The Journal of CPRI,
Vol. 10, No. 1, March 2014 pp. 41-50

Real Time Simulation of Multi-Area Power System with Polar Fuzzy Controller

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The Fuzzy Logic Controller has proven its worthiness for nonlinear complex systems. Multi-area power system is quite complex and nonlinear in nature. In this paper, Fuzzy logic controller (FLC) is developed for three area nonlinear power system. But there are inherent drawbacks of FLC such as its performance depends on number of rules, long computation time, large memory requirement etc. To overcome these problems, a polar fuzzy controller (PFC) is proposed to control the load frequency deviations in multi area power system. The PFC works on the basis that an angle acts as an input and controller response as an output. In conventional PI controller and FLC, two gains are to be tuned;whereas the PFC needs only one gain to be tuned, because the angle of PFC is calculated from the ratio of frequency deviation and the integral of frequency deviation. Hence, only one gain is sufficient to tune it. In PFC, only two rules are sufficient in the rule base. The work is extended to test the performance of proposed PFC in real time environment with the help of OPAL-RT simulator (OP 5142 v 10.2.4).

Keywords: *Load frequency control, Polar fuzzy Controller, Real time simulation, AGC.*

1.0 INTRODUCTION

The multi area inter connected power system is highly nonlinear complex system. A lot of research has been done in the area of load frequency control (LFC) of multi area power system [1-2]. The successful operation of interconnected power systems requires the matching of total generation with total load demand and associated system losses [2-3]. With time, the operating point of a power system changes, and hence, it may experience deviations in nominal system frequency and scheduled power exchanges to other areas, which may yield undesirable effects [4-5].

There are two variables of interest, namely, frequency and tie-line power exchanges [6-7]. Fuzzy controller is based on a logical system called fuzzy logic which is much closer to human thinking and natural language than classical logical systems [8-10]. Fuzzy set theoryand fuzzy logic establish the rules of a nonlinear mapping. The main goal of LFC in interconnected power systems is to protect the balance between production and consumption [11]. Because of the complexity and multi-variable conditions of the power system, conventional controllers may not give satisfactory solutions [12-13]. On the other hand, their robustness and reliability make fuzzy controllers useful in solving a wide range of control problems [14-16]. Load frequency control in two area system using fuzzy logic controller is found to be suitable[17-18]. But the fix rule basedfuzzy controllers have some drawbacks such as difficulty in knowledge acquisition,

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no adaptability etc. and hence for dynamic time varying system, it is unable to give good performance.

To overcome these problems, Polar fuzzy controller (PFC) is proposed in this paper. It is quite simple in construction and has great power to control complex nonlinear power systems. The polar fuzzy controller used in this paper needs only two rules in the rule base as compared to 49-rules in simple FLC. The proposed PFC, FLC and conventional PI controllers are used to control the frequency of a three area nonlinear power system which is consisting of Thermal, Hydro and Nuclear systems.The results are compared for all these controllers.

The main emphasis of this paper is to validate the developed controllers in real time environment.

2.0 HISTORY OF REAL TIME SIMULATORS

This section deals with the historical development of real time simulators for fast prototyping and system development.

In real-time simulation, the accuracy of computations depends not only upon precise dynamic representation (modeling) of the system, but also on the length of time used to produce results.In real-time simulation the simulator accurately produces the internal variables and outputs of the simulation within the same length of time that its physical counterpart requires. In fact, the time required to compute the solution at any given time-step must be shorter than the wall-clock duration of the time-step. However, if all simulator operations are not achieved within the required fixed time-step, the real-time simulation will giveerror called “overrun”.

There are number of benefits of real time simulation such as time saving, reduction in development cost, increased test functionality, reduced risk etc.Simulator technology has been evolved as shown in Figures 1 and 2. Earlier the real time simulators are physical or analogue type such as HVDC simulators & TNAs for Electro-Magnetic Theory(EMT), protection and control studies. Then they are evolved to hybrid Analogue and Digital simulators capable of studying EMT behavior [19], to fully digital real-time simulators. With the development of microprocessor and floating-point DSP technologies, physical simulators have been gradually replaced with fully digital real-time simulators.

DSP-based real-time simulators were developed using proprietary technology, and used primarily for Hardware in Loop (HIL) studies [20]. However, the limitations of using proprietary hardware were recognized quickly, leading to the development of commercial supercomputer-based simulators, such as HYPERSIM from Hydro-Quebec [21], which is no longer commercially available. Attempts have been made by universities and research organizations to develop fully digital real-time simulators using low-cost standard PC technology, in an effort to eliminate the expansive high-end supercomputers [22]. Such development was very difficult due to lack of fast, low-cost inter-computer communication links. However, the advent of low-cost, readily available multi-core processors [23] and related Commercial of the Shelf (COTS) computer components has directly addressed this issue, clearing the way for the development of much lower cost and easily scalable real-time simulators [24]. COTS-based high-end real-time simulators equipped with multi-core processors have been used in aerospace, robotics, automotive and power electronic system design and testing for a number of years. The latest trend in real-time simulation consists of exporting simulation models to FPGA [25].

In this paper, for the real time simulation, RT 5142 simulator is used which is manufactured by OPAL-RT, Ontario, Canada.

3.0 DEVELOPMENT OF FUZZY LOGIC CONTROLLER

The fuzzy logic controller (FLC) has been developed in this section to control the frequency deviation of three area nonlinear power system.

FLC is consisting of two inputs (i.e. frequency deviation Δf and integral of frequency deviation ∫Δf) and one output (i.e. control action). Each input is divided intoseven triangular membership functions. Hence, the FLC works on the basis of 49 rules as shown in Table 1.

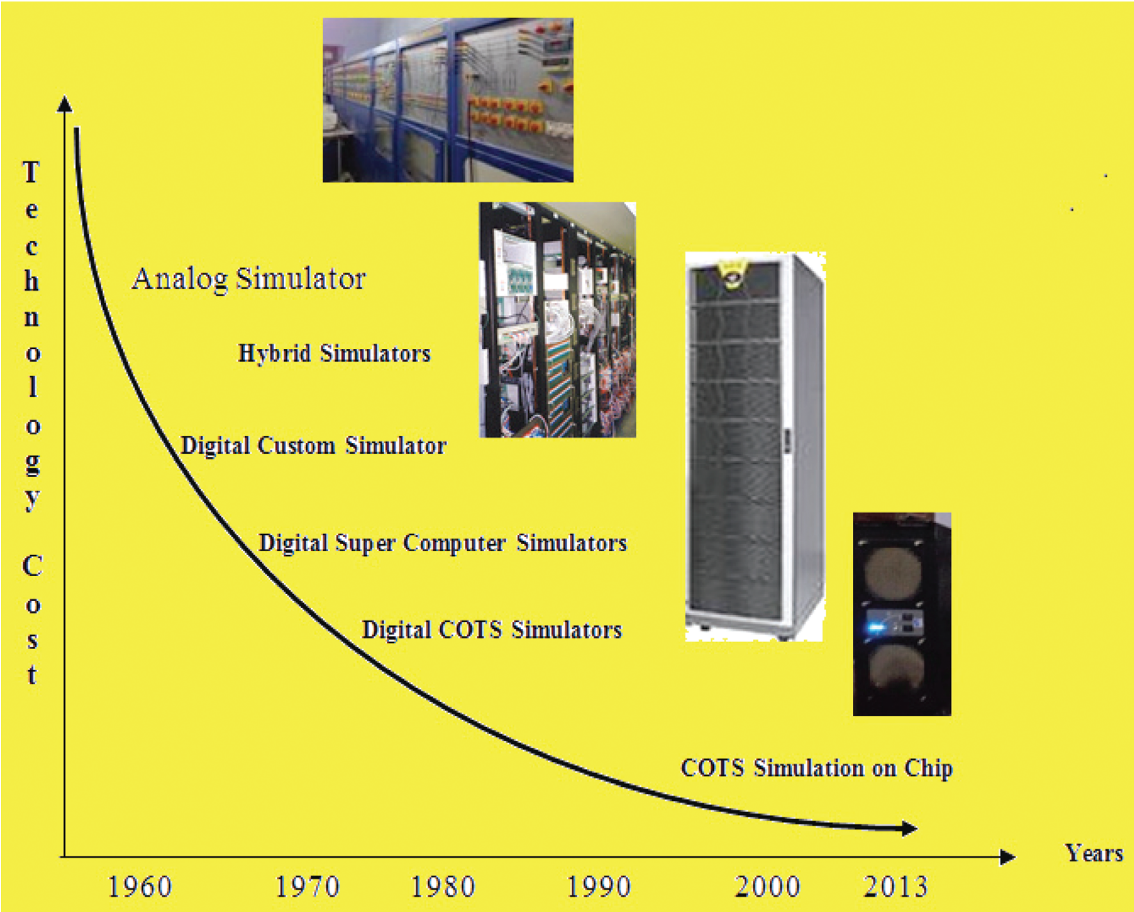

FIG. 1 EVOLUTION OF REAL-TIME SIMULATION TECHNOLOGIES

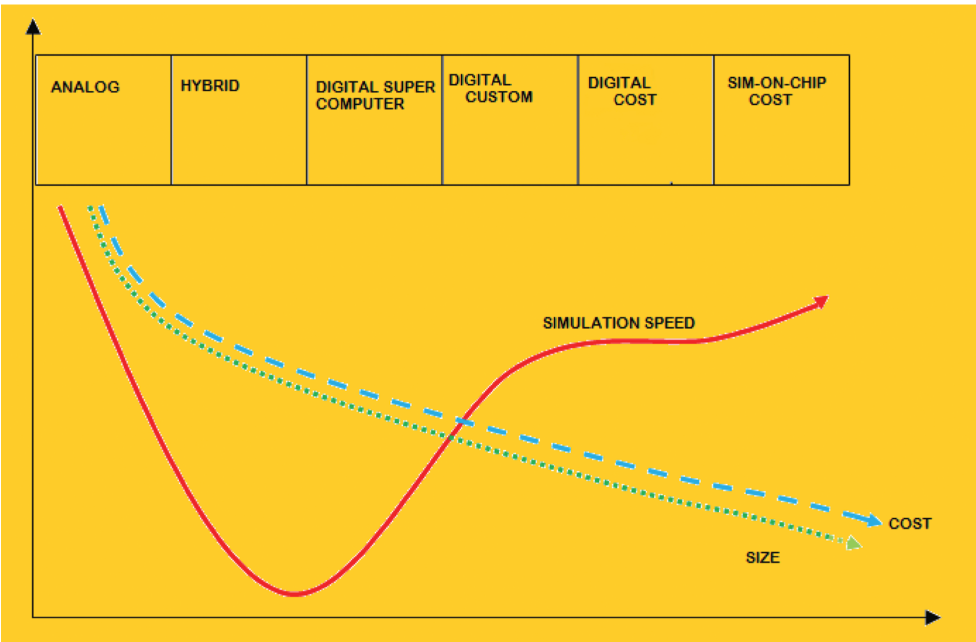

FIG. 2 PERFORMANCES OF DIFFERENT SIMULATORS

TABLE 1

FAM TABLE FOR FLC

		ACE						
		nb	nm	ns	z	ps	pm	pb
Error	nb	pb	pb	pm	pm	ps	ps	z
	nm	pb	pb	pm	pm	ps	z	z
	ns	pb	pm	pm	pm	z	ns	ns
	z	pb	pm	pm	z	ns	nm	nb
	ps	pm	pm	ns	ns	nm	nb	nb
	pm	ps	ps	ns	nm	nb	nm	nb
	pb	ns	ns	nm	nm	nm	nm	nb

4.0 POLAR FUZZY CONTROLLERS

The polar fuzzy set uses the angle as its variable and the linguistic value changes with the angle θ, defined on the unit circle and their membership values are μ(θ). Polar fuzzy is useful in situations that have a natural basis in polar coordinates or in situations where the value of a variable is cyclic in nature such angular speed or frequency. Polar fuzzy sets differ from standard fuzzy sets only in their range as they are defined on a universe of angle. Hence it repeats shapes after every 2π radian [26-28].

In this section, the working of PFC is described. The block diagram of polar fuzzy logic controller is shown in Figure 5. Primarily frequency deviation and its integralare defined in complex plane and this complex quantity (consisting of real and imaginary part) is then converted into equivalent polar co-ordinates (i.e. angle and magnitude). The input to polar fuzzy controller is angle and its output is intermediate control action. Two fuzzy Gaussian membership functions are used which are large positive (LP) and large negative (LN) for input angle. These two membership functions are complimentary to each other. The range of angle θ is from 0 to 11. Most of the time, PFC operates in first quadrant. This can easily be seen in rule viewer as shown in Figure 3. Control action should be such that system attains desired frequency as quickly as possible with minimum deviation and oscillations. Output of the fuzzy logic controller (UFLC) of PFC is defined into two linguistic variables namely, positive (P) and negative (N), which are triangular membership functions as shown in Figure 4. Only two simple rules have been considered.

Rule 1 - If θ is LP then UFLC is P.

Rule 2 - If θ is LN then UFLC is N.

Hence, the output of FLC unit of PFC is a function of angle (θ) i.e.

$U_{FLC} = f_1(\theta)$,

and final PFC output $U = U_{FLC} * R$

Where

θ = angle in degree = $\tan^{-1}(ce/e)$;

R = Magnitude = $\sqrt{(e^2+ce^2)}$;

$e=K_o * \Delta f$ and

ce =integral of frequency deviation.

Two triangular output membership functions P (positive) and N (negative) are taken in the range -0.15 to +0.15 for FLC of PFC. The output of FLC and magnitude multiplied together to get the final output 'U'.

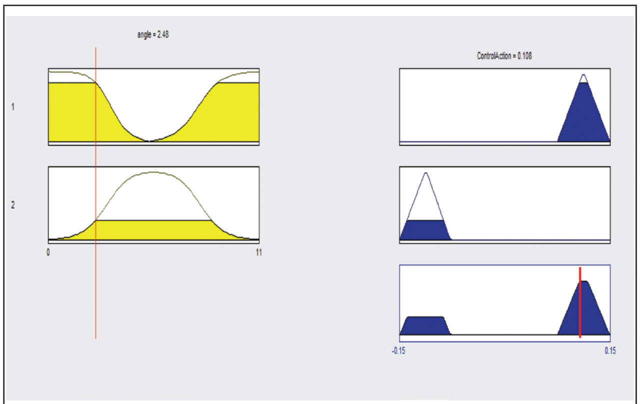

FIG. 3 POLAR FUZZY CONTROLLER RULE VIEWER

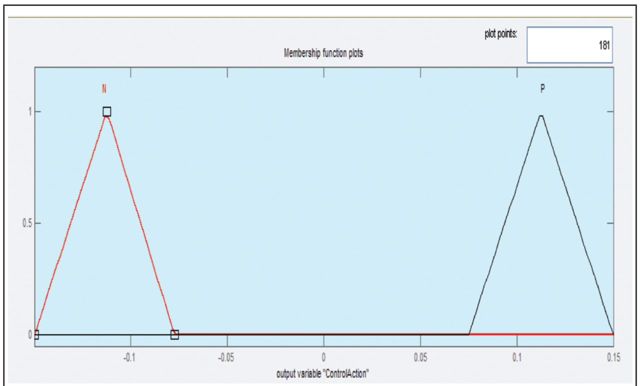

FIG. 4 FUZZY SETS OF OUTPUT VARIABLE FOR PFC

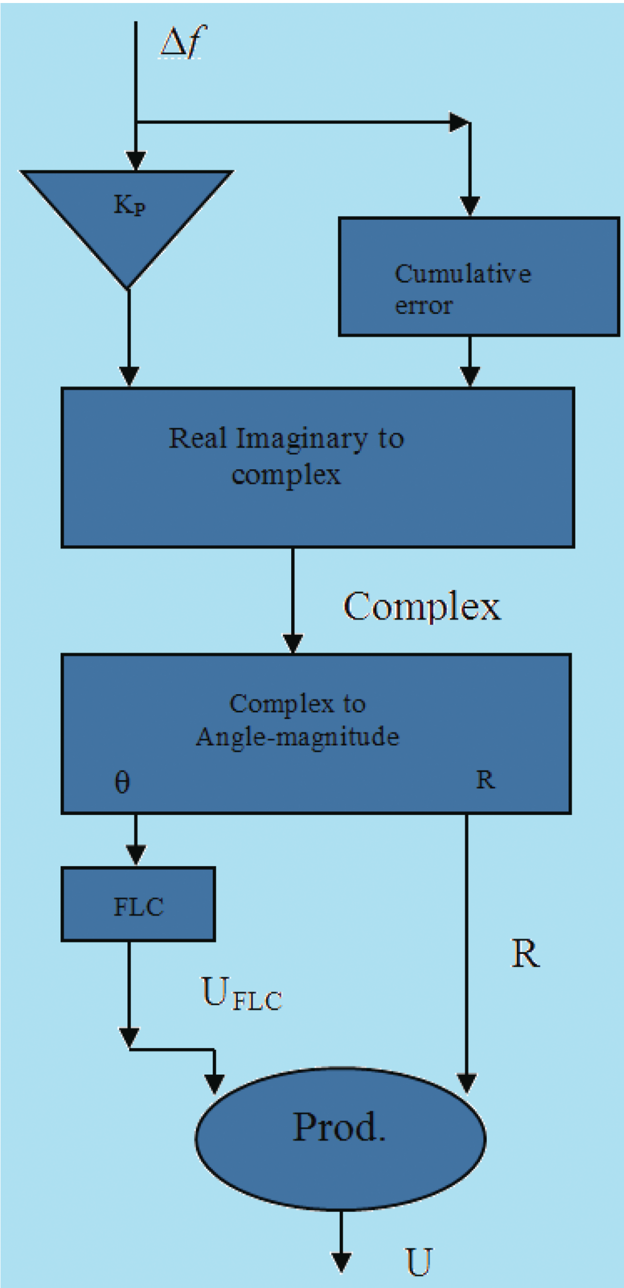

FIG. 5 BLOCK DIAGRAM MODEL OF POLOR FUZZY CONTROLLER

5.0 LOAD FREQUENCY CONTROL OF THREE AREA NONLINEAR SYSTEMS WITH DIFFERENT TYPE OF CONTROLLERS IN RT LAB ENVIRONMENT

The nonlinear models of thermal, hydro and nuclear systems are developed in Matlab/ Simulink environment. For nonlinear thermal system, Backlash (Dead-band), Boiler dynamics and Generation Rate Constraint (GRC) are considered. For hydro system, GRC and Backlash nonlinearities are considered and for nuclear system backlash nonlinearity is considered. These non-linearities are described below:

i. Governor Dead Band (Backlash)

The mechanical fly-ball governors are used in turbines to control the steam/water input to it. Normally, they are slow in response and also suffer from the problem of backlash. All governors have a dead band in response, which is important for power system frequency control in the presence of disturbances. The maximum value of dead band for governors of large steam turbines is specified as 0.06% (0.03 Hz for 50 Hz supply frequency).

ii. Generation Rate Constraint (GRC)

The generation rate constraint of a generating plant is the constraint or limit of maximum rate of change of electrical power output of the plant when there is change in demand. The GRCs result in larger deviations in area control errors as the rate at which generation can change in the area is constrained by the limits imposed. Therefore, the duration for which power needs to be imported increases considerably as compared to the case where generation rate is not constrained. The reheat units of thermal area have a generation rate around 3% per min to 10% per min. i.e. the maximum rate of valve opening and closing speed is restricted by these limits. For nuclear area, the generation rate is within the safe limits and therefore GRC can be ignored. But for Hydro area it is taken as 4.5% to 6.0% and for nuclear it is ignored.

iii. Boiler Dynamics

In most of the thermal units drum type boilers are used. These boilers are also known as recirculation boilers, which circulates the drum liquid to absorb the heat energy from wall of the furnace. Steam flow from boiler and MW output of generator are closely related under nominal change in power output. But under severe changes, the steam conditions (temperature and pressure) cannot be maintained to the same level due to boiler dynamics. The boiler dynamics are modeled in Simulink as shown in Figure 6. The parameters of boiler dynamics are:

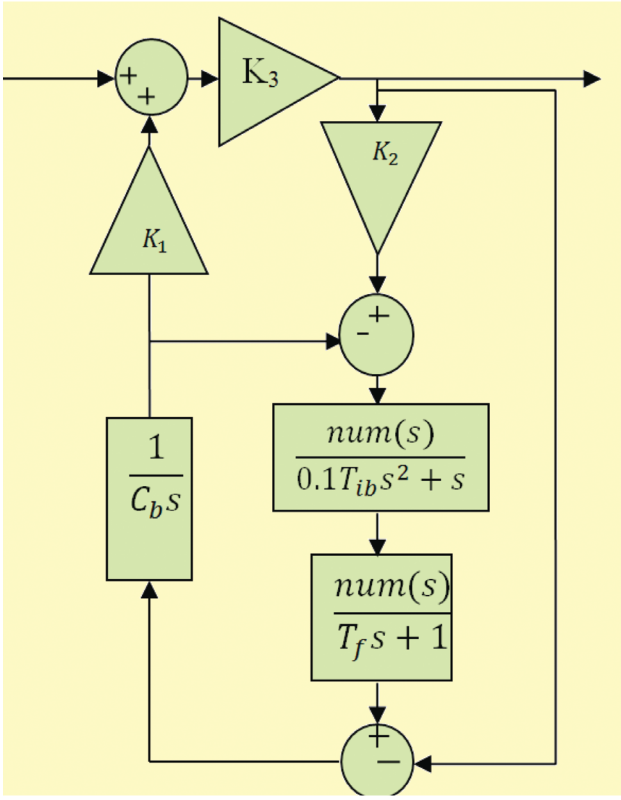

FIG. 6 BOILER DYNAMICS

Where:

K_1=0.85; K_2=0.095; K_3=0.92; C_b=200; T_d=0 sec;

T_f=25 sec; K_{ib}=0.03; T_{ib}=26 sec; T_{rb}=69 sec

These nonlinearities are included in power model development. The conventional PI, FLC and PFC controllers developed in earlier sections have been implemented for controlling the nonlinear three area power system in real time environment and the performance have been compared. In RT lab environment one master, two slaves and one console are grouped. The conventional PI controlled three area hydro-nuclear-thermal system is taken as Master Subsystem, FLC controlled three area system is considered as Slave1 Subsystem and PFC controlled three area system is considered as Slave 2 Subsystem as shown in Figure 7.

Here one slider load is used for load variation in the range of 0-1%. There is one opcom block attached in each subsystems which helps in communication between the subsystems. The block diagram of real time simulation is shown in Figure 8.

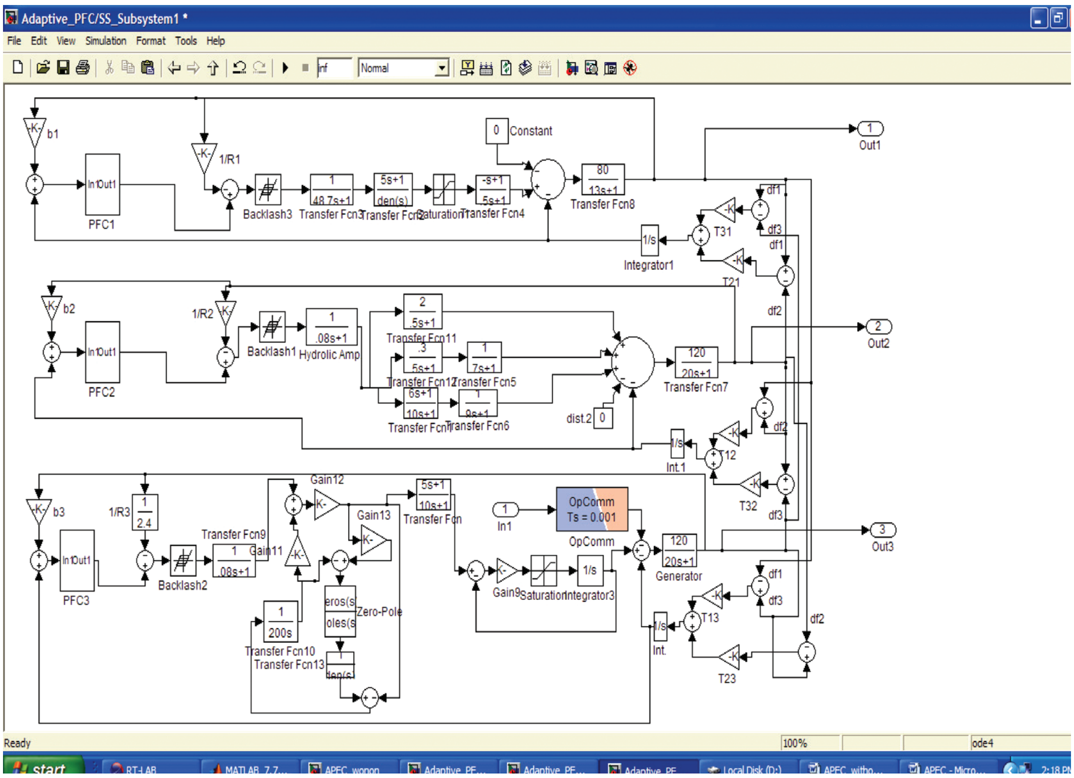

FIG. 7 NON-LINEAR THREE AREA SUB SYSTEM WITH PI CONTROLLER AS MASTER, FUZZY CONTROLLER AS SLAVE 1 AND PFC AS SLAVE 2 SUBSYSTEM IN RT LAB ENVIRONMENT

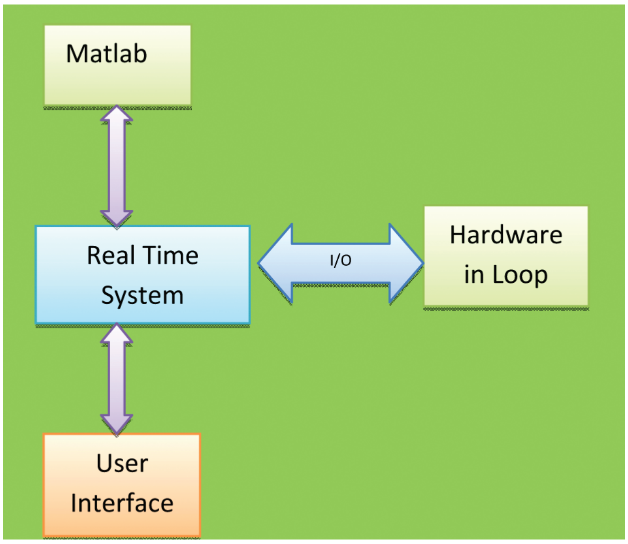

FIG. 8 BLOCK DIAGRAM OF REAL TIME

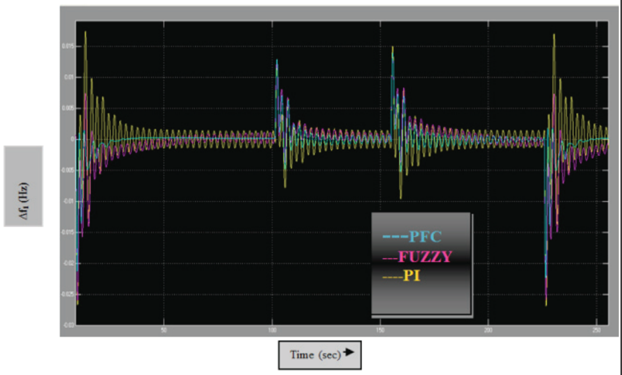

FIG. 9 REAL TIME RESPONSE OF THERMAL SYSTEM OF THREE AREA NONLINEAR POWER SYSTEM WHEN RANDOM DISTURBANCES GIVEN IN THERMAL AREA IN RT LAB ENVIRONMENT

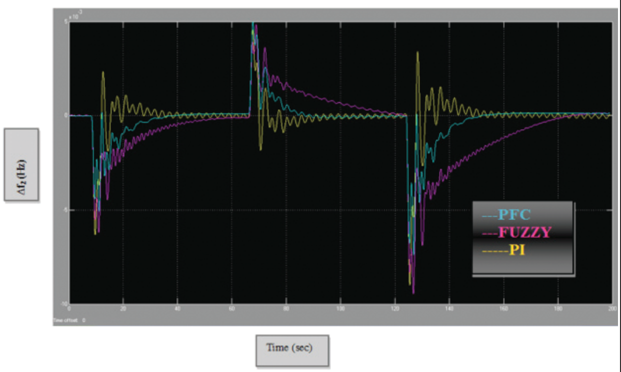

FIG. 10 REAL TIME RESPONSE OF NUCLEAR SYSTEM OF THREE AREA NONLINEAR POWER SYSTEM WHEN RANDOM DISTURBANCES GIVEN IN THERMAL AREA IN RT LAB ENVIRONMENT

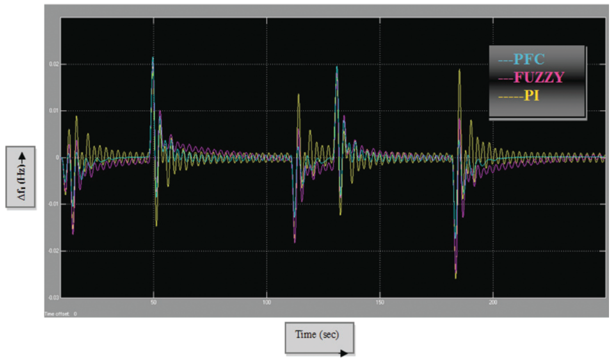

FIG. 11 REAL TIME RESPONSE OF HYDRO SYSTEM OF THREE AREA NONLINEAR POWER SYSTEM WHEN RANDOM DISTURBANCES GIVEN IN THERMAL AREA IN RT LAB ENVIRONMENT

6.0 RESULTS AND DISCUSSION

The simulation results are shown in Figures 9-11. In Figures 9-10 the frequency responses of thermal and nuclear areas respectively of PFC controlled power system settle quickly to normal value with minimum deviations as compared to FLC and conventional PI controllers. But in case of hydro - areathe PFC response is much more similar duringinitial transients because the controller unable to do much in thatperiod as shown in Figure 11. After the initial transients the frequency deviation of PFC becomes zero earlier than other controllers. Hence, from the results, it is clear that polar fuzzy controller has superior performance over other controllers also in real time environment.

7.0 CONCLUSIONS

In this paper, PFC, FLC and conventional PI controllers are developed and implemented for three area (hydro-nuclear-thermal) nonlinear power system with different random disturbances,with the help of OPAL-RT real time simulator OP 5142 v 10.2.4. it is concluded that PFC gave better results in terms of lessersettling time, frequency dip and minimum oscillations in real time environment over, fuzzy and conventional PI controllers under different operating conditions.

The work may be further extended to make tuned adaptive PFC using different techniques such as artificial neural network or evolutionary techniques like genetic algorithms, particle swarm optimization or ant optimization etc. The PFC may be also used for other control applications.

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