

Automatic Generation Control of Multi-area Power System using Active Disturbance Rejection Control

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Abstract - All national power system networks are multi-area networks interconnected by tie-lines. Automatic Generation Control (AGC) ensures the frequency and tie-line power errors are zero in the steady state so that nominal frequency and tie-line schedules are maintained. This can be achieved by sophisticated controllers. In this paper a three area power system is considered. The three areas consists of non reheat turbine thermal generator, reheat turbine thermal generator and hydro generator respectively. A control technique based on Active Disturbance Rejection Control (ADRC) is employed for this purpose. The resulting system is simulated using MATLAB Simulink software. The performance of ADRC is compared with classic PID Controller tuned by Zeigler-Nichols method. The outcome of ADRC is very good with low overshoots and minimum settling times.

Keywords: Multi-area Power System, Automatic Generation Control, Frequency error, Tie-line Power error, Active Disturbance Rejection Control, PID Control.

I. INTRODUCTION

Maintaining a nominal frequency and rated voltage within allowable limits is the most important requirement of power system operation. This ensures proper power system operation avoiding blackouts. Load Frequency Control (LFC) and Automatic Voltage Regulator (AVR) Control loops are mostly used in power systems to ensure quality power with rated frequency and voltage to the customer [1]-[2]. The scheme in which generation is adjusted automatically to restore the frequency to nominal value, as the system load changes continuously is called as Automatic Generation Control (AGC) which can make the interconnected power system more economic and reliable. The role of AGC is to divide the loads among system stations and generators so as to achieve maximum economy and to correctly control the scheduled interchanges of tie-line powers while maintaining a reasonable uniform frequency [3]-[5].

In order to improve the performance and stability of these control loops, proportional-integral-derivative (PID) controllers are normally used. But these fixed gain controllers fail to perform under varying load conditions and hence provide poor dynamic characteristics with a large settling time, overshoot and oscillations. In order to achieve a better dynamic performance, system stability and sustainable utilization of generating systems, PID gains must be well tuned [14]-[15]. Two main variables that change during transient power load are area frequency and tie line power interchanges. The concept of Load frequency control (LFC) is directly related to the aforementioned variables since the task is to minimize these variations. The key factor is to maintain the steady state deviations at zero. In this respect, effective measures like Active Disturbance Rejection Control (ADRC) have been developed that allow practical control [13].

ADRC as originally proposed by J. Han has three components namely tracking differentiator, nonlinear feedback control and nonlinear extended state observer. This triple combination proves to be a powerful tool for disturbance rejection control. It has been streamlined, simplified and parameterized so that it can be easily deployed across various hardware-software platforms and easily tuned by factory personnel in industry. In terms of design, the main parameters of focus in ADRC are the input and the output. This simply means that in order to perform its control tasks, the main information is analyzed from the input and output portions of the system. ADRC is able to detect the disturbance in the real system and also able to reject it. In this manner, its activity is very directed and efficient against the uncertainty in the system or any external disturbance [9]-[12].

II. LOAD FREQUENCY CONTROL

Load frequency control has gained its importance with the growth of interconnected power systems. LFC loop controls the real power and frequency of the power system. The objectives

of LFC are to maintain reasonably uniform frequency, to divide the load between generators and to control the tie-line interchange schedules.

A. Mathematical Modelling of Load Frequency Control

1) Generator:

Generator is a device or machine which converts mechanical energy into electrical energy. Applying a small perturbation due to load change, the swing equation of a synchronous generator may be written as

$$\frac{2GH}{\omega_s} \frac{d^2 \Delta \delta}{dt^2} = \Delta P_m - \Delta P_e$$

In terms of small deviation in angular velocity

$$\frac{d \Delta \omega}{dt} = \frac{1}{2H} (\Delta P_m - \Delta P_e) \text{ p.u., on base G}$$

Expressing angular velocity also in p.u on a base ω_s ,

$$\frac{d \Delta \omega}{dt} = \frac{1}{2H} (\Delta P_m - \Delta P_e)$$

Taking Laplace Transform,

$$\Delta \Omega(s) = \frac{1}{2Hs} (\Delta P_m(s) - \Delta P_e(s)) \dots (1)$$

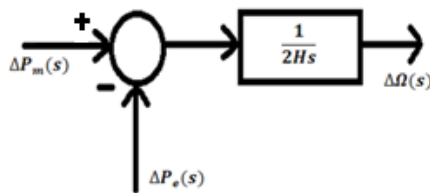


Fig 1 Block Diagram of Generator

2) Load:

The load on a power system consists of variety of electrical loads. Resistive loads are frequency insensitive loads such as lighting and heating loads. Motor loads are frequency sensitive loads. Depending on the speed-load characteristics of the driven devices, the sensitivity of load with respect to frequency is known.

Hence the composite load change may be expressed as

$$\Delta P_e = \Delta P_L + D \Delta \omega \dots (2)$$

$\Delta P_L = \text{Non Frequency Sensitive load change}$

$D \Delta \omega = \text{Frequency Sensitive load change}$

$$D = \frac{\text{Percentage change in load}}{\text{Percentage change in frequency}}$$

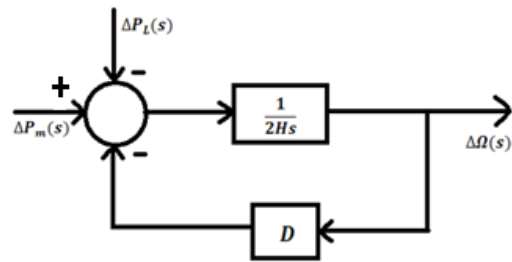


Fig 2 Block Diagram of Generator and Load

By elimination of the simple feedback loop, the above block diagram of the combined generator and load can be modified as

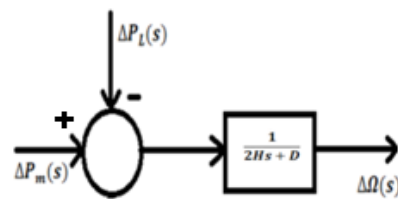


Fig 3 Block Diagram of Generator and Load

3) Turbine:

A turbine unit in power systems is used to transform the natural energy, such as the energy from steam or water, into mechanical power that is supplied to the generator. Generally there are three types of turbines available in power systems. They are Non-reheat, Reheat and Hydro turbines

Non-Reheat Turbine

Non-reheat turbines are first-order units. A time delay occurs between switching the steam valve and producing the turbine torque. The transfer function can be of the non-reheat turbine is represented as

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1 + T_T s} \dots (3)$$

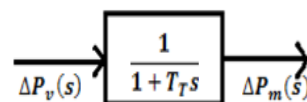


Fig 4 Block Diagram of Non-reheat Turbine

Reheat Turbine

Reheat turbines are having various stages due to low and high steam pressure. Hence the transfer function of reheat turbine can be represented as

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1 + sKT_T}{1 + sT_T} \quad \dots (4)$$

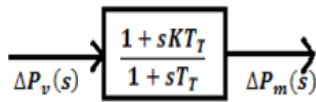


Fig 5 Block Diagram of Reheat Turbine

Hydro Turbine

Hydraulic turbines are non-minimum phase units due to the water inertia. In the hydraulic turbine, the water pressure response is opposite to the gate position change at first and recovers after the transient response. Thus the transfer function of the hydraulic turbine can be represented as

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1 - sT_w}{1 + 0.5T_w} \quad \dots (5)$$

where T_w is the water starting time.

For stability concern, a transient droop compensation part in the governor is needed for the hydraulic turbine. The transfer function of the transient droop compensation part can be represented as

$$G_{TDC}(s) = \frac{1 + sT_{H1}}{1 + sT_{H2}} \quad \dots (6)$$

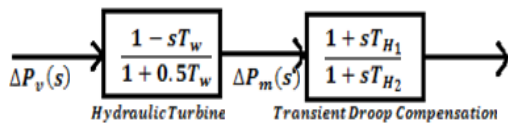


Fig 6 Block Diagram of Hydraulic Turbine

4) Governor:

The speed governor mechanism acts as a comparator whose output ΔP_g is the difference between the reference set power ΔP_{ref} and the power $\frac{\Delta\omega}{R}$ (Load change).

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R} \Delta\omega$$

On applying Laplace transform,

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R} \Delta\Omega(s) \quad \dots (7)$$

The command ΔP_g is transformed through the hydraulic amplifier to the steam valve position command ΔP_v . Considering a simple time constant

T_g , the transfer function of the governor can be represented as

$$\Delta P_v(s) = \frac{1}{1 + T_g s} \Delta P_g(s) \quad \dots (8)$$

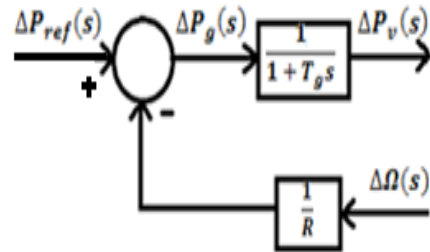


Fig 7 Block Diagram of Governor

B. AGC of Single-Area Power System

By mathematical modeling of the governor, turbine, generator and load scheme of the AGC for an isolated power system can be given as follows

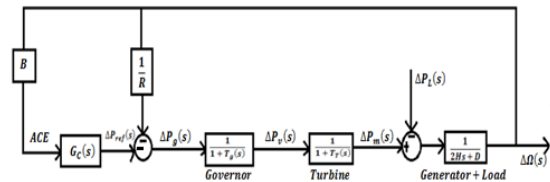


Fig 8 AGC of isolated Power System

where B = frequency bias factor = $D + \frac{1}{R}$

$G_c(s)$ = Controller transfer function

ACE = Area Control Error

C. AGC of Multi-Area Power System

Consider two area represented by an equivalent generating unit interconnected by a lossless tie line with reactance X_{tie}

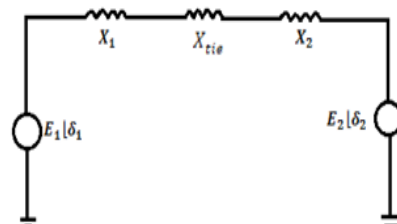


Fig 9 Equivalent network of two area power system

During normal operation, the real power transferred over the tie line is given by

$$P_{12} = \frac{E_1 E_2}{X_{12}} \sin \delta_{12} \quad \dots (9)$$

where $X_{12} = X_1 + X_{tie} + X_2$ and

$$\delta_{12} = \delta_1 - \delta_2 \quad \dots (10)$$

Assuming there is a small deviation in the tie-line flow from the nominal value

$$\Delta P_{12} = \left. \frac{dP_{12}}{d\delta_{12}} \right|_{\delta_{12_0}} \Delta \delta_{12} = P_s \Delta \delta_{12}$$

The synchronizing power coefficient is defined as

$$P_s = \left. \frac{dP_{12}}{d\delta_{12}} \right|_{\delta_{12_0}} = \frac{E_1 E_2}{X_{12}} \cos \Delta \delta_{12_0}$$

The tie-line power deviation then takes the form

$$\Delta P_{12} = P_s (\Delta \delta_1 - \Delta \delta_2) \quad \dots (11)$$

Conventional LFC is based upon tie-line bias control, where each area tends to reduce the Area Control Error (ACE) to zero. The control error for each area consists of a linear combination of frequency and tie-line errors

$$ACE_i = \sum_{\substack{j=1 \\ \neq i}}^n \Delta P_{ij} + K_i \Delta \omega_i \quad \dots (12)$$

where K_i determines the amount of interaction during a disturbance in the neighbouring areas. For overall satisfactory performance K_i is equal to the frequency bias factor B_i .

$$ACE_i = \sum_{\substack{j=1 \\ \neq i}}^n \Delta P_{ij} + B_i \Delta \omega_i \quad \dots (13)$$

D. HVDC Link

A High Voltage Direct Current (HVDC) electric power transmission system uses direct current for the bulk transmission of electrical power, in contrast with the more common alternating current (AC) systems. For long-distance transmission, HVDC systems may be less expensive and suffer lower electrical losses. It allows power transmission between unsynchronized AC transmission systems. Since the power flow through an HVDC link can be controlled independently of the phase angle between source and load, it can stabilize a network against disturbances due to rapid changes in power. It also requires fewer conductors per unit distance than an AC line, as there is no need to support three phases and there is no skin effect.

Due to inherent technical and economic merits of DC transmission system over AC transmission systems, DC transmission systems have gained momentum for their development [3]. The DC link is simply represented by a transfer function as follows

$$G_{HVDC}(s) = \frac{K_{dc}}{1 + sT_{dc}} \quad \dots (14)$$

K_{dc} = Gain of DC link

T_{dc} = Time Constant of DC link

III ACTIVE DISTURBANCE REJECTION CONTROL

Active disturbance rejection control (ADRC) takes over from proportional–integral–derivative (PID) controller. ADRC generalizes the discrepancy between the mathematical model and the real system as a disturbance, and rejects the disturbance actively, hence the name active disturbance rejection control. It can simply be understood as a combination of an extended state observer (ESO) and a state feedback controller where ESO is utilized to observe the generalized disturbance, which is also taken as an extended state. The state feedback controller is used to regulate the tracking error between the real output and a reference signal for the physical plant [6]-[8].

The virtual state (sum of internal and external disturbances, denoted as total disturbance) is estimated online with a state observer and used in the control signal in order to decouple the system from the actual perturbation acting on the plant. Hence the states of n^{th} order system along with disturbances are estimated by $(n+1)^{\text{th}}$ order Extended State Observer (ESO).

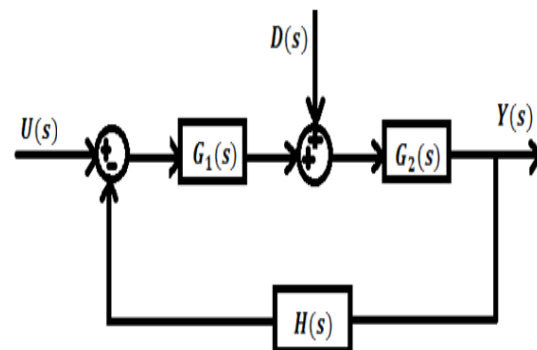


Fig 10 Basic Structure of Power System with primary loop

A. Design of ADRC for n^{th} Order System

1) Plant Remodelling:

ADRC is developed for a general transfer function of a physical model considering it as a primary loop. General form of the physical model is represented with transfer function as

$$G_p(s) = \frac{Y(s)}{U(s)} = \frac{b_{m+1}s^m + b_m s^{m-1} + \dots + b_2 s + b_1}{a_{n+1}s^n + a_n s^{n-1} + \dots + a_2 s + a_1}, n \geq m \dots (15)$$

where U(s) and Y(s) are input and output of the plant respectively. a_i and b_j are coefficients of transfer function.

By longhand division, the plant can be remodeled as

$$s^{n-m}Y(s) = b_0 u(s) + D(s) \dots (16)$$

where

$$b_0 = \frac{b_{m+1}}{a_{n+1}} \dots (17)$$

D(s) includes both internal and external disturbances. Hence after remodelling, the plant is of order n-m with high frequency gain of b_0 . The basic objective of ADRC is to implement a Extended State Observer (ESO) that can provide an estimate of disturbance d(t), such that it compensates the impact of d(t), on the process by means of disturbance rejection. Therefore the remaining is being handled by a simple proportional controller. Hence the disturbance is observed and cancelled by using ADRC.

2) Observer Gains:

Extended State Observer (ESO) is utilized to observe the generalized disturbance, which is taken as an extended state. Hence the state space mode of the system can be represented as

$$SX(s) = AX(s) + BU(s) + E(s)D(s) \dots (18)$$

$$Y(s) = CX(s) \dots (19)$$

$$X(s) = \begin{bmatrix} x_1(s) \\ x_2(s) \\ \vdots \\ \vdots \\ x_{n-m+1}(s) \end{bmatrix}_{(n-m+1) \times 1}$$

$$A = \begin{bmatrix} 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & 1 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}_{(n-m+1) \times (n-m+1)}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ \vdots \\ b_0 \\ 0 \end{bmatrix}_{(n-m+1) \times 1}$$

$$C = [1 \ 0 \ \dots \ \dots \ \dots \ 0]_{1 \times (n-m+1)}$$

$$E = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ \vdots \\ 1 \end{bmatrix}_{(n-m+1) \times 1}$$

The state space model of the disturbed process can be represented as

$$sZ(s) = AZ(s) + BU(s) + L(Y(s) - \hat{Y}(s))$$

where $\hat{Y}(s) = CZ(s)$;

$$Z(s) = [Z_1(s) \ Z_2(s) \ \dots \ Z_{n-m+1}(s)]_{1 \times (n-m+1)}^T;$$

$$L = [l_1 \ l_2 \ \dots \ l_{n-m+1}]_{1 \times (n-m+1)}^T$$

Assuming all the Eigenvalues of ESO are located at $-\omega_o$, the observer gains are chosen as

$$l_i = \binom{n-m+1}{i} \cdot \omega_o^i, i = 1, 2, \dots, n-m+1 \dots (20)$$

Hence by proper designing of ESO, $Z_i(s)$ will be estimating the values of $X_i(s)$ closely. Then $Z_{n-m+1} = \hat{D}(s) \approx D(s)$

The basic idea of ADRC design is based on the assumption that the transfer function of the plant has no finite zeros. In case the transfer function has finite zeros, then convert the model into a transfer function without finite zeros. The error between the two models can be included into the generalized disturbance term. A well tuned ESO outputs \hat{x}_i will track x_i closely. Therefore $\hat{x}_{n+1} \approx x_{n+1} = D$

The generalized disturbance $d(t)$ can be removed by the time domain estimated value x_{n+1} with control law

$$U(s) = \frac{U_o(s) - Z_{n-m+1}(s)}{b_o}$$

Now the system is reduced to a pure integral plant by substituting

$$\begin{aligned} s^{n-m}Y(s) &= b_o \cdot \frac{U_o(s) - Z_{n-m+1}(s)}{b_o} + D(s) \\ &= U_o(s) - \widehat{D}(s) + D(s) \approx U_o(s) \end{aligned}$$

3) **Controller Gains:**

The control law for the pure integral plant is

$$U_o(s) = K_1(R(s) - Z_1(s)) - K_2Z_2(s) - \dots - K_{n-m}Z_{n-m}(s)$$

To simplify the tuning process, all the closed-loop poles of the controller are set to $-\omega_c$, ω_c represents the bandwidth of the controller. Then the controller gains have to be selected as

$$k_i = \binom{n-m}{n-m-i+1} \omega_c^{n-m-i+1}, i = 1, 2, \dots, n-m. \dots (21)$$

Increasing ω_c increases the tracking speed of the output of ADRC controlled system. The basic topology of the ADRC is given in Fig. 11.

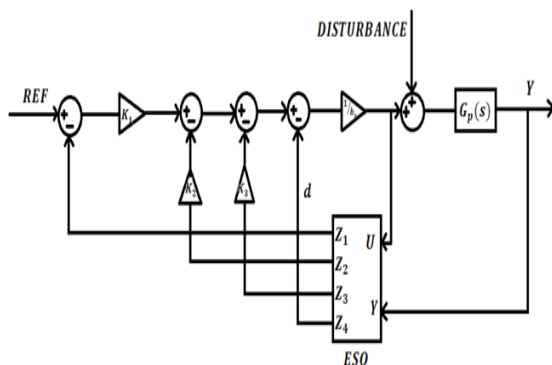


Fig 11 Basic Block Diagram of ADRC

The above basic block diagram of ADRC is for a fourth order system. The proposed ADRC control is designed for non-reheat thermal, reheat thermal and hydraulic plants i.e. finding controller gains and observer gains using the plant transfer function for the respective plants. Here the reference inputs for ADRC are taken as Area Control Errors of the system i.e. ACE_1 , ACE_2 and ACE_3 . The external disturbances for ADRC have been created by the load changes in the particular areas i.e. ΔP_{L1} , ΔP_{L2} and ΔP_{L3} . $G_p(s)$ represents the overall transfer function of the plant considered.

B. Design of ADRC for Non-Reheat Thermal Plant

Table I Data for Non-Reheat Thermal Plant		
Governor Gain	K_{g1}	1
Governor Time Constant	T_{g1}	0.1 sec
Turbine Gain	K_{T1}	1
Turbine Time Constant	T_{T1}	0.4 sec
Generator Inertia Constant	H_1	5 sec
Frequency Sensitive factor	D_1	1.25 p.u
Change in Load	ΔP_{L1}	0.1 p.u Step
Speed Regulation	R_1	0.05 p.u
Synchronizing Coefficient	P_s	22.6 p.u.

For the above data, the overall transfer function of primary loop of non-reheat thermal plant is

$$\begin{aligned} G_p(s) &= \frac{Y(s)}{U(s)} \\ &= \frac{1}{0.4s^3 + 5.05s^2 + 10.625s + 21.25} \dots (22) \end{aligned}$$

From the plant transfer function $n=3$, $m=0$, $a_4=0.4$, $b_1=1$

Therefore from (17)

$$b_o = \frac{1}{0.4} = 2.5 \dots (23)$$

The model of ESO is obtained as

$$\begin{aligned} \begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{pmatrix} &= \underbrace{\begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{pmatrix}}_A \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} + \underbrace{\begin{pmatrix} 0 \\ 0 \\ 2.5 \\ 0 \end{pmatrix}}_B u \\ &+ \underbrace{\begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}}_E \dot{d} \\ y &= \underbrace{(1 \ 0 \ 0 \ 0)}_C \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} \end{aligned}$$

For observer bandwidth $\omega_o = 20 \text{ rad/s}$, ESO may be written in terms of observer gains as

$$\begin{aligned} \begin{pmatrix} \dot{\hat{x}}_1 \\ \dot{\hat{x}}_2 \\ \dot{\hat{x}}_3 \\ \dot{\hat{x}}_4 \end{pmatrix} &= \begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} \hat{x}_1 \\ \hat{x}_2 \\ \hat{x}_3 \\ \hat{x}_4 \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 2.5 \\ 0 \end{pmatrix} u(t) \\ &+ \begin{pmatrix} 80 \\ 2400 \\ 32000 \\ 160000 \end{pmatrix} (y - \hat{y}) \\ &= \underbrace{\begin{pmatrix} -80 & 1 & 0 & 0 \\ -2400 & 0 & 1 & 0 \\ -32000 & 0 & 0 & 1 \\ -160000 & 0 & 0 & 0 \end{pmatrix}}_{A-LC} \begin{pmatrix} \hat{x}_1 \\ \hat{x}_2 \\ \hat{x}_3 \\ \hat{x}_4 \end{pmatrix} \\ &+ \underbrace{\begin{pmatrix} 0 \\ 0 \\ 2.5 \\ 0 \end{pmatrix}}_B u(t) \\ &+ \underbrace{\begin{pmatrix} 80 \\ 2400 \\ 32000 \\ 160000 \end{pmatrix}}_L y(t) \quad \dots (24) \end{aligned}$$

Controller gains, for $\omega_c = 10 \text{ rad/s}$, are obtained from (21) as

$$K_1 = 1000, K_2 = 300, K_3 = 30$$

C. Design of ADRC for Reheat Thermal Plant

Governor Gain	K_{g2}	1
Governor Time Constant	T_{g2}	0.2 sec
Turbine Gain	K_2	0.5
Turbine Time Constant	T_{T2}	0.4 sec
Generator Inertia Constant	H_2	5 sec
Frequency Sensitive factor	D_2	1.25 p.u
Change in Load	ΔP_{L2}	0.1 p.u Step
Speed Regulation	R_2	0.05 p.u
Synchronizing Coefficient	P_s	22.6 p.u

The overall transfer function of primary loop of reheat thermal plant is obtained as

$$G_p(s) = \frac{Y(s)}{U(s)} = \frac{1}{4s^2 + 10.5s + 21.25} \quad \dots (25)$$

From the plant transfer function $n=2, m = 0, a_3 = 4, b_1=1$

From (17), (20) and (21)

$$b_o = \frac{1}{4} = 0.25$$

Observer Gains: $l_1 = 60 ; l_2 = 1200 ; l_3 = 8000$

Controller Gains: $K_1 = 25 ; K_2 = 10$

D. Design of ADRC for Hydro Plant

Governor Gain	K_{g3}	1
Governor Time Constant	T_{g3}	0.2 sec
Water Time Constant	T_W	1 sec
Generator Inertia Constant	H_3	3 p.u sec
Transient Droop Compensation Time Constant	T_{H1}	0.5 sec
	T_{H2}	0.513 sec
Frequency Sensitive factor	D_3	1 p.u
Change in Load	ΔP_{L3}	0.1 p.u Step
Speed Regulation	R_3	0.05 p.u
Synchronizing Coefficient	P_s	22.6 p.u

Since Hydraulic plant consists of non-minimum phase turbine, an all pass filter is cascaded with the turbine in order to cancel out the positive zero and provide the necessary phase lead [9]. Hence the transfer function of the plant is given as,

$$\begin{aligned} G_p(s) &= \frac{Y(s)}{U(s)} \\ &= \frac{s + 1}{0.6156s^3 + 4.3806s^2 + 26.713s + 21} \quad \dots (26) \end{aligned}$$

From the plant transfer function $n=3, m=1, a_4=0.6156, b_2=1$

From (17), (20) and (21)

$$b_o = \frac{1}{0.6156} = 1.624431$$

Observer Gains: $l_1 = 60 ; l_2 = 1200 ; l_3 = 8000$

Controller Gains: $K_1 = 25 ; K_2 = 10$

IV. TUNING OF PID CONTROLLER

A Proportional-Integrator-Derivative (PID) Controller is a control loop feedback mechanism which continuously calculates an error value as the difference between a desired set point and a measured process variable. The basic structure of PID controller is given by

$$G_{PID}(s) = K_p + \frac{K_I}{s} + K_D s \quad \dots (27)$$

where K_p, K_I and K_D are proportional, integral and derivative gain constants. One of the best possible methods for tuning PID controller is Zeigler-Nichols Method. It is a heuristic method which is performed by initially setting the integrator and derivative gain constants as zero. Then the proportional gain constant is tuned until the output

of the control loop has stable and consistent oscillations. Assuming the tuned proportional gain to be K_u with the oscillation period of T_u , the gain constants of the PID controller are obtained as follows.

Case (i): Classic PID Controller

$$K_P = 0.6K_u ; K_I = T_u/2 ; K_D = T_u/8 \dots (28)$$

Case (ii): PID with some overshoot:

$$K_P = 0.33K_u ; K_I = T_u/2 ; K_D = T_u/3 \dots (29)$$

Case (iii): PID with no overshoot:

$$K_P = 0.2K_u ; K_I = T_u/2 ; K_D = T_u/3 \dots (30)$$

For the system considered, $K_u = 1.05$ and $T_u = 1.60$.

	K_P	K_I	K_D
Classic PID	0.63	0.8	0.2
PID (some overshoot)	0.3465	0.8	0.5333
PID (no overshoot)	0.21	0.8	0.5333

V. SIMULATION AND RESULTS

Simulation is carried out for the three area power system with ADRC and PID Controllers. A HVDC link is placed in parallel with HVAC tie line which is connected between area-1 and area-2. The basic structure of the three area system proposed is given below

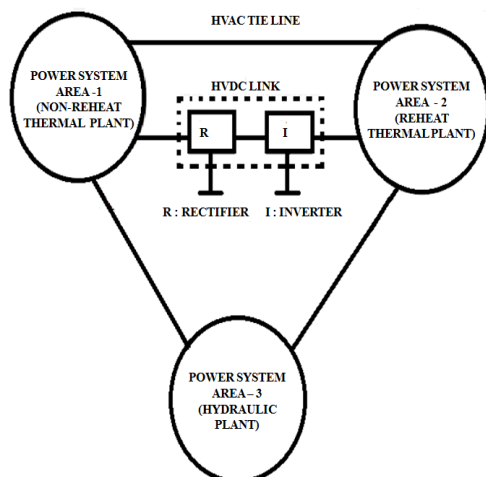


Fig 12 Proposed Three Area Power System

The three area AGC model using ADRC in Simulink is shown below

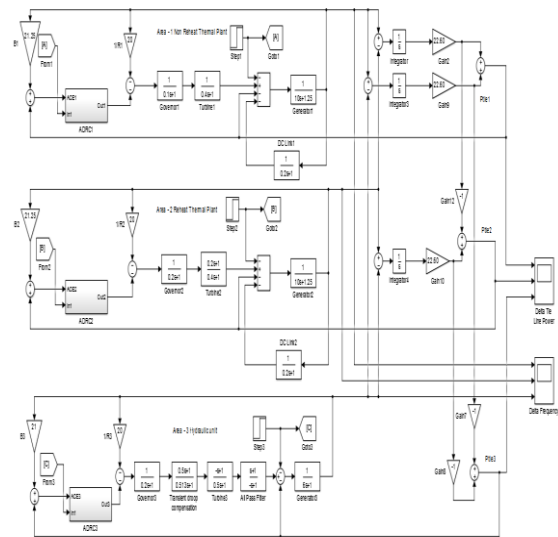


Fig 13 Simulation of Three Area Power System using ADRC

The three area AGC model using PID Controller in Simulink is shown below

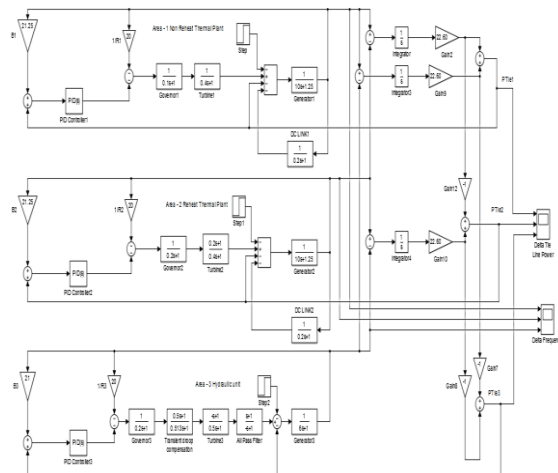


Fig 14 Simulation of Three Area Power System using PID Controller

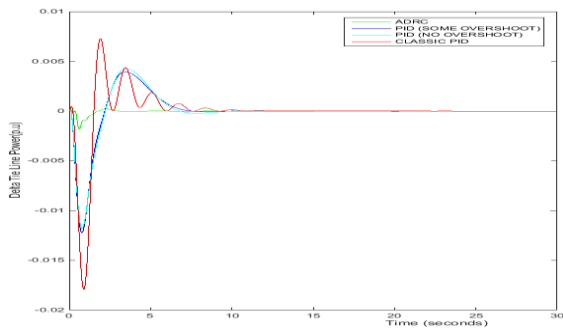


Fig 15 Tie line power deviation of area-1

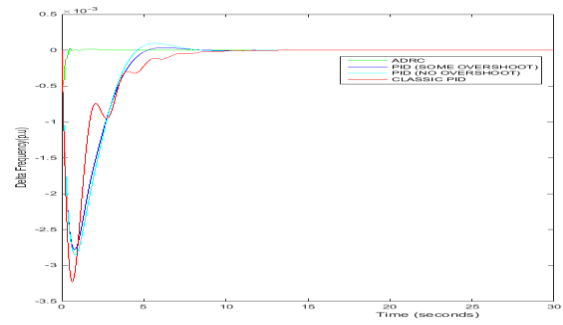


Fig 19 Frequency deviation of area-2

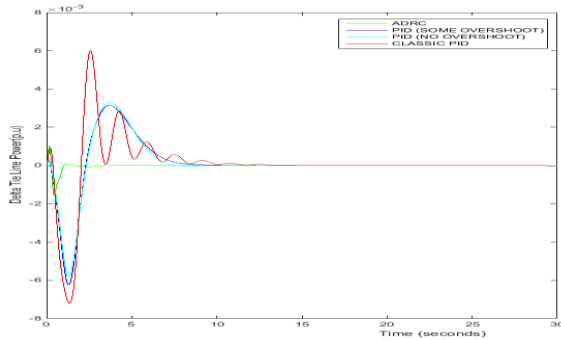


Fig 16 Tie line power deviation of area-2

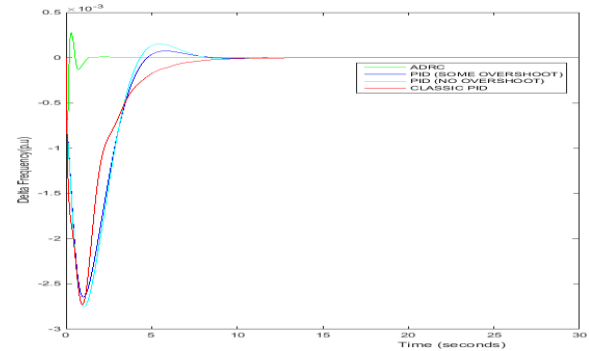


Fig 20 Frequency deviation of area-3

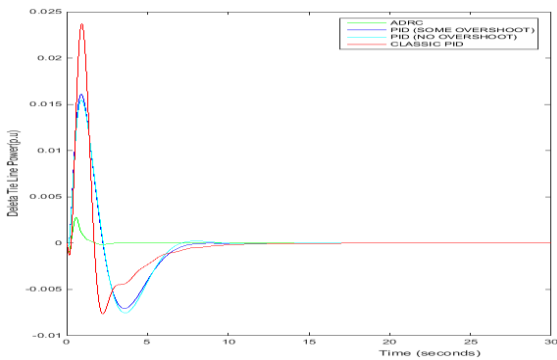


Fig 17 Tie line power deviation of area-3

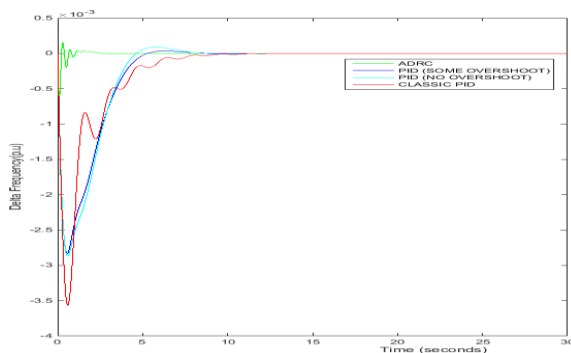


Fig 18 Frequency deviation of area-1

VI. DISCUSSION

ADRC and PID Controllers are employed as secondary controllers for the considered three area power system. The performances of these controllers are shown in Figs. 15-20. From these figures, it is observed that both the controllers brought the steady state frequency and tie line power deviations to zero. However PID controller tuned by Zeigler Nichols method for three different cases (Classic PID, No overshoot and Some overshoot) have large settling times and overshoots compared to the ADRC. The performance of ADRC, from Figs. 15-20, is clearly justified.

VII. CONCLUSIONS

Automatic Generation Control plays a key role in maintaining the changes in frequency and tie line powers to near zero. Thus it aims at reducing the steady state error, overshoots and settling times of the frequency and tie line power errors. ADRC, which is a robust control, acts as a secondary loop for AGC in improving its performance. Therefore the designed ADRC can reduce both the internal and external disturbances. The results of the three area power system, Figs. 15-20, clearly show that ADRC is much better compared to Zeigler-Nichols tuned PID Controller.

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