Long Term Dynamics of Islanded Coal Fired Station with Fluctuating Loads

J.E. Mayer
Connell Wagner Pty Ltd
Brisbane, Australia
mayerj@conwag.com

K.S. Smith
Mott MacDonald Limited
Glasgow, UK
kenneth.smith@mottmac.com

***Abstract*— This paper describes the analysis methodology and model development for a long term dynamic study involving a proposed islanded coal fired power plant supplying a large fluctuating mining load. Concerns were raised regarding the ability of the power plant to operate successfully and reliably when subjected to large load fluctuations. Individual models of boilers, turbines, governors, excitations systems and loads have been developed using the PSCAD/EMTDC time domain analysis tool. The models have been combined to provide a unique, single integrated representation of the entire power plant and electrical load. This has enabled the long term dynamic performance of the proposed system to be assessed and the load compensation requirements identified.**

***Index Terms*— long term, dynamic study, boiler model, load compensation, PSCAD/EMTDC**

I. INTRODUCTION

A large international mining company (confidential client) is developing a copper and gold mine and associated processing facilities at a remote location in central Asia. The required electrical power will be supplied by a dedicated, islanded coal fired power plant (3 x 140 MW). The load includes a large number of high power mining hoists and mill drives that impose a significant load fluctuation on the dedicated power plant.

Concerns were raised questioning the ability of the boilers and turbo-alternators to operate successfully and reliably when subjected to such large load fluctuations. The mining company was about to begin the power station procurement process and needed to be aware of any special design or operational features to be provided. To address these questions Connell Wagner was commissioned to perform long term dynamic modelling of the integrated boiler/turbine/alternator units. The analysis focused on the boiler conditions and their impact on the steam turbines, the power output of the turbo-alternators, and the system frequency in response to load fluctuations. Mott MacDonald was engaged by Connell Wagner to assist with the study and review the output.

II. FLUCTUATING LOADS

The mine and processing facility load will include induction motor loads, such as pumps, fans, crushers, conveyors and the like. Additionally there will be three significant load types which could impact on the dynamic performance of the power station. These are large mills, electric shovels and mining hoists.

There are two types of grinding mills proposed, SAG mills and ball mills. These will not present a fluctuating load during operation, but will cause a large change in power during starting and large step change in power if tripped due to an alarm or fault. For this study, only the starting power demands were studied because load rejection was not seen as a unique problem for this site. Power station technology (i.e. steam bypass valves) are a well known strategy to prevent turbo-alternator over-speeding in case of loss of load. The mill starting requires a large, but slow ramping of power from zero to full load. In the case of the SAG mills, this requires a ramp up to 19 MW over typically 90 to 120 seconds. The ball mills start unloaded and are ramped to 10 MW over 10 seconds.

Electric shovels were not considered as the mining company had not made a decision on electric versus diesel power. Also the shovels were relatively small compared to the other fluctuating loads and only two shovels are being considered.

Mining hoists represent the major fluctuating load on the site. Mining hoists will be used to transport ore from the underground mine to the surface. These are very large friction drum hoists with dual skips. As a full skip is being hoisted to the surface, the empty skip returns to the bottom of the shaft. The hoists will be driven by large a.c. synchronous motors with semi-conductor converter drives. The underground mine development is planned to ultimately include four hoists. The hoists will operate on a two minute cycle (i.e. two minutes from an empty skip leaving the surface to when a full skips reaches the surface and is emptied). When the hoist leaves the bottom of the shaft, there is a large accelerating power until the skip reaches full coasting speed. At the top of the shaft the skip decelerates and stops. The peak power drawn during acceleration is approximately 16 MW and the coasting power is approximately 10 MW. The converter drive can maintain unity power factor under all operating conditions. Figure 1 shows the load profile of a single hoist, over several cycles.

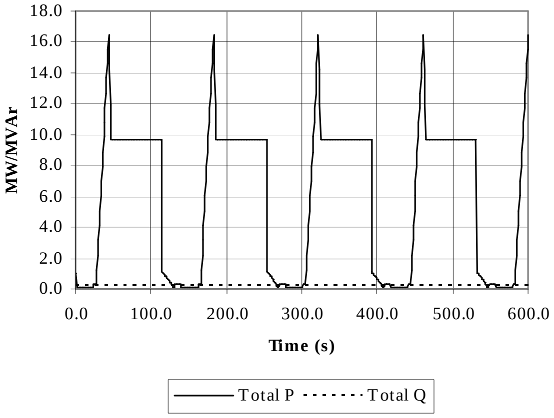


Figure 1 Mining hoist load profile

When multiple hoists are in operation, the timing of the hoists, relative to each other becomes critical. The study included several combinations of hoists in service and relative timing. Normally the hoists will operate in pairs and within each pair, the hoist operation would be optimally timed to prevent coincidence of hoist acceleration. However pairs of hoists will operate independent of the other pair. Therefore coincidence of two hoists is possible. For example Figure 2 shows the load profile of four hoists perfectly offset from each other to prevent coincident acceleration and Figure 3 shows the load profile if two hoist pairs perfectly coincide. In each case, the mean or averaged power over 120 seconds is the same, but the peak power and the rate of change of power is considerably different.

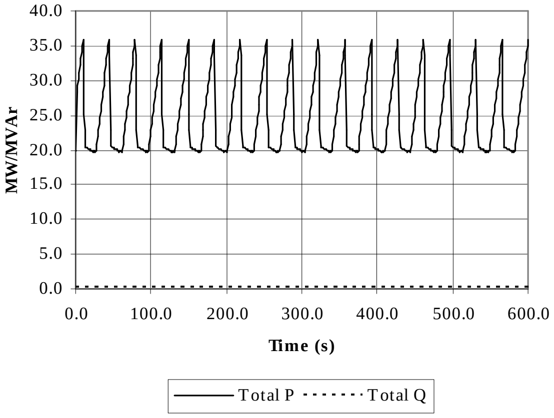


Figure 2 Load profile for four mining hoists with perfectly offset timing

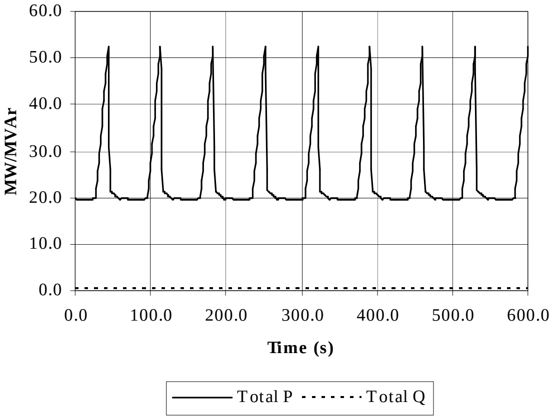


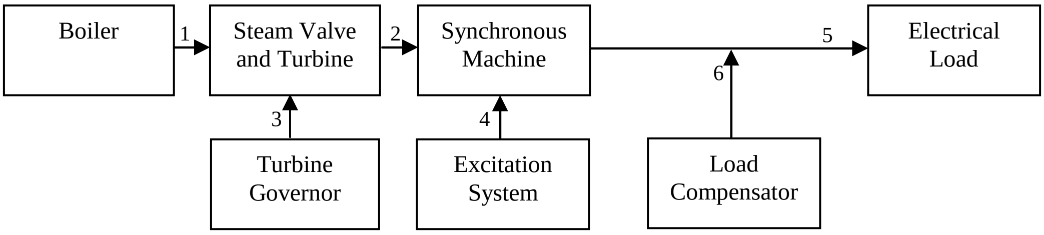
Figure 3 Load profile for two pairs of mining hoists with hoists in opposing pairs coinciding

III. MODEL DEVELOPMENT

The model was developed to allow the impact of the fluctuating loads on the power plant to be assessed and identify any special power plant design requirements as a consequence of the unique load characteristic. Individual models of the boilers, turbines, governors, alternator excitation systems, base loads and fluctuating loads were developed using the PSCAD/EMTDC program. The combined models provide a unique, single integrated representation of the entire power plant and the fluctuating electrical load. This allowed the long term dynamic conditions to be assessed over time periods of several minutes or longer, sufficient to take account of the varying demands of the mining hoists and mill drives. Figure 4 shows the individual component blocks of the model.

Individual boiler, turbine and machine models have been discussed in the technical literature [References 1 to 6], however there is limited published work discussing modelling of boilers coupled to turbo-alternators, especially on an islanded system with significant fluctuating loads. The available literature has been used to create the individual elements of the integrated model and these have been compared to actual test data where available to validate their output.

The boiler model represents a coal fired, drum type boiler which provides a steam pressure output. The steam pressure is controlled by adjusting the boiler firing in response to steam pressure changes. The steam pressure and steam valve position (i.e. valve area) determines the steam flow into the turbine, which produces the driving mechanical torque on the alternator shaft.



1 Steam pressure and flow
2 Mechanical torque and speed
3 Steam valve position
4 Field voltage and current
5 Electrical system (V, A, kW and kVAr)
6 Positive or negative electrical power (kW only)

Figure 4 Component blocks of the integrated model

The alternator produces an electrical power output with its terminal voltage controlled by the excitation system and its frequency proportional to shaft speed. The steam valve position is controlled by a governor operating in droop control mode to maintain system frequency and share load equally between the alternator sets. This arrangement allows long term analysis of the power plant response to load fluctuations. This type of modelling differs from traditional transient stability analysis, which is only valid for a short time period after a disturbance (typically a few seconds) and assumes an infinite source of steam at constant pressure.

The most complex of these models was the drum boiler model. The model was created from a combination of material published in [1] and [2]. Whilst the overall model appears quite simple, some of the components are complex and required significant effort to program and tune the gains, time constants and other parameters within the model. Figures 5 and 6 show two examples of several sets of comparisons between the boiler model and published test data [1], [2], [3] from real boilers of similar rating to those proposed for the power station. This was a critical part of the project because the study would have lost its credibility if the boiler model was not proven to be correct against recognised published data. Fortunately a number of recognized international sources of actual boiler test results were located. For example Figures 5 and 6 show a comparison to IEEE data in [3].

The PSCAD/EMTDC block diagram of the drum boiler model is shown in Figure 7. This block diagram is simplified, in that it does not show all of the initialisation components, which have been removed for the purposes of clarity.

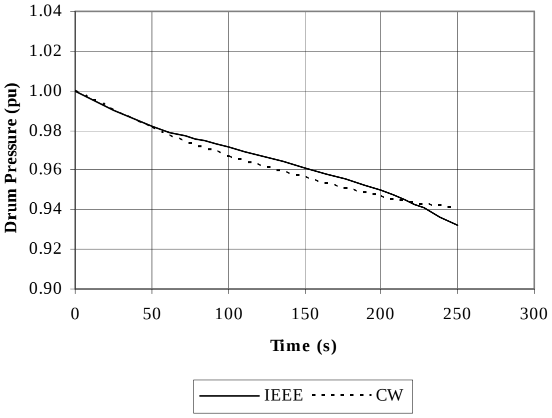


Figure 5 Example drop in drum pressure for a 10% change in valve position with heat input frozen (100% load point)

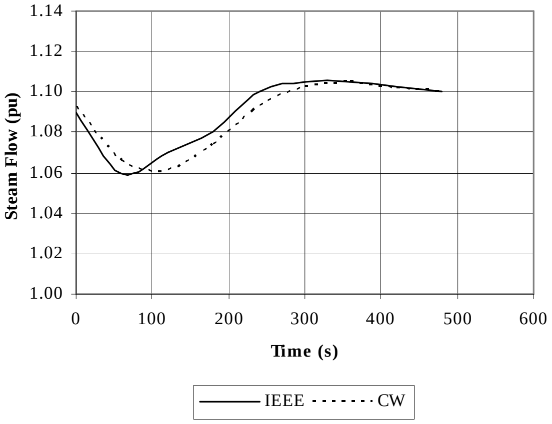


Figure 6 Example steam flow for a 10% change in valve position with the boiler controls active (100% load point)

The turbine governor was modelled using a simple electro-hydraulic droop governor as described in [4]. Figure 8 shows the block diagram. The excitation system used was a standard IEEE ST1A model as described in [5]. The alternator parameters used were taken from the 160 MVA fossil steam unit in [6].

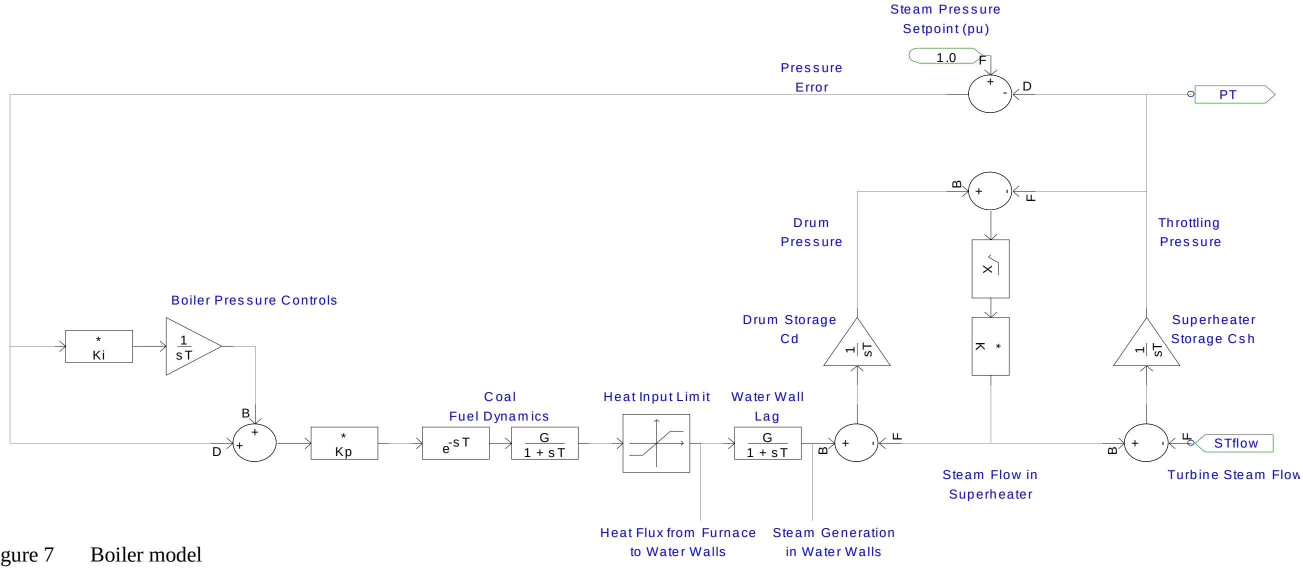


Figure 7 Boiler model

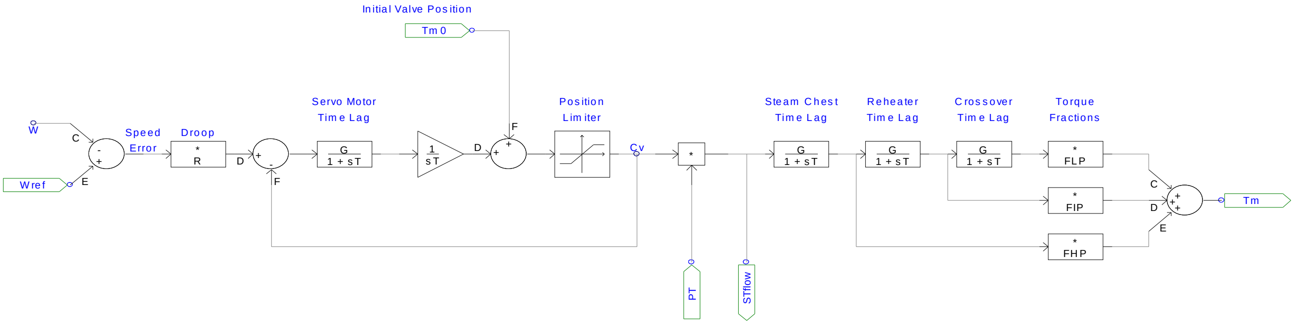


Figure 8 Governor model

IV. STUDY RESULTS

Once the overall integrated model was developed and validated, numerous scenarios were modeled and analysed. Variations to scenarios included changing the number of generator units in service, the numbers of hoists and their relative timing as well as modelling mill starts. The data was presented in graphical form and summarised in table format. The main parameters of interested included:

- Drum pressure
- Throttling pressure
- Heat input to the boiler
- Steam flow
- Valve position
- Turbine shaft torque
- System frequency
- Rate of change of frequency
- Average generator electrical power
- Generator electrical power fluctuation

The studies showed that under certain conditions, significant fluctuations in the real power loads produce unacceptable operating conditions for the boiler, main steam valve and turbine. Figures 9 to 13 show example graphical outputs that were produced for a severe scenario with two generators in service and the load case from Figure 3 in which the load of two pairs of hoists coincide. The timescale of the output graphs has been shortened to 300 seconds for clarity. For this case, it is the dashed lines in the plots that are of interest. The significant cyclic variation in system frequency due to the load change forces a continual variation in the boiler steam flow, valve position and throttling pressure.

Additional simulations were carried out to include the effects of various load compensation technologies to reduce the cyclic demand imposed on the power plant. The intention was that the external load compensator would "smooth out" the load fluctuations seen by the power station.

Models of these power compensation schemes were developed to assess their positive impact on the power plant operation. The load compensators studied included "peak lopping" diesel generators, resistive load banks and flywheel energy storage devices.

Diesel generators could be used to generate the hoist peak power, smoothing out the load seen by the power station. The disadvantage would be that the diesel generators need to be operated at no less than 40% continuous load, so there is a high fuel cost and only 60% of the generator capacity available to generate during hoist peaks.

Resistive load banks could be a simple and low capital cost solution, however they apply additional load to the power station between hoist peaks and this energy is essentially wasted, resulting in additional fuel costs.

Flywheel energy storage systems could be used to supply power during hoist peaks and draw power from the system to recharge between hoist peaks. Whilst this increases the average load on the power station slightly, this additional energy is returned to the system during the hoist peak (minus any losses) so there is very little wasted energy and minimal additional fuel costs. The key disadvantage is the very high capital cost. These flywheel storages systems are in the order of AUD $1millon per MW of installed capacity.

The cost of diesel at the site is very high due to the remote location, so the mining company intends to seriously consider load banks (4 x 5 MW units) or the flywheel system (20 x 1 MW units) and conduct a net present value financial exercise to select the best engineering and financial option. For comparative purposes the output graphs for the flywheel load compensator are over-layed on each graph in Figures 9 to 13. The flywheel results are shown by the solid lines.

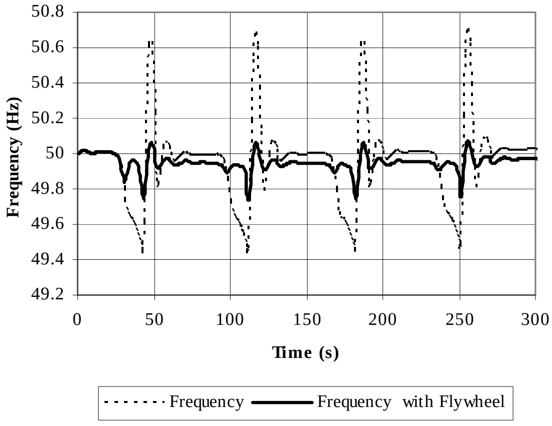


Figure 9 Simulation outputs of system frequency with 2 offset hoist pairs coinciding

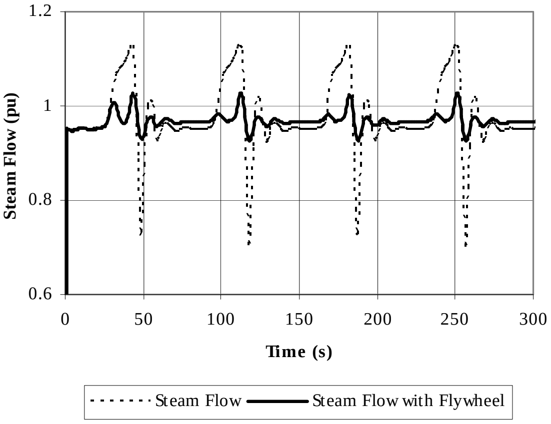


Figure 10 Simulation outputs of steam flow with 2 offset hoists coinciding

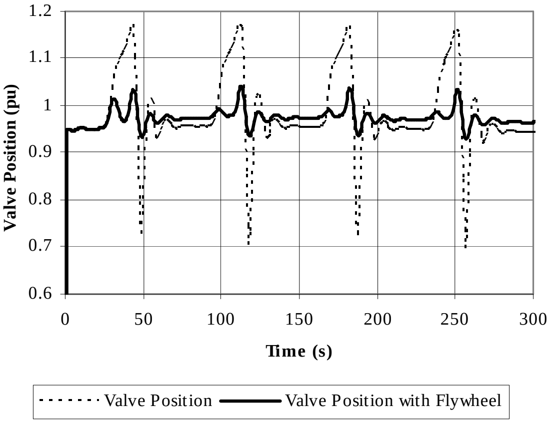


Figure 11 Simulation outputs of valve position with two offset hoist pairs coinciding

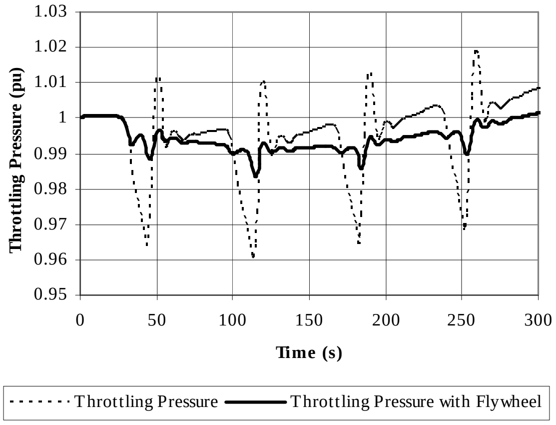


Figure 12 Simulation outputs of throttling pressure with two offset hoist pairs coinciding

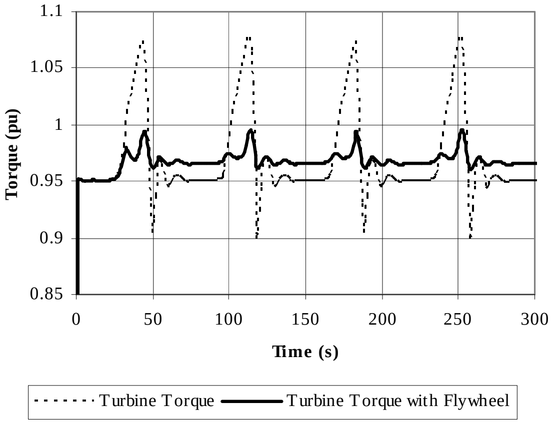


Figure 13 Simulation outputs of turbine torque with two offset hoist pairs coinciding

The simulations have confirmed that any of the active power compensation schemes will successfully smooth out the active power load variation seen by the power station, dramatically improving boiler steam and turbine mechanical conditions. In Figures 9 to 13 the positive impact of the flywheel system on the power station operation is dramatic. Figures 14 and 15 show the output of the flywheel system and the stored energy within the flywheel system.

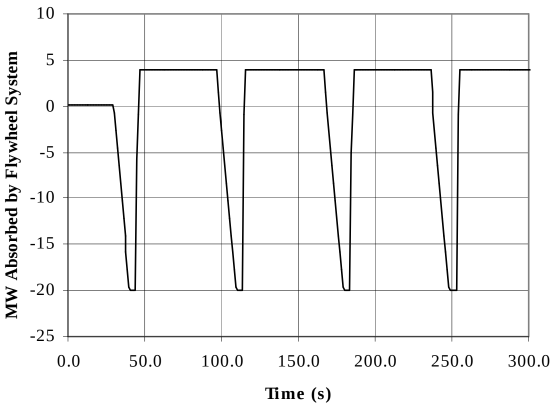


Figure 14 Flywheel generation (-ve) and recharge (+ve)

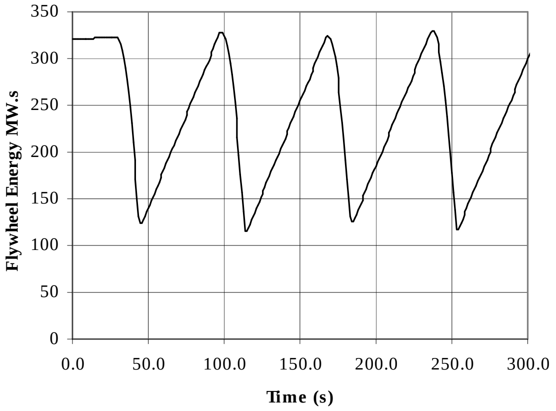


Figure 15 Flywheel kinetic energy

V. CONCLUSION

This study, carried out during the pre-FEED, has been extremely useful to the mining company when specifying the power station plant and considering load compensation schemes for the fluctuating loads.

The study outputs demonstrate that the power station will not operate successfully and reliably in the long term if subjected to some of the significant load fluctuation scenarios. Therefore if the mining operation cannot control these load fluctuation scenarios, some form of load compensation is necessary. The analysis and modelling presented in the paper confirms that a load compensation scheme will be effective in reducing the transient power swings experienced by the power plant. The practicalities and technical risks will be investigated during the next phase of the design process and will include a detailed cost/benefit analysis

VI. REFERENCES

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