Switch Mode Power Supplies for Electrostatic Precipitators

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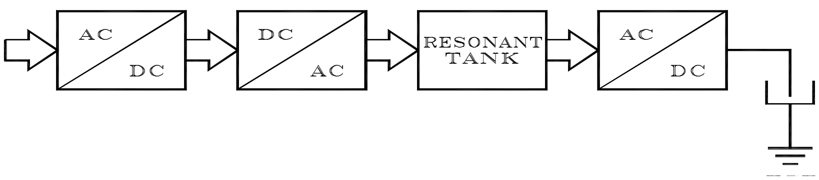
I. Introduction

Switch Mode Power Supplies (SMPS) are being introduced to the electrostatic precipitator market at price points that are very competitive with the linear transformer/rectifier sets and SCR based controls. The new switch mode power supplies have dramatically different performance and physical characteristics than the linear power supplies they will be replacing. As they are applied to the ESP application the new power supplies will have a major impact on many aspects of precipitator design, construction, operation, and maintenance. Suppliers and users of ESP's need to become familiar with this new power supply technology, in order to assess the specific effect that its introduction will have on their businesses. This paper will provide an overview of the changes that can be anticipated as SMPS are applied to ESP applications.

II. Description of Switch Mode Power Supplies

A functional block diagram of a typical switch mode power supply is shown below:



The AC/DC block takes the three- phase input and rectifies and filters it in order to create a fairly smooth DC bus of approximately 650 volts dc. The DC/AC block consists of an integrated gate bipolar transistor (IGBT) full bridge circuit which converts the DC bus into a high frequency AC waveform. The Resonant Tank block combined with the last AC/DC block steps up the high frequency AC, rectifies it, and thus delivers high voltage DC to the ESP load. This block, which is oil-filled, is the high frequency equivalent to a conventional 60hz. T/R set.

This circuit topology results in a number of major differences from linear power supplies.

Because the step-up transformer operates at high frequency it can be approximately 1/10 the size and weight of an equivalent 60hz. transformer. It will also use significantly less cooling fluid. The circuit design requires that the AC/DC and DC/AC modules be located very close to the step-up transformer. Therefore it is both practical and necessary for the switch mode power supply system to consist of <u>one physically integrated</u> package, unlike current systems in which the control cabinet and transformer/rectifier set are separate units, and are often located a considerable distance apart.

Since the IGBTs can be quickly turned off on command and do not wait for the line current to decay to zero, the circuit can turn on and off over 250 times faster than a linear power supply. This will allow new control algorithms with particular benefits for intermittent energization.

Because the AC input voltage is rectified, filtered, and then switched very fast (25 kHz) in small packets of energy, the ripple voltage is only 3-5% of the DC voltage level as compared to 35-45% for linear 60hz. power supplies.

The three-phase input results in a much higher power factor (.94 versus .63), and lower power consumed per kilowatt of power delivered to the precipitator load.

In summary the major differences in electrical characteristics for a switch mode power supply are:

1) Small integrated control and T/R package
2) Faster control response
3) Higher average output voltage
4) Less power consumed

For a detailed comparison of switch mode and conventional 60-hertz precipitator power supplies, refer to the table in Appendix A which compares nineteen performance and physical parameters.

Each of the improvements listed above has a potentially large impact on ESP construction, operation, and maintenance. The changes in control response and output voltage seem likely to enhance the actual collection efficiency, and hence the overall performance of many precipitators. The smaller integrated packages can change the way ESP power systems are designed, installed, and serviced. Let's examine each of these issues in more detail.

III. Enhanced Collection Efficiency Due To Switch Mode Power Supplies

These is a growing body of evidence that the new switch mode power supplies do provide improved collection for many precipitator applications. This seems to be primarily due to the ability to deliver a higher average voltage and current to the ESP load, while operating just below the sparking level and/or the back corona level for higher resistivity ashes. This benefit is likely for all ashes; low, medium and high resistivity.

An EPRI funded study did field tests using a prototype NWL SMPS on a slip-stream precipitator at Alabama Power-Plant Miller. The results were very encouraging in that depending on the test conditions approximately 30% improvement in percentage penetration was achieved. A conventional linear T/R set and SCR control was also tested to provide a base reference level. The table shown in Appendix B details the test conditions and results. It may be of interest to note that this study also tested a SMPS combined with a narrow width (1-3micro-sec) pulsed power supply. This combined unit provided the most improvement. This is also detailed in the results table.

Testing conducted at the Lansing Board of Water and Light Moores Park facility in Lansing MI. is also of interest. This was a steam generation plant burning low sulfur (1%) coal. Powerspan Corp. (formerly Zero Emissions Technology) conducted tests of a three phase linear power supply system the output of which is similar to what SMPS units will provide. The testing showed a higher average power and voltage delivered to the ESP load, as well as reduced sparking, and improved collection. The results were documented in a paper presented at the American Power Conference Proceedings- *Performance Improvements From the Use of Low Ripple Three Phase Power supply for Electrostatic Precipitators* [1]

A paper presented at the September 1998 proceedings of the ICESP – *A Novel and Versatile Switched Mode Power Supply for ESP's* [2] documented precipitator performance improvements due to the use of SMPS. The testing was done on a cement kiln ESP under various operating conditions. In the conclusions it was stated-"the prototype test has indicated that this SMPS can improve collecting efficiency, both in cases of low and moderate dust resistivity. The improvement is higher in case of occurrence of back corona"

A second paper presented at the same ICESP conference also discussed ESP performance improvements achieved by the use of SMPS. This paper – *The HVDC Current Source For ESP*[3] concluded that SMPS units provided higher average voltage, reduced sparking, and hence improvements to precipitator efficiency.

An early adopter of the first NWL built SMPS units has shown promising results. PPC installed an SMPS unit as a replacement for a 60 Hz. power supply on a paper mill ESP. The following is an excerpt from the field engineer's report to NWL-"The existing power supply was operating in the low 30kv range and was sparking heavily. When we installed the SMPS we were able to increase the secondary kv to approximately 40kv- a dramatic improvement. The SMPS now runs current limited at or near 40kv with a clear stack." PPC has installed SMPS units at other sites, and continues to report improved collection versus 60hz. units.

The testing done to date on the use of SMPS can not yet be considered to be conclusive proof of enhanced precipitator collection under all conditions. The industry is still in the early stage of understanding the total effects of these new power supplies on ESP performance. However, at this point in time it is reasonable to assume that for many applications, performance improvements can be achieved through the use of SMPS units. As more units are field installed, further data will be accumulated and analyzed. NWL will continue to publish such information as it becomes available.

IV. Impacts of a Small Integrated Package

The different physical configuration of a SMPS unit will have an affect on at least three major aspects of precipitator design, construction, and operation-

1) Physical arrangement of ESP rooftops, control houses, bus ducts, etc.
2) Maintenance and servicing.
3) Sourcing of the power supply and other related components.

Physical Arrangement

A switch mode power supply is the electrical equivalent of the control cabinet, T/R set, and current limiting reactor used in a linear 60hz. ESP power supply. The SMPS is contained in one outdoor enclosure, while the conventional unit consists of separate indoor and outdoor enclosures. A quick comparison of the of the key physical characteristics for a 1000mili-amp ESP power supply shows the following:

	SMPS	Linear 60hz.
Footprint (square feet)	8	18
Weight (lb.)	750	3900
Fluid Volume (gallons)	25	140

The size and weight reductions from using SMPS units offer new approaches to ESP design. There is no longer a need for a large climate controlled space for control cabinets, and the power and control wiring to the units will be simpler and easier to install than with conventional power supplies. For new ESP construction there should be significant cost savings available.

Another major change with SMPS units is that their size and weight allow the possibility of mounting them directly onto entrance flanges, thus eliminating a significant amount of duct work, and thus offering another opportunity for cost reduction on new precipitator construction.

The reduction in fluid volume may decrease the need for expensive high flash point fluid, or if such fluid is still desired, there will be a much lower cost premium than for current systems. The fluid containment issue is now much easier to manage, due to the large volume reduction.

Maintenance and Service

History has shown that for a number of reasons the high voltage step-up transformer contained within the T/R Set is one of the more likely components to fail within an ESP power supply system. When such a failure occurs, the T/R Set must be removed from the ESP for a time consuming repair or replacement process. Furthermore, the T/R Set is the most expensive component within the system, thus preventing many ESP users from stocking complete spare units, and thereby creating a difficult problem when a transformer failure does occur.

The situation is dramatically different with a SMPS unit. The T/R set component of a 1000ma SMPS unit will weigh roughly 300 lbs., and will cost significantly less than a 60hz. T/R. This makes it more affordable for the ESP user to keep spare T/R sets, as well as making it much easier to get them on and off the ESP.

SMPS T/R's will also save far less variation in electrical ratings and physical arrangements than 60hz. units. One key reason for this is that the input to the T/R comes from the inverter, and is always the same voltage and frequency, and thus a major T/R set rating variable is eliminated. Less variation in ratings will make it practical for the SMPS supplier to maintain an inventory of replacement T/R sets for quick shipment to a job site. Furthermore, in emergency situations, air-freight shipment will no longer be prohibitively expensive due to the relatively light weight of the T/R set. When an ESP user knows that replacement T/R's are readily and quickly available, it may then be practical to forego the expense of carrying spares on site. In summary, the user now has several better options for servicing T/R's than is presently available.

SMPS units will also be inherently easier to troubleshoot since all measurement points are located in an integrated unit, and are not split between a control cabinet and T/R set, which are often located a considerable distance apart.

Overall, there can be a much different approach to servicing and supporting SMPS units on precipitators. This will result in significant operational benefits for ESP suppliers and users.

Sourcing of Power Supplies

Current ESP power systems consist of the three major components listed below:

1) Voltage control and associated communications hardware and software.
2) Control cabinet including SCR, firing circuit, switch-gear, metering, etc.
3) T/R Set

The engineering and manufacturing expertise required for each of these components is somewhat diverse, few suppliers excel in all three; and therefore, many ESP suppliers have chosen to acquire these parts from different vendors. Furthermore, in order to offer exclusive content in their products, many ESP OEMs have developed their own proprietary voltage controls and communications products.

As a result of these factors, ESP suppliers have had to perform as the overall electrical systems integrator, and resolve incompatibilities between the various vendors' products. Due to the maturing of the technologies used, the systems integration problems are not as difficult as they were in the past, but some still exist today, causing delays and increasing project costs.

The introduction of SMPS to the ESP market will change the options available to ESP suppliers and users for buying power supplies and communications software. The SMPS units introduced to the market to date are offered only as a complete package, including the voltage control.

Those ESP OEMs that now have their own proprietary voltage control and communications products will soon have a choice to make. It is technically feasible to modify a 60hz voltage control to work with SMPS units. NWL has already performed the effort to adapt the NWL 60hz. control for SMPS use. However, there will be a significant development effort required to design an interface and insure compatibility between an alternate voltage control and the rest of the power supply system. Due to other industry trends there seems to be a move by the major ESP OEMs away from having their own proprietary voltage control and communications systems. The introduction of SMPS units may accelerate such moves, due to the effort required to adapt to SMPS.

More importantly, the use of SMPS units will mandate single point of contact for both the purchase and maintenance of the ESP power supply system, thus offering obvious benefits to ESP OEMs and users.

Conclusions

The introduction of switch mode power supplies for use on electrostatic precipitators will have a number of impacts on the industry. To summarize the major points:

1) Improved collection performance
2) New options for locating and installing power supplies.
3) Different approaches to maintenance and service.
4) Changes to power supply purchasing strategies.

Each of the above factors offers potential cost savings for both new and retrofit installations. Lower power consumption due to the improved power factor will result in direct cost savings. The full impact of all the potential savings has not yet been defined.

We are still in the early stages of understanding how to best apply SMPS units to ESP applications. The systems commercially available today are relatively unproven, and offer limited power and voltage options. But as with all new technology, the systems will continue to improve. Higher power and voltage ratings and more features and options will soon be available. There is little doubt that switch mode power supply technology will eventually become the standard solution for ESP power supplies.

Participants at all levels of the ESP market- new system suppliers, rebuild & repair firms, consultants, and users should begin the process of understanding what impact these new power supplies will have on their business.

Note

NWL is pursuing a number of initiatives to further develop this technology. There are ongoing efforts to develop higher power units, document improvements in precipitator performance, and verify long term reliability. Companies who have any interest in partnering on these efforts should contact NWL.

References

1. Boyle, P., Paradiso, G., Thelen, P., Performance Improvements From Use of Low Ripple Three Phase Power Supply for Electrostatic Precipitator, Proceedings of the American Power Conference, Vol. 61-1, Illinois Institute of Technology, Chicago, IL. 1999

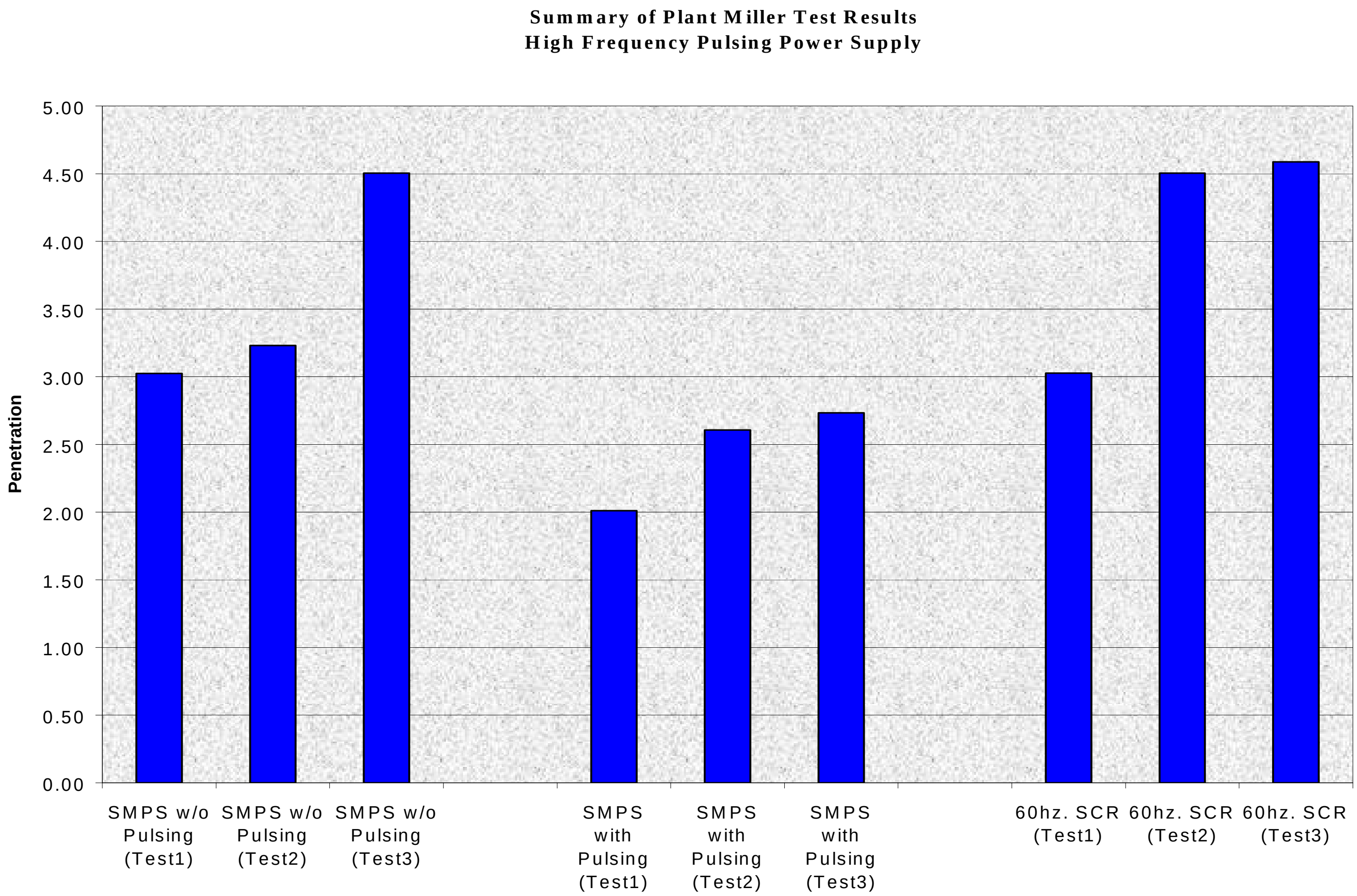
2. Reyes, R., Wallgren, B., Wramdemark, A., A novel and Versatile Switched Mode Power Supply For ESP's, Proceedings of the International Conference-Electrostatic Precipitators, September 1998, Kyongju, Korea

3. Chen, Y., The HVDC Current Source For ESP, Proceedings of the International Conference-Electrostatic Precipitators, September 1998, Kyongju, Korea

Appendix A
Comparison of SMPS to 60hz. Power Supplies
1000ma Unit

Parameter	SMPS	60hz. T/R
Output Voltage kVdc Average	70	65
Output current mAdc	1000	1000
Output Power kW	70	65
Peak Output Voltage kV	71.8	109.2
% Ripple kVp-p	3-5	35-45
Input Voltage (VAC)	460	460
Input phases	3	1
Input line current line (AAC)	98.8	237
Losses (kW)	4.0	3.5
Power factor	.94	.63
Input kVA	32.2	109
Operating frequency	25 kHz	60 Hz
Arc shutdown time	30 micro-seconds	8.33 mili-seconds
Cooling	Forced Air (1/2 HP fan)	Natural Convection
Volume envelope (cubic feet)	22	60
Plan envelope (square feet)	8	18
Weight (lb.)	750	3860
Gallons of fluid	18	135
Wiring from T/R to control	Factory	Field

Appendix B
Chart 1



Appendix B
Table 1

Test Conditions and Data
Plant Miller Tests
High Frequency Pulsing Power Supply

	Date	Test	Inlet	Boiler	Flow	Sec.	Sec.	Inlet	Outlet	BHA	Penetration
Power Supply Mode		No.	Temp.	Load	Rate	Voltage	Amp.	Loading	Loading	Response	
			(F)	(MWe)	(acfm)	(kV)	(mA)	(gr/dscf)	(gr/dscf)	(Outlet)	(%)
SMPS w/o Pulsing (Test1)	3/3/00	1	380	702	3,602	42	10	2.05	0.062	0.175	3.02
SMPS w/o Pulsing (Test2)		2	392	702	3,678	42	10	1.95	0.063	0.163	3.23
SMPS w/o Pulsing (Test3)		3	393	700	3,738	42	10	1.71	0.077	0.174	4.50
SMPS w/ Pulsing (Test1)	3/6/00	1	390	691	3,286	30	10 - 15	2.09	0.042	0.062	2.01
SMPS w/ Pulsing (Test2)		2	393	692	3,358	30	10 - 15	1.65	0.043	0.057	2.61
SMPS w/ Pulsing (Test3)		3	392	691	3,283	30	10 - 15	1.72	0.047	0.056	2.73
60hz. SCR (Test1)	8/25/00	1	400	701	3,112	28.7	3.89	2.28	0.069	0.085	3.03
60hz. SCR (Test2)		2	394	701	3,141	29.1	3.85	1.51	0.068	0.092	4.50
60hz. SCR (Test3)		3	391	701	3,309	29.7	3.49	2.18	0.100	0.117	4.59