Comparison of PowerPlus™ with Three Phase T/R Power Supplies

Introduction:
High frequency switchmode power supplies, including NWL's PowerPlus, have become the preferred electrostatic precipitator (EP) energization equipment of choice world-wide. However, a number of suppliers who do not have established switchmode power supply solutions are instead proposing a three phase transformer/rectifier (T/R) power supply.

The three phase T/R power supply will provide collection improvements over a conventional single phase T/R system, but still does not reach the performance levels and control flexibility of the PowerPlus solution. The PowerPlus provides lower ripple (and therefore higher kVDC operation) throughout the operating range of the EP field, higher power factor (less kVA demanded from the user to operate the EP), reduced arc energy dumped into the EP field, faster and more precise intermittent energization (IE) control, faster and more precise arc recovery, less weight on the EP roof, and a factory wired integrated system that requires less cost and time to install.

Comparison of Key Performance Parameters:

Ripple:
It is common for an EP field to operate somewhere between 50% and 100% of rated kVDC depending on the level of the gas loading in the field and the field location in the EP (inlet versus outlet). The PowerPlus unit maintains the kVDC within 2 or 3 kV of the peak kVDC throughout its operating range. This differential is the ripple voltage.

By comparison, the three phase T/R uses phase control SCRs so as the kVDC level is reduced from rated output, the difference between peak kV and kVDC increases. As the operating kVDC of the EP field is reduced from rated kVDC to ½ of rated kVDC, the kV ripple increases by a factor of 3.[2]

One of our EP customers in Germany, Balcke- Durre, ran extensive tests comparing a three phase T/R power supply versus the PowerPlus unit and found that the PowerPlus provides superior collection of particulate (better than a three phase T/R power supply) primarily due to maintaining this small difference between kVDC and kVpeak throughout the operating range. The faster arc recovery and precise control also helped in obtaining better results.

Power Factor:
Power factor is the ratio of the kW supplied to the power supply divided by the kVA needed from the user source. It is well established that fields closer to the outlet of the EP operate at lower kVDC and higher mADC than the inlet field. For a PowerPlus unit, the power factor for operation in the range of 40% to 100% of rated power is in the range of .92 to .94.
By contrast, the three phase T/R, using phase cant/Rolled SCRs, will increase the delay angle (reduced conduction angle) when operating at less than rated kVDC. For a three phase T/R supply with 40% total reactance, the power factor will vary from roughly .84 at rated kVDC to .43 at ½ of rated kVDC (assumes rated mADC at both points)[1].

So, an outlet field operating at rated mADC and 67% rated kVDC will still require rated KVA from the user's feeder source. The power plant consumes the kVA internally instead of supplying it to the grid. The plant loses revenue due to the poor power factor of the three phase T/R power supply. For a detailed analysis of reducing kVA using PowerPlus, please refer to the kVA savings white paper on our website, http://www.nwl.com/powerplus.

Arc Energy:
When the EP arcs, high level discharge current and current from the user feeder source will be dumped into the short in the EP. In the PowerPlus unit, the energy stored in the transformer windings is very low and the IGBTs shut down in 30 to 70 usec. There is no surge current drawn from the feeder source during arcing.

For a three phase T/R power supply and controller, there is significantly more energy stored in the HV windings, and the SCRs take nearly ½ cycle of line frequency to shutdown. During this ½ cycle it takes for the SCRs to shutdown, approximately 2 to 2.5 times rated Iac is being delivered through the power system and into the arc. All circuit breakers and contactors will constantly experience this wear and tear deterioration from arcing surge currents that does not occur with the PowerPlus units.

The end result is that the three phase T/R unit will dump approximately 1000 times more energy into an arc than the Power Plus unit. For more information on the fast arc response of the PowerPlus unit, refer to the analysis in the document P+_faster_arc_response.ppt, which can also be found at the aforementioned website.

IE Mode of Operation:
In IE mode, the Power supply system for the EP turns ON the output for a short period of time and then turns OFF the output for a different period of time. The main purpose of IE mode is to raise the peak voltage to the EP field while not exceeding the DC level at which back corona will start to develop in the dust layer on the plates. The ability of the

power supply to reach high peak kV levels for short periods of time (typically 1.5 to 4 msec) makes it less likely that back corona is to develop and more likely that the product of kVDC and kVpeak can be increased. Increasing this product (kVpeak*kVDC) increases the amount of particulate collected.

Because the PowerPlus operates at high frequency (50 kHz resonant with switching frequencies up to 25 kHz), the ON and OFF times of the PowerPlus can be controlled precisely and with resolution down to 0.1 msec. Numerous companies are taking advantage of this fast precise IE control to further reduce the power consumed by the EP operation.

The three phase T/R power supply system is only a slight improvement over the standard single phase T/R system. In fact, the use of three phases may impose additional constraints (do not want multiple IE cycles to all end up loading the same phase of the three phases). The result is that the IE timing is limited to ½ cycle resolution of ON time and full cycle resolution of OFF time.

Victor Reyes, in a paper from the ICESP conference held in Korea in 1998, collected data that supports the superiority of switchmode IE over IE with a conventional T/R system with SCR control:

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A NOVEL AND VERSATILE SWITCHED MODE POWER SUPPLY FOR ESP'S

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Power supply	Mode	IDC mA	UDC kV	U_{peak} kV	U_{min} kV	D_o mg/Nm³	P_{in} kW	S_{in} kVA	PF
T/R	IE (Nec=3)	275	36	61	28	92	15	32	0.47
SMPS	IE*)	380	38	68	28	81	23	25	0.92

*) t-ON=1,7ms; t-OFF = 6 ms

Table 5

The switchmode unit is superior in every category.

Switch mode units such as the PowerPlus are currently the only means to provide the flexibility of operation required to provide adequate particulate collection with the coal variation and EP operating condition variations that often result in higher particulate resistivity.

Precise and Fast Arc/Spark Recovery:

When there is a voltage breakdown in the EP, the kV must be lowered or turned OFF to allow the ions in the breakdown area to clear out (Quench period). The voltage can then be ramped back quickly to a level close to where the arc occurred (Setback level) and then slowly ramped to a higher kVDC level until the next arc occurs (Spark per minute control). Our experience with the smooth DC operation of the PowerPlus unit is that when voltage breakdown in the EP occurs, it is more likely to be an event requiring a quench period than the older conventional systems that have a lot of ripple (and therefore, tend to spark more).

In comparing the PowerPlus control response with the three phase T/R, it is best to visualize two ways to fill a clear bucket to a marked level. One way to fill the bucket is with golf balls; the other is to fill the bucket with basketballs. The golf balls represent small amounts of energy, the basketballs represent large amounts of energy, the bucket represents the capacitance of the EP, and the line on the bucket represents the kV at which the EP arcs.

The PowerPlus unit throws golf ball amounts of energy very fast (approximately 140 times faster than a three phase T/R) and can quickly and precisely get close to the line on the bucket (setback level). By slowly reducing the throwing rate as the level nears the line, it will continue to throw golf balls in the bucket at a while remaining close to the arcing level (line on the bucket). This method allows fast AND precise control of the kVDC level. The end result is spark per minute control that operates close to the highest kVDC that the EP can tolerate with minimal amounts of sparking and arcing.

The control of the three phase T/R is analogous to filling the bucket with basketballs at a very slow throwing rate. It is easy to visualize the three phase T/R will have greater difficulty establishing precise setback levels and spark per minute control. (The resolution of a basketball is not nearly as precise as the resolution of a golf ball.) It is also quite easy to visualize that it is much more difficult to slowly approach and hold a level close to the line on the bucket (KV arc level of EP) when throwing basketballs rather than golf balls.

PowerPlus allows the user to get increased dust collection from the EP that cannot be obtained with the slow control of large amounts of energy that is used by the three phase T/R power supply. The PowerPlus combination of shorter quench time, faster recovery to setback kV level, and precise slow ramping close to the kV arc level all lead to improved EP performance.

Size and Weight:
In approximate terms, the size of the complete PowerPlus unit (by volume) is typically 50 to 60% of the volume of the three phase tank alone. The weight of the complete PowerPlus unit is typically 30 to 45% of the weight of the three phase T/R tank. In addition, the three phase T/R power supply still has a separate SCR controller that must be located other than on the EP roof.

Integrated System:
The PowerPlus is a completely inter-wired factory-tested power supply. The user only has to provide 3 phase power, a few 120 VAC interlock wires and a shielded twisted pair for communications purposes.

By contrast, the three phase T/R power supply has two components, a T/R HV tank and an SCR controller. These two components are in different locations and must be inter-wired at the power plant site. Three phase power must be routed first to the SCR controller and then onto the HV tank. All of the kVDC and mADC wiring must be field-wired. Depending on the location of the current limiting reactance, the primary voltage signal may also have to be field-wired. The result is more wires, more conduits, and more labor required to prepare the three phase T/R power supply for operation. The requirement to field inter-wire the three phase T/R power supply also increases the likelihood of wiring errors and greatly increases the pre-start up inspection time required to verify that the three phase T/R power supplies are operating properly once energized. When the total installed cost has been evaluated, PowerPlus has usually been a competitive power supply solution.

Conclusion:
NWL has built three phase SCR controlled power supplies for many years for applications such as the TV transmitter market. We could have also decided to propose the three phase T/R with SCR control to the EP market, but, we did not. As described above, the PowerPlus unit is superior to the three phase T/R in numerous categories.

For the special case of low resistivity dust, the three phase T/R is superior to the traditional single phase T/R system, but it still falls short of the PowerPlus in electrical performance and true cost when the effects of revenue lost to poor power factor, the total amount of dust collected, and total installed cost are considered.

Hyundai Motor Company manufactures the Sonata and the Genesis models. Both models provide transportation but the Genesis is superior in all categories of performance. Likewise, the three phase T/R power supply will adequately collect low resistivity dust, but the PowerPlus power supply, like the Genesis, is the superior product in every category.

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References:

1. GE Canada, *The Power Converter Handbook, 1976*, p. 148
2. Schaefer, Johannes, *Rectifier Circuits: Theory and Design* (J Wiley and Sons, 1965), p. 263