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PowerPlus Tech Note #304

Sizing PowerPlus to Replace Conventional T/R Sets

The main reason to upgrade from T/R sets to PowerPlus is to improve the collection efficiency of Electrostatic Precipitators (ESPs). The improvement in collection efficiency can be demonstrated arithmetically through the use of well-proven equations. We will start with the fundamentals of particle collection.

The collection efficiency of a precipitator is defined by the Deutsch-Anderson equation.

$$\eta = 1 - e - (A/V)\ \omega \qquad (1)$$

where η = efficiency
A = effective collecting electrode area
V = gas flow rate through the precipitator
e = base of natural logarithm
ω = particle migration velocity

Key: Increasing the particle migration velocity improves the efficiency of the precipitator.

The migration velocity, ω, represents the velocity of charged particle in the electric field moving toward the collector surface. It is defined by the following equation.

$$\omega = (a/2\pi\theta)EoEp \qquad (2)$$

where a = particle radius
θ = gas viscosity or frictional resistance coefficient of the gas
Eo = strength of the field in which the particles are charged (represented by peak voltage)
Ep = strength of the field in which particles are collected (represented by average voltage)

Since $(a/2\pi\theta)$ represents characteristics of the ESP that are relatively constant for a given precipitator and particulate load, the above equation can be generalized as

$$\omega \approx K2\ (kVdc)(kVpeak) \qquad (3)$$

where $K2 = (a/2\pi\theta)$ = a constant for a given WESP

Key: to improve the particle migration velocity for a given precipitator design, the product of “kVdc multiplied by kVpeak” must be increased to a higher value.

“kVdc multiplied by kVpeak” is the single most important calculation to describe precipitator efficiency (for ESP operation where back corona does not exist). The reason that the switch-mode PowerPlus provides improved precipitator performance when compared to conventional TR sets with current limiting reactors and SCR control is that the kVdc of the PowerPlus is very nearly equal to the kVpeak level.

The precipitator arcs and sparks at a level determined by the peak kV level applied to the field. The voltage cannot go any higher. The highest value of “kVdc times kVpeak” for a given field is therefore the just below (kV_arc level)^2.

Due to its circuit topology and high frequency operation, the PowerPlus operates at a voltage that is very close to its peak voltage output. Therefore, the product of “kVdc times kVpeak” is very close to the maximum possible value of (kv_arc level)^2.

Conversely, due to its single phase input and SCR phase control, a conventional T/R set inherently has 35%-45% peak-peak kV ripple at typical load conditions. It is quite common for the kV peak to exceed the kVdc level by 10 to 15 kV for a 55 kVdc TR set. Because the flashover level of the field is determined by the peak kV, the kVdc level will be much lower than the kVpeak level. The result is that the kV product of “kVdc multiplied by kVpeak” for a conventional SCR-TR system is significantly lower than a power supply with low ripple such as PowerPlus. This low value of kV product for the conventional TR reduces the particle migration velocity leading to reduced precipitator efficiency.

Key: The low kV ripple of PowerPlus results in a near optimal value of “kVdc multiplied by kVpeak” that improves precipitator efficiency above the efficiency level possible using conventional TR sets

Based on experience with the typical ripple levels observed on operating TR sets, the PowerPlus voltage rating needs to be approximatley 15kVdc above the conventional TR set kVdc rating. The chart below summarizes the recommended PowerPlus kVdc rating:

Voltage of T/R Set	Voltage of PowerPlus
45 to 55	70
55 to 65	83
66 to 80	100

The relationship between the particle migration velocity and the resulting corona current in the precipitator will determine the current rating needed for the PowerPlus unit. The following equation shows the relationship between migration velocity and corona current.

$$\omega = (a/2\pi\theta)((2I/K) + C) \qquad (4)$$

where ω = particle migration velocity
$(a/2\pi\theta)$ = constant for a given WESP
I = corona current
K = ion mobility
C = constant

For moderate to high currents, $2I/K$ is much greater than C, making C negligible (this is the case for most ESP fields). The above equation can therefore be simplified to:

$$K1I \approx K2\,(kVDC)(kVpeak) \qquad (5)$$

where
$K1 = (a/\pi\theta K)$ from eq. (4)
$K2$ as defined for eq. (3) $= (a/2\pi\theta)$ = a constant for a given precipitator

It has been observed that the V-I curve for a PowerPlus unit is shifted to the right compared to a T/R set V-I curve. Otherwise, the curves are quite similar. The reason for this shift seems to lie with equation (5).

As a matter of convenience, the V-I curve for a T/R set plots mAdc versus kVdc. Equation (5) shows that the current is not a function of kVdc, but, rather, the variable “kVdc multiplied by kVpeak”. In other words, the same current should exist for the same kV product regardless of the type of power supply used.

Using the V-I curve of a conventional T/R set under particulate loading, it becomes a simple matter to estimate the mAdc level required of PowerPlus.

Key: To correlate the current level of a PowerPlus unit to that of a conventional unit, a V-I curve must be generated that is related to “kVdc multiplied by kVpeak” and not only to the variable kVdc

To estimate the amount of current required for the PowerPlus unit, we start by defining a new value, ***kV_effective***, where kV_effective = square root (“kVdc multiplied by kVpeak”). Equation (5) can then be rewritten as

$$I \approx (K2/K1) *(kV\_effective)^2 \qquad (6)$$

We have identified the critical data needed from a precipitator field energized by a conventional TR set for determining the current rating of the PowerPlus unit:

1. kV peak at which the field arcs
2. V-I curve (mAdc v kVdc) under particulate loading (may need several curves if the particulate varies)
3. For each kVdc point on the V-I curve, the corresponding kV peak value

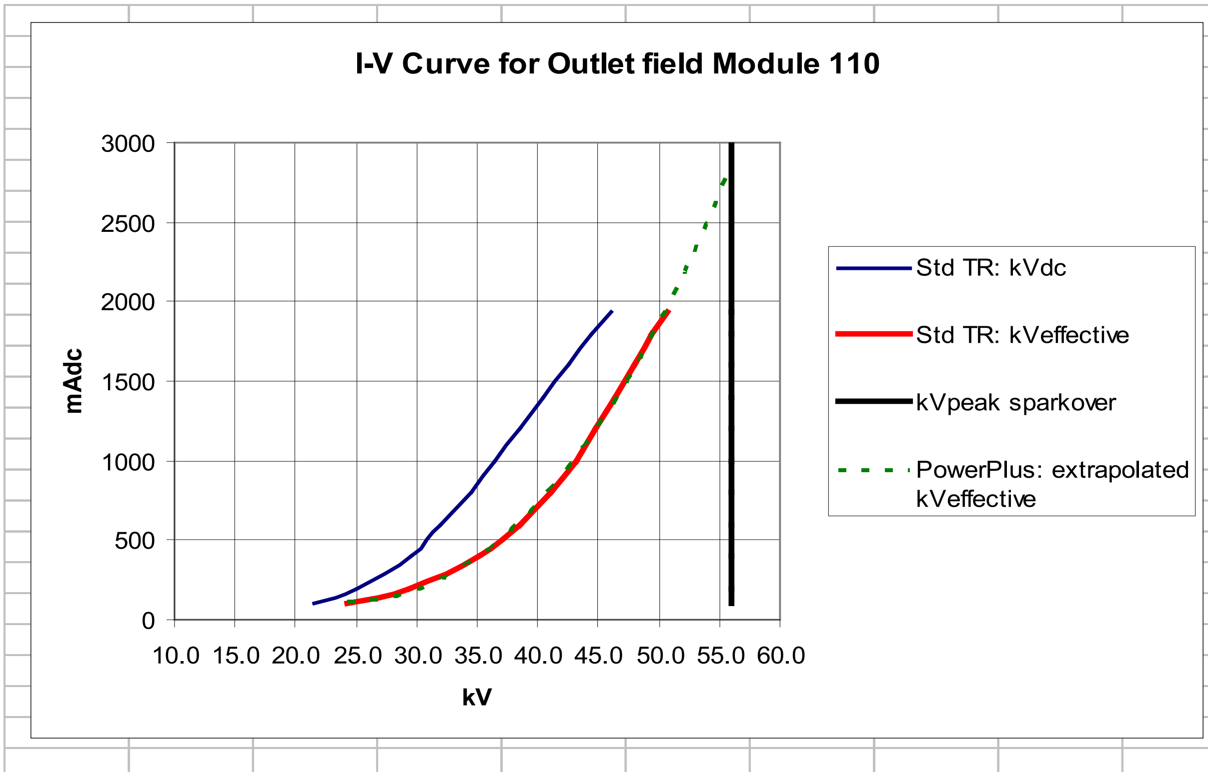
With this data, the mAdc versus kV_effective curve can be plotted. For a conventional TR set, this curve stops well below the kV_arc-over level. The V-I curve is then extrapolated to the kV_arc-over level to estimate the current level needed when the PowerPlus operates at a higher kVdc level.

An example based on data collected from a WESP module 110 follows:

The V-I curve on the next page is based on the actual V-I data taken from the outlet field of number110 Module WESP energized with the existing T/Rs. The blue curve is the traditional plot of mAdc versus kVdc.

The solid red curve combines the kVdc and kV peak data from the conventional TR set operation to plot mAdc versus kV_effective where kV effective is the square root(kVdc*kVpeak). The dashed green curve is then the red curve extrapolated to the kV-peak level at which the outlet field arcs.

The intersection of this extrapolated green curve with the KVpeak arc level is obtained when PowerPlus units energize the field. This intersection point now provides the mAdc level required from the PowerPlus unit. It can be seen that the outlet section will be expected to operate at about 56 kVdc at 2850 mAdc.



Based on the WESP load at the time of this data collection, any switchmode supply rated less than these values will be undersized. A power supply that is limited in current output cannot then reach the required kVdc levels needed to provide improved collection of particulate (for cases where no back corona exists). Consequently it is recommended that 200 kW, 70 kVdc, 2860 mAdc PowerPlus units are used for this application.

Reference:
[1] White, H.J., Industrial Electrostatic Precipitation, Addison-Wesley, 1963, pg 198-207

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