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Design of A New Deregulated Market Structure for an Indian Grid with Focus on Different Controllers

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The main objective of this paper is to create a new deregulated market structure namely Dyadic Market Structure which provides an optimal environment to nurture private sectors and also to protect customer interests. The four area interconnected system (Andhra Pradesh, Karnataka, Kerala and Tamil Nadu) of the Southern Regional Grid is considered as a public sector of this structure and its frequency response is improved by secondary regulation by using various controllers like PI, PID and Fuzzy logic Controllers. The simulation is carried out using MATLAB SIMULINK.

Keywords: *Deregulation, Dyadic market structure, Secondary regulation, MATLAB SIMULINK, Indian independent system operator (IISO), PI, PID, Fuzzy controller and POWERCO.*

1.0 INTRODUCTION

This paper enunciates a structure which introduces private sector competition and increases power generation. In other words, this structure infuses the necessary thrust to the power sector of our country modeling perfection in every aspect. The International Energy Agency estimates that India requires $135 billion to provide universal access of electricity to its population [1]. The electricity sector in India has an installed capacity of 214.630 GW as of February 2013 whereas by 2021 it is estimated that India requires 1918 Tera Watt Hours (TWh) of electricity [2]. The 17th electric power survey of India report claims that over 2010–2011, India's industrial demand accounted for 35% of electrical power requirement, domestic household use accounted for 28%, agriculture 21%, commercial 9%, public lighting and other miscellaneous applications accounted for the rest. The electrical energy demand for 2016–2017 is expected to be at least 1392 TWh, with a peak electric demand of 218 GW. The electrical energy demand for 2021–2022 is expected to be at least 1915 TWh, with a peak electric demand of 298 GW. Therefore a stable market structure with a healthy environment for competition has to be introduced to meet this enormous demand in the coming years. Deregulation at each sector of electricity allows a better environment for the production, transmission and distribution of power.

2.0 REGULATED MARKET STRUCTURE

The present market structure prevalent in India is a regulated vertically integrated monopolistic structure controlled by Government with the Ministry of Power acting as the apex central government body which controls and regulates electricity sector. After the Electricity Act of 2003 private sectors were allowed to generate power and considerable steps are taken by the

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government to improve the amount of power generated and its quality.

3.0 DEREGULATED MARKET STRUCTURE

In the years to follow, a deregulated market structure has to be introduced in India illuminating the whole country and eliminating the present power crisis. There are many countries which have adapted deregulated market structure [3] some of those traditional deregulated structures are featured below.

A. Poolco Market Structure

It is a time frame based market where three stages are involved. The first stage is receiving offers where bids are submitted in this auction based market system, the second stage is a real time invocation of services and the third stage is fixing Market Clearing Price of the system [4]. An ISO overlooks the functioning of the entire system.

B. Bilateral Market Structure

The DISCOs have the choice to contract any GENCO for power from any control area. All transactions should be cleared through an impartial entity called as Independent System Operator (ISO) [5, 6].

C. Hybrid Market Structure

A hybrid market structure is a combination of Bilateral Market structure and Poolco structure where Power sector runs based on auction however the DISCOs have the authority to choose GENCOs of their choice by signing agreements.

D. Reasons for New Structure

Though there exists deregulated structure of varied choices and utility values each has its own disadvantage. The Poolco Market Structure was introduced in some states in America, but was met with severe criticism in those areas as the cost of power in those regions is 32% more than the cost in regulated states. Moreover the deregulated structure will be crippled by various problems like black marketing, lack of clarity in decision making, collusion, unhealthy competition etc. [7]. In order to weed out all these cons of deregulated structure, a new deregulated structure which suits the Indian market is elaborated in this paper. There are 12 ancillary services in deregulated environment [8]. This paper concentrates on frequency related ancillary service [9].

4.0 DYADIC STRUCTURE

Dyadic Structure is the deregulated structure designed with the motive of supplying cleaner, cheaper and complete electricity. In this structure individual units which compete with each other are called as POWERCOs. Each POWERCO system consists of GENCO, TRANSCO and DISCO units required for supplying to an area. Figure 1 shows that POWERCO 1 has one GENCO supplying power to two TRANSCOs. Each TRANSCO in turn supplies to another three DISCOs.

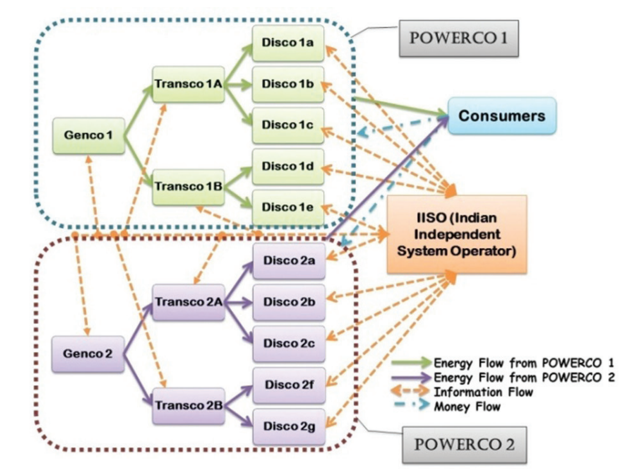

FIG. 1 DYADIC MARKET STRUCTURE.

A TRANSCO is erected based on the demand of a region. Depending on the demand, a region may consist of 3–5 districts and then the TRANSCO supplies to different DISCOs in its region. Thus a customer has to contact the corresponding DISCO to get his supply of Electricity. This structure tackles each and every problem faced by the previous deregulated structures. A POWERCO can have large number of GENCOs with at least 10% reserve capacity. The flexibility of previous structures is retained in this structure where the DISCO can buy power from any of the GENCOs of its own POWERCO. The POWERCOs are given the authority to price their power and consumers are free to choose from the different POWERCOs. Indian Independent System Operator is an impartial body which monitors the overall proceedings of the system. IISO has the authority to enforce the laws and maintain the delicate balance between the dyadic units i.e. between POWERCO and the consumers.

A. Suggested Rules for IISO

- IISO obtains the necessary collateral from the POWERCO for its entry into the energy industry signing a contract with the IISO breaching of which will lead to penalties.
- IISO must oversee the amount of generation done by a POWERCO.
- The amount of pollution exhaled through the GENCO system should comply with the rules of Pollution Control Act for appropriate power plants. Production of clean energy should be encouraged.
- It enforces environmental laws to safeguard our ecosystem in transmission as well as distribution divisions.
- Transmission lines and transmission stations have to be approved before they are built in an area.
- IISO should review POWERCOs periodically at a time gap of 8months
- A 5-star rating should be provided to scale the performance of the POWERCO which takes reserve capacity, renewable energy, pollution, customer problem solving capabilities and transmission losses into account.

B. Public and Private Sector

The highlight of this structure is to introduce private sector without affecting the already existing structure. The established structure of the Government will compete in the Dyadic market structure as a Public Sector Unit providing stability to the system. The public sector unit is considered as a single POWERCO with its power-plants, grids and load dispatch center are considered as its GENCO, TRANSCO and DISCO.

The public sector unit will compete with other private structures by following the rules laid down by the Indian Electricity Act. The private sector do not have direct rights for using nuclear or hydro-electric power plant hence they have to invest in Non-Conventional and Renewable Source of Energy whose cost is higher than the normal cost of production of thermal or hydroelectric power plants. However the private sector gain their competitive edge in transmission and distribution of electricity where newer technologies like FACTS and HVDC can be introduced reducing the losses as the estimated transmission loss for Indian power generation is around 24–32% also billing theft and other technical losses account for another 16% [10]. Therefore a balanced competition is created in the system as the cost of generation of private POWERCOs is balanced by the loss of power of the Public POWERCOs. The future of power sector is taken into account where the generation cost of renewable sources of energy will be reduced by technological advancements, which is guaranteed through the investment by these private POWERCOs.

5.0 SOUTHERN REGIONAL GRID AS POWERCO

For our modeling of the Dyadic structure we have taken Southern Regional grid of India which will act as a public sector POWERCO. In order to improve efficiency of the system without altering the basic structure secondary regulation is introduced. Figure 2 represents the model diagram of this four area system.

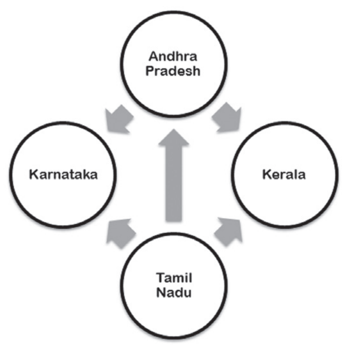

FIG. 2 MODELING OF STATES IN FOUR AREA SYSTEM.

In this system there are 11 GENCOs and 4 DISCOs. Area 1 (Andhra Pradesh) has three GENCOs representing thermal power plant, hydro power plant and Gas/Diesel power plant respectively. Area 2 (Karnataka) and Area 4(Tamil Nadu) has the same number of power plants in the same order. On the other hand, Area 3 (Kerala) does not have thermal power plants hence this area is characterized with two GENCOs. Note that thermal power plant in an area actually represents all the thermal power plants present in that area. In this four area structure, Andhra Pradesh borrows power from Tamil Nadu and also supplies power to Karnataka and Kerala whereas Karnataka and Kerala only receives power from Tamil Nadu and Andhra Pradesh. Tamil Nadu gives power to the DISCO of every state.

6.0 FORMATION OF BLOCK DIAGRAM

The load present in the DISCO is shared by the power plants not only present in the same area but also in the neighboring areas. In order to model this system we introduce the concept of Area Participation Factor (APF) and Power-plant Participation Factor (PPF).

Area Participation Factor (APF) refers to the power received by a DISCO from a GENCO. APF can be calculated as the ratio of power supplied to DISCOx to the total demand of DISCOx.

$$\text{APF} = \begin{bmatrix} 0.9383 & 0 & 0 & 0.0616 \\ 0.10712 & 0.8225 & 0 & 0.0703 \\ 0.3066 & 0 & 0.4911 & 0.2014 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Thus, APF_{14} represents area 1's power share of 6.16% from area 4. Here each row represents an area which receives power and each column represents the power sent by the corresponding area.

Area Control Error (ACE) of the 4 areas have to be shared by each power plant since each power plant has different governor actions. The sudden load change will be regulated at different rates for different power plants. Therefore an ACE Participation Factor is created for each power plant to compensate the sudden load disturbances that are produced in the system. For example thermal power plants can increase its power generation within a very short time threshold therefore ACE participation factor value is high for a thermal power plant.

A power plant has a specified installed capacity and a base load to satisfy. PPF refers to the total amount of power contracted by the DISCO from a power plant. It is the ratio of total demand met in that area to the demand met by the power plant. In this matrix each row represents an area and each column represents a power plant.

$$\text{PPF} = \begin{bmatrix} 0.849 & 0.115 & 0.0354 \\ 0.468 & 0.371 & 0.160 \\ 0 & 0.691 & 0.308 \\ 0.656 & 0.0505 & 0.293 \end{bmatrix}$$

For example, PPF_{23} represents the share of power of Hydro Power plant in area 2 (Karnataka). The sum of each row is equal to 1 as the load to the GENCOs of that area is proportionally shared by these power plants.

The maximum demand, installed capacity and inertia constant are taken into consideration for calculation purpose.

Whenever a load is demanded by a DISCO it is reflected as a local load to the area in which the DISCO belongs. However load varies from time to time as consumption of electricity is not static. An increase in load always results in decrease in frequency which is initially compensated by the stored kinetic energy of the system. The frequency is then brought to its original value by frequency regulation. However only primary frequency regulation is not enough to make the system to come back to its original system frequency of 50 Hz therefore secondary regulation is also added to the system which operates at a time period of the order of 1 minute after primary regulation creates a coarse impact on the system [11].

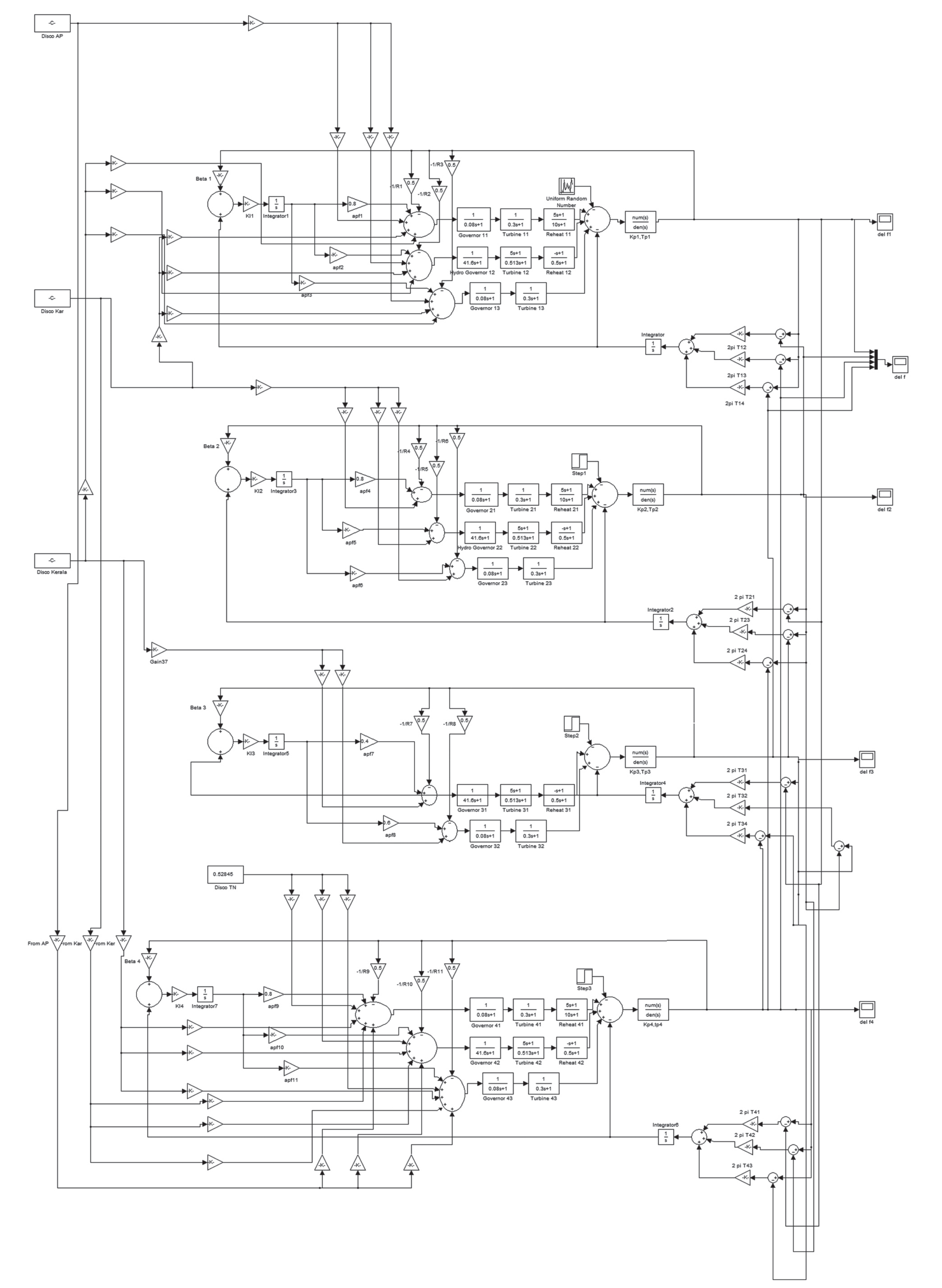

FIG. 3 SIMULINK OF FOUR AREA SYSTEM OF SOUTHERN REGIONAL GRID HAVING 11 GENCOs AND 4 DISCOs AS PUBLIC SECTOR UNIT.

By using frequency regulation the peak overshoot, undershoot and settling time is reduced. Presently Indian market structure does not use secondary regulation but in order to improve its overall efficiency secondary regulation must be added to the system. In this block diagram the systems are modeled using their standard transfer function for governor, turbine and load.

$$ACE_1=B_1\Delta f_1+\Delta P_{tie1,\,2}+\Delta P_{tie1,\,3}+\Delta P_{tie1,\,4}$$

$$ACE_2=B_2\Delta f_2+\Delta P_{tie2,\,1}+\Delta P_{tie2,\,3}+\Delta P_{tie2,\,4}$$

$$ACE_3=B_3\Delta f_3+\Delta P_{tie3,\,3}+\Delta P_{tie3,\,2}+\Delta P_{tie3,\,4}$$

$$ACE_4=B_4\Delta f_4+\Delta P_{tie4,\,1}+\Delta P_{tie4,\,2}+\Delta P_{tie4,\,3}$$

Here ACE refers to area control error, B refers to the damping coefficient and Δf refers to the frequency deviation of the system.

The disturbances to the system are given in the form of step signal or random signal. The peak overshoot, undershoot and settling time are measured. Various controllers are used for providing secondary regulation to the system. ACE is provided as the control signal. The gain of the controller must be adjusted to obtain the least settling time for the four area system. The overall Simulink diagram is shown in Figure 3. The regulation of the system is carried out as such increasing the credibility and reliability of the power plant present in the system giving better frequency response to the public sector. The data is taken from SRLDC as on 12th of February 2013 [12]. Other data and time constants are given in the Appendix.

7.0 CHOICE OF CONTROLLERS

In the Southern Regional Grid without the presence of secondary regulation, the frequency settles with a substantial deviation as the load varies continuously. Without secondary regulation fine adjustments could not be done hence we use controllers to reduce the overshoot value and improve the stability of the system. Commonly a simple integral controller or proportional integral control can be used to perform LFC tasks. The frequency response of an integral control system is shown in Figure 4

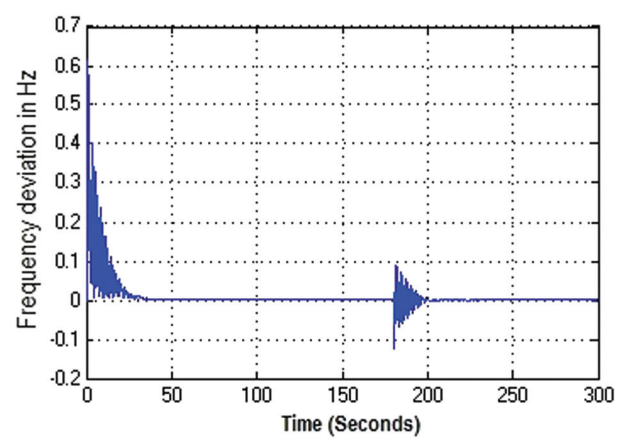

FIG. 4 FREQUENCY RESPONSE OF AREA 1 IN THE PUBLIC SECTOR UNIT WITH PI CONTROLLER.

When the SIMULINK model is executed, the system is stable and the four area interconnected system settling at zero. Initially the system responds to the power drawn by the DISCOs which is about 1.018 p.u. Once the system is stabilized it is subjected to a perturbation of 10% increase in demand, which is applied at t=180 secs, whose response to this disturbance is noted down and compared with other controllers.

A PID controller is then used in the place of PI controller and its response is also noted down which is shown in Figure 5.

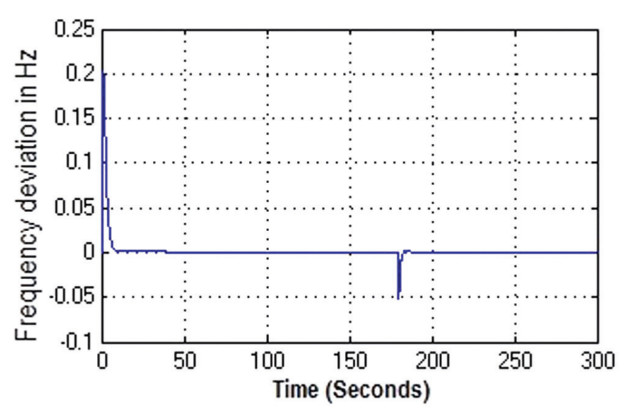

FIG. 5 FREQUENCY RESPONSE OF AREA 1 IN THE PUBLIC SECTOR UNIT WITH PID CONTROLLER.

A SIMULINK model is a then executed for Fuzzy controllers here the fuzzy controllers are also coupled with PI and PID controllers for a detailed performance analysis. A Fuzzy Associative Memory table is created for a five variable system using the MAMDANI model to incorporate fuzzy control in the LFC system. Table 1 represents the Fuzzy rules for the four area system.

TABLE 1

RULES FOR THE FOUR AREA SYSTEM

	NB	NS	ZE	PS	PB
NB	NB	NB	NS	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PS	PB
PB	ZE	PS	PS	PB	PB

Figure 6 shows the response of area 1 with Fuzzy Logic Controller for step input disturbance signal applied to area 1 at 180 secs and Figure 7 shows the response of area 1 with Fuzzy PI controller and Figure 8 shows the frequency response of Fuzzy PID controller. A detailed comparison of all these controllers' frequency response with their static and dynamic response is given in Table 2.

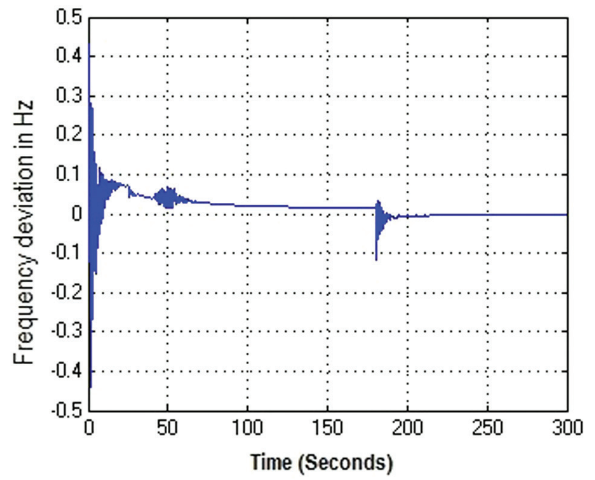

FIG. 6 FREQUENCY RESPONSE OF AREA 1 IN THE PUBLIC SECTOR UNIT WITH FUZZY LOGIC CONTROLLER.

It can be observed from the table that the response characteristics of PID and Fuzzy PID controllers are drastically better than the other controllers. Fuzzy PID can be used to reduce the wear and tear of the system as PID responds immediately to a system variation.

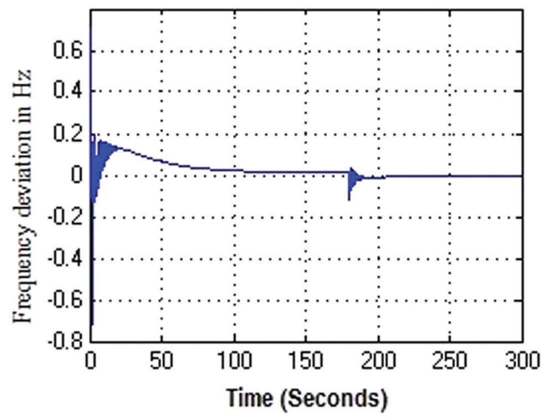

FIG. 7 FREQUENCY RESPONSE OF AREA 1 IN THE PUBLIC SECTOR UNIT WITH FUZZY PI CONTROLLER.

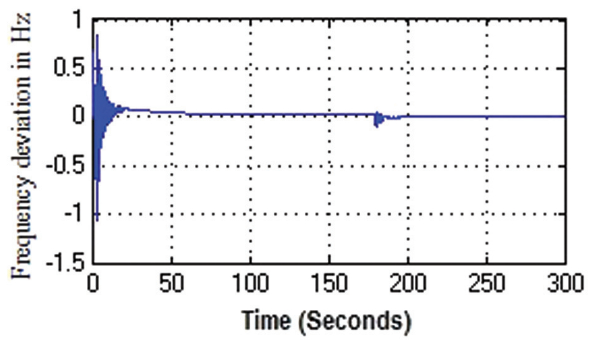

FIG. 8 FREQUENCY RESPONSE OF AREA 1 IN PUBLIC SECTOR UNIT WITH FUZZY PID CONTROLLER.

TABLE 2

COMPARISON OF FREQUENCY RESPONSE OF THE CONTROLLERS

Controllers	**Peak undershoot**	**Peak overshoot**	**Settling time**
PI	–0.1252	0.0905	64
PID	–0.051	0.002	24
Fuzzy	–0.1165	0.0325	58
Fuzzy PI	–0.112	0.0316	46
Fuzzy PID	–0.109	0.039	28

8.0 ADVANTAGES

- New Untapped resources have to be looked upon as the source of energy leading to the development of renewable energy.

- Overall development of the system as GENCO, TRANSCO and DISCO have to be efficient, leading to introduction of better technologies in these fields like FACTS, HVDC.
- Consumers are trained to have healthy practices since POWERCO can ensure that consumers follow proper energy management ethics by enforcing these norms with penalties.
- This is the only market structure to provide equal competition by allowing small time players to come into the system.
- Pollution can be reduced and subsidies might be given to provide clean and green energy.

9.0 CONCLUSION

Thus Dyadic structure provides an optimal market structure of deregulated environment. It challenges all the problems faced by the electricity sector such as power crisis, transmission losses, frequency deviation, pollution, renewable energy, complete electrification, collusion, black marketing, and competition among different POWERCOs. It has nurtured an environment where the power sector can blossom thereby providing the necessary impetus to industrial investments, agricultural growth and overall economic development of our country.

APPENDIX

All the notations carry the usual meanings

(a) System data

$Pr_1, Pr_2, Pr_3, Pr_4, = 10000$ MW;

$T_t = 0.3$ s;

$T_g = 0.08$s, $T_w = 1$s;

$T_R = 10$s, $T_r = 5$s, $T_1 = 41.6$s, $T_2 = 0.513$ s;

$R_1, R_2, R_3, R_4 = 2$ Hz/p.u. MW;

$T_{tie\text{-}line,\ power} = 0.0866$ p.u. MW/rad

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