Measurement and Verification Methodology for Coal Fired Power Plant Energy Efficiency Improvement

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Summary

Energy efficiency improvement at existing coal fired power plants is one of the most cost effective ways to solve the energy shortage problem. Stakeholders from the power plants are interested in quantifying the improved performance such as the capacity increases, coal savings and environmental impacts. These impacts can be verified by an independent measurement and verification (M&V) inspection body credibly and transparently.

In this poster, a cost-effective and reliable M&V methodology to evaluate the Energy Efficiency (EE) performance enhancement in power plants is presented. To illustrate, the savings verification for EE improvement interventions that are completed at a power plant, located in Mpumalanga, South Africa, which has six 500 megawatt (MW) units with turbine Maximum Continuous Rating (MCR) at 36.90%, is taken as a case study. The EE improvement project in this power plant entails the identification of the plant EE improvement opportunities through the gathering and analysis of the real time process data for two seasons (winter and summer) to determine the significant contributors to the deterioration of the plant heat rate. EE improvement solutions to the entire plant, including the primary energy, boiler, turbine and auxiliaries, are proposed to reduce the heat loss wherever applicable.

The objective of M&V is to measure and verify the coal savings and the equivalent electricity savings that will occur due to the EE improvement strategies in the power plant. In order to reduce M&V cost and complexity, historical operational data for each of the six generation units such as the generated and sent-out power, coal consumptions, calorific values (CV) of the consumed coal, ambient temperature, etc., during the baseline period are analyzed to build both the coal consumption baselines and the sent-out power baselines for each generation unit. After the implementation of the EE interventions, the sent-out power will increase while consuming same amount of coal or the coal consumption will be reduced while producing the same sent-out power. To evaluate the coal and equivalent electricity savings, energy models are identified to characterize the accurate relationship between the coal consumption and the sent-out power.

After the implementation, the coal consumption, coal CV, the generated power and the sent-out power are also monitored. In the meantime, the energy models are applied to retrieve the amount of coal that would have been consumed without the EE interventions. The coal savings due to the EE interventions are the differences between the retrieved coal consumption and the measurement coal consumption. The coal savings can be easily translated to electricity savings by the established energy models. The M&V methodology is also applicable to other similar power plant EE improvement projects.

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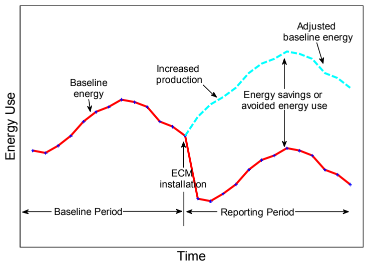
1. Introduction

This poster introduces a Measurement and Verification (M&V) methodology for the savings verification of an energy efficiency (EE) improvement project to be implemented at a coal fired power plant in South Africa. M&V is an impartial, credible, transparent and replicable process to assess the energy savings for the energy efficiency activities. A general M&V methodology is illustrated in Figure 1. The proposed M&V methodology verifies the achieved energy savings by analysing and comparing the plants' online operational data both in the baseline and post-implementation period. This energy efficiency improvement verification approach is inherently cost-effective and more reliable to reflect the actual power plant efficiency than the design values or the results from short-term test under ideal conditions.

Figure 1. General M&V methodology

(Source: International Performance M&V Protocol 2012)



2. Scoping study

The studied power plant was completed and commissioned in 1979. The plant has six 500 MW independent generation units, Unit 1-6, with designed efficiency at rated turbine Maximum Continuous Rating (MCR) of 36.90%.

The proposed project activities to be implemented in the power plant aim to improve the current unit heat rate by 1% after identifying the energy efficiency enhancement opportunities through internal energy flow analysis. The EE activities will be performed for the primary energy, the boiler, turbine and the auxiliaries as well at the power station. Some major retrofitting and refurbishing EE improvement technologies are listed in Table 1. The EE improvement project is commenced from May 2012 and the planned project duration is 3 years.

Table 1. Planned Energy Efficiency Activities

	Energy Efficiency Activities
Primary energy	Improve imported coal quality
	Fix boiler and turbine passing valves
Boiler	Replacement of creep damaged pipework
	Conduct air heater leakage tests and raise defects for repair of air ingress
	Optimise air/fuel ratio in the mills
Turbine cycle	Improve high main and boiler feed pump turbine condenser backpressures
	Re-tube main and boiler feed pump turbine condensers
Electrical	Implement energy efficient lighting project
	Condensate extraction pump variable speed driver retrofit
	Switch off conveyor belts that are not coaling

3. M&V plan

The M&V plan plays a key role in the whole M&V process and gives the complete procedure for the savings evaluation of an EE project.

M&V options: Option C, **whole facility measurement** is selected for this M&V project since the savings contributed from individual intervention are not easy to be isolated for each power generation unit.

M&V boundaries: Six sub-boundaries are defined to be each generation unit of the studied power plant. The project boundary is the summation of the six sub-boundaries. Only the savings inside the boundary will be reported by M&V.

Metering plan and data requirements: Note that there is always a trade-off between the desired measurement accuracy and the M&V cost. In order to control the metering cost, the plant's operational data from both the baseline and post-implementation period are collected to establish the baseline and calculate the savings. In this project, the following data throughout 2011 are adopted for the baseline development:

- Hourly sampled coal consumption per unit;
- Daily sampled CV values per unit;
- Hourly sampled sent-out power per unit;
- Hourly sampled generated power per unit.

Baseline: Both the sent-out power increase and corresponding coal savings can be expected for this project. Therefore, both the power and coal consumption baselines are established for each generation unit. Without loss of generality, baseline development for Unit 1 in January 2011 is taken as example to illustrate the baseline methodology. Let $C_d(i), d = 1,2,\ldots,31, i = 1,2,\ldots,24$ denote the coal consumption at the *i*-th hour on the *d*-th day in January 2011; $S_d(i)$ and $G_d(i)$ denote the sent-out and generated power, respectively. CV_d denote the daily calorific value of the coal. The average daily baseline in January for the coal consumption can be calculated by

$$C(i) = \frac{\sum_{d=1}^{31} C_d(i)}{31}. \tag{1}$$

When replace $C_d(i)$ by $S_d(i)$ or $G_d(i)$ in Eq. (1), the sent-out and generated power baselines $S(i)$ and $G(i)$ can also be obtained. Baselines for Units 2-5 in other months in 2011 are also developed similarly for this project.

Baseline adjustments: At post-implementation period, say in January 2013, the coal consumption $\widehat{C_d}(i)$, sent-out power $\widehat{S_d}(i)$, generated power $\widehat{G_d}(i)$ and the coal calorific value $\widehat{CV_d}$ can also be obtained. Let $Q(i)$ be the thermal energy from the coal burning and $Q(i) = C(i) \times CV$. The ratio

$$h_s = \textstyle\sum_{i=1}^{24} S(i) / \sum_{i=1}^{24} Q(i),$$

the adjusted sent-out power

$$\widetilde{S_d}(i) = h_s \times \widehat{C_d}(i) \times \widehat{CV_d}, \tag{2}$$

and the adjusted coal consumption

$$\widetilde{C_{sd}}(i) = \widehat{S_d}(i) / (h_s \times \widehat{CV_d}). \tag{3}$$

By using Eq. (1), the adjusted sent-out baseline $\tilde{S}(i)$ and adjusted coal consumption baseline $\widetilde{C_s}(i)$ can be obtained. The adjusted generated power baseline $\tilde{G}(i)$ and adjusted coal consumption baseline $\widetilde{C_g}(i)$ are also obtained similarly.

Savings calculation: In this project, both the savings from the sent-out power increase and the savings from the reduction of internal power consumption are reported. Specifically,
Sent-out power increase: $\Delta P_s(i) = \hat{S}(i) - \tilde{S}(i)$.
Coal savings related to sent-out power increase: $\Delta C_s(i) = \widetilde{C_s}(i) - \hat{C}(i)$.
Internal power consumption reduction:
$\Delta P(i) = [\tilde{G}(i) - \tilde{S}(i)] - [\hat{G}(i) - \hat{S}(i)]$.
Coal savings related to internal EE improvement:
$\Delta C(i) = [\widetilde{C_s}(i) - \hat{C}(i)] - [\widetilde{C_g}(i) - \hat{C}(i)] = \widetilde{C_s}(i) - \widetilde{C_g}(i)$.

Note that the savings should be calculated for the same month across the baseline and post-implementation period to guarantee fair comparison.

4. Sent-out power performance assessment

By the implementation of the EE interventions, the plant will generate and send out more power while consuming same amount of coal or the coal consumption will be reduced while producing the same output. The intervention to repair the air heater leakage on Unit 5 is completed in December 2012. The expected savings for this intervention is 20 MW. The performance for this intervention will be assessed 3 times in 3 subsequent months. The sent-out power baseline and post-implementation load profiles, performance summary and the time-of-use savings figures are given in this section.

Figure 2. Sent-out power load profiles

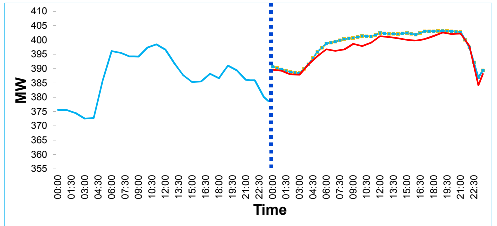


Figure 3. Coal consumption load profiles

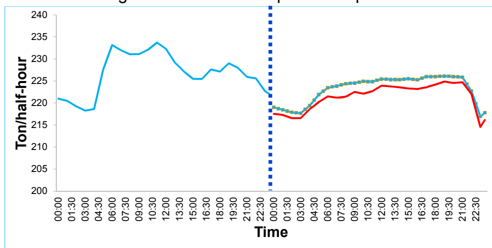


Table 2. Performance summary in January 2013

Description	DSM target	Reporting period	YTD	ITD
Weekday evening peak average demand impact (kW)	n/a	1.03	0.04	1.03
Energy consumption impact (MWh)	n/a	938.9	938.9	938.9
Coal consumption impact (kton)	n/a	1.05	1.05	1.05

Table 3. Average time-of-use sent-out power savings

Weekday (MW)	Morning Off-peak	Morning Standard	Morning Peak	Midday Standard	Evening Peak	Evening Standard	Off-peak
Baseline	391.17	398.92	400.32	402.12	403.12	402.20	391.46
Actual	390.38	396.62	397.31	400.12	402.10	401.62	390.30
Impact	**0.78**	**2.29**	**3.01**	**2.00**	**1.03**	**0.58**	**1.16**

Saturday (MW)	Morning Off-peak	Morning Standard	Midday Off-peak	Evening Standard	Evening Off-peak	Sunday (MW) Off-peak
Baseline	392.27	400.75	402.36	403.12	396.83	398.22
Actual	391.27	397.94	400.53	402.10	395.96	396.66
Impact	**1.00**	**2.81**	**1.83**	**1.03**	**0.87**	1.56

5. Internal EE performance assessment

After fixing the air heater leakage on Unit 5, less thermal energy is wasted for the power generation than that in the baseline period. Therefore, the auxiliary devices for Unit 5 will work less harder and consume less electrical energy. Therefore, besides the assessment of the sent-out power performance, the internal EE performance is also evaluated. The internal power baseline and post-implementation load profiles, performance summary and the time-of-use savings figures are given in this section.

Figure 4. Internal power consumption load profiles

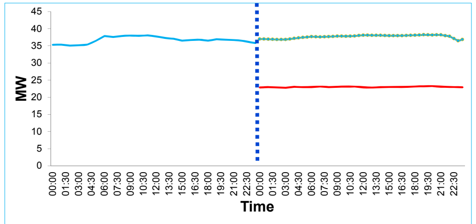


Figure 5. Coal consumption load profiles

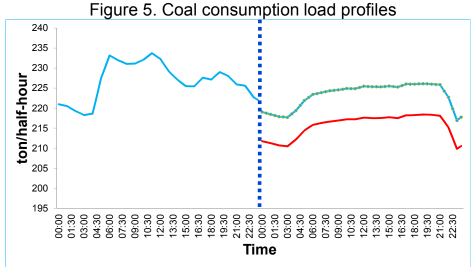


Table 4. Performance summary in January 2013

Description	DSM target	Reporting period	YTD	ITD
Weekday evening peak average demand impact (kW)	n/a	14.98	0.63	14.98
Energy consumption impact (MWh)	n/a	8788.2	8788.2	8788.2
Coal consumption impact (kton)	n/a	4.54	4.54	4.54

Table 5. Average time-of-use power savigns

Weekday (MW)	Morning Off-peak	Morning Standard	Morning Peak	Midday Standard	Evening Peak	Evening Standard	Off-peak
Baseline	37.06	37.65	37.71	37.98	38.17	38.12	37.05
Actual	22.92	23.00	23.05	22.99	23.19	23.12	22.96
Impact	**14.14**	**14.65**	**14.66**	**14.99**	**14.98**	**15.00**	**14.09**

Saturday (MW)	Morning Off-peak	Morning Standard	Midday Off-peak	Evening Standard	Evening Off-peak	Sunday (MW) Off-peak
Baseline	37.14	37.77	38.02	38.17	37.59	37.65
Actual	22.93	23.07	22.96	23.19	23.04	23.01
Impact	**14.21**	**14.71**	**15.06**	**14.98**	**14.54**	**14.65**