Application of Switch Mode Power Supplies on South African Coal

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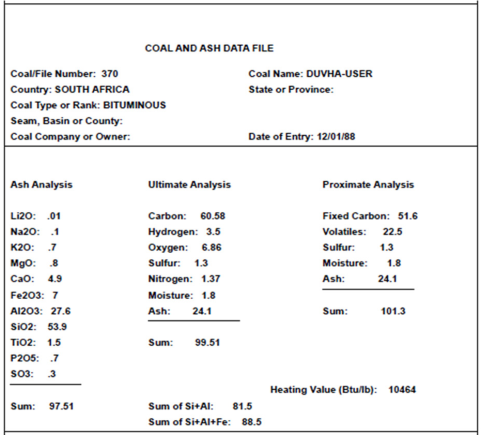
The purpose of this paper is to discuss and reveal the successful application of PowerPlus™ switch mode precipitator power supplies at Duvha Power Station Unit 5 precipitator in Emalahleni, South Africa. Unit 5 is a 600MW boiler burning local coal. Eskom, the local utility, was receiving tremendous pressure from environmental authorities to develop a plan for reducing the particulate matter emissions from their operating coal fired boilers.

The existing precipitators have two parallel casings each with two passes of five series fields - twenty fields in total. Lane spacing 300mm - number of lanes 176 - collector plate area 133,100 m^2 - plate height 13,75 m - field length 5,5 m - flow area 726 m^2 - design temperature 130ºC - design volume flow 995 m^3/s - gas entry velocity 1,37 m/s - design migration velocity 4,30 cm/s - design ash loading 15,9 g/m^3 (with the coal burnt today it is almost double) - design efficiency 99,6% - SCA 133.8 s/m. The station is utilizing SO_3 injection to aid in control of the resistivity of the ash to be collected and the injection rate remained constant at 15ppm throughout the project.



COAL AND ASH DATA FILE

Coal/File Number: 370
Coal Name: DUVHA-USER
Country: SOUTH AFRICA
State or Province:
Coal Type or Rank: BITUMINOUS
Seam, Basin or County:
Coal Company or Owner:
Date of Entry: 12/01/88

Ash Analysis		Ultimate Analysis		Proximate Analysis	
Li_2O:	.01	Carbon:	60.58	Fixed Carbon:	51.6
Na_2O:	.1	Hydrogen:	3.5	Volatiles:	22.5
K_2O:	.7	Oxygen:	6.86	Sulfur:	1.3
MgO:	.8	Sulfur:	1.3	Moisture:	1.8
CaO:	4.9	Nitrogen:	1.37	Ash:	24.1
Fe_2O_3:	7	Moisture:	1.8		
Al_2O_3:	27.6	Ash:	24.1	Sum:	101.3
SiO_2:	53.9				
TiO_2:	1.5	Sum:	99.51		
P_2O_5:	.7				
SO_3:	.3				
				Heating Value (Btu/lb):	10464
Sum:	97.51	Sum of Si+Al:	81.5		
		Sum of Si+Al+Fe:	88.5		

The engineers at Eskom worked with a renowned ESP modeling company to determine the best mix of conventional transformer rectifiers and PowerPlus to achieve the lowest outlet emissions and a cost effective solution. The decision was made to outfit the first three fields with new power supplies while leaving the remaining two fields with the existing transformer-rectifiers and Castlet MCSII controls. The decision was also made to interface the new power supplies with the existing Castlet PPMS central management system for monitoring and optimization.

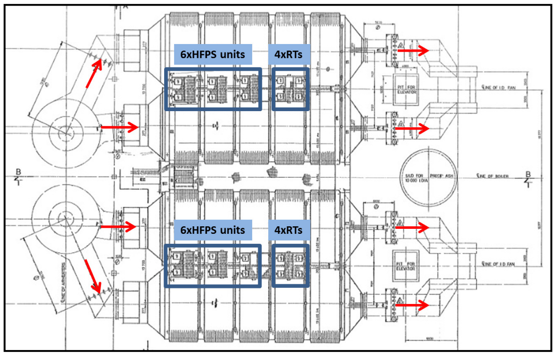


Figure 1. Plan View of Duvha 5 ESP Showing Power Supply Modifications

The mechanisms behind theorized improvement in collection of particulate with an upgrade in power supply technology is twofold. First and the largest contributor is the increase in average voltage. With high frequency switch mode power supplies, the output voltage is nearly flat DC. This resultant wave shape produces peak and average voltages that are almost synonymous.

Formula 1. Deutsch-Anderson Equation and Migration Velocity [1]

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

$$\eta = 1 - e^{-\left(\frac{A\omega}{Q}\right)}$$

where

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

It can be seen above that increasing the particle migration velocity improves the efficiency of the precipitator.

The Deutsch-Anderson equation however neglects 3 significant process variables and assumes the following; first, it does not take rapping losses into account, hence it is a steady state equation; second, it assumes that all particle sizes and shapes are homogenous, and as a result the migration velocity is the same for all particles in the gas stream.

The migration velocity, ω, represents the velocity of charged particle in the electric field moving toward the collector surface. When doing modelling, the challenge is to choose the correct migration velocity. It can be calculated by theory, but normally deviates significantly from practice. This is because the ground principle on which it is calculated is a simplification of reality.

It is defined by the following equation.

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

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/2πθ) represents characteristics of the ESP that are relatively constant for a given precipitator and particulate load, the above equation can be generalized as

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

where K2 = (a/2πθ) = a constant for a given ESP

So 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. The reason that the switchmode 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.

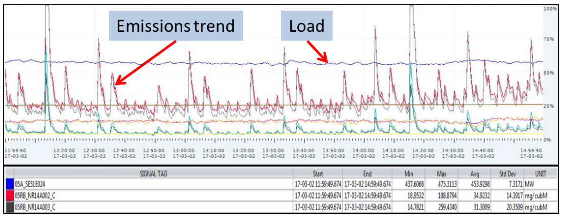
The second, more subtle mechanism is the improvement in spark response. Spark response has historically been line frequency dependent and still is in Silicon Controlled Rectifier (SCR) devices. A PowerPlus can detect, quench a spark and begin recovery within 4.03 milliseconds where a conventional power supply requires at greater than 16-20 milliseconds depending on the incoming line frequency and processing speed of the controller.

Figure 2. Spark Response Comparison (To be supplied later)

The Duvha installation was done with the unit on load due to the lack of outage opportunity. The installation of PowerPlus units and interfacing to the PPMS were the only modification done to the unit.

The installation had its challenges, but with teamwork between Eskom and the contractor these were overcome with valuable lessons learned. One damaged control printed circuit board was the result of a wiring mistake and another appeared to be shipping damage and was repaired and returned to service. The biggest challenge was the interfacing between the different control systems to the PPMS. The implementation of the different rapping philosophies posed the biggest challenge, but regular correspondence between the NWL software developers and the Castlet PPMS developer these were overcome. The end result had the PowerPlus unit controlling the rapping of the conventional rectifiers in the last two fields as well. The strategy that was followed for performance measurement included a baseline efficiency test before the PowerPlus installation and an efficiency test after the installation and optimization phase. The post installation test was however not done yet due to unit load issues currently experienced. Indications from the stack monitor however showed positive results.

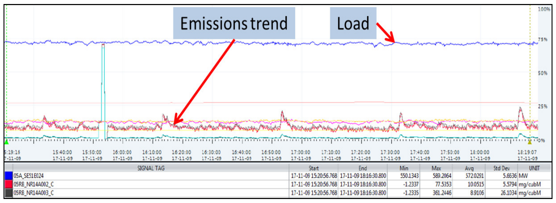
The PowerPlus units were installed in July and August of 2017 and started up in the middle of August. Immediately upon startup the results were very promising. Because it was not possible to do the post installation test yet it is better to compare the average emissions values as observed from the dust monitor before the installation with values as observed after the installation. On 2 March 2017, before the installation, the average emissions reading between 12:00 and 15:00 (hottest time of the day) were 35mg/Nm^3 at an average load of 453MW and a gas stream temperature of 134C.



	SIGNAL TAG	Start	End	Min	Max	Avg	Std Dev	UNIT
🟦	05A_SE51E024	17-03-02 11:59:49.674	17-03-02 14:59:49.674	437.6068	475.3113	453.9298	7.3171	MW
🟥	05RB_NR14A002_C	17-03-02 11:59:49.674	17-03-02 14:59:49.674	18.9532	108.8794	34.9232	14.3917	mg/cubM
⬛	05RB_NR14A003_C	17-03-02 11:59:49.674	17-03-02 14:59:49.674	14.7821	259.4340	31.3009	20.3509	mg/cubM

Figure 3. Load and emissions trend before PowerPlus

After the installation and optimisation the outlet emissions observed from the dust monitor on 9 November 2017 between 15:00 and 18:00 reduced to +/-10mg/Nm^3 and sometimes as low as 5 mg/Nm^3 at an average load of 570MW and a gas stream temperature of 135C . The emission trends showed occasional spiking due to rapping which increased the overall average slightly. It is however very prominent how the rapping spikes differ from the pre- and post-installation trends.



	SIGNAL TAG	Start	End	Min	Max	Avg	Std Dev	UNIT
🟦	05A_SE51E024	17-11-09 15:20:56.768	17-11-09 18:16:30.800	550.1343	589.2064	572.0291	5.6636	MW
🟥	05RB_NR14A002_C	17-11-09 15:20:56.768	17-11-09 18:16:30.800	-1.2337	77.5353	10.0515	5.5794	mg/cubM
⬛	05RB_NR14A003_C	17-11-09 15:20:56.768	17-11-09 18:16:30.800	-1.2335	361.2446	8.9106	26.1034	mg/cubM

Figure 4. Load and emissions trend after PowerPlus

It can thus unofficially be confirmed that at least 71% reduction in particulate emissions was observed by installing PowerPlus units and do proper rapping optimisation on all the fields.

There are several key facts about this project:

- All work was performed with the unit on-line. Only fields were taken out of service as required.
- No ESP mechanical work was performed during the project.
- No changes were made to gas flow distribution.
- No modifications were made to operation of the boiler.
- Existing SO3 injection system was not adjusted before, during or after this work.
- Over a period of months, after installation of the PowerPlus, rapping was optimized to reduce spiking.

Eskom is currently awaiting an opportunity to do a full post installation efficiency test on the ESP where after results will confirm the exact gain from the project.

References

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