NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

Model Reference Control & Protection Theory and Implementation for Nuclear Plants using Real Time Simulations

Anthonie Cilliers

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Contents

Postgraduate School of Nuclear Science and Engineering

Background

- Traditional plant control systems:
  - Traditional protection and control of nuclear plants operate by measuring variables inside the plant and initialising processes based on predefined rules from the design knowledge base.
  - As plants become more complex the predefined protection and control rules become more complex and large safety margins has to be designed into these rules.
  - Information from measurement equipment provides a picture of the plant at any time, but without predefined operational limits, it can not provide any indication of the expected behaviour of the plant.

- Nuclear plant simulators
  - The advancements in processor speeds and the development of sophisticated numerical algorithms allows the simulation of plant processes in real time.
  - The simulator can only predict expected plant behaviour because it is blind to faults that occur in the plant.

Model Control & Protection Theory

- The model control & protection theory consists of two parts:
  - A dynamic operating window around the operating point that moves along with the operating point, this allows tighter control as well as early recognition of unexpected behaviour.
  - Fault isolation & identification, once unexpected behaviour has been recognised the fault data is isolated from expected transient information and analysed to classify the fault into a category, location, size and cause.

Static Operating Window

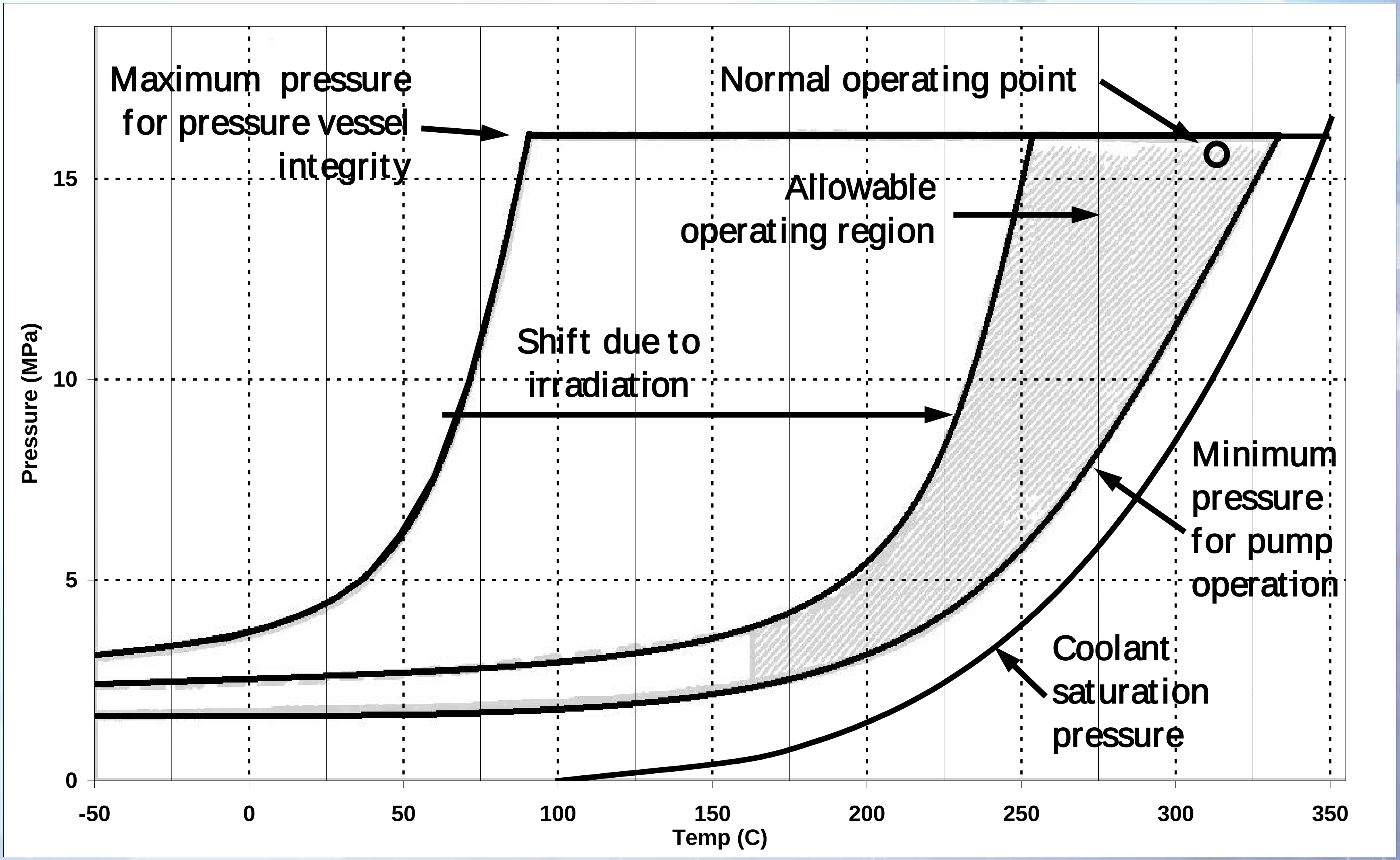
The following parameters are monitored for direct reactor trips:

1. Nuclear flux,
2. Coolant temperature ("Tavg" and "ΔT")
3. Coolant pressure (pressuriser pressure)
4. Pressuriser water level,
5. Coolant flow rate and reactor coolant pump breaker position,
6. Coolant pump speed,
7. Steam generator steam and feedwater flow rates,
8. Steam generator water level,
9. Operating status of the turbo-alternator set,
10. Safety injection, containment spray or Phase B containment isolation.

To allow for start-up, shutdown, and transient conditions different trip set-points apply under different conditions.

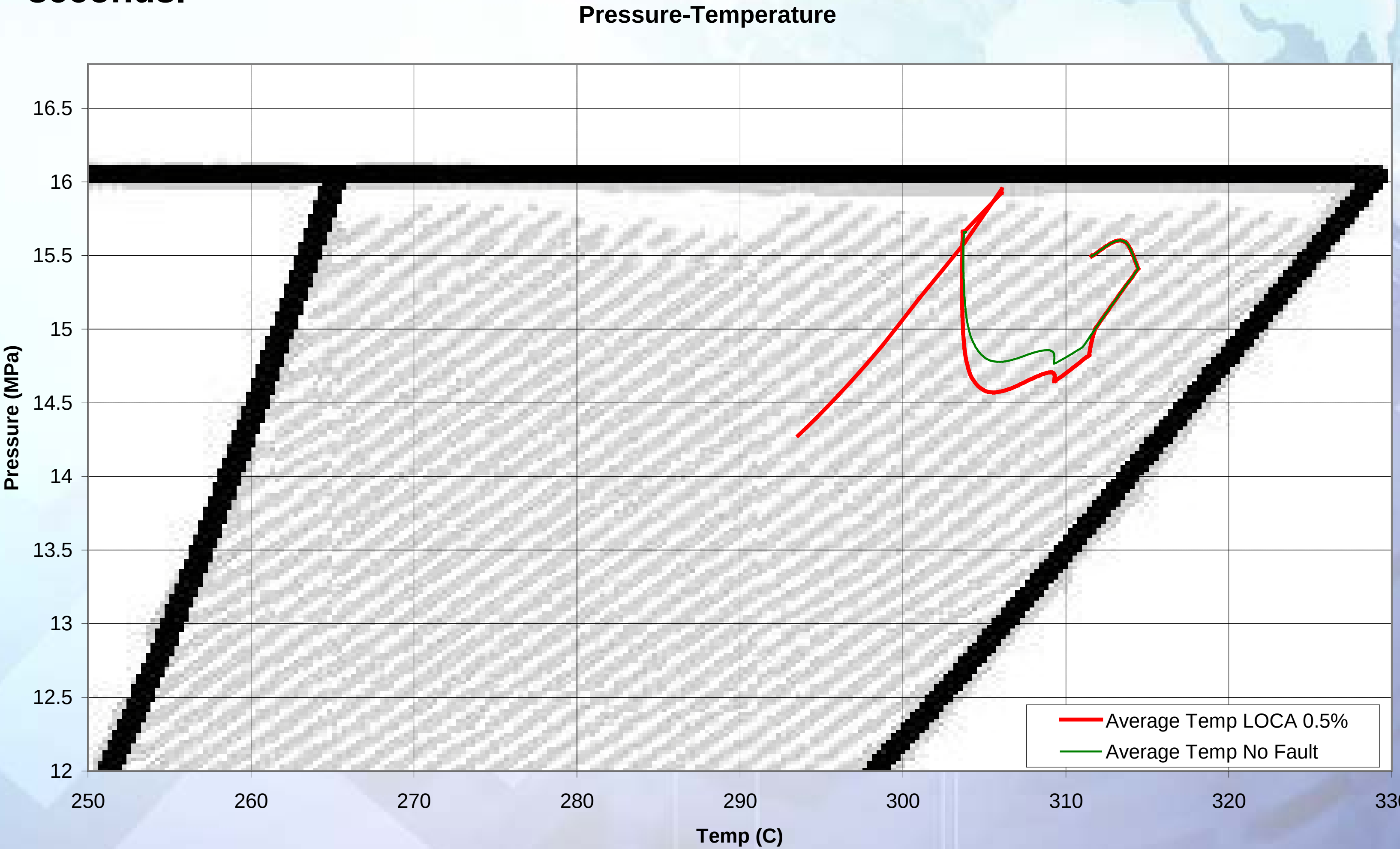
This creates a static operating window for the plant to operate in.

Static operating window



Dynamic Operating Window

The simulator would predict all transients until a fault occurs, at which time the simulator and measured parameters would drift away from each other within seconds.



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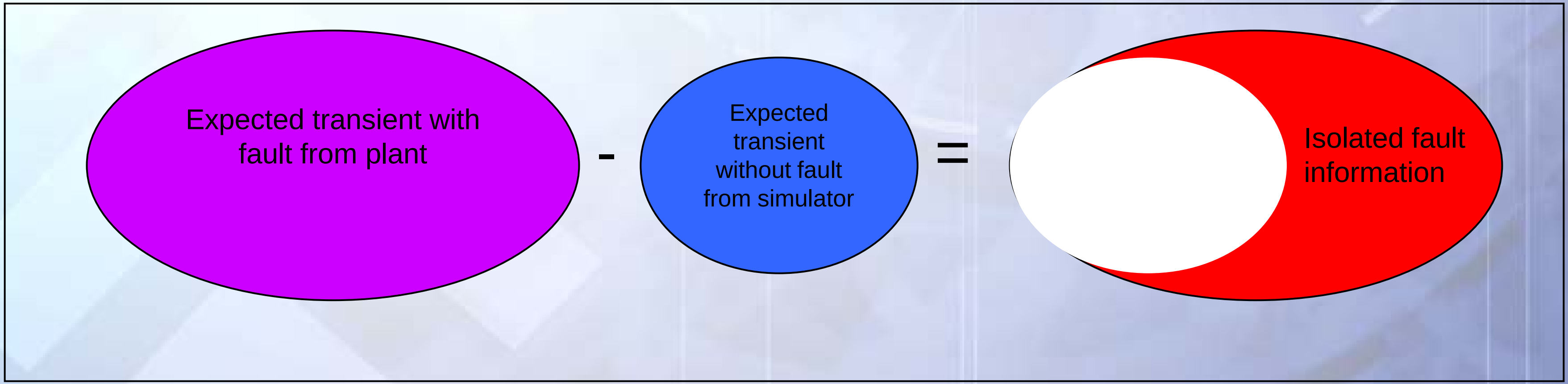
Fault Isolation & Identification

- Isolate fault data is by recording measured data from the plant and comparing it with expected real time data from the plant simulator.
- The difference between the two data sets constitute unexpected plant operation information.

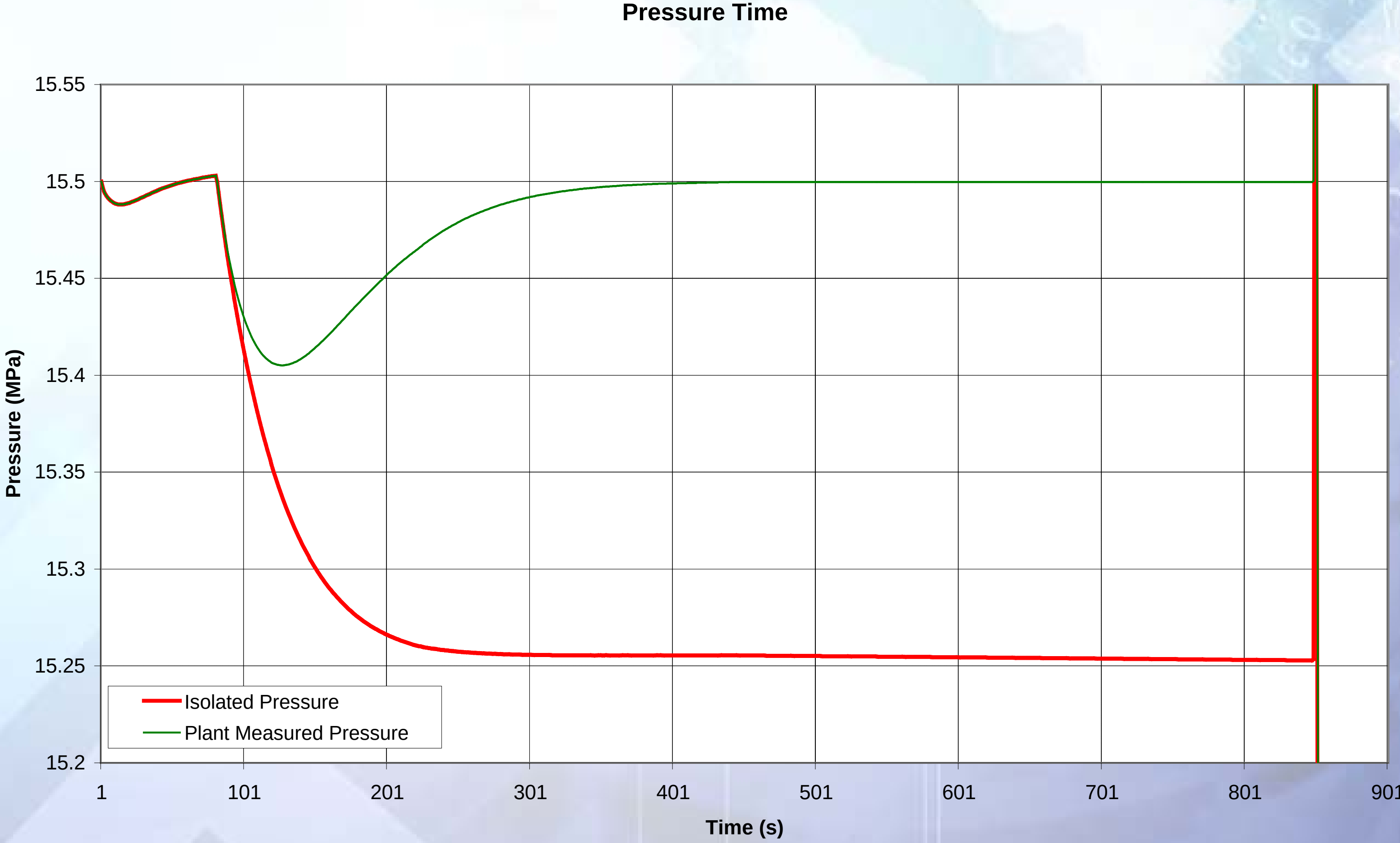
or

- Compare the expected operation of the control instrumentation under expected conditions with the actual control instrumentation operation.
- Removing the stabilising effect of the control instrumentation from the measured data results in transient data showing all faulty behaviour without the behaviour being countered by the control system.



Steady State LOCA

- The effectiveness of our proposed APN system is shown using the example of a break smaller than the classified small break LOCA. A small break LOCA is defined as a break with an equivalent diameter between 9.5mm and 25mm.

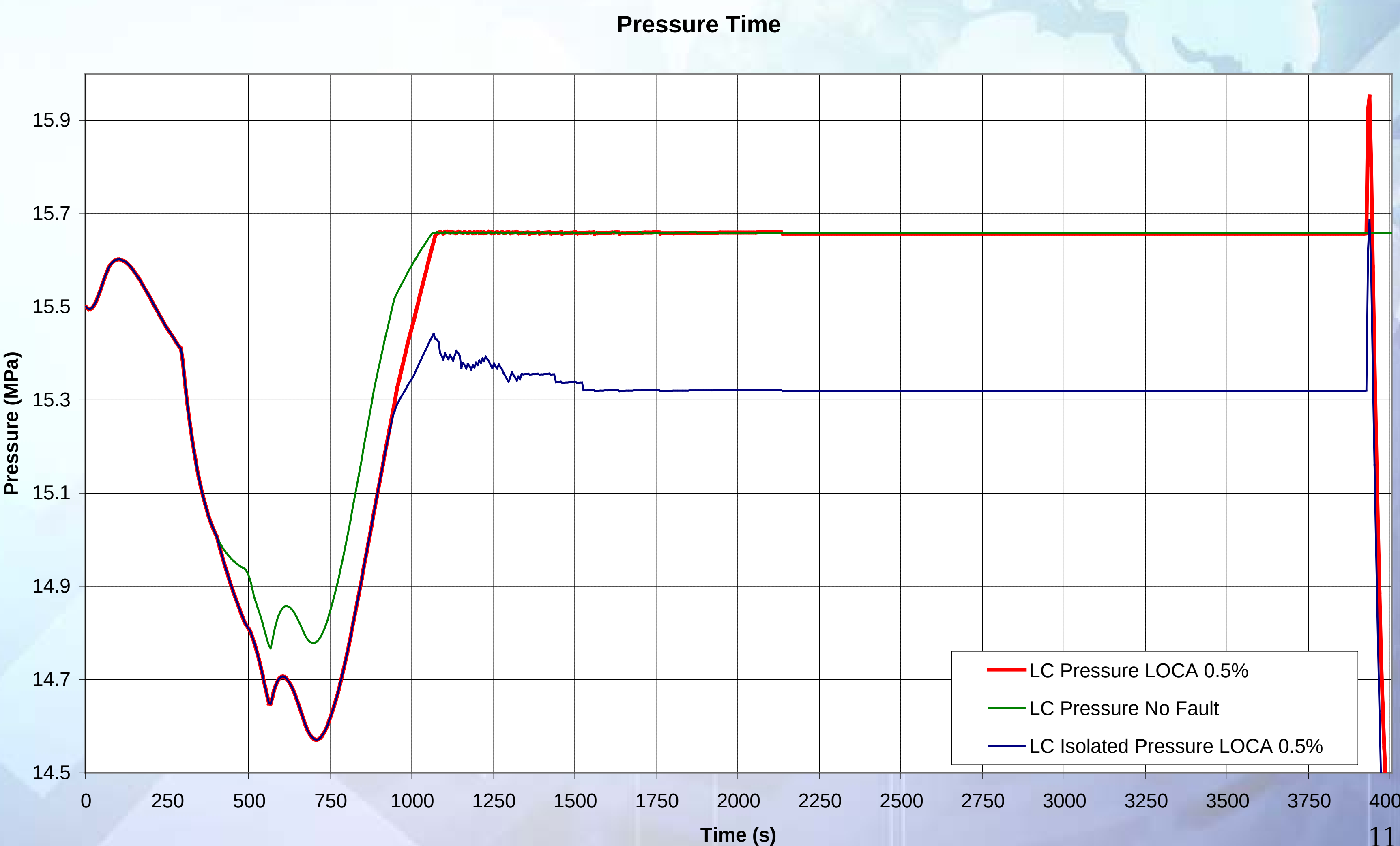


Results

- The fault occurs after 400 seconds and the fault would normally be detected 64 minutes after its occurrence.
  - The reactor trip is initiated by a Reactor Building High Pressure detection and the mitigating sequence following such a detection.
  - No indication is given as to what the cause of the Reactor Building High Pressure is.
- After removing the pressurizer Heater and Spray effects:
  - the rate of change of the measured pressure becomes positive after 640 seconds, 240 seconds after the fault occurred. After this time the positive effect of the heater outweighs the negative effect of the fault.
  - Since the unexpected heater effect are removed from the measured data it is clear that the plant is losing pressure due to an unexpected cause.
  - This would alert the operator of the fault within 4 minutes, 60 minutes earlier than would be the case in existing systems.

Load Change LOCA

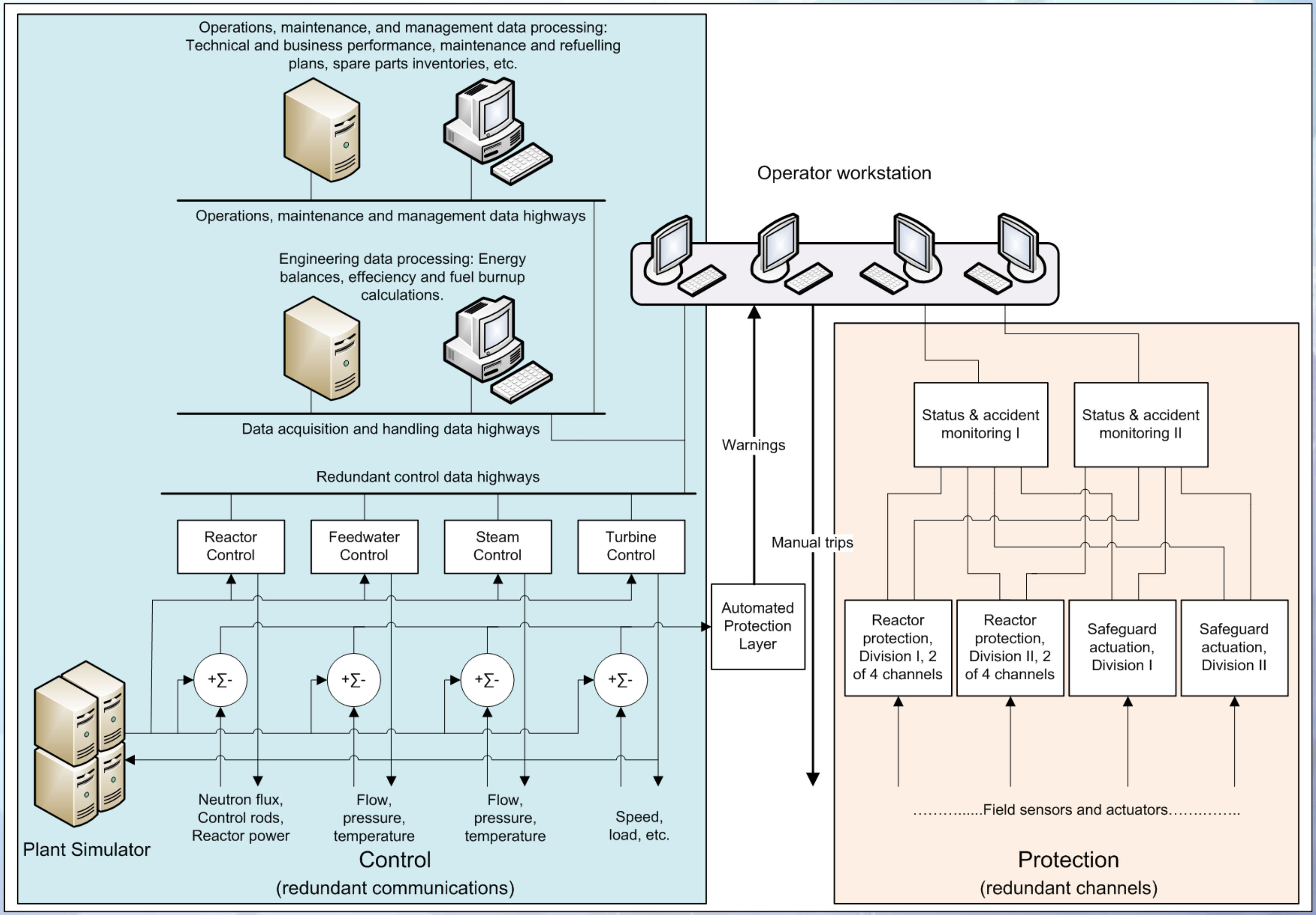
Smaller than Small Break LOCA during a transient state of the plant.



Results

- The added effect of the heater on this fault is not recognised at first because the heater is operating at full capacity to stabilise the effect of the expected transient.
  - The heater is expected to proportionally decrease capacity as the transient is stabilised, during this time the unexpected effect of the heater is detected and removed from the expected effects.
- After removing the pressurizer Heater and Spray effects:
  - The rate of change of the measured pressure does become positive after 1100 seconds, 700 seconds after the fault occurred. After this time the positive effect of the heater outweighs the negative effect of the fault and the pressurizer spray.
  - The unexpected heater and spray effect is removed from the measured data.
  - This would alert the operator of the fault within 11 minutes 40 seconds, 47 minutes earlier than would be the case in existing systems.

APL Implementation



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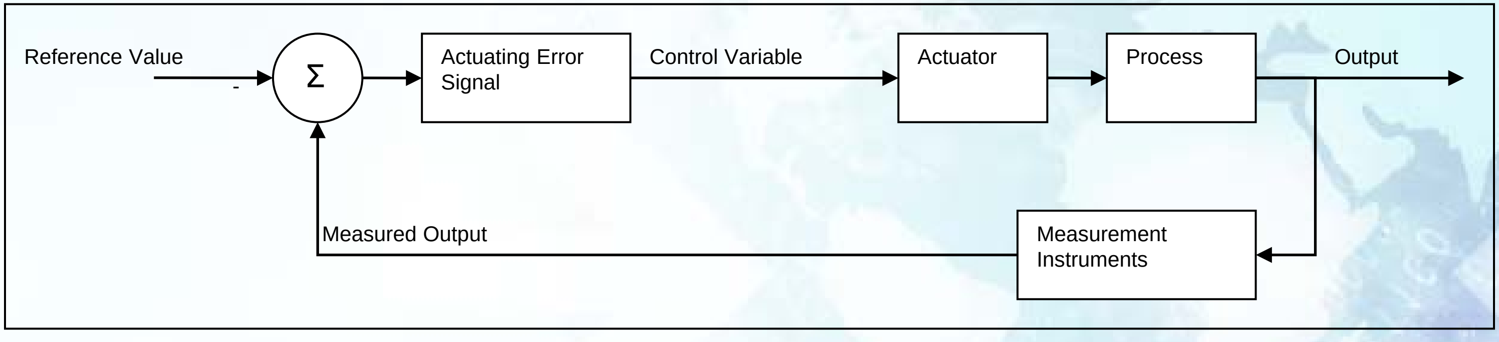
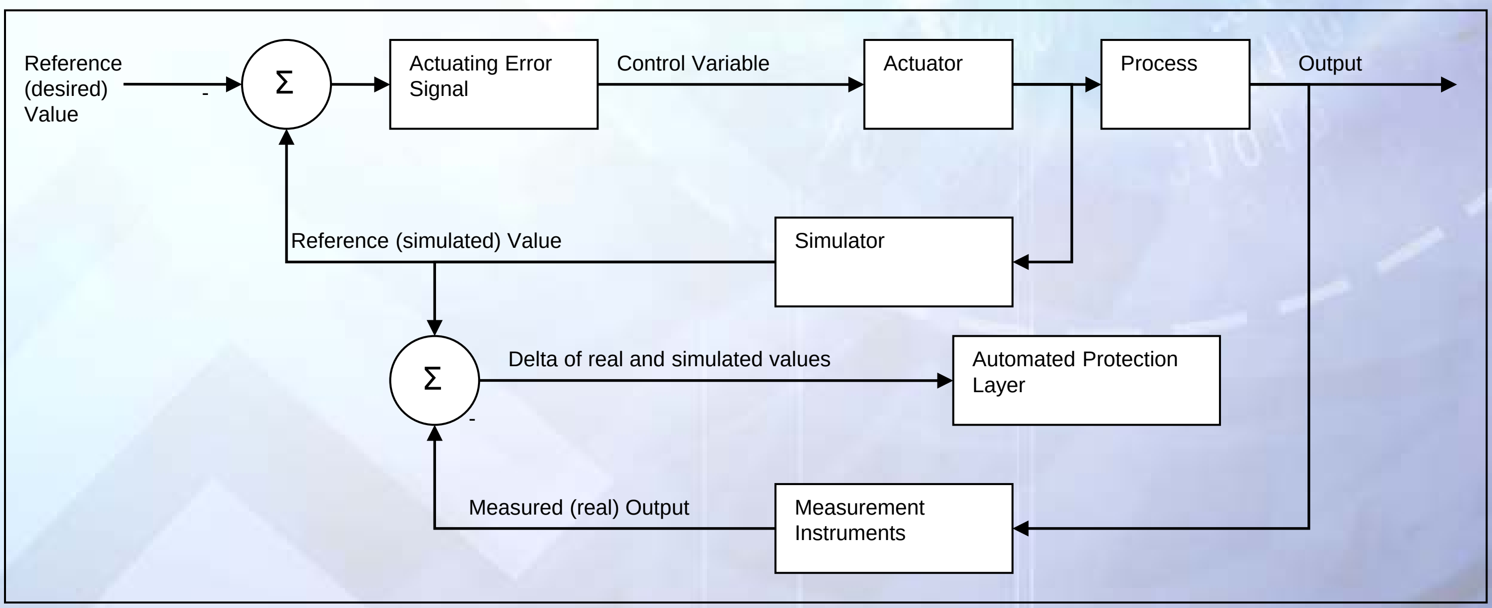
APL Implementation



Conventional closed loop control system



Proposed Model reference control system

Questions