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NPP TEMELIN INSTRUMENTATION AND CONTROL SYSTEM UPGRADE AND VERIFICATION

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ABSTRACT

Two units of VVER 1000 type of the Czech nuclear power plant Temelin, which are under construction are being upgraded with the latest digital instrumentation and control system delivered by WEC. To confirm that the functional design of the new Reactor Control and Limitation System, Turbine Control System and Plant Control System are in compliance with the Czech customer requirements and that these requirements are compatible with NPP Temelin upgraded technology, the verification of the control systems has been performed. The method of transient analysis has been applied. Some details of the NPP Temelin Reactor Control and Limitation System verification are presented.

1. INTRODUCTION

There are four pressurised water reactors of the VVER 440 type under operation and two pressurised water reactors of the VVER 1000 type under construction in the Czech Republic at present. Nuclear generated electricity represents about 20% of total production and this share will grow up to 40% after two 1000 MW units of Temelin NPP start to operate.
Construction of the NPP Temelin VVER 1000 units has continued with the upgrading of the original design. The Temelin upgrading program includes the modernisation of all parts of the NPP, which could negatively influence the future license issue. The following innovations have been implemented:

- Modernisation and upgrading of the instrumentation and control systems including the reactor protection system and engineering safeguard features,
- Fuel replacement and modification of the reactor core,
- New diagnostic system,
- Innovations of some components and subsystems of the primary and the secondary systems,
- Design and construction of a full scope simulator,
- The improvement of safety documentation.

The US company Westinghouse Electric Corporation (WEC) was selected for the delivery of the instrumentation and control system, primary side diagnostic system and nuclear fuel.

The instrumentation and control system upgrade includes:

- Primary Reactor Protection System (PRPS) and Diverse Protection System (DPS),

- Reactor Control and Limitation System (RCLS),
- Plant Control System (PCS) and Turbine Control System (TCS),
- Post Accident Monitoring System (PAMS),
- Incore Instrumentation System (IIS),
- Unit Information System (UIS),
- Main Control Room (MCR), Emergency Control Room (ECR) and Technical Support Center (TSC).

The WEC Eagle Family microprocessor based system is applied for the safety related systems (PRPS, RCLS, PAMS) and for the systems that are non-safety related (PCS, TCS, IIS, UIS, MCR, ECR, TSC) the Westinghouse Distributed Processing Family microprocessor based system is used. All instrumentation and control systems are interconnected by a network of communication data interface highways WESTNET II, WESTNET III .

The detailed requirements on the functional design of the RCLS, TCS and PCS have been specified by the Czech specialists. To confirm that these functional requirements are compatible with existing plant systems, components and technology and that RCLS, TCS and PCS are in compliance with customer requirements, the Czech experts apply the method of dynamic simulation and transient analysis.
Using both full scale simulator and the dynamic plant model of EGP the specialists of the CEZ, SKODA and EGP companies have evaluated the performance of RCLS, TCS and PCS during the normal operation and anticipated transients. A brief outline of the Temelin control system philosophy and functional design and some details of its verification follows, next.

2. REACTOR CONTROL AND LIMITATION SYSTEM

Reactor Control and Limitation System is a high integrity system that must automatically maintain key process variables within a normal operating region well below the safety limits. The RCLS consists of three major functional parts with the following priorities:

- the limitation functions (Limitation System),
- the coordination functions (Control Coordinator),
- the reactor control functions (Reactor Control System which includes main safety related control systems and subsystems).

Limitation System (LS)

The main objectives of the LS are the enhancement of defense in depth and the prevention of protection system actuation in the event of a series of upsets specified by Czech customer.
The LS directs the action of the Reactor Control System in response to a specified set of plant component failures or electrical grid upsets. This response is characterised by one or more of the following actuations:

- Actuation „b"- the LS logic blocks automatic or manual withdrawal of the control rods,
- Actuation „a"- the LS logic actuates a control rod bank insertion at the maximum controlled speed,
- Actuation „c"- the LS logic actuates a full trip of one bank of control rods,
- Actuation „d"- the LS logic actuates a full trip of several banks of control rods (in the early operation period the full trip of all control banks is assumed)

All Limitation System actuations override manual rod control.
The LS contains more than sixty limitation functions and each of them is specified by logical algorithms. Many of LS functions resulting in actuation „a", "c", „d" are interlocked, so that they are active only above a specified reactor power. The remaining LS functions requiring control

rod insertion do not require reactor power interlock and remain active until initiating condition clears.

Detailed functional requirements (logical algorithms) for the Temelin limitation system as well as the list of anticipated upsets were specified by the Czech customer. Recently all LS functions have been simulated by the Czech analysts and compatibility with plant technology has been analysed.

Control Coordinator (CC)

The Control Coordinator represents a quite new approach in the NPP control philosophy and therefore it will bee discussed in more details.

The CC provides system management and coordination. It identifies the requirements of the various systems and subsystems and links the systems together to obtain appropriate operation of the plant from shutdown conditions to full power. It generates signals that modify operation of plant systems in response to the plant conditions and to the requirements of the electrical grid.

The CC manages the reactor and turbine control modes and provides interfaces between the Reactor Control System, Steam Dump Control System and the Turbine Control System. It initiates the transition between system statuses as required during transients and for the start up and shut down.

There are 6 possible reactor modes and 6 possible turbine modes, as follows:

Reactor modes:

- Manual control on control rod position RU_R
- Automatic control on reactor power N_R
- Automatic control on main steam collector pressure P_R
- Automatic control on primary coolant average temperature T_R
- Limitation system (automatic and manual control is not possible)
- Reactor trip (reactor trip breakers open, rod control is not possible)

Turbine modes:

- Manual control RU_T
- Automatic control on turbine power N_T
- Automatic control on main steam collector pressure P_T
- Automatic control on turbine speed S_T
- Fast Valve Control RRV
- Island operating mode OST

Each control mode combination in conjunction with other plant operating conditions defines a unique system status. The transition allowed between the system statuses are defined in the transition matrix. Using the system status transition matrix, the Control Coordinator is able to provide systems management in the events of the change of plant operating conditions, operator input and in the event of the actuation of the LS. The LS actuations „a“, „c“, „d“ will block the selection of all reactor power control modes until the reactor power level has been reduced to a defined safe power level.

The Control Coordinator is the central location for three main unit set point controllers and unit power set point calculations. These include:

- Main Steam Collector Pressure Set Point Controller which provides the main steam collector pressure reference set point used by the Reactor Control System, Turbine Control System, and Steam Dump Control system,
- Reactor Power Set Point Controller which provides reactor power reference set point used by the Reactor Control System,
- Primary Coolant Temperature Set Point Controller which provides the primary coolant temperature reference set point used by the Reactor Control System.

The turbine power reference set point is calculated in the TCS but the Control Coordinator provides interfaces to the Turbine Power Set Point Controller in the TCS.

There are still some additional functions performed by the Control Coordinator.

- Management of the remote dispatching interface in the TCS, while the turbine is in mode N_T. The remote dispatching interface allows a dispatcher to change the target load reference and to coordinate the operation of NPP Temelin with other production facilities on the electrical grid.
- Management of the cooldown mode control. This mode is designed for unit operation between hot standby and cold shutdown to set up the proper operating modes in the Steam Dump System.

Although the Control Coordinator acts as direct interface only between Reactor Power Control System, Turbine Control System and Steam Dump System, in consequence of its actions the operation of other control systems and subsystems is affected.

RCLS Control Functions.

The RCLS control functions are performed by the following control systems:

- Reactor Power and Rod Speed Control System.
- Pressurizer Pressure and Water Level Control System.
- Feedwater Control System (Steam Generator Water Level Control, Feedwater Pump Speed demand Control)..
- Auxiliary Feedwater Control System
- Steam Dump Control System.
- Feedwater Tank Pressure and Water Level Control System.
- Condenser Hotwell Level Control System

Implementation of the control systems listed above is accomplished using the WEC Eagle Family microprocessor based system. This system is manufactured from the high quality hardware modules that are housed in cabinets designed to withstand seismic events and to reject interference from outside noise sources. But if any functional deficiency is identified during or after control system installation on the Temelin site, it will be difficult to carry out any corrections and changes. Therefore substantial verification of all arts of the RCLS before its installation is very important.

3. REACTOR CONTROL AND LIMITATION SYSTEM VERIFICATION:

The program for Temelin Control and Instrumentation System verification was prepared by the specialists of SKODA , CEZ and EGP two years ago. The main objectives of this program have been:

- To confirm that functional requirements on RCLS, TCS and PCS defined by the Czech customer are compatible with NPP Temelin technology.
- To confirm with a high degree of confidence that RCLS, TCS and PCS functional design are in compliance with Czech customer requirements.
- To obtain evidence that the new main control systems can control the Temelin power unit with acceptable performance for all specified normal operating conditions and events.
- To identify deficiencies and required changes, if necessary.

The method of transient analysis has been selected for the verification. Two analytical tools have been used:

- Full scale plant simulator
- The detailed dynamic model designed by the Temelin general designer EGP

Both computer codes contain complete technology (all systems of the primary and secondary sides of the Temelin NPP and full scale of the RCLS, TCS and PCS in compliance with WEC documentation for the Temelin Unit 1.) They can cover the full scope of normal and anticipated transients for which the RCLS is designed.
The verification program has been divided into two stages. During the first stage the testing of the individual (separated) control systems without respecting interfaces between main control systems have been carried out. The second stage of the verification program has been concentrated on the RCLS and TCS full verification. The verification of the Control Coordinator in cooperation with Limitation System and reactor and turbine control systems has been performed by transient analysis.

The following events have been analysed:

- Loss of one reactor coolant pump at reactor powers: 100% N_{nom} (LS(a+c) actuation), 88% N_{nom} (LSa actuation) and 68% N_{nom} (without LS actuation- stabilisation only by means of control system)
- Simultaneous loss of two opposing reactor coolant pumps at reactor powers: 100% N_{nom} (LS(a+c) actuation), 72% N_{nom} (LSa actuation), and 50% N_{nom} (without LS actuation)
- Simultaneous loss of two adjacent reactor coolant pumps at reactor powers: 100% N_{nom} (LS(a+c) actuation), 72% N_{nom} (LSa actuation), and 40% N_{nom} (without LS actuation)
- Step load changes and full load rejections
- Reactor trip
- Turbine or generator trip without reactor trip from the powers: 100% N_{nom} (LS(a+c) actuation), 73%N_{nom} (LSa actuation), and 38% N_{nom} (without LS actuation)
- Loss of a 400kV transformer from the same power levels as turbine trip
- Loss of one turbine driven feedwater pump at reactor powers: 100% Nnom (LS(a+c) actuation) and 73% Nnom (LSa actuation)
- Loss of both operating turbine driven feedwater pumps at reactor powers: 100% Nnom (LSd actuation) and 38% N_{nom} (LSa actuation)
- Loss of one circulating water pump at reactor full power (LSa actuation)
- Loss of both operating circulating water pumps at reactor powers: 100% N_{nom} (LSd actuation), and 38% N_{nom} (LSa actuation)
- Loss of one or two operating condensate pumps (without stand-by) at turbine full power (LSa actuation)
- Loss of all three operating condensate pumps (without stand-by) at turbine full power (LSd actuation) and at 38% of full power (LSa actuation)
- Loss of low pressure feedwater heaters. The LSa initiated by the loss of feedwater heater reduces reactor power to such a level that a required feedwater flow corresponds to the available condensate flow. Ten different scenarios related to the loss of feedwater heaters or the heater bypass line have been simulated and functional algorithm and system logic have been confirmed.
- Loss of high pressure feedwater heaters- changes in feedwater temperature
- Island Mode event and Fast valving event
- Evaluation of performance of the control system during remotely dispatched control and load regulation and during power unit shut down to cold conditions and power unit heatup

Partial evaluation of protection system actuation has been performed. The following events have been analysed:

- coolant pipe breaks (different size of break)
- main steam line breaks and main feedwater line breaks
- steam generator tube rupture (one and more tubes)

For illustration, some results of transients caused by two of the above listed plant anticipated incidents are presented.

A. Loss of the two adjacent main coolant pumps at full reactor power.

The design of the plant is such that plant operation is allowed to continue with up to two main coolant pumps idle. A simple trip of 1 or 2 main coolant pump must not, therefore, cause the reactor to trip when the RCLS operates as designed. The promptly initiated LS must bring the plant to power condition maintainable for a long period of time, if needed.
The test started from the initial steady state at nominal reactor power and pressure in the main steam collector of 6.2 MPa. The trip of two coolant pumps caused LS actuation (c+a). Maximum allowed reactor power of 41% was established as the reactor power setpoint. The major calculated parameters of the primary and secondary system are provided in Figures 1 to 8. Dynamic behaviour of the plant in response to the limitation actuation has been analysed. The Limitation System, Control Coordinator and all reactor and turbine control systems actuated properly. Non of the plant parameters resulted in a reactor trip.

B. Loss of one of the two operating turbine- driven feedwater pumps at full reactor power

Two turbine- driven feedwater pumps are designed for NPP full power operation. One feed water pump was manually tripped. The LS received neutron flux information from PRPS and status information indicated that the feedwater pump is out of service. This status information is generated in the Plant Control System. The Control Coordinator analysed the information and initiated actuation LS (c+a) which caused a rapid reactor power reduction to 50%. This quickly reduced the demand on feedwater flow to avoid potential reactor trip. The major plant parameters are illustrated in Figures 9 to 16.
Upon tripping one of the main feed water pumps the total feedwater flow to steam generators decreased instantaneously. The steam generator pressure increased and SG level decreased rapidly mainly due to the decrease in feedwater flow rate and level collapse caused by pressure increase. The SG level decrease initiated the start up of one of the auxiliary feed water pumps. The Feedwater Control System restored the water level to the nominal water level in 10 minutes.
The turbine- generator power decreased simultaneously with the reactor power, but at the beginning of the transient the rate of decrease of generator power was less than that of reactor power. This difference was primarily the consequence of the large energy content stored in the Moisture Separator and Reheaters, which are located between the high and low pressure turbines. .

4. CONCLUSION

The NPP Temelin control system is being upgraded with the new digital technology delivered by WEC. To confirm that the functional design of the RCLS, TCS and PCS is in compliance with the Czech customer requirements and that these requirements are compatible with NPP Temelin upgraded technology, the verification of the control system has been performed. The method of transient analysis has been applied. The evaluation has not yet been completed, but the preliminary results of analyses demonstrate that the new control system can ensure acceptable operation of the Temelin units in normal operating conditions as well as during anticipated transients.

Loss of the Two Adjacent Main Coolant Pumps (at Full Reactor Power)

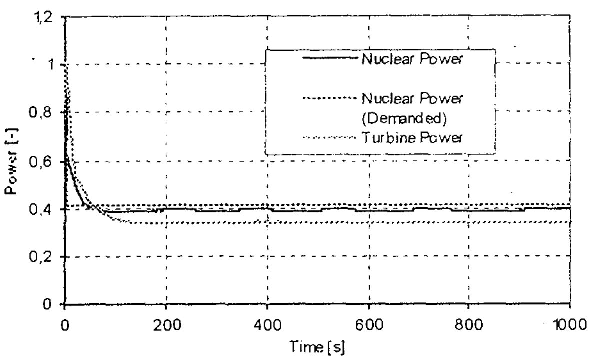


Figure 1

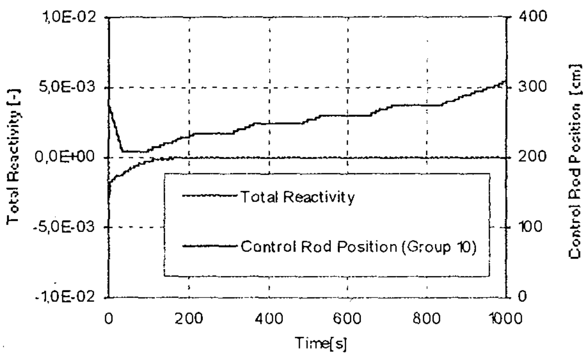
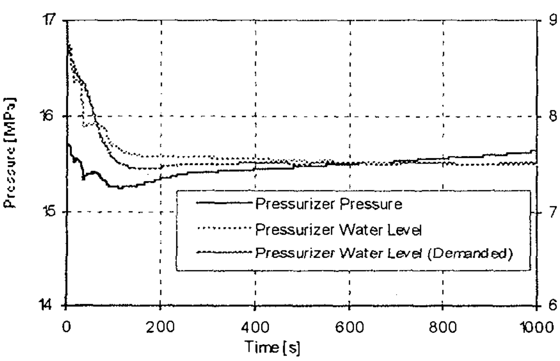


Figure 2



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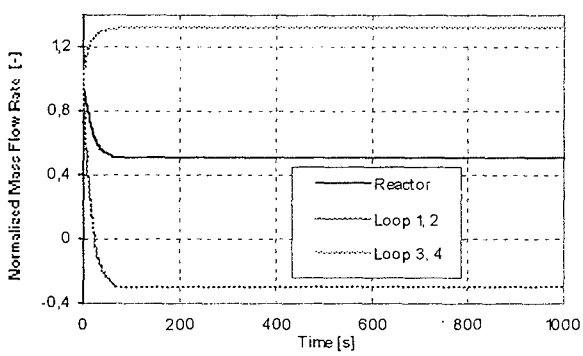

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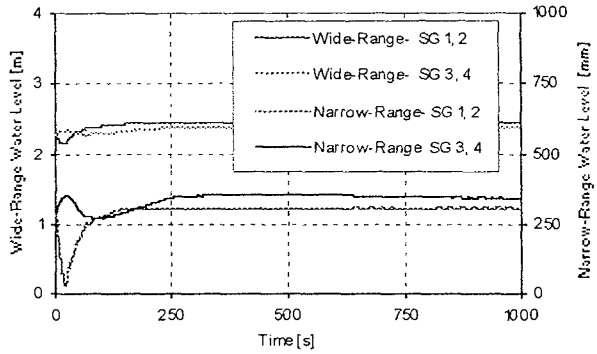


Figure 5

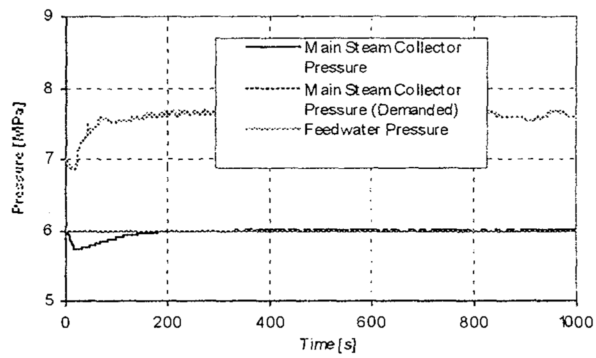
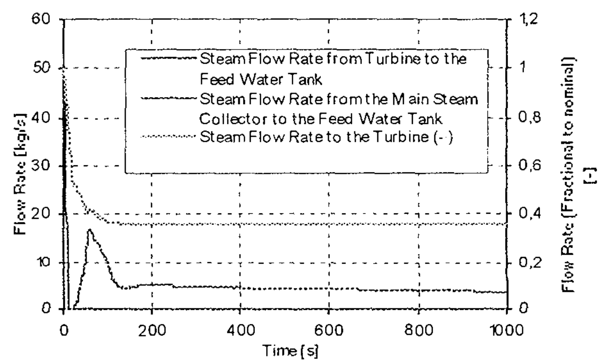


Figure 6



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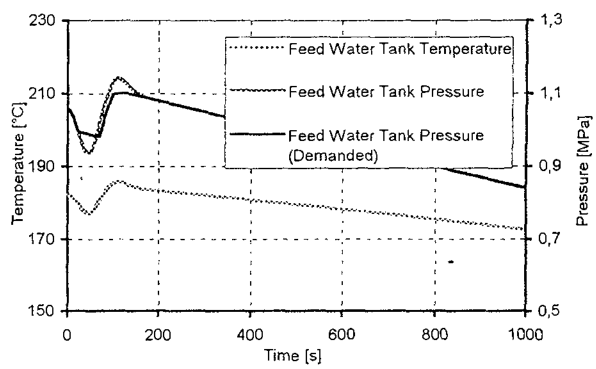


Figure 8

Loss of one Turbine- driven Feedwater Pump
(at full Reactor Power)

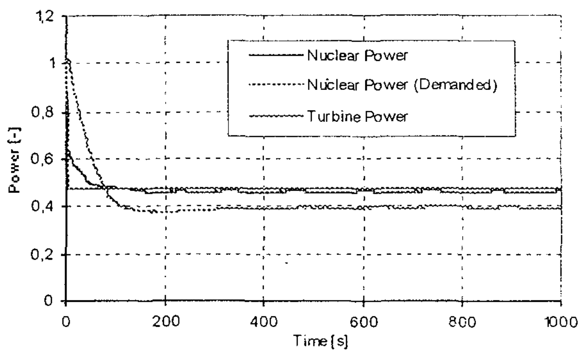


Figure 9

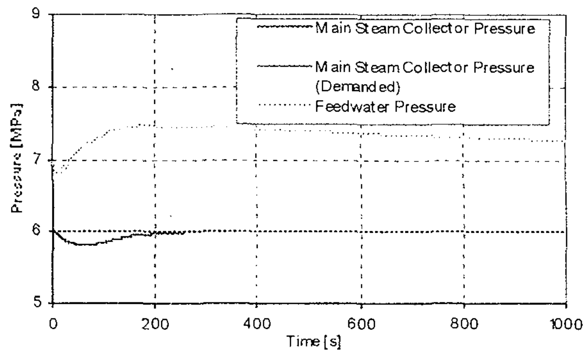


Figure 13

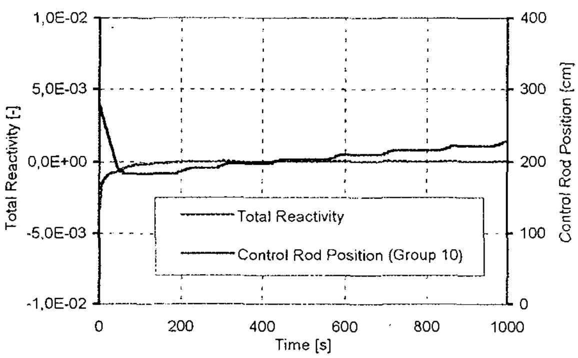
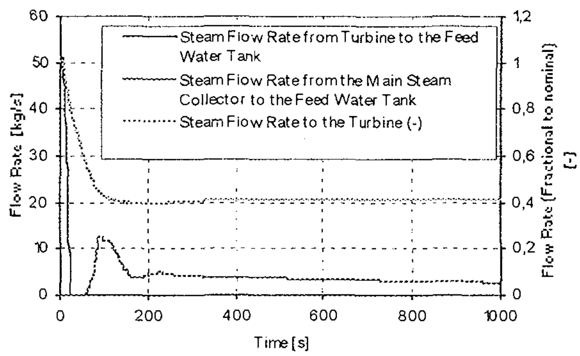


Figure 10



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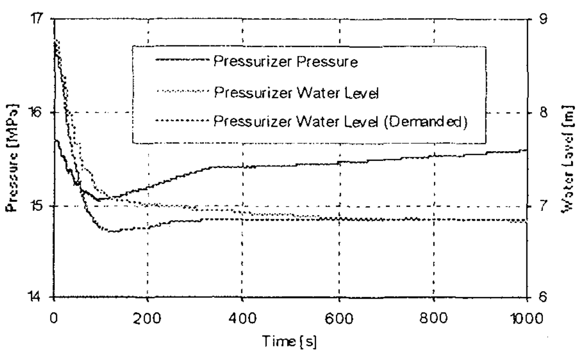

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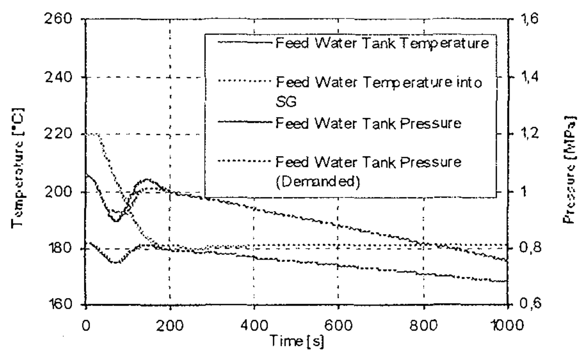

Figure 15

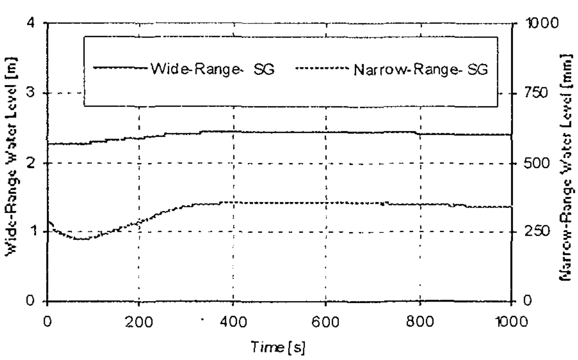

Figure 12

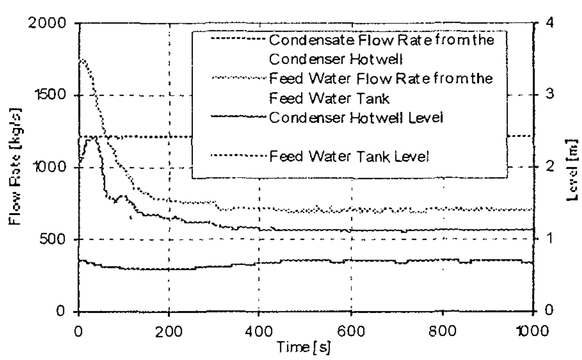

Figure 16