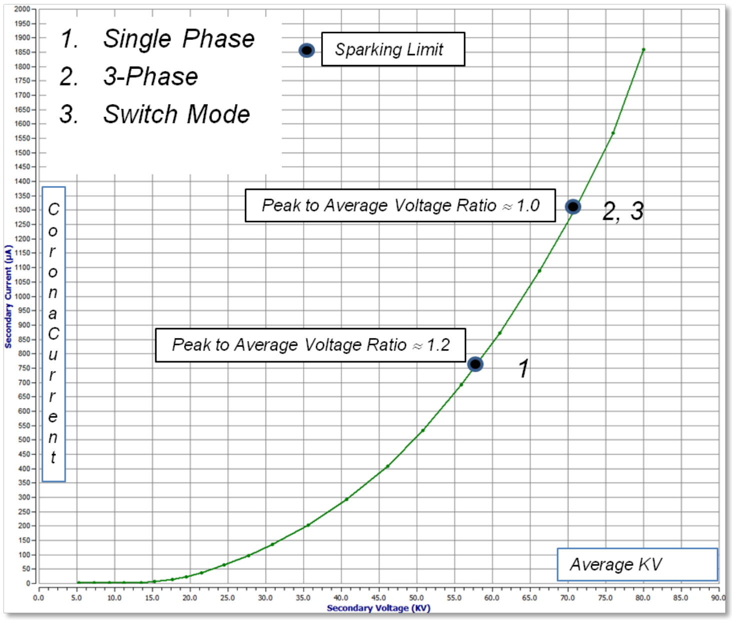
LABORATORY TESTING OF PRECIPITATOR POWER SUPPLIES

In addition to modeling, laboratory testing was used to test a select group of precipitator power supplies. The goal of this testing was to confirm the results of the modeling and identify additional power supply characteristics that would be encountered in actual operation.

For laboratory testing, a test ESP was constructed which allowed for the entire mechanical configuration of the precipitator to be changed. For example, different discharge electrodes can be configured at various plate spacings, and precipitator problems like close clearances and tracking insulators can be introduced. For each test, the test ESP was equipped with one of three commercially available precipitator power supplies: single-phase, high frequency switch mode, and a low frequency 3-phase.

An example of the laboratory testing is shown in Figure 2 and demonstrates the benefit of low ripple power supplies. Figure 2 shows the combined result of three tests, one for each power supply.

Figure 2. VI Curve for Single-Phase and Two Low Ripple Power Supplies



In each test, the power supply was operated from zero power to the point where sparking occurred and the typical average Voltage-Current (VI) curve plotted. It is interesting to note that the shape of the VI curve was established by the discharge electrode selected and the physical configuration of the test ESP. Therefore, all three power supplies tracked identically along the curve. In all three cases, precipitator sparking occurred at 71 kV which limited the power supply from going any higher. For the single-phase precipitator power supply (1), which is high ripple, when the peak voltage was 71 kV, the average voltage was 57 kV, which amounts to a peak-to-average-voltage ratio of about 1.2. For the 3-phase and high frequency switch mode precipitator power supplies (2, 3), which are both low ripple, when the peak voltage was 71 kV, the average voltage was very near 71 kV, which amounts to a peak-to-average-voltage ratio of 1.0. The ability to gain that much average voltage produces a substantial increase in the average current. The net result is more corona power into the ESP. A reduction in the peak-to-average-voltage ratio from 1.2 to 1.0 results in a 20% increase in voltage. This amount of voltage increase tracking a typical VI curve can produce up to 35% more average current.

SPARK DELAY, ENERGY AND QUENCH

When a spark occurs, it dissipates all of the energy stored in the precipitator field and the spark extinguishes. In response to the spark, the power supply quenches or turns off for a period of time, and then reapplies power to re-charge the precipitator field. However, the power supply does not turn off the instant the spark occurs. There is a delay based on the type of power supply, and during this delay, energy is delivered to the spark from the power supply. Table 1 shows the delay period and the amount of energy delivered to the spark during the delay for various power supplies. Each power supply type analyzed delivers less than 0.1% of the total spark energy.

The majority of energy (>99.9%) dissipated by the spark comes from the energy stored in the capacitance of the precipitator field and not the power supply as shown in the following analysis:

The capacitor comprised by the precipitator field stores energy in the form of an electric field. As discussed previously, the size of the capacitor is approximately 10 nf per milliamp of power supply and for a 1000 milliamp power supply, this would be approximately 0.1 µf. This is not an insignificant amount of capacitance. The amount of energy (measured in joules) stored by the field capacitance is given by:

Equation 1. $W = 0.5*C*V^2$

where:
W = energy stored (joules)
C = capacitance (farads)
V = voltage (volts)

For the precipitator field with a capacitance of 0.1 µf, operating at 45 kV, there are 101 joules stored in the capacitive field which will be dissipated at spark. Therefore, referring to Table 1, the energy delivered to the spark by each power supply is much less than 0.1% of the total energy dissipated by the spark.

We can also calculate the power in a spark. If we take the earlier example and assume the spark will dissipate the 101 joules of stored precipitator field energy in 1 millisecond, then we have the following:

Equation 2. $P = dW/dt$

where:
P = power (watts)
dW = change in energy (joules)
dt = change in time (seconds)

This yields 101,000 watts. In an internal BHA study conducted in 2002, an actual measurement made of the spark current on an operating precipitator field was on the order of 22,000 amperes. This precipitator field had rigid discharge electrodes, 16 in. wide gas passages, a single-phase power supply rated at 70 kV, 750 mA and controlled by an SQ-300® automatic voltage control. This energy output occurs over a very short period of time and at least partially explains why repeated sparking in the same location can cause damage, such as wire breakage in a weighted wire precipitator.

In summary, the amount of energy delivered by each power supply to the spark is proportionally very small. Care should always be exercised with large precipitator fields (which increase capacitance) and wide plate spacing (which increases voltage) since spark energy is directly proportional to the capacitance and the square of the voltage.

HARMONICS AND TOTAL HARMONIC DISTORTION

Precipitator power supplies connect to the power line and draw power not only at the fundamental frequency but at harmonic frequencies which are whole number multiples of the fundamental frequency. This non-linear load causes distortion of the input waveform and can cause many problems in the electrical distribution system including heating of conductors, nuisance breaker trips, and interference with other plant equipment. It is therefore important to have a measurement of how much distortion exists for each power supply type. One widely accepted measurement is total harmonic distortion (THD) which is a summation of all of the harmonics present in the system. The modeling data in Table 1 shows that the low frequency designs exhibit the lowest input THD and can therefore be expected to provide significantly fewer installation and maintenance problems due to harmonics. In addition, the power factor for each power supply type is also shown.

Precipitator power supplies also produce harmonics at the output. The DC waveform is made up of many frequencies including a fundamental frequency and its harmonics. This is particularly troubling in precipitator power supplies because ground is a current-carrying power lead and is therefore energized with harmonic frequencies. Since all of the plant equipment and the neighboring facilities plant equipment are connected through ground, the potential exists to cause interference with other plant equipment, including other precipitator power supplies. This is particularly true as radiated RF emissions increase with frequency.

Some of the known problems with high THD at the output are equipment failure, heating of conductors, crosstalk between power supplies, and interference with other plant equipment. In actual practice, these types of problems are often difficult to identify and solve and they are often specific to the location as well. To predict the likelihood of encountering these types of problems, a measurement of how much distortion exists in the output DC waveform is useful. THD can be used here as well. The output THD for each power supply type is shown in Table 1. In this case, the THD is calculated for frequencies above 1000 hertz. Again, the low frequency designs exhibit the lowest output THD and can be expected to encounter fewer problems in this area. To overcome some of these difficulties when applying high frequency designs, manufacturers provide detailed bonding and grounding specifications which must be meticulously followed.

The internal electrical connections inside the precipitator are also an area of concern. Historically, the precipitator was constructed for low frequency operation with connections being bolted together or using a friction fit. Both of these connection types may be inadequate for high frequency operation[11] leading to voltage drops at the connections, both in the high voltage distribution system and the ground system. A particularly interesting problem occurs when the voltage drop in the internal ground connection causes crosstalk and interference between precipitator power supplies. This can be very difficult to troubleshoot and correct without addressing the internal connections of the precipitator. Experience has shown that for a given installation, it is difficult to predict if the internal connections will be a concern when converting to high frequency power supplies. A generalization would be the higher the frequency, the more one would expect problems. This generalization has been experienced in the industry where some power supplies are trouble-free and others experience problems, but it is often site-specific.

APPLICATION DATA - LOCATION, SIZE, WEIGHT, AND FOOTPRINT

Electrical performance discussed previously is a very important consideration in the selection of a precipitator power supply. Perhaps as important, however, is its physical configuration. Table 2 shows the physical characteristics for four commercially available, roof-mounted precipitator power supplies. The differences are significant.

Table 2. Comparison of Four Precipitator Power Supplies

Comparison of Four Commercially Available Roof-Mounted Precipitator Power Supplies in Different KWs

Power Supply	Low Ripple Output	Frequency	External Control Cabinet	CLR Included in TR Set[1]	Cost Comparison[2]	Footprint on Roof (Sq Ft)	Footprint Comparison[3]	Weight on Roof (Lbs)	Weight Comparison[4]	Cooling on Roof
SMPS(1) 21 KW	Yes	High	No	-	1.49	14.15	0.66	1,050	0.56	Fan
SMPS(2) 20 KW	Yes	High	No	-	1.78	8.37	0.39	528	0.28	Pump & Fan
3 Phase 24 KW	Yes	Low	Yes	Yes	1.16	28.51	1.33	3,527	1.88	Passive
Single Phase 24 KW	No	Low	Yes	Yes	1.00	21.43	1.00	1,874	1.00	Passive
SMPS(1) 35 KW	Yes	High	No	-	1.89	13.81	0.64	1,200	0.64	Fan
SMPS(2) 28 KW	Yes	High	No	-	1.76	8.37	0.39	528	0.28	Pump & Fan
3 Phase 32 KW	Yes	Low	Yes	Yes	1.16	28.51	1.33	3,638	1.94	Passive
Single Phase 32 KW	No	Low	Yes	Yes	1.00	21.43	1.00	1,874	1.00	Passive
SMPS(1) 70 KW	Yes	High	No	-	2.31	15.33	0.65	1,300	0.46	Oil Circulator & Fan
SMPS(2) 60 KW	Yes	High	No	-	1.70	8.37	0.35	528	0.19	Pump & Fan
3 Phase 72 KW	Yes	Low	Yes	Yes	1.17	31.02	1.31	3,968	1.41	Passive
Single Phase 72 KW	No	Low	Yes	Yes	1.00	23.73	1.00	2,822	1.00	Passive
SMPS(1) 120 KW	Yes	High	No	-	2.31	22.23	0.86	2,300	0.65	Oil Circulator & Fan
SMPS(2) 120 KW	Yes	High	No	-	2.22	11.83	0.46	1,100	0.31	Pump & Fan
3 Phase 120 KW	Yes	Low	Yes	Yes	1.12	37.55	1.45	5,071	1.44	Passive
Single Phase 120 KW	No	Low	Yes	Yes	1.00	25.83	1.00	3,527	1.00	Passive

[1] The Current Limiting Reactor (CLR) is applicable only to 3-phase and single phase. Locating the CLR in the TR set increases its footprint and weight. The CLR can be located remotely.

[2] Within each size, the cost of SMPS(1), SMPS(2), and 3-phase is compared to single phase. For Single Phase and 3-Phase, cost includes external control cabinet and CLR in TR set.

[3] Within each size, the footprint of SMPS(1), SMPS(2), and 3-phase is compared to single phase. For Single Phase and 3-Phase, the footprint excludes the external control cabinet.

[4] Within each size, the weight of SMPS(1), SMPS(2), and 3-phase is compared to single phase. For Single Phase and 3-Phase, the weight excludes the external control cabinet.

The high frequency power supply designs shown are integrated units, meaning the entire power supply is contained in one package. This is a necessary configuration since it would be quite difficult to separate the transformer and electronics with high frequency. Having an integrated unit is a very convenient and efficient design with all of the power supply components located in one place. The power supply is packaged as a complete assembly instead of individual components that must be connected together.

The high frequency power supply designs are also physically smaller and lighter. The high frequency power supply designs utilize active cooling which helps achieve the smaller size and weight. This can become very important when trying to fit equipment on a crowded precipitator roof that has a limited ability to carry additional load.

However, there are some disadvantages to this configuration. An integrated unit often means the sensitive electronics are located in a harsh environment. This directly affects the reliability of the power supply, and having personnel service equipment in this environment is less than ideal. In addition, active cooling is another system which must be maintained, with additional energy required to operate these systems. Finally, an integrated unit means there is one source of supply for parts and service which can cause significant service interruptions if there are problems.

The low frequency power supply designs shown in Table 2 are not integrated but have separate control cabinets. This is possible with low frequency designs since standard electrical wiring can be used to connect components. The separate control cabinet allows the high voltage transformer to be located on the roof while the control electronics are located remotely, often in an environmentally controlled room. This configuration has been successfully used for many years with the single-phase power supply. The low frequency power supply designs are physically larger and heavier. They utilize passive cooling for the transformer which eliminates the need to supply and maintain an additional cooling system. Lastly, separating the controls and transformer allows each component to be sourced from multiple suppliers which helps assure a continuous supply.

There are also disadvantages to this configuration. As previously discussed, it is sometimes a challenge to find a suitable location for equipment that is larger and heavier. To solve this problem, the power supply can be located away from the main precipitator structure and then connected by means of high voltage cable. In addition, there is wiring and cabling between components which must be considered.

COST

Cost is also a significant consideration in the selection process of precipitator power supplies. Table 2 shows the comparative cost of four commercially available, roof-mounted precipitator power supplies and again, the differences are significant. The cost shown is the capital cost, or the cost to purchase the entire power supply. For the sake of comparison in Table 2, within each kW size range, the cost of the single-phase power supply was set to 1.00. The cost of the other three power supplies was then compared to the single phase. As can be seen, as the kW size increases, the differences in cost increase as well.

High frequency power supply designs are more expensive. However, since they are integrated, there is less field wiring, and installation cost should therefore, be less than the low frequency power supply designs. On the other hand, due to the combination of environment, high frequency and active cooling, maintenance cost is expected to be more than the low frequency power supply designs.

Low frequency power supply designs are less expensive. However, since they are separate components which must be connected in the field, the wiring and installation cost should be more than the high frequency power supply designs. Since they operate at a lower frequency, have passive cooling, and the electronics are in a protected environment, the maintenance cost should be less than the high frequency power supply designs.

RELIABILITY

The predicted reliability is the most difficult parameter to quantify. It is well known and accepted that the reliability of the single-phase precipitator power supply is excellent. There are many cases of this type of power supply operating continuously for more than 40 years. This is a reliability benchmark that one would like to duplicate with low ripple power supply designs.

Anecdotal evidence has shown that high frequency power supplies have had a poor reliability record, although it has improved in recent years. They suffer from such challenging factors as operating at high frequencies while connected to a device designed for low frequency (precipitator), significant internal heating, active cooling systems, harsh environment, radio frequency interference and harmonics. All of these factors have contributed to reliability issues. Suppliers have made changes over the years in an attempt to address each issue with varying degrees of success. Current experience indicates that additional effort is needed to equal the reliability of a single-phase power supply.

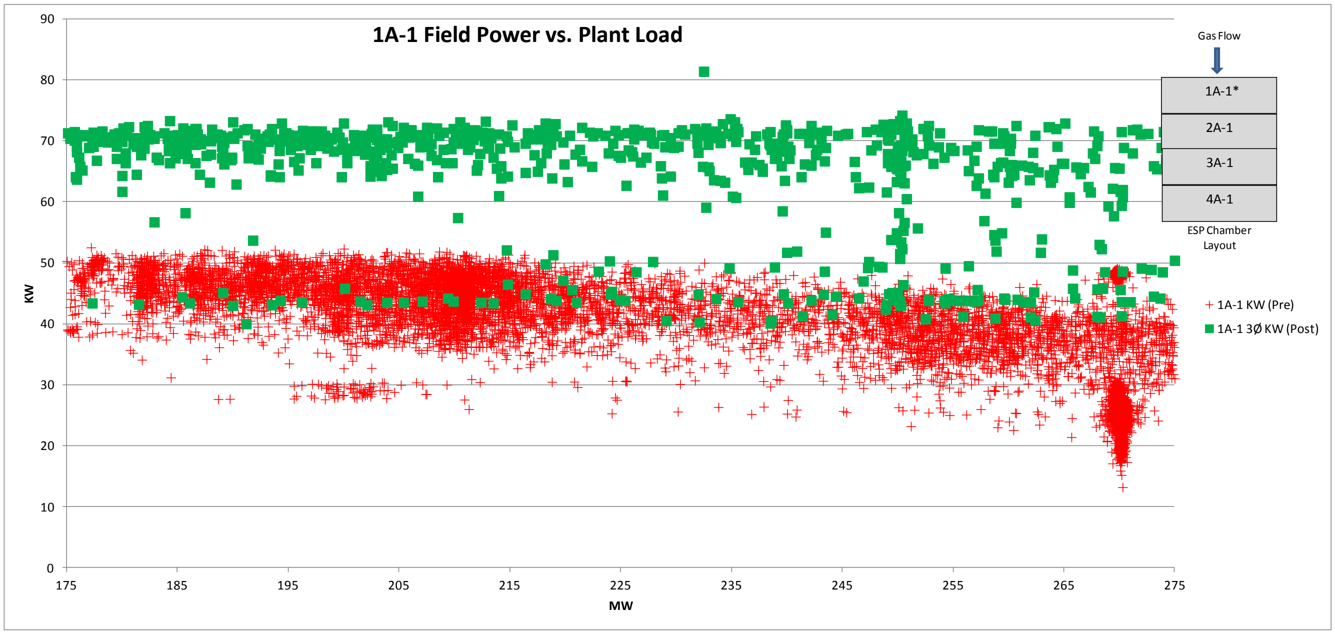
One of the goals of field testing the low frequency 3-phase power supply was to evaluate reliability. The results to date are promising; there have been no failures of the 3-phase power supply during the six-month test run. The results were somewhat expected considering the 3-phase is basically an extension of the single-phase power supply design which has an excellent reliability record, and the modeling and lab testing results support this.

FIELD TESTING OF SINGLE-PHASE AND 3-PHASE POWER SUPPLY AND OPERATING CONDITION OF THE ESP

The ESP used for performing the 3-phase power supply test is on a tangentially-fired boiler. It burns coal with a sulfur content of 1.9 lb/MBtu, has no selective catalytic reduction (SCR) system and no scrubber. The ESP consists of two boxes with rigid discharge electrodes and 16 in. wide gas passages. There are 4 fields (each 12 ft x 50 ft), and there are 8 TR sets per box (2 x 4 matrixes). Fields 1 and 2 have 70 kV, 750 mA conventional TR sets; fields 3 and 4 have 70 kV, 1000 mA sets. All TR sets are controlled by B&W PGG SQ-300® automatic voltage controls. On the "A" box, the inlet field 1A-1 TR set was replaced with a 480 V, 109 A, 90 kV, 900 mA, 3-phase TR set for the purpose of testing.

The results obtained when comparing the operating power levels of the test 3-phase power supply and the conventional power supply are shown in Figure 3.

Figure 3. MW vs. kW (Pre and Post 3-Phase Install)



As shown in Figure 3, the 3-phase power supply typically produced ESP kW values 1.5 times that of the conventional power supply (as determined by the average 3-phase power/average single-phase power). This field test confirmed the results of the laboratory testing which indicated that low ripple power supplies are expected to provide more precipitator field power. A significant impact on opacity was not anticipated because the test only involved 1/16th of the ESP.

Conditions at the field test site and the operation of the low frequency 3-phase power supply that has been installed continue to be monitored. More tests will be run at varied precipitator loads.

SUMMARY

A systematic study was performed using electrical modeling, laboratory tests, and field tests to determine the advantages and disadvantages of the many types of ESP power supplies. The results show that:

- A 3-phase low frequency precipitator power supply was developed and field tested as a result of this study to overcome many of the deficiencies discovered in the analysis of precipitator power supplies.
- The increase in corona power from a low ripple power supply can be achieved with several different technologies (SMPS, 3-phase low frequency, mid-frequency).
- Modeling data showed that the energy delivered by the precipitator power supply to the spark was insignificant compared to the total energy dissipated by the spark.
- Harmonics are unwanted and have been shown to be a concern on both the input and output of the precipitator power supply. Low frequency designs (including the 3-phase) produce fewer harmonics.
- Integrating all components into one package has the advantage of the most compact configuration. This can have the disadvantage of placing the power supply in a harsh environment which affects service life and maintenance and restricts the user to a single source of supply.
- Providing a separate transformer and control cabinet has the advantage of placing the electronic controls in a controlled environment and allows for duplicate sources of supply. This has the disadvantage of the need for a remote control cabinet and larger size and weight.
- Low frequency power supply designs (including the 3-phase) use passive cooling while high frequency power supply designs require active cooling. The increase in components and complexity for active cooling increase cost and maintenance.
- High frequency precipitator power supply designs provide low ripple at higher cost, lower reliability, but in a smaller, lighter integrated package.
- Low frequency precipitator power supply designs (including the 3-phase) provide low ripple at lower cost, higher reliability, but in a larger, heavier package with a separate control cabinet.
- The 3-phase and high frequency switch mode precipitator power supplies provide the lowest ripple voltage on an ESP load.
- The field test showed the 3-phase precipitator power supply produced an average 50% higher power in the ESP compared to the single-phase precipitator power supply. This suggests that like other low ripple power supplies, the 3-phase power supply can produce higher ESP collection efficiencies.

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