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, suppliers without established switchmode power supply solutions have designed a three phase transformer/rectifier (T/R) power supply instead.

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; 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 major customers in Germany, Balcke- Durre, ran extensive tests comparing a three phase T/R power supply to a the PowerPlus unit and found that the PowerPlus provided 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 controlled 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.

Arc Energy

During an arcing event, 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 the half 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 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 this document.

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 develops 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 kV_{peak} can be increased. Increasing this product (kV_{peak}*kVDC) increases the amount of particulate collected.

Because PowerPlus operates at high frequency (50 kHz resonant with switching frequencies up to 25 kHz), ON and OFF times are precisely controlled with resolution down to 0.1 msec. Numerous companies take advantage of this fast precise IE control to further reduce the power consumption in their precipitators.

The three phase T/R power supply system is only a slight improvement over the standard single phase T/R system with respect to IE operation. 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.

Switchmode 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 spark or arc occurs. 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 collects dust from the EP in quantities unmatched by 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 remote from 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 reactor, 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 field wiring requirement also increases the likelihood of installation problems and time required to inspect the power supplies post startup. 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 numerous industries, including TV transmitter market. We could have also pursed three phase T/R with SCR control technology for 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 still falls short of the PowerPlus in electrical performance and true cost when the cumulative effects of poor power factor, total amount of dust collected, and total installed costs are considered.

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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