Measurement & Verification of Coal Fired Power Station Maintenance Projects

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***Abstract*— A South African electricity utility implemented numerous power station improvement projects aimed at either increasing efficiency or output megawatts. This paper presents an overview of the process used to measure and verify (M&V) the energy and demand impacts of two projects at one of the power stations. The projects were a steam feed pump refurbishment and a high pressure turbine re-blade. The projects were M&V'd using the International Performance Measurement & Verification Protocol (IPMVP). This involves establishing a baseline model for the performance of the two units affected by the project. The post implementation performance of each unit is then compared to its baseline, after making adjustments for changes in operating conditions between the baseline and assessment periods. Both projects resulted in an increase in megawatts sent out. Additionally the turbine re-blade resulted in a 2.7% increase in efficiency.**

***Index Terms*—Measurement and Verification, coal fired power station, energy efficiency, steam feed pump, turbine re-blade.**

I. Introduction

The South African electricity utility, Eskom, has been implementing numerous projects on its power stations to increase their efficiency or output. The projects at three of the utility's coal fired power stations are being audited by our university for the project financier. This paper presents the results of two of the projects implemented so far at a 1.6GW coal fired power station, namely:

- A steam feed pump refurbishment on unit 6
- A high pressure turbine re-blade on unit 8

(All of the 8 units at this power station are rated at approximately 200MW.)

The International Performance Measurement & Verification Protocol (IPMVP) [1] was adopted as the protocol to use to evaluate the savings or gains from each of these projects. The IPMVP sets out options for determining energy efficiency gains or savings relative to an adjustable baseline, or model, of the pre-implementation system. Under this system, impacts are reported relative to how the pre-implementation system would have performed had it been operating in the conditions of the new system.

For example, if a project is implemented which should reduce the coal consumption of a station, the savings may be over or under stated if one simply compares the coal consumption from before and after implementation. This is because the efficiency of the station changes with:

- Coal quality,
- Load requirement,
- Cooling water temperature,
- Weather, etc.

While the savings could be evaluated at only one operating point (e.g. full load or maximum continuous rating (MCR)), the savings vary with the load requirement and other factors. Therefore the cumulative and average savings need to be determined using the actual operating points over the assessment period.

Another example is the case of the high pressure turbine re-blade which allowed unit 6 to output extra MW as compared to before - i.e. a new MCR was achieved. The benefit of these extra MW is only realised if the load requirement from the grid operator is high enough to make use of that extra capacity. Thus the average impacts over an assessment period of several months may be less than the increase in MCR.

Therefore the methods of the IPMVP allow the impacts that the grid actually sees, as opposed to peak impacts, to be reported.

Guidelines such as the IPMVP [1], SANS 50010 [2] and [3-5] are typically applied to demand side measures as opposed to supply side measures, however the principles are equally applicable to generation projects [6]. Furthermore adhering to the IPMVP provides stakeholders with greater confidence since it requires that the M&V process be open and transparent. Additionally all the measures at various different power stations will be assessed in a consistent and similar manner.

The IEA guideline on measuring and reporting efficiency performance in coal fired power plants [7] was also consulted along with [8]. These guidelines provide methods for evaluating overall power station efficiency improvement using overall power station performance metrics or measurements. These methods report impacts on a power station level making it difficult to identify improvements from projects with very small impacts.

The two projects above were expected to achieve impacts of a few megawatts each and the turbine re-blade a coal saving of 10kt per annum, which is very small compared to the power station overall capacity and coal consumption. Additionally, the station engineers were concerned that the savings from these measures would be negated by the continuous decrease in efficiency on other units which were needing maintenance after several postponements of planned outages.

Therefore it was decided to report impacts on a generation-unit level for these projects.

II. Steam Feed Pump Project

The purpose of the project was to increase the send out power of unit 6 of the power station. This was to be done by refurbishing the steam feed pump (SFP), which had had various reliability issues, and ensuring its utilisation for loads above 140MW.

The send out power, P_{SO}, is the difference between the generated power, P_{Gen} and auxiliary power, P_{Aux}.

$$P_{SO} = P_{Gen} - P_{Aux} \tag{1}$$

The feed water to the boilers can be provided by both an electrical feed pump (EFP) and a SFP. The SFP is powered by steam leaving the low pressure turbine while the EFP is powered by electricity from the unit transformers. EFPs reduce the send out as they increase the auxiliary consumption. However, they have to be used for loads less than 140MW as there is insufficient steam pressure at these loads for the SFP to operate.

The power station engineers expected an increase in send out of 4.42MW with the SFP running. The parasitic effect on the thermal cycle using the SFP was expected to be negligible.

A. Baseline Model and Performance Assessment

The demand impacts are a result of reduced auxiliary consumption. Therefore the consumption of the auxiliaries forms the baseline. The auxiliary consumption is a function of generator output. The higher the load requirement of the generator the higher the auxiliary consumption. i.e.:

$$P_{Aux} \, \alpha \, P_{Gen} \tag{2}$$

$$P_{Aux} = P_{Aux}(P_{Gen}) \tag{3}$$

Fig. 1 is a plot of the auxiliary power vs the generator output for unit 6. Using a regression analysis tool, the relationship between auxiliary power and generator output is obtained for the baseline period.

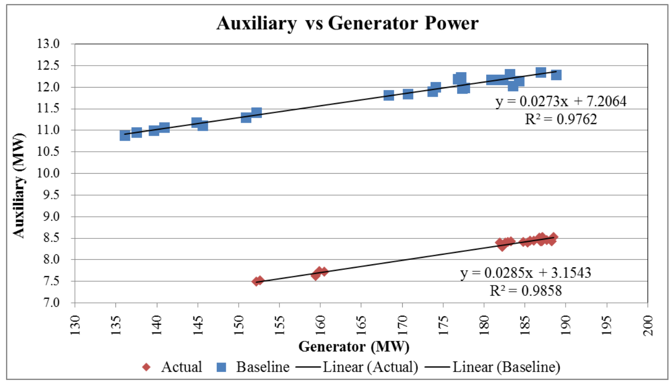

Figure 1. Auxiliary power consumption as a funciton of generator output

The relationship is of the form:

$$P_{Aux\,BL} = m \cdot P_{Gen\,BL} + c \tag{4}$$

Where: $P_{Aux\,BL}$ is the auxiliary consumption during the baseline period and $P_{Gen\,BL}$ is the generator output during the baseline period.

Fig. 1 also shows the same relationship during the assessment period. For any generator output above 140MW, less auxiliary power is required. For any generator output below 140MW there is no difference in auxiliary consumption.

The auxiliary power that the baseline system would have used had it been operating under the conditions of the new system ($P_{Aux\,Adj}$) can be determined by inserting the post-implementation generator output, $P_{Gen\,Act}$, into equation (4), giving:

$$P_{Aux\,Adj} = m \cdot P_{Gen\,Act} + c \tag{5}$$

When: $P_{Gen\,Act} > 140\text{MW}$

And: $P_{Aux\,Adj} = P_{Aux\,Act}$ (6)

When: $P_{Gen\,Act} \leq 140\text{MW}$

Where: $P_{Aux\,Adj}$ is the adjusted auxiliary consumption, $P_{Aux\,Act}$ is the actual auxiliary consumption and $P_{Gen\,Act}$ is the actual generator output during the assessment period.

The impacts are then:

$$P_I = P_{Aux\ Adj} - P_{Aux\ Act} \qquad (7)$$

Where: P_I is the power impact and $P_{Aux\ Act}$ is the actual auxiliary consumption during the assessment period.

Half-hourly data was gathered for 3 months prior to and 2 months after the refurbishment of the SFP. The average impacts were calculated for the 2 month period after the refurbishment. The baseline and assessment period generator load is graphed in Fig. 2 for an average weekday.

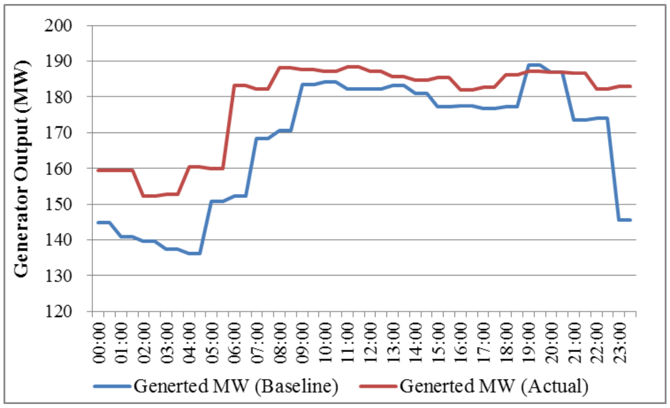

Figure 2. Average weekday generator output for the baseline and assessment periods

The auxiliary consumption for the baseline and assessment periods is plotted in Fig. 3. The actual generator load (assessment period) differs from that of the baseline period, therefore the baseline auxiliary consumption was adjusted, as can be seen in Figure 3. The impact in this case would have been under reported if the baseline and actual had simply been subtracted without making adjustments for the increase in generator load from baseline to assessment period. The send out power is presented in Fig. 4 below.

The project achieved an average impact of 3.84MW during the weekday morning peak (7-10am) and 3.8MW during the weekday evening peak impact (6-8pm). The unit sent out an extra 2.6GWh, on average, every month during the assessment period.

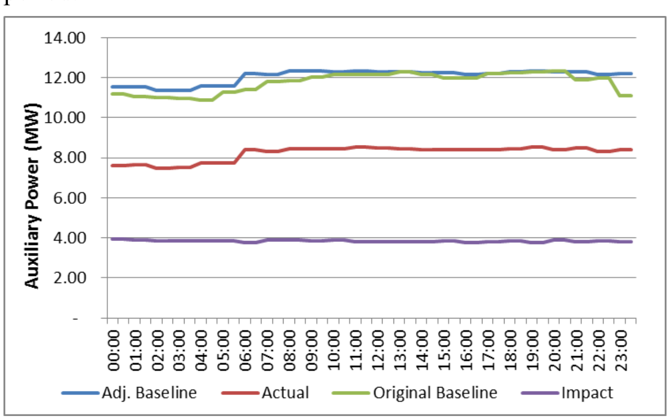

Figure 3. Average daily auxiliary load profiles for the baseline and assessment periods

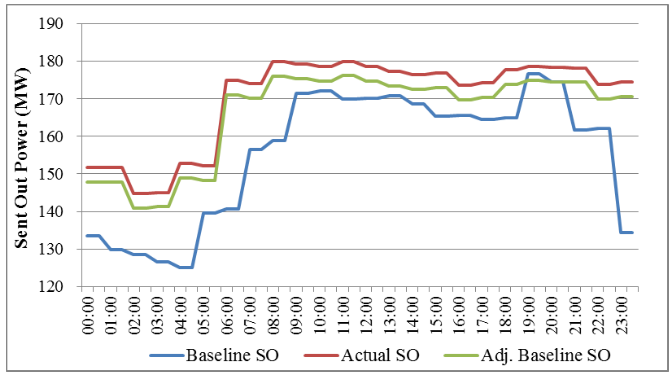

Figure 4. Send out power for the baseline and assessment periods

III. High Pressure Turbine Re-blade

This project involved the replacement of the high pressure turbine blades on unit 8. The original turbine blades date back to 1969 and significant solid particle erosion damage was found on all of the original turbine blades. This resulted in the unit being unable to run at the required steam flow rate of 208kg/s and generating 190MW instead of the designed 195MW.

After the project was implemented the unit was recertified with an MCR of 195MW. Therefore the unit can provide an extra 5MW when needed. To evaluate the average impact seen by the grid it is necessary to determine how often the unit is required to exceed its old MCR of 190MW.

The power station engineers expected an increase of 3% in the unit efficiency and an annual coal saving of 10.1kt.

A. Baseline Model and Performance Assessment

To determine the baseline, the generator output during the assessment period has to be compared with the old MCR. Whenever the generator is supplies over 190MW the project has an impact on the grid since this would not have been possible prior to the intervention.

The baseline relations are therefore:

$$P_{Gen\ Adj\ BL} = P_{Gen\ Act} \quad \text{for} \quad P_{Gen\ Act} \leq MCR_{BL} \qquad (8)$$

And

$$P_{Gen\ Adj\ BL} = MCR_{BL} \quad \text{for} \quad P_{Gen\ Act} > MCR_{BL} \qquad (9)$$

Where: $P_{Gen\ Adj\ BL}$ is the adjusted baseline, $P_{Gen\ Act}$ is the actual generator output and MCR_{BL} is the MCR of the unit before the project was implemented.

In other words:

- If the actual power generated by the unit is less than or equal to the baseline MCR, the baseline equals the actual power generated (i.e. there is no impact since the generator was capable of reaching loads of 190MW or less prior to the intervention anyway.)

- If the actual power generated by the unit is more than the baseline MCR, the baseline equals the old MCR.

Then the impact are determined using:

$$P_I = P_{Gen\ Adj\ BL} - P_{Gen\ Act} \tag{10}$$

Fig. 5 shows the adjusted baseline and actual generator output for the post implementation period.

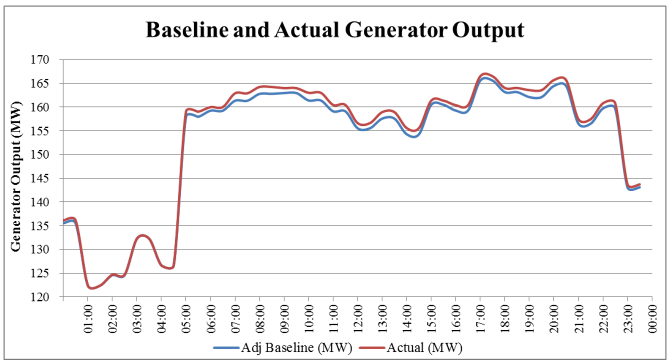

Figure 5. Adjusted generator output and actual generator output

The project achieved an average impact of 1.4MW during the weekday morning peak (7-10am) and 1.2MW during the weekday evening peak impact (6-8pm). The unit sent out an extra 0.61GWh, on average, during the assessment period.

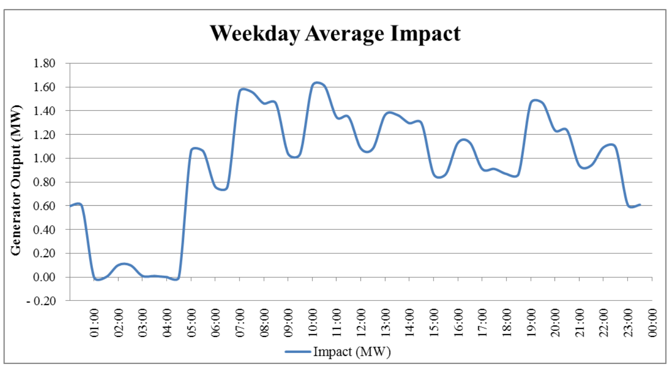

Figure 6. Average weekday impact for the turbine re-balde project

In order to determine the efficiency gains, due to the turbine re-blade, the pulverized fuel (PF) mass flow rate was correlated with the mill electrical currents for both the baseline and assessment periods using a well-established relationship between the two. The total coal burnt for unit 8 was then calculated.

The coal quality or calorific value (MJ/kg) did not vary significantly between the baseline and assessment periods. Thus the heat rate and cycle efficiency could be calculated. The results are presented in Table I.

TABLE I. UNIT 8 OPERATION AFTER THE TURBINE RE-BLADE

	Unit 8 Baseline	Unit 8 Actual
Coal Flow (kg/s)	26.76	26.62
Generated (MW)	185.54	186.92
Aux power (MW)	12.78	12.81
Sent Out (MW)	172.76	174.12
HHV CV (MJ/kg)	21.46	21.40
Cycle Efficiency %	29.73%	30.56%
Heat Rate (MJ/kWh)	12.11	11.78
Sent Out %	93.11%	93.15%

The turbine re-blade project resulted in a 2.7% increase in efficiency for unit 8 and a reduction in heat rate of 0.33MJ/kWh.

IV. CONCLUSIONS

Reliable power plant operating data is not easy to obtain. Often the coal burnt for the entire station is estimated based on coal accounting procedures and that for individual units is calculated using indirect methods. Also, the coal quality may not be continuously sampled. This makes it particularly challenging to determine coal and efficiency impacts from maintenance or improvement projects.

The source and quality of the data used in M&V calculations needs to be carefully considered especially for determining coal impacts. Electrical impacts are prone to less uncertainty because the generator output, auxiliary consumption and sent out power are usually accurately measured and continuously recorded.

The IPMVP has been successfully applied to these two projects at this coal fired power station. The methodology should be extended to include emission impacts (CO_2, NO_x, SO_x and particles) and also water consumption impacts.

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