UPGRADING STEAM GENERATOR LEVEL CONTROL STRATEGY AT NUCLEAR POWER PLANTS

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ABSTRACT

Control systems play a vital role in the operation and performance of nuclear power plants. Steam Generator level control at nuclear power plants is critical for both plant protection and equipment safety and applies equality to high and low levels of water within the Steam Generator. Stabilizing water level of the steam generator in nuclear power plant is a very important problem since dynamics of the system have non-linear characteristics, non-minimum phase phenomenon and multi input multi output system. The swell and shrink effect is one of main factors for frequent forced outage of the nuclear power plant. Plant outage studies at Nuclear Power Plants have identified Steam Generator level control and feed water control systems as major contributors to plant unavailability. The possible ways to improve the transient and steady state responses of the existing poor control system strategy at Pickering nuclear power plant is proposed. An enhanced and robust controller for the level control of the steam generator will be discussed in the proposed strategy.

KEYWORDS: Steam generator; reliability; level control; transient condition; Nuclear power;

1. INTRODUCTION

The steam generator is the normal heat sink for the reactor, so in order to ensure cooling of the fuel, it is very important to maintain the ability of the steam generator to remove the heat from the heat transport system.
Poor control of steam generator water level is the main cause of unexpected shutdowns at nuclear power plants. Particularly at low powers, it is a difficult task due to shrink and swell phenomena and flow measurement of steam and feed water errors. In addition, the steam generator is a highly complex, nonlinear and time-varying system and its parameters vary with operating conditions. Since there are problem with stability control, only a highly experienced operator can operate during low power and start-up, Therefore, it seems that design of a suitable controller is a necessary step to enhance plant availability factor in order to prevent such costly reactor shutdown.

2. STEAM GENERATOR LEVEL CONTROL AT NUCLEAR POWER PLANT

Steam Generator level control is critical for both plant protection and equipment safety and applies equally to high and low levels of water within the Steam Generator. The purpose of the level control system is to bring the up to level at Steam Generator start-up and maintain the level at constant steam load. A dramatic decrease in this level may uncover the Steam Generator tubes, allowing them to become overheated and damaged. An increase in this level may interfere with the process of separating moisture from steam within the, reducing Steam Generator efficiency and carrying moisture and impurities into the process or turbine.
The functions of this control models can be broken down into the following:

- Operator adjustment of the set-point for level
- Compensation for the *shrink & swell* effects
- Automatic control of level
- Manual control of the feedwater control valve(s)
- Bump-less transfer between auto and manual modes
- Indication of level and steam flow
- Indication of feed water valve(s) position and feed water flow
- Absolute/deviation alarms for level

‘Bubbles’ which, under boiling conditions, lie below the water/steam level interface, have volume and can therefore displace water to create a misrepresentation of the true water level in the Steam Generator. If the pressure changes due to load demand, these steam bubbles expand to give the appearance of a water level higher than it really is (*swelling).* This can cause the feed water input to be decreased, probably at a time when, in fact, more water is needed.
The application of a level control strategy will depend on the nature of the process - from conditions where the steam load is steady to those where demands continuously vary and are

usually unpredictable. Three types of level control strategies are therefore supplied to cover the different demand criteria, single element, two element and three-element systems.

The single element level control scheme (See Fig. 1) measures only the water level in the Steam Generator hence the term "single element." The output from a differential pressure transmitter with a high static pressure range provides the process input for a single-loop controller. If any discrepancy is detected between the level and its set point, the controller will send a signal to adjust the feed water control valve(s).

While single-element level control is acceptable for steady Steam Generator load conditions, it can't respond quickly enough to compensate where load changes become more frequent, unpredictable, or severe. More information must be included and processed to predetermine the amount of water to be added to compensate for load changes. This requires the flexibility of a multi-loop controller and more field devices for input.

The two-element control scheme (See Fig. 2) measures steam flow and level influence on the feed water valve position. It is capable of providing tight control in conditions of Steam Generator load change — typically continuous-type processes with good feed water pressure regulation. The steam flow transmitter that feeds a signal to the feed water flow computer measures steam flow. The controller compares the level measurement with the set point and, if required, sends a corrective output signal.

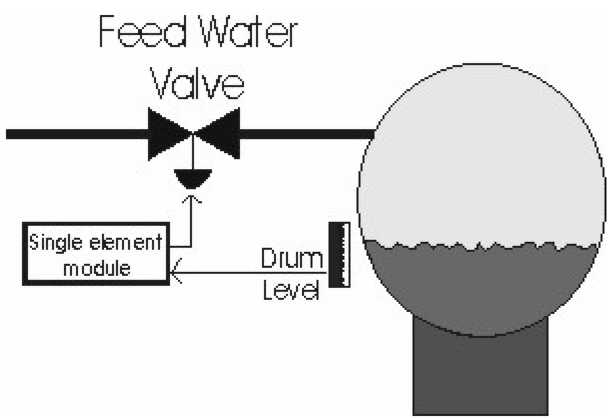


Fig. 1. Single element level control

The feed water flow computer combines the signals from the two variables and produces an output signal to the feed water control valve(s).

In plants such as those with mixed, batch and continuous, which are processes where there may be an unstable feed water system or large and unpredictable steam demands, a three-elements level control scheme should be considered. Here, the application provides control of feed water flow in relationship to steam flow. The instrumentation is the same as that for a two-element scheme, except that the output of the feed water flow computer becomes the set point of the feed water flow controller.

The essence of three-elements level control technique is to maintain a constant inventory within the evaporator, by maintaining the inflow of water to the equal to the steam flow leaving. This control scheme works well for steady state operation or slow changes in load. However for units required to perform with significant load changes or those subjected to transient, the 3-element level control no longer effectively represents the physical process. The “ 3-element” level control is shown schematically in Fig. 3. The demand for feed water is equal to the steam flow, plus or minus a flow adjustment due to the error in level from the desired level set point. The feedback on level error produces a rate of flow (increase or decrease) to account for the mass of water which must be added or removed to bring the level back to the level set point.

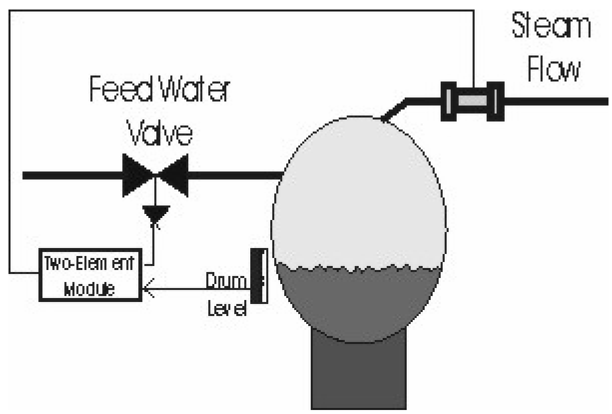


Fig. 2. Two-element level control

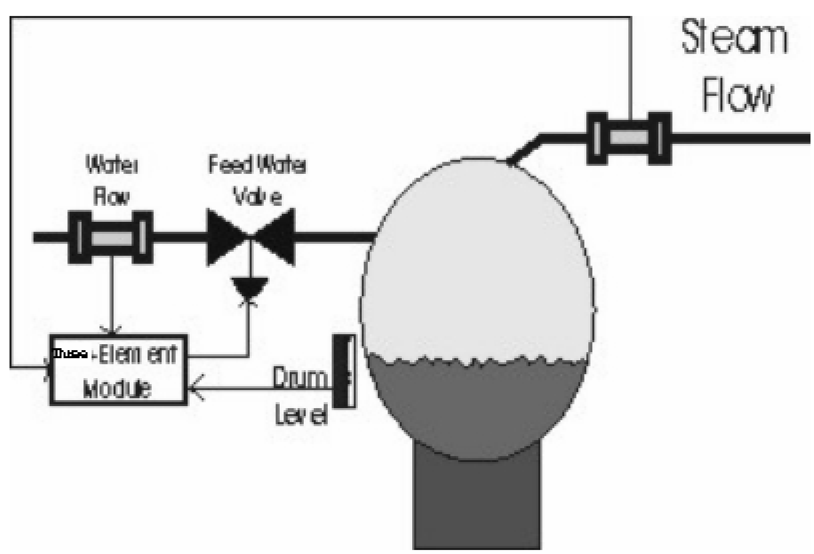


Fig. 3. Three-element level control

3. LEVEL CONTROL AT PICKERING NUCLEAR

The Steam Generator water level control system controls the water level of a group of Steam Generators that are fed the same feed water line. Each of these groups of Steam Generators consists of three Steam Generators, and there are 4 of these groups (a Steam Generator group is commonly known as a Steam Generator quadrant).

Plant outage studies at Pickering Nuclear have identified that Steam Generator level control and feed water control systems are major contributors to plant unavailability. The operator must handle such events manually to avoid a plant trip during low load operation or setback.

Level and feed water control are quite difficult to obtain manually and sometimes is just impossible because of "*shrink & swell* " effects.

The replacement of the analog controller and upgrading control strategy for level and feed water system at Pickering Nuclear with fault-tolerant digital controllers, smarter, more flexible, and more reliable, could improve system reliability dramatically. Its operation could improve transient and steady state response.

Pickering uses a poor three-element control strategy for level and feed water control. Each quadrant of Steam Generators has a feed water control set consisting of two 100% main control valves and a 10% startup/shutdown control valve. One main control valve is controlled by the Steam Generator control level system and the other is controlled manually from a manual control station. The duty of the two main valves can be interchanged by a hand-switch.

The Fig. 4. Shows the schematic diagram for level and feed water control at Pickering Nuclear. Existing Steam Generator level control has been designed for steady state condition and in transient and set-back conditions and in low level operation it is a poor Steam Generator level control for the following reasons:(See Appendix A TO E)

- The control system is not bump-less so if the control system fails/changes to manual, undesired control signal may be applied for control valves and this may trigger a reactor trip.
- Manual operation of the level is both difficult and risky.
- Unmeasured disturbances within the system such as Steam Generator blow down cause oscillations in level and feed water flow. Appendix B
- Due to the lack of internal flow control loop "cascade control", the time response of the control system is slow and introduces high oscillation.
- Poor control in transition mode like setback, load rejection and turbine trip.
- Frequent and costly component calibration problems.
- Swelling and shrinking effects not considered in this control system.
- Fluctuations in process parameters as level and feed water flow varies.
- Large level oscillation at low power operation (10%FP).

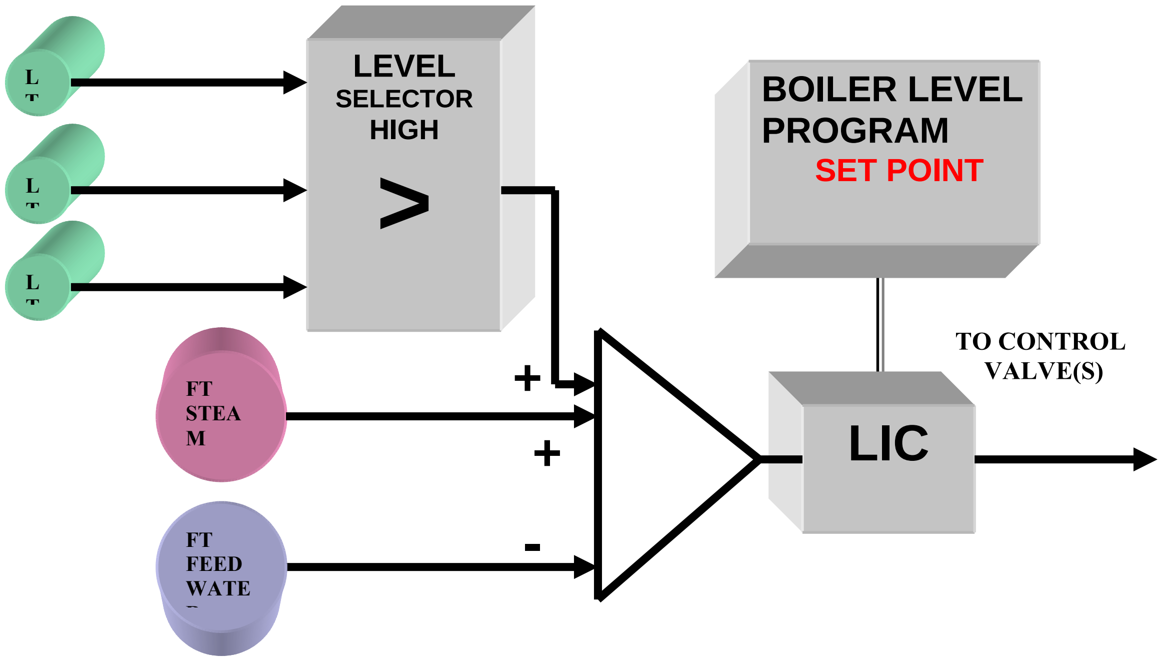


Fig. 4. Schematic diagram for existing level control at Pickering

4. UPGRADING LEVEL CONTROL AT PICKERING NUCLEAR

The implementation of an advanced process control strategy, which provides functionality to operate the Steam Generator level, and feed water on automatic control with minimal operator intervention could prove successful. The level control must have a feed-forward signal load and pressure change. The feed-forward signal for level control is the rate of change of mass inventory versus load and pressure. The full equation for the mass balance around the steam generator is as follow (neglecting other minor losses such as blow-down):

$$m \cdot in = m \cdot out + d(M)/dt + d(\delta M)/dt + d(\Delta L)/dt \qquad (1)$$

Where:

m· in =Feed water flow rate into the Steam Generator

m·out =Steam flow rate from the Steam Generator

M=f(m· out)= Mass inventory in Steam Generator from M versus Steam Generator load

$\partial M = f(pd)$= *change in mass inventory due to pressure* ∂M *versus pressure*

ΔL= *Level error in the Steam Generator*

Then d*(M)/dt* required for the level control would be given by:

$$d(M)/dt = d(m \cdot out)/dt * d(M)/d(m \cdot out) \qquad (2)$$

Thus, the feed-forward for load effects is the rate change of steam flow multiplied by the gradient of the Mass versus load.

Similarly for pressure:

$$d(\delta M)/dt = d(Pd)/dt * d(\delta M)/d(Pd) \qquad (3)$$

ie. The feedwater signal is the rate of change of pressure multiplied by the gradient of mass change versus pressure.

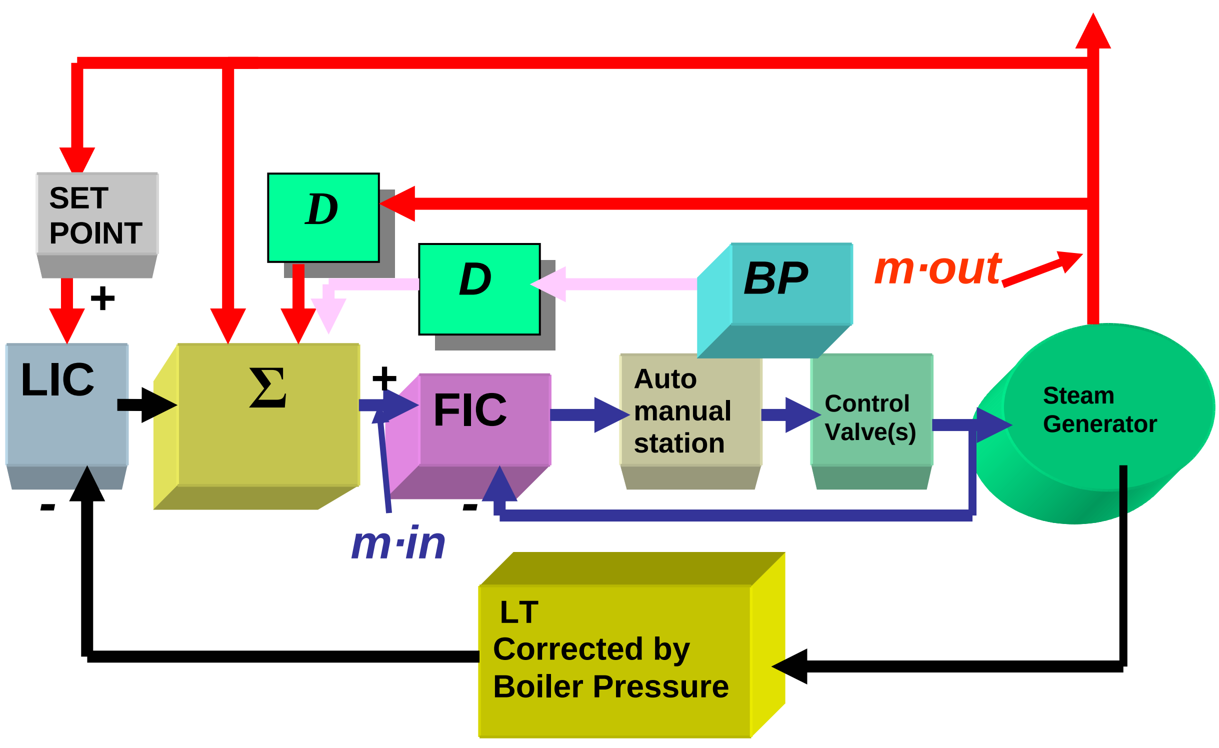


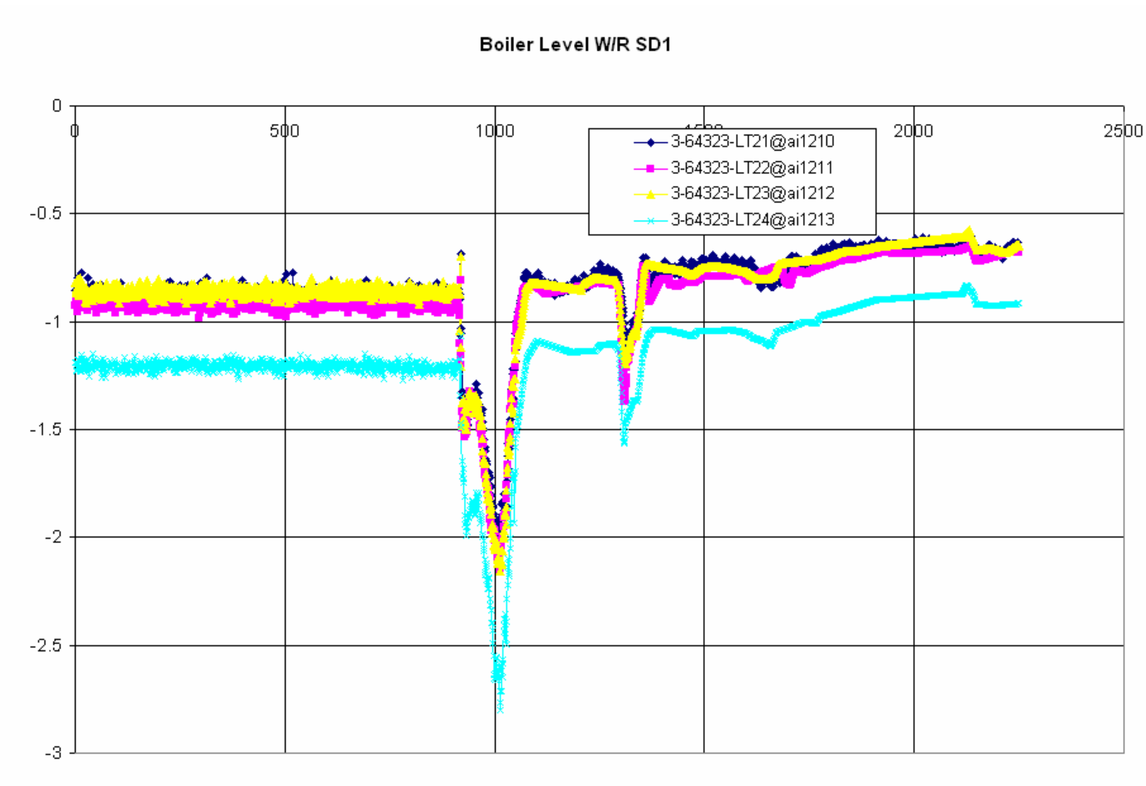
Fig. 5. Schematic diagram for improved level control at Pickering

5. CONCLUSION

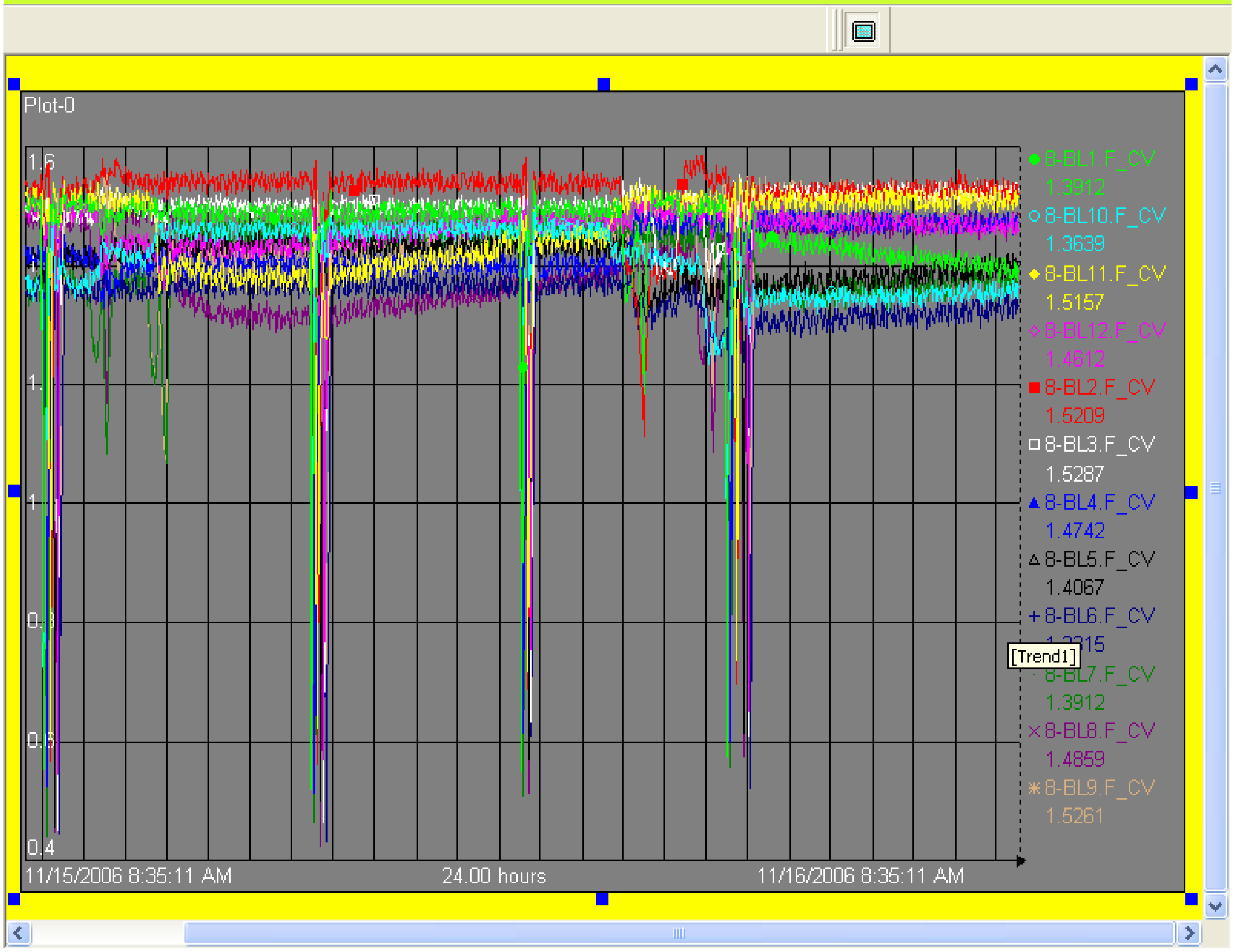
It has been my intention to show that the upgrading of existing Steam Generator level control strategy at Pickering Nuclear would benefit greatly. The following are then, as a result, very tangible advantages for its performance:

- Minimal operator intervention will be needed.
- Some unmeasured disturbances within the system such as Steam Generator blow down would be corrected by fast cascade control loop.
- By using memory module (hardware or software), the control system will be bumpless
- Having considered the swelling and shrinking effects add great value to this control system.
- No more calibration needed for parameters.
- Increased power plant reliability and availability.

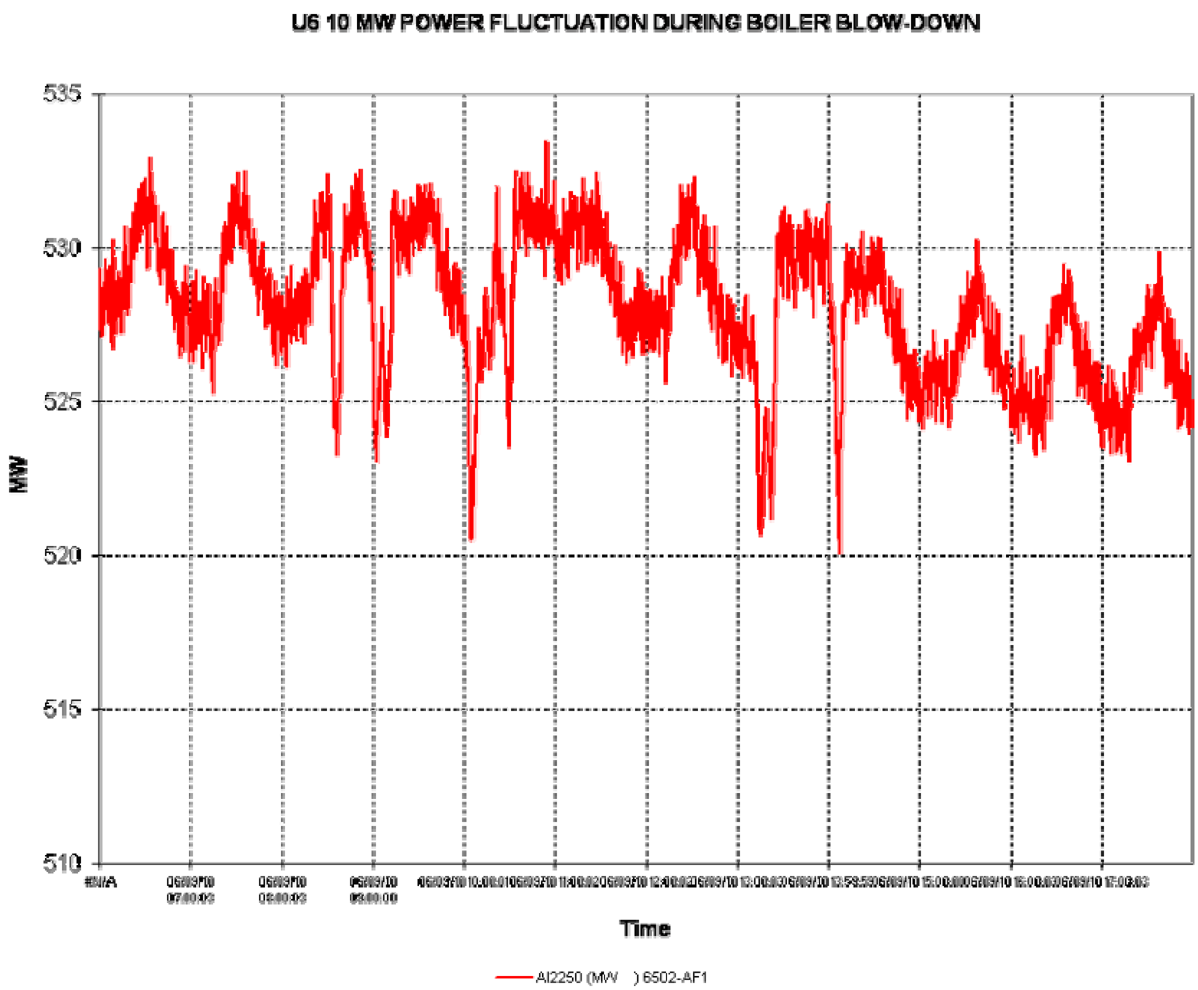
APPENDIX A: Forced outage from shrink effect at Bruce Power Plant on Jul 22, 2006.



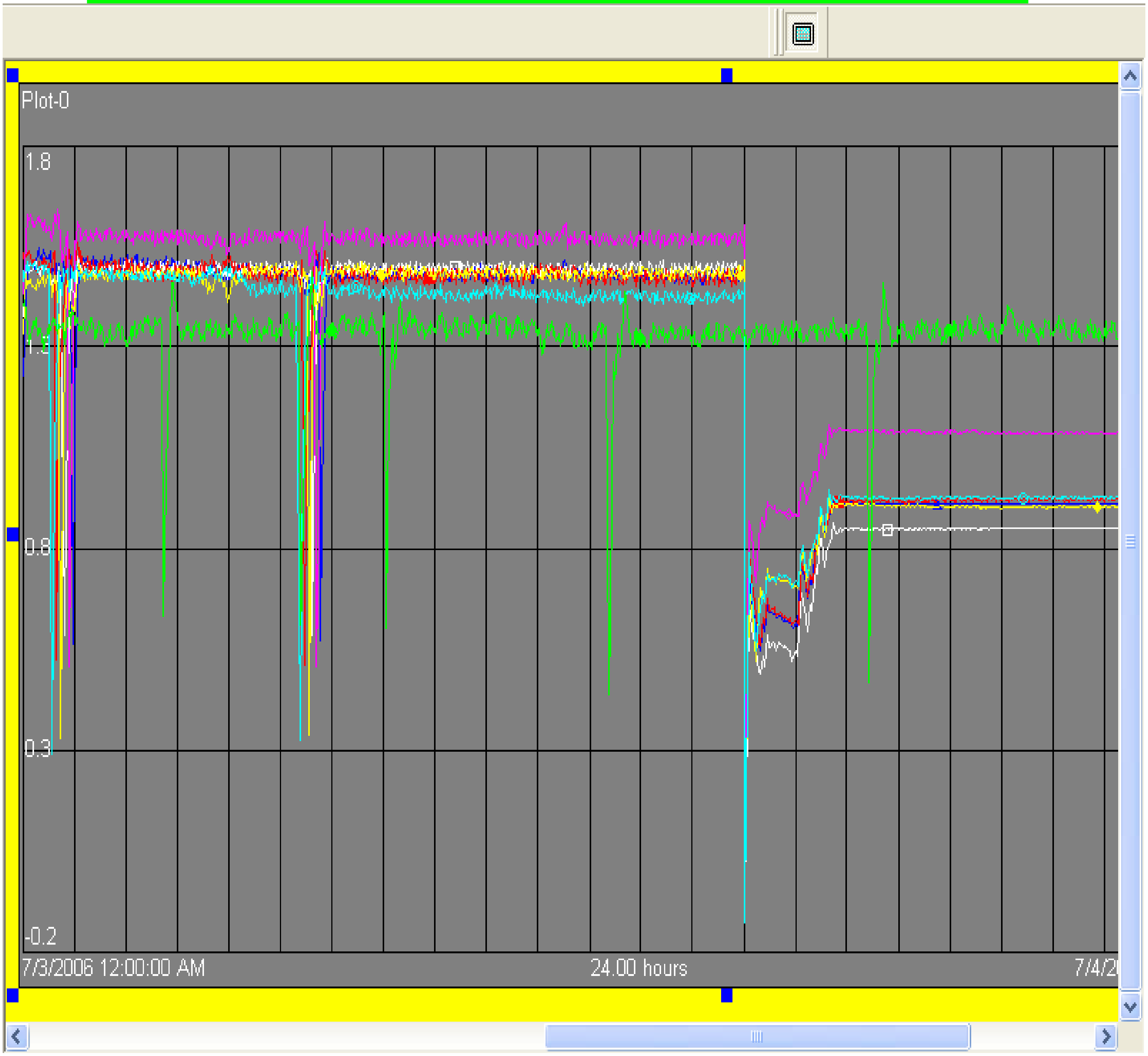
APPENDIX B: BOILER LEVEL FLUCTUATION DURING BLOW-DOWN



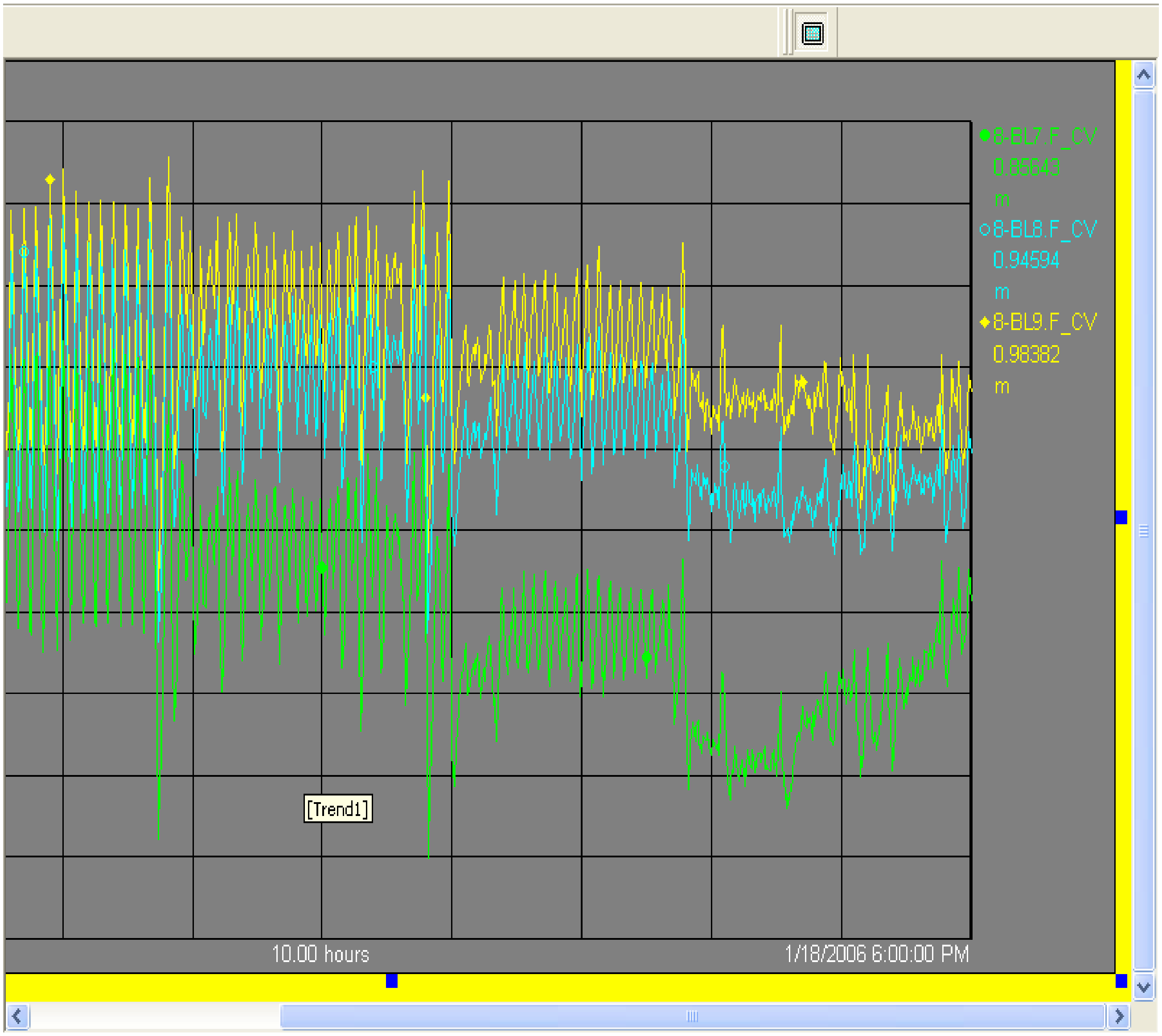
APPENDIX C:


U6 10 MW POWER FLUCTUATION DURING BOILER BLOW-DOWN
535
530
525
520
515
510
MW
Time
AI2250 (MW) 6502-AF1

APPENDIX D: FORCED OUTAGE FROM BOILER LEVEL CONTROLLER FAILURE



APPENDIX E: BOILER LEVEL FLUCTUATION AT LOW POWER



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