Intelligent Controllers for Load Frequency Control of a Two-Area Power System

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Outline of Talk

- Frequency Regulation
- Power System Modelling
  - Non-Reheat steam turbine
  - Reheat steam turbine
  - Hydraulic turbine
- Compensator Design
  - PID controller
  - Fuzzy logic controller
  - ANN controller
- Simulation of Compensated Systems
- Conclusion

Frequency Regulation

- The mismatch between the generating capacity of a power system and the load demand at any given moment in time is reflected in the system’s frequency.
- Large deviations from a chosen nominal value of frequency are undesirable.
- Power system’s frequency is traditionally regulated using proportional-integral-derivative (PID) controllers.
- Frequency is dependent on real power generated.
- When real power generated > load demand, frequency increases and vice versa.
- The primary control action is performed by the governor (range of seconds)
- The secondary control action is performed by the LFC (range of minutes)

Frequency Regulation

- Another parameter of interest when dealing with more than area system is the Area Control Error (ACE).
- It is a measure of power that is obtained from other area(s) when/after a disturbance has occurred.
- A basic guiding principle in power system is that each area must absorb its own load under steady state conditions.
- A constant ACE will imply that one area will have to support the other on a steady-state basis.

$$ACE_1 = \Delta P_{12} + B_1 \Delta f_1$$

$$ACE_2 = \Delta P_{21} + B_2 \Delta f_2$$

Aims

- To perform a comparative analysis of three different compensators on systems operating with different turbines.
- Design suitable compensators to provide the secondary control actions to the systems based on the following criteria:
  - Steady-state error for frequency and Area Control Error
  - Deviation from nominal frequency
  - Settling time

Power System Modelling

- Two types of Power Systems:
  - ❑ Hydro
  - ❑ Thermal
- Three types of turbines available:
  - ❑ Hydro Power System→ Hydraulic turbine
  - ❑ Thermal Power System →Reheat and Non-Reheat turbine

Turbine Modelling

- Non-Reheat Steam Turbine

$$G_{NR}(s) = \frac{1}{1+sT_{CH}}$$

T_{CH} is the delay between the change in the valve opening position and the mechanical torque of the turbine.

- Reheat Steam Turbine

$$G_R(s) = \frac{1 + sF_{HP}T_{RH}}{(1 + sT_{CH})(1 + sT_{RH})}$$

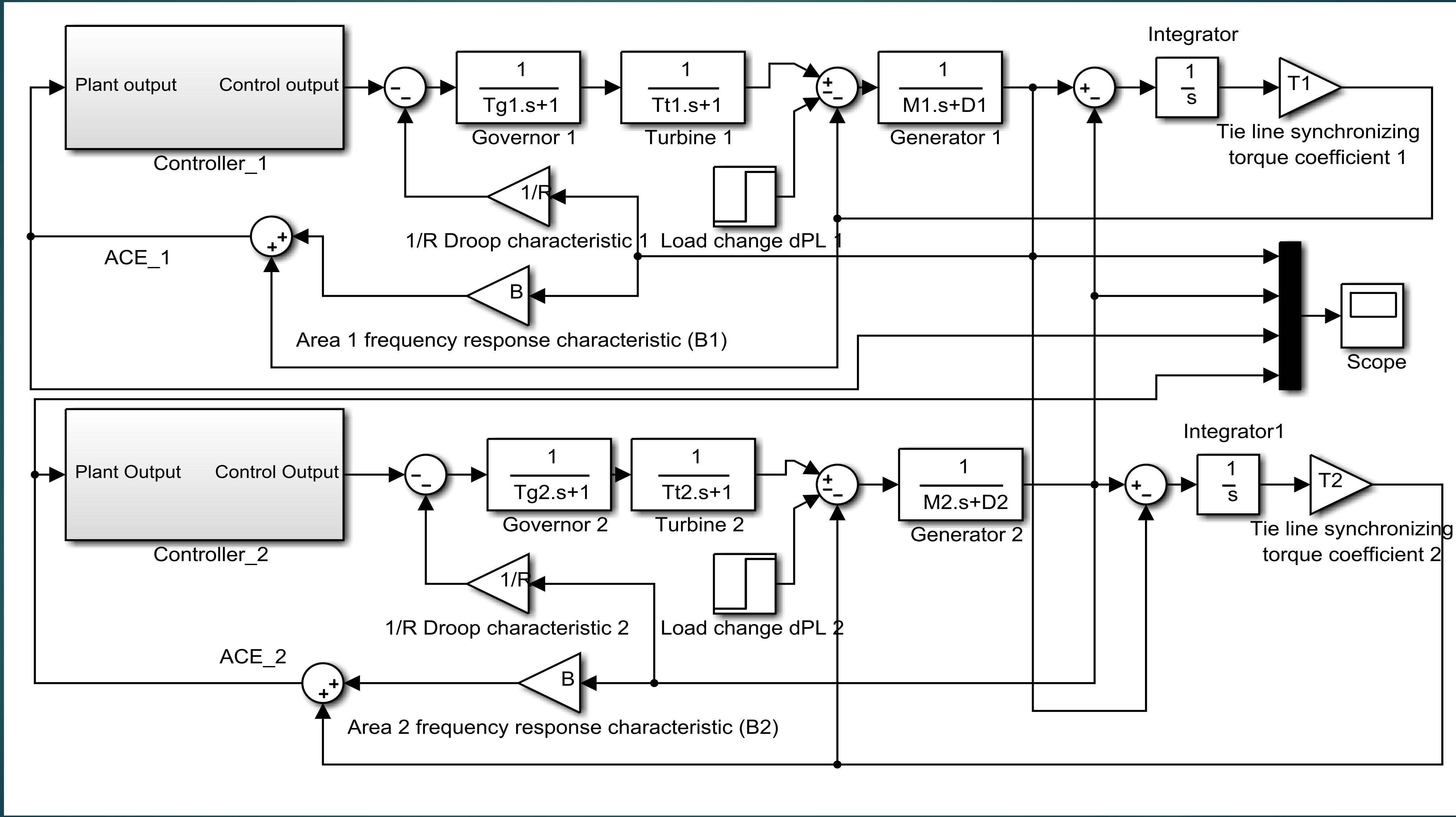
T_{RH} is the time constant of the reheater

F_{HP} is the rating of the high pressure stage with respect to total generated mechanical power of turbine.

- Hydraulic Turbine

$$G_{NR}(s) = \frac{1-sT_w}{1+s(T_w/2)}$$

Two Area Power System Model



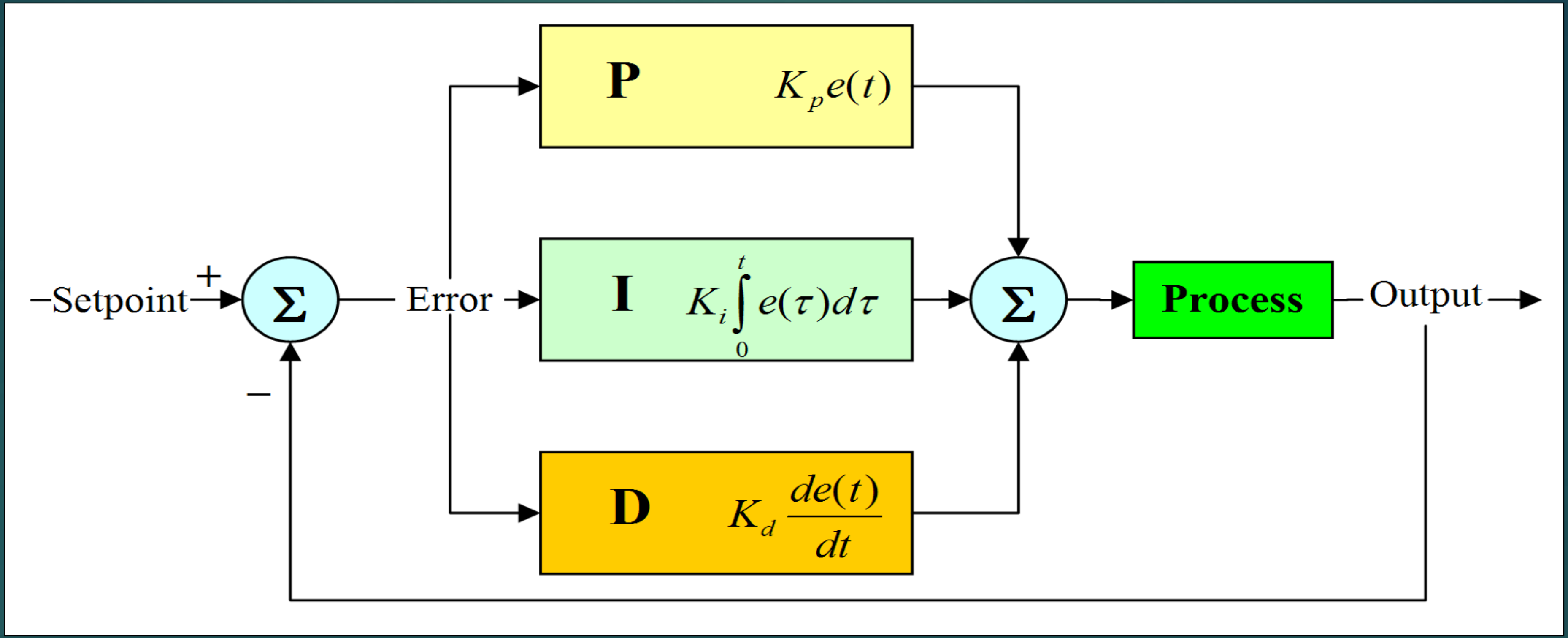
Compensator Design

The three chosen compensators are:

- PID
- Fuzzy Logic
- NARMA-L2

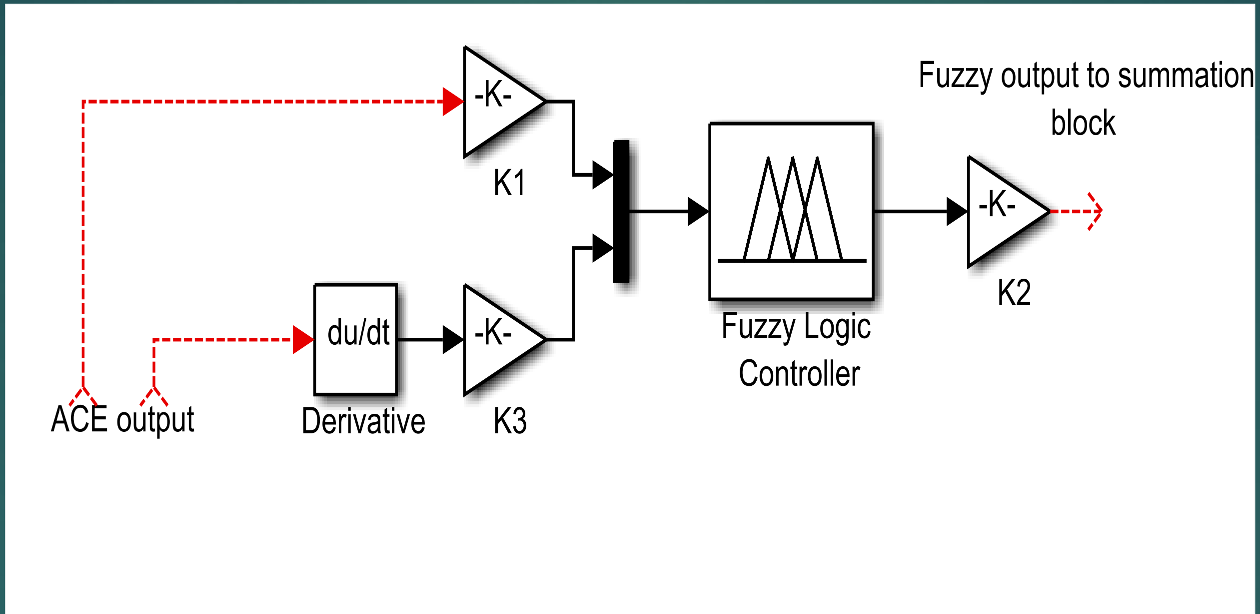
The PID controller was chosen for a proper comparative analysis to be carried out between a conventional controller and intelligent ones

PID Controller



- PID controller is the extreme form of a lead-lag compensator
- K_P , K_i and K_d are the gains of the Proportional, Integral and Derivative terms of the PID
- Tuning of parameters by self tuning algorithm in MATLAB

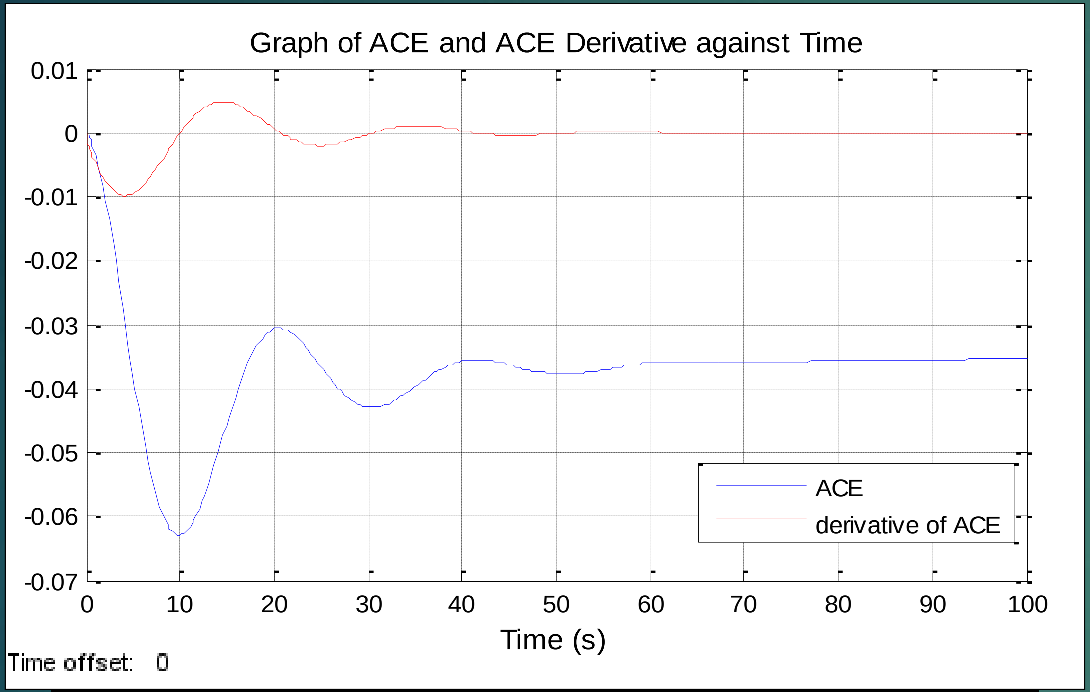
Fuzzy Logic Controller

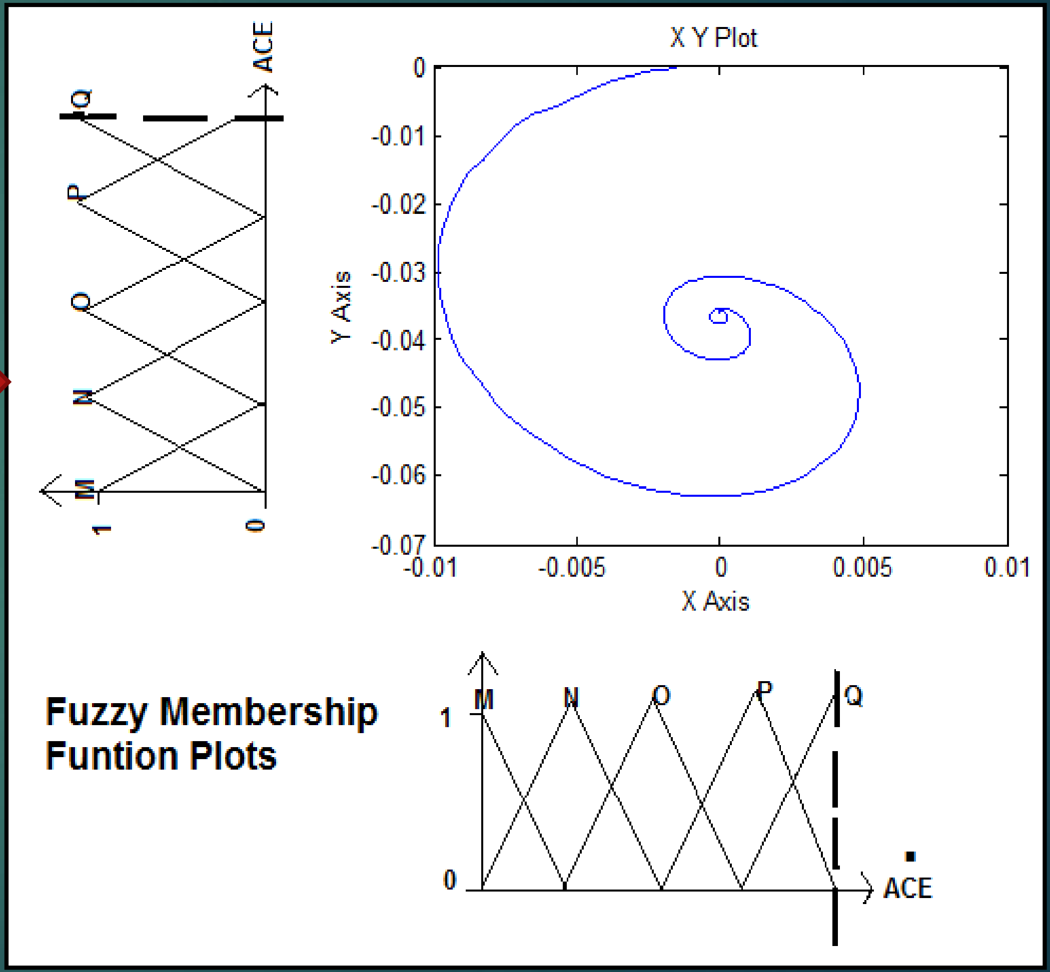


- K1, K2 and K3 are the scale factors of controller
- Stages of Fuzzy Logic Controller design:
  - Fuzzification
  - Rule base set up
  - Decision-making stage
  - Deffuzification

Fuzzy Logic

Fuzzification and Rule-base Set-Up





Rule-base Set-Up

M: Large Negative

N: Small Negative

O: Zero

P: Small Positive

Q: Large Positive

Fuzzy Logic

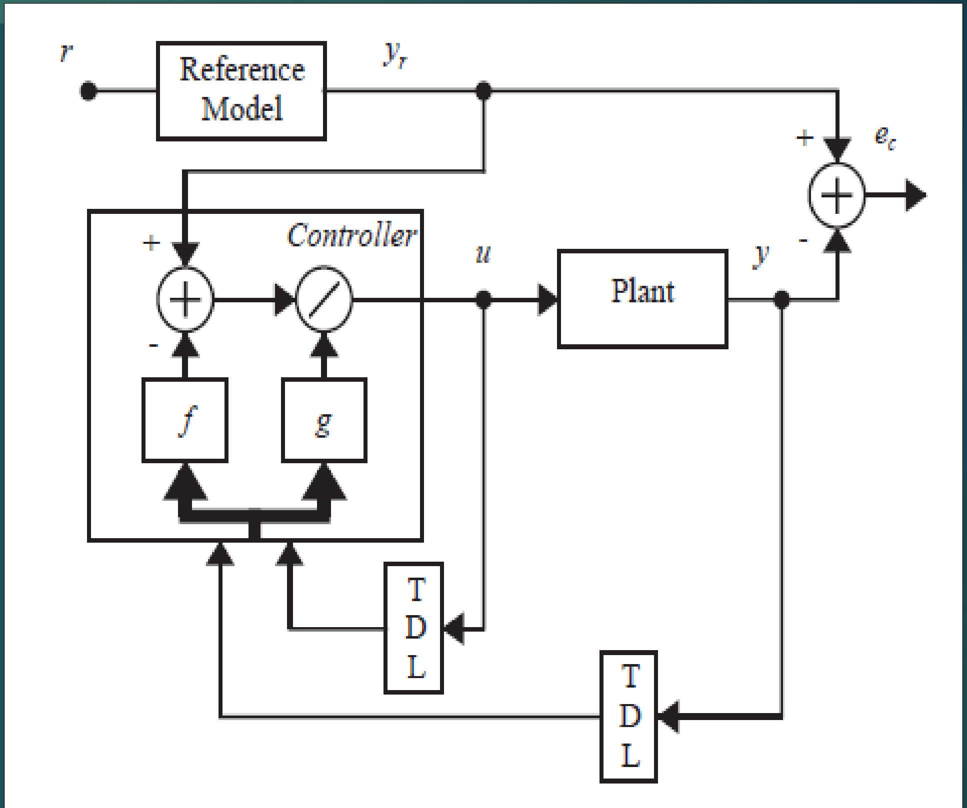
Decision-Making and Defuzzification

- Execution of rules according to Rule Table to obtain a Fuzzy control output from the Inference System
- Rule Table was taken from previous research on LFC
- Defuzzification consists of producing a non-Fuzzy control action from the Inference System that will rectify the ACE output
- Method used: centroid

ANN-NARMA-L2

Architecture

- Nonlinear Autoregressive Moving Average (NARMA-L2)
- ACE output *y* should follow the reference model output *yr* to completely eliminate error in the system
- Controller should provide control input u to adjust ACE output *y* by finding the ratio of two previously determined functions.
- Design consists of two stages:
  - Plant Identification
  - Control Design

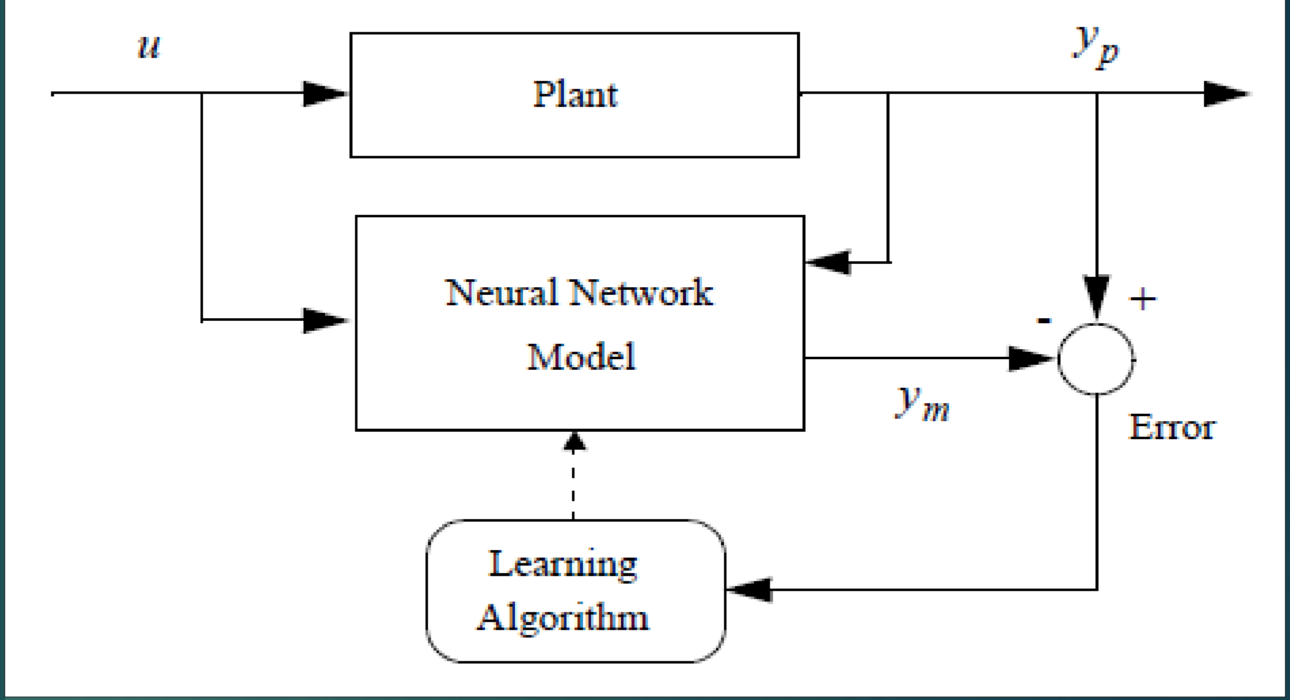


$$u(k+1) = \frac{y_r(k+d) - f[y(k), \dots, y(k-n+1), u(k), \dots, u(k-n+1)]}{g[y(k), \dots, y(k-n+1), u(k), \dots, u(k-n+1)]}$$

ANN-NARMA-L2

Plant Identification

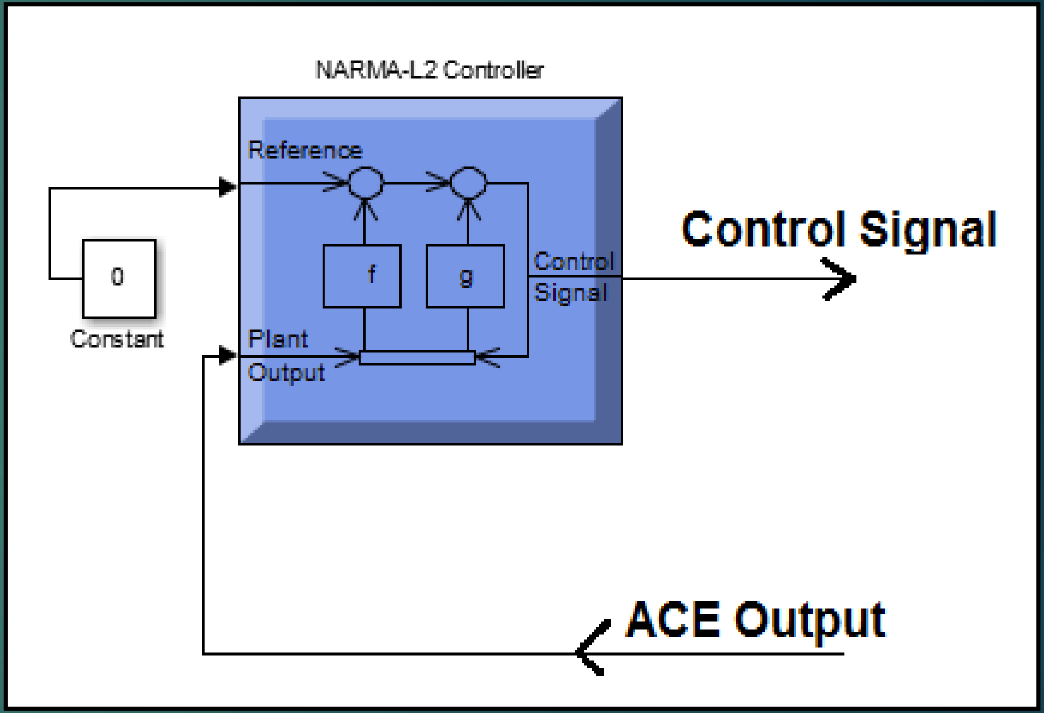
- Training of ANN such that it is representative of the actual dynamics of the plant
- The parameters of the Network architecture were chosen from previous published papers
- Training data was obtained by importing the input and output data of the PID into the network
- Training function chosen was the Levenberg-Marquardt back-propagation algorithm



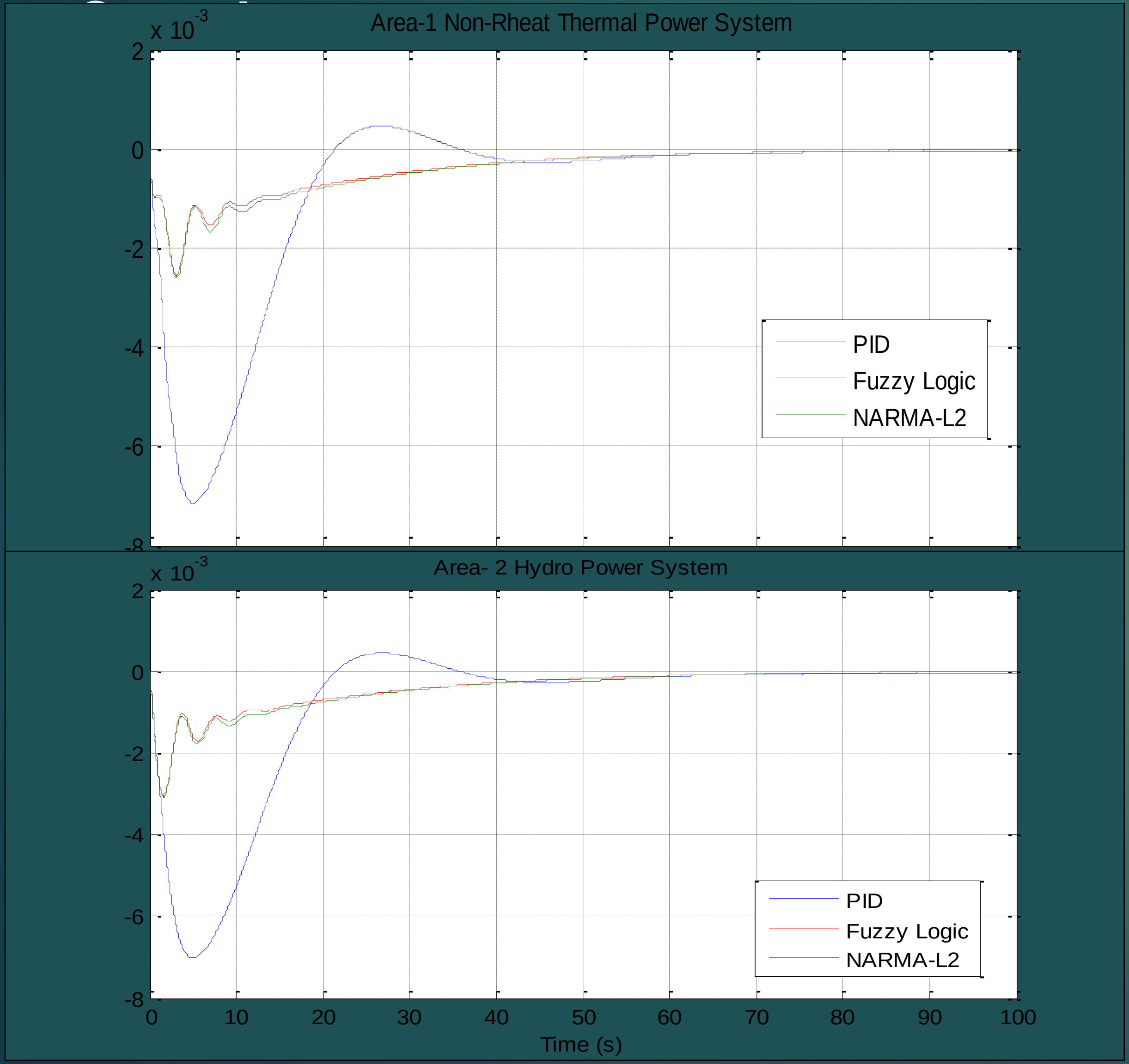
ANN-NARMA-L2

Control Design

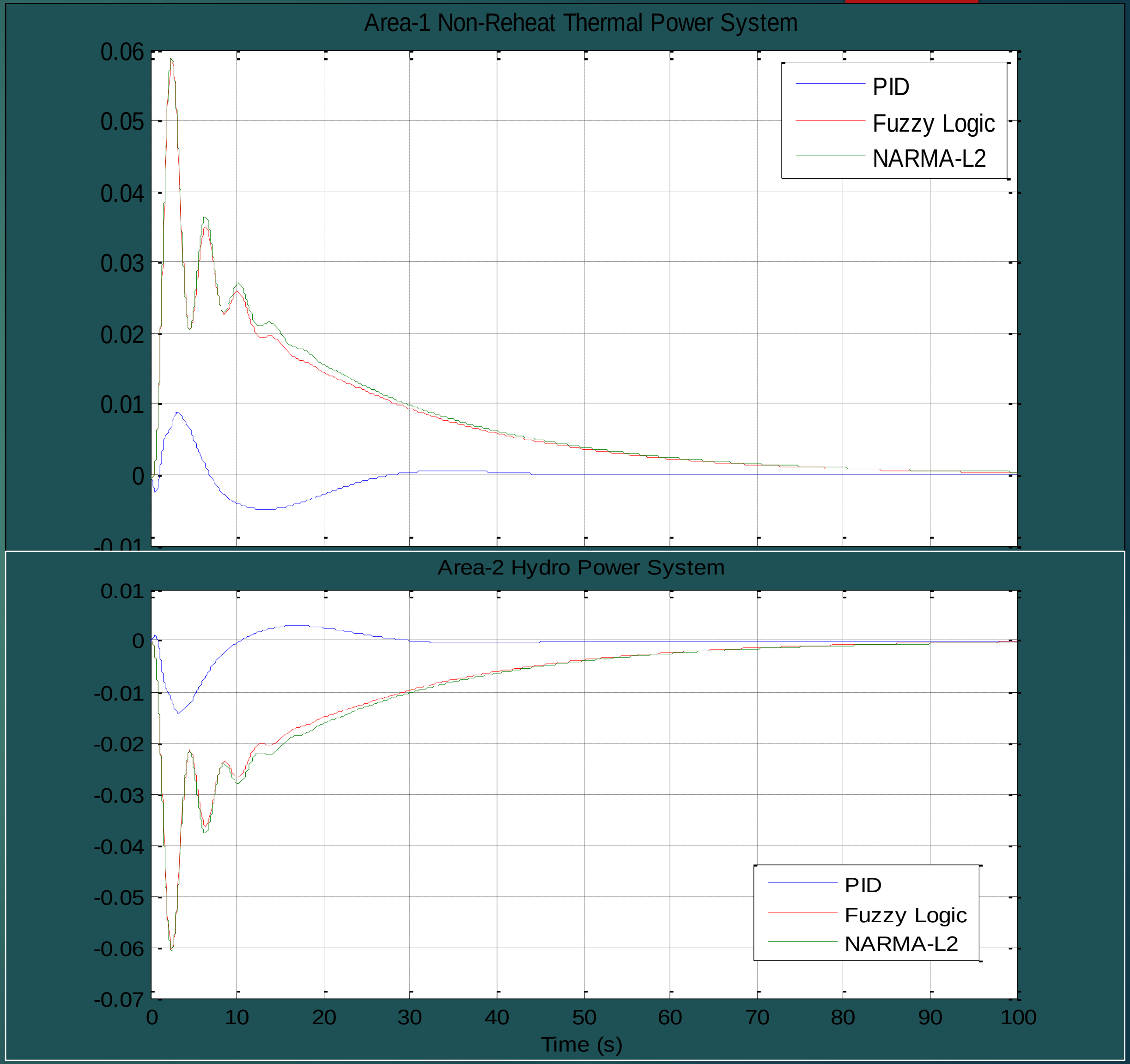
- The reference model must be zero such that the plant ACE output *y* follows the reference model output y_r and becomes zero
- A constant set to ‘0’ is inserted at the reference input of the controller



Hydro-Non Reheat Thermal Power

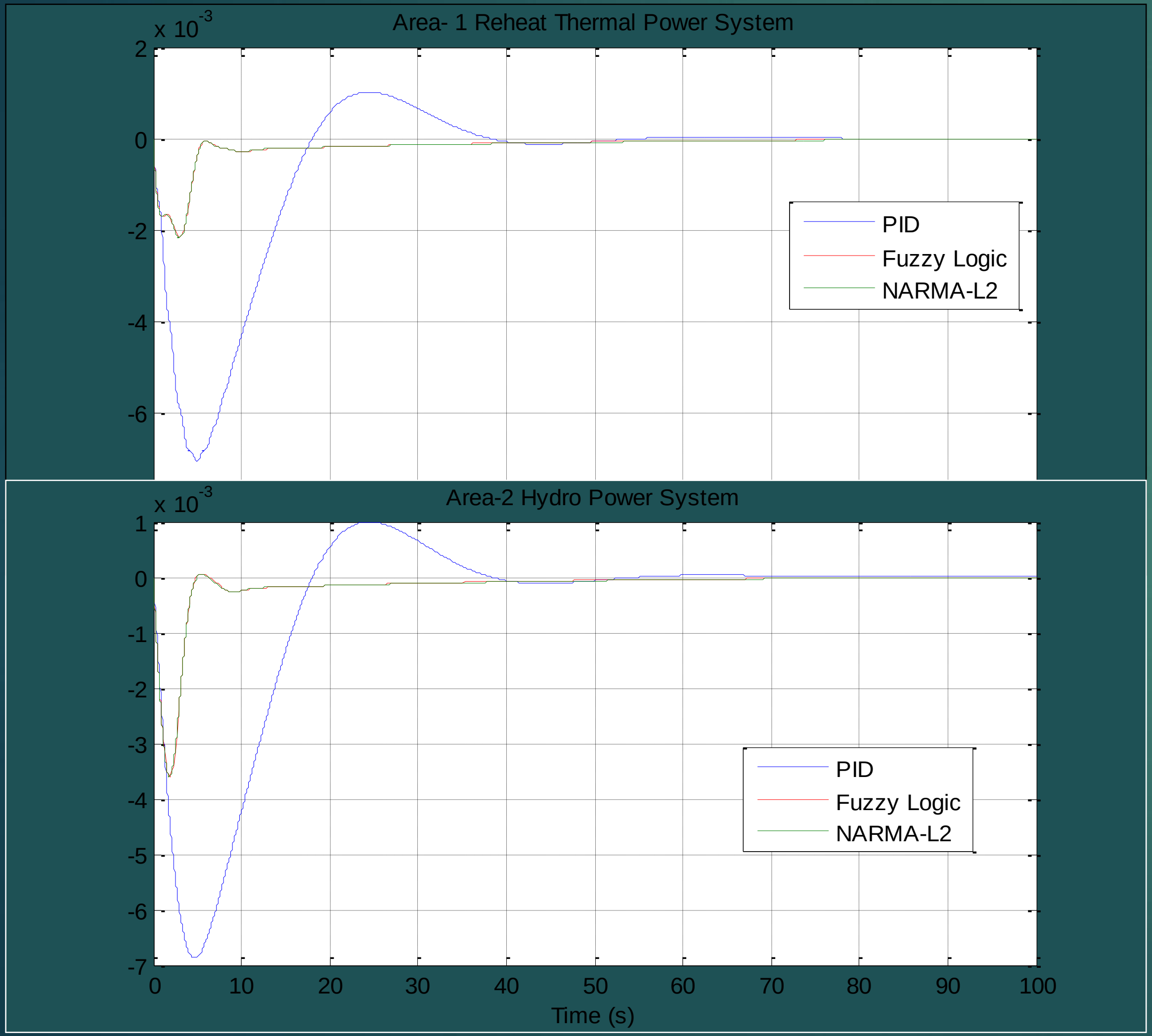


Frequency

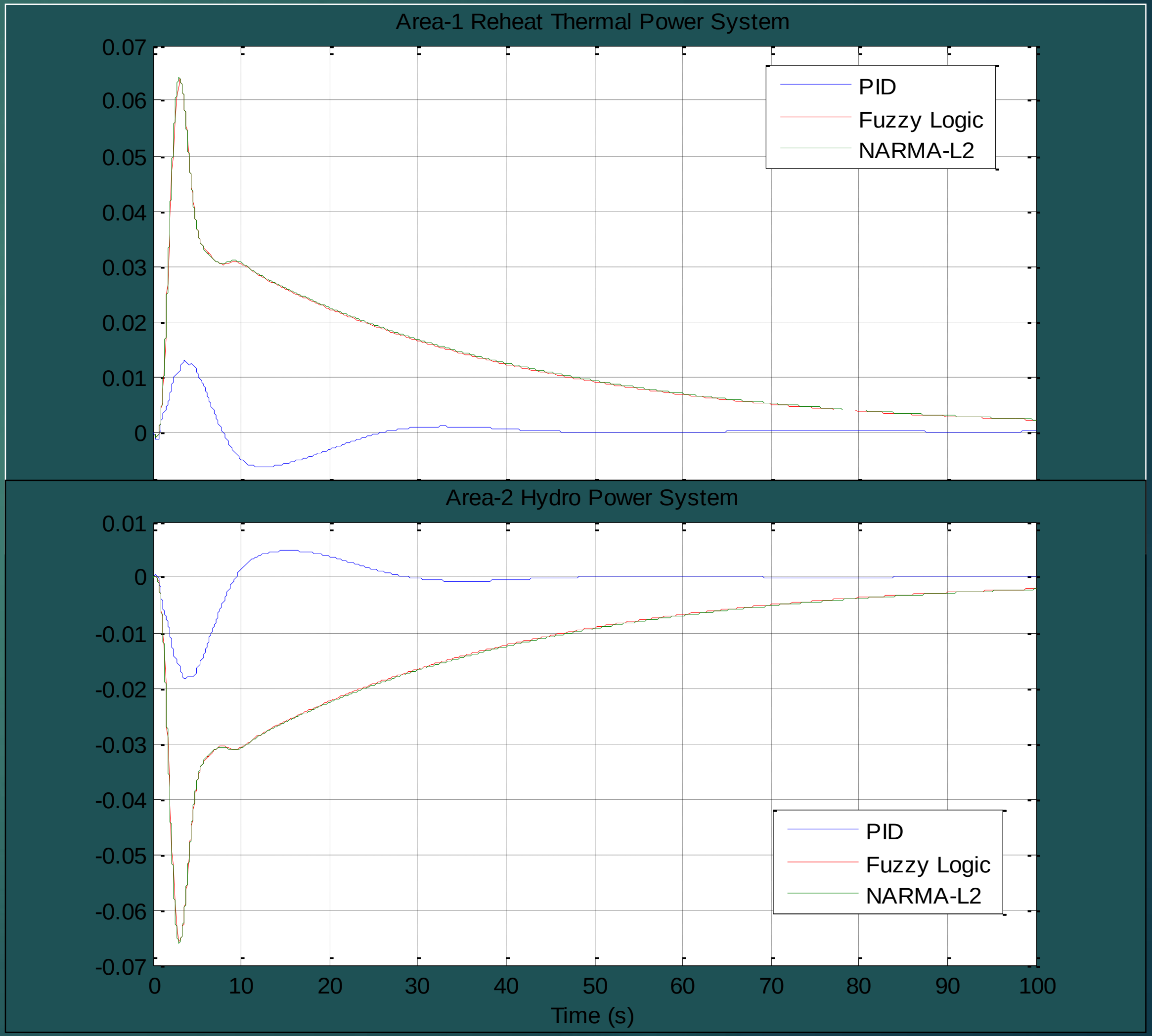


ACE

Hydro-Reheat Thermal Power System

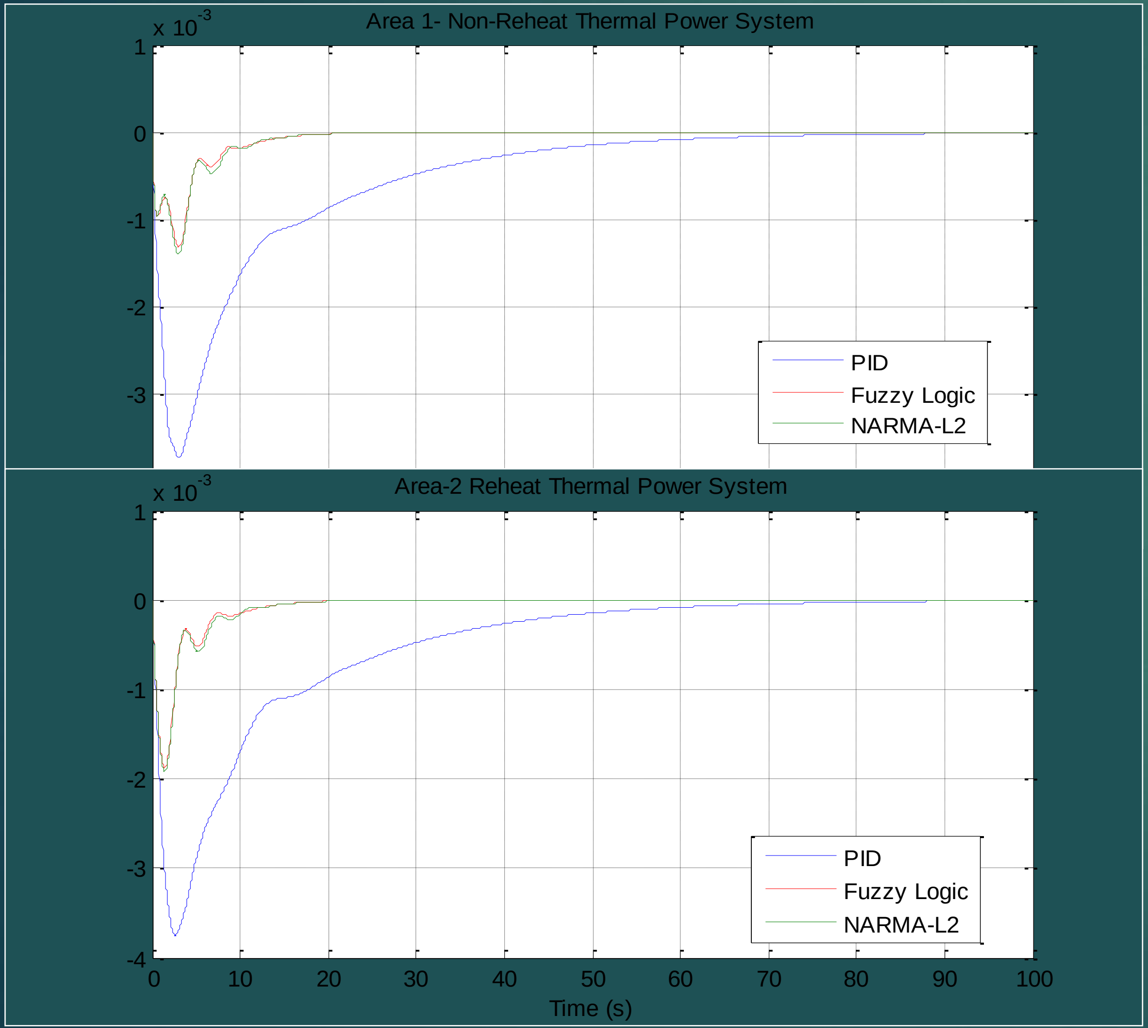


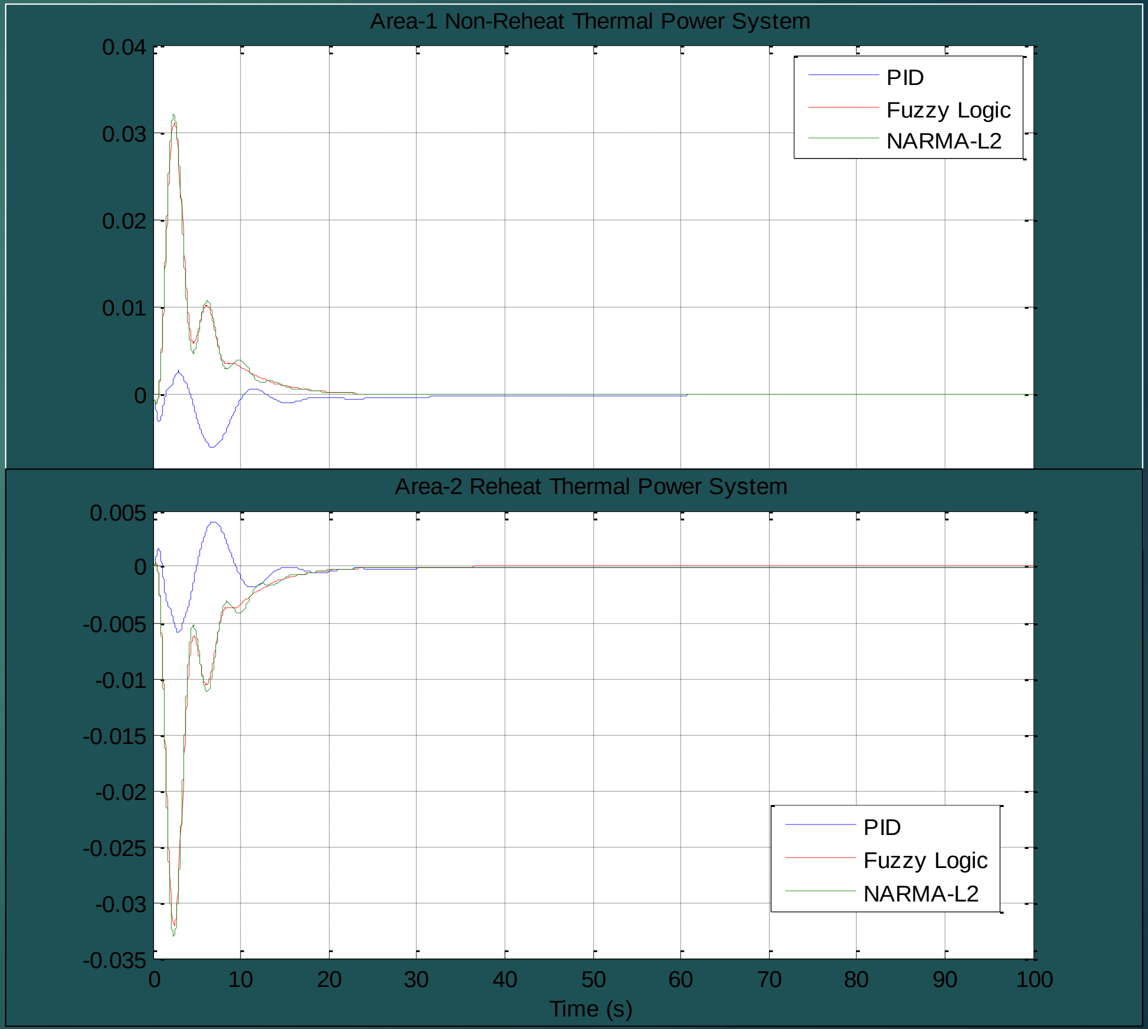
Frequency



ACE Output

Non Reheat-Reheat Thermal Power System





Frequency

ACE Output

Conclusion and Further Works

- Percentage frequency overshoot and undershoot have been reduced considerably for the Intelligent controllers c.f. PID controller
- The ACE outputs however got worse but ultimately goes to zero !!!
- To improve response of systems:
  - Design of Fuzzy-PID to eliminate errors due to variable load-change
  - Adaptive membership functions plots of the Fuzzy Logic and adaptive inputs to NARMA-L2 to match variable load-change
- Validate results on areas with two or more generating units and with more interconnected areas.

Thank You...