Model based simulation application – coal power plant

The Simulink simulation application can be used by an electricity generation company using the Benson coal boiler to monitor any increase in generated and sent out power using certain indicators.

The Benson coal power plant boiler is a cost effective and an improved version of a coal fire boiler employed in electricity generation from a coal thermal power plant as opposed to the drum boiler. Benson boilers are used in Eskom’s coal thermal power plant. A simulation application was designed and built into the Simulink environment to compute the generated and sent out power profiles using various mathematical models developed and embedded in the simulation architectural algorithm to forecast the dynamic behaviour of the real plant using the predictors.

All predictors were loaded in the source blocks while the predicted outputs displayed in the sink blocks in the Simulink environment. The predictors used in these models, included air heater temperature, main stream super heater temperature, high pressure heater temperature, condenser pressure, mass of coal burnt and auxiliary power consumption. Multiple linear regression models were developed and built from the before and after an outage generated and sent out power profiles using six months’ analysed data from one unit of the Eskom’s Benson boiler rated 600 MW in each of the scenarios.

The ‘once through’ coal thermal power plant is an effective and more efficient plant when compared to the ‘drum type’ and can operate even under extreme pressures [1]. The major fuel used in the coal fire plant is coal.

The coal is usually pulverised and mixed with preheated air before blasting into the boiler. The major components of the ‘once through’ coal thermal power plant include boiler, super heater, reheater, turbine, condenser, feed water pump, economiser; they are all connected to form a closed circuit [2].

Modelling and simulation to forecast the true dynamics of the behaviour of a coal thermal power plant is crucial. The building and development of accurate models to predict the generated and sent out power of a Benson coal power plant in correlation to the input parameters (air heater temperature, main stream super-heater temperature, high pressure heater temperature, cold and hot well condenser pressure, mass of coal burnt and temperature and auxiliary power) are of paramount importance in achieving the objective of this study. Furthermore the derived mathematical models were embedded in the mathematical blocks in the Simulink environment and were imported from the Simulink library. The multiple linear regression models of the generated and sent out power were embedded in the mathematical blocks which were later masked and converted to a single mathematical block using the ‘create sub-system command’ contained in the Simulink. This sub-system embodied the mathematical models was coupled to the input parameters (source blocks were used for the input parameters and each source was a sequence interpolated block exported from the Simulink library) and the desired outputs (sink blocks were used for the outputs and each sink was a scope block). The simulation application is more user friendly than the graphical user interface and is easy to simulate. By using the simulation application, we can predict the response(s) of the plant with a significant confidence which can lead to proper control and optimisation of the real power plant [3].

Simulation and model-based design

Simulink is an environment for multi-domain simulation and model-based design for dynamic and embedded systems [4]. It provides an interactive graphical environment and a customisable set of block libraries that let one design, simulate, implement, and test a variety of time-varying systems, including communications, controls, signal processing, video processing, and image processing [5]. The key features of the Simulink include:

- **Extensive and expandable libraries of predefined blocks**: These predefined blocks are made up of the source where the predictors are loaded, the mathematical blocks that embedded the mathematical models and the sink blocks from where the response(s) is displayed.
- **Interactive graphical editor for assembling and managing intuitive block diagram**: These graphical editors make it possible to create a sub-system from series of mathematical, sink and source blocks and as a result a compact customised simulation application can be built.
- **Application programming interfaces (APIs) that let one connect with other simulation programmes and incorporate hand-written codes**: Allow us to create programmes and easily integrated it into the simulation application.
- **MATLAB Function blocks**: Bring MATLAB algorithms into Simulink and embedded system implementations, Model analysis and diagnostics tools to ensure model consistency and identify modelling errors. This ascertains that the simulation application is running successfully.
as no error reports are detected after the compiler completes the run-time for each simulation run.

Objectives

The primary objectives of the study include:

• To develop and built multiple linear regression models for the power generated and power sent out from the coal thermal unit plant using the predictors (air heater temperature, main stream super heater temperature, high pressure heater temperature, condenser well pressure, condenser well temperature, mass of coal burnt and auxiliary power)

• To use the mathematical models and build a compact, reliable and robust simulation application suitable to predict the dynamic behaviour of the coal thermal power plant outputs (power generated and sent out for both the before and after outage scenarios) given the data set of the predictors

• To be able to deduce the achieved impact as an increase in the power generated and sent out for a particular month after outage using the data set of the predictors

Methodology

The data for the three months (January – March 2013) before the outage and three months (September – November 2013) after the outage for both the predictors and desired responses were analysed into an average month-day over a 48 time interval of 30 minutes. Multiple linear regression models were developed and built for the before and after outage scenarios [6]. The mathematical models were embedded into mathematical blocks from the Simulink library. The model blocks were coupled to the source blocks (sequence interpolate blocks holding the various predictors) and the sink blocks (scope blocks displaying the outputs). The analysed data of the predictors for a given month are loaded to the source blocks and upon clicking the start button the simulation starts running using the ordinary differential equation solver (ODE 45) to perform the computational compilation [7,8]. Finally the profiles of the modelled power generated and the modelled power sent out using the predictors’ data set of the months after the outage were displayed in the sink blocks.

Analysis of the before and after outage data set

The study shows that the average month analysed data over a one hour interval for both the predictors and outputs for the last month (March) before the outage and the first month (September) after the outage. There is definitely an increase in the power generated after the outage and it was accounted by the fact that the key predictor parameters such as air heater temperature, main stream temperature, high pressure heater temperature increased when comparing the before and after outage scenarios owing to the energy efficiency intervention within the coal thermal power plant [9]. It is interesting to note that the auxiliary power consumption of the after outage was lower compared to the before outage of the coal thermal power plant.

Building and developing the mathematical models

Multiple linear regression models were developed and built for both the power generated and power sent out for the before and after outage scenarios. The mathematical model equations are shown in Equations 1 and 2.

\[
P_g = \beta_0 + \beta_1 T_a + \beta_2 T_s + \beta_3 T_h + \beta_4 P_c + \beta_5 T_c + \beta_6 M \quad (1)
\]

\[
P_s = \beta_0 + \beta_1 T_a + \beta_2 T_s + \beta_3 T_h + \beta_4 P_c + \beta_5 T_c + \beta_6 M + \beta_7 P_a \quad (2)
\]

Each of the input parameters and their scaling value in the mathematical models given in Equations 1 and 2 are shown in Tables 1 and 2.

Table 1: The mathematical models of the power generated.

<table>
<thead>
<tr>
<th>IP</th>
<th>SC</th>
<th>M.B V</th>
<th>M. A V</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_a</td>
<td>(\beta_1)</td>
<td>-0.212</td>
<td>-0.713</td>
<td>P_g</td>
</tr>
<tr>
<td>T_s</td>
<td>(\beta_2)</td>
<td>-0.714</td>
<td>3.604</td>
<td></td>
</tr>
<tr>
<td>T_h</td>
<td>(\beta_3)</td>
<td>0.934</td>
<td>5.828</td>
<td></td>
</tr>
<tr>
<td>P_c</td>
<td>(\beta_4)</td>
<td>0.497</td>
<td>-9.239</td>
<td></td>
</tr>
<tr>
<td>T_c</td>
<td>(\beta_5)</td>
<td>0.407</td>
<td>1.849</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>(\beta_6)</td>
<td>2.03</td>
<td>1.654</td>
<td></td>
</tr>
<tr>
<td>P_a</td>
<td>(\beta_7)</td>
<td>203.87</td>
<td>-2.955</td>
<td></td>
</tr>
</tbody>
</table>

IP = Input parameters, SC = Scaling constants
M. B V = Model before scaling values
M. A V = Model after scaling values

From Table 1, it can be eluded that increased in the super heater temperature, high pressure heater temperature as well as the mass of coal burnt can result in an increased in the power generated owing to the positive scaling constant associated to these input parameters with respect to the mathematical model for the after outage modelled equation.
Table 2: Shows the mathematical models of the power sent out.

<table>
<thead>
<tr>
<th>IP</th>
<th>S.C</th>
<th>MBV</th>
<th>MAV</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_s$</td>
<td>$\beta_1$</td>
<td>-0.181</td>
<td>0.095</td>
<td>$P_s$</td>
</tr>
<tr>
<td>$T_c$</td>
<td>$\beta_2$</td>
<td>-0.032</td>
<td>1.362</td>
<td></td>
</tr>
<tr>
<td>$T_h$</td>
<td>$\beta_3$</td>
<td>1.532</td>
<td>5.163</td>
<td></td>
</tr>
<tr>
<td>$P_s$</td>
<td>$\beta_4$</td>
<td>-3.187</td>
<td>8.571</td>
<td></td>
</tr>
<tr>
<td>$T_c$</td>
<td>$\beta_5$</td>
<td>0.614</td>
<td>-4.515</td>
<td></td>
</tr>
<tr>
<td>$M$</td>
<td>$\beta_6$</td>
<td>0.487</td>
<td>0.912</td>
<td></td>
</tr>
<tr>
<td>$P_s$</td>
<td>$\beta_7$</td>
<td>21.49</td>
<td>40.36</td>
<td></td>
</tr>
</tbody>
</table>

IP = Input Parameters, SC = Scaling Constants
MBV = Model Before scaling Values
MAV = Model After scaling Values

Similarly, increases in the predictors (super heater temperature, high pressure heater temperature as well as the mass of coal burnt) would again result in an increase in the power sent out based on their scaling constant value for the after outage modelled equation.

Simulation application designed and the modelled outputs

*Figure 1* shows the architectural and sequential programmable work flow simulation application that was designed and built to simulate the performance of the coal thermal power plant in terms of the power generated and power sent out for the before and after outage conditions in the Simulink environment. The derived mathematical models for both the before and after outage of the power generated and power sent out are combined into a system block represented by the schematic diagram of the real plant. All the predictors are loaded into the respective source blocks (sequence interpolate blocks) while the desired outputs were displayed in the sink blocks represented on the scope blocks contained in the Simulink libraries. The simulation was configured to start (00:00) and stop (23:00), since the analysed data ‘inputted’ into the source blocks of the simulation were for a 24 hour period over a one hour interval.

*Figures 2 and 3* illustrate the modelled power generated and the modelled power sent out in the before and after the outage scenarios from the analysed data for the month of September, corresponding to the first month after the outage. The difference between the modelled power generated in the after outage and the before outage (representing the adjusted baseline if no intervention has taken place) corresponded to the power increment owing to the intervention.

The difference between the modelled power sent out after and before the outage (using the modelled equation of the power sent out to the present data after the outage and before the outage assuming no energy efficiency intervention occurred) justified an achieved power increased which can be detected on the national grids. From the simulation result, the average month (September) power generated using the modelled equations for the before and after outage were 493.86 MW and 507.9 MW, that corresponded to an average increment of 12.04 MW. In addition the average month (September) power sent out using the modelled equations for the before and after outage were 474.30 MW and 485.2 MW, that translated to an average power increment of 10.90 MW and this gained in the power sent out could be observed on the grid.

![Figure 1: The architectural layout of the simulation application in the Simulink environment.](image)

*Figure 2* illustrates the profiles of the modelled power generated in the after and before outage scenario for the month of September obtained from the scope block after running of the simulation.

![Figure 2: Simulated modelled power generated for the month of September.](image)

Profiles of the modelled power sent out in the after and before outage scenario for the month of September obtained from the scope block after running of the simulation are shown in *Figure 3*. 

![Figure 3: Profiles of the modelled power sent out.](image)
Conclusion

The developed and built simulation application can be employed by the electricity production company using a coal power plant for their electrical power generation to predict their increment on the power generated and power sent out owing to the implementation of an energy efficiency initiative in the plant. The simulation application can be used to simulate the profiles of power generated and power sent out due to variation of specific predictors with the rest held constant. It can be used to automate the power generated and sent out using the analysed data of the predictors in a bid to quantify the power increment as well as the energy gained. With the aid of the simulation application the performance of the coal power plant can adequately be tracked. Finally, using the simulation application, the power generated and sent out can be predicted and visualise without the use of power meters to perform actual measurements.

Acknowledgement

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References