ISSN (Online) : 2319 – 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, Volume 3, Special Issue 1, February 2014

International Conference on Engineering Technology and Science-(ICETS'14)

On 10th & 11th February Organized by

Department of CIVIL, CSE, ECE, EEE, MECHNICAL Engg. and S&H of Muthayammal College of Engineering, Rasipuram, Tamilnadu, India

Load Frequency Control for A Multi Area Power System Involving Wind, Hydro and Thermal Plants

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Abstract- In an interconnected power system, as a power load demand varies randomly both area frequency and tie-line power interchange also vary. The objectives of load **frequency control (LFC) are to minimize the deviations in these variables (area frequency and tie-line power interchange) and to ensure their steady state errors to be zero. In this area of energy crisis, renewable energy is the most promising solution to man's ever increasing energy needs. But the power production by these resources cannot be controlled unlike in thermal plants. As a result, standalone operation of renewable energy is not reliable. Hence grid-connection of these along with conventional plants is preferred due to the improved performance in response to dynamic load. It is observed that fluctuations in frequency caused due to load variations are low with increase in penetration of renewable resources. Load frequency control (LFC) including PID controller is proposed in order to suppress frequency deviations for a power system involving wind, hydro and thermal plants owing to load and generating power fluctuations caused by penetration of renewable resources. A system involving two thermal plants, a wind farm and a hydro plant will be modelled using MATLAB.**

Index Terms--Distributed power generation, load frequency, Control (LFC), wind power, hydro power, and thermal power plants.

I. NOMENCLATURE

ΔPC	Command signal
ΔF	Change in Frequency
ΔYE	Changes in steam valve opening
R	Speed regulation of the governor
Ksg	Gain of speed governor
Tsg	Time constant of speed governor
Rp	Permanent droop
Rt	Temporary droop
Tg	Main servo time constant
D	Change in load with respect to frequency
Tw	Water starting time
Tr	Reset time

II. INTRODUCTION

The high Indian population coupled with increase in industrial growth has resulted in an urgent need to increase the installed power capacity. In India, majority of power production, around 65 per cent is from thermal power stations. Due to problems related to uncertainty in pricing and supply of fossil fuels, renewable resources have been identified as a suitable alternative like solar, wind, and biogas plants are using in recent days. However, standalone operation of renewable resources is not reliable as they are intermittent in nature. The intermittent nature of resource increases the frequency deviations which further add to the deviation caused by load variation. This necessitates the grid connection of renewable resources wind and solar.

Frequency deviation is undesirable because most of the AC motors run at speeds that are directly related to frequency. Also the generator turbines are designed to operate at a very precise speed. Microcontrollers are dependent on frequency for their timely operation. Thus it is imperative to maintain system frequency constant. This is done by implementing Load Frequency Control (LFC). There are many LFC methods developed for controlling frequency. They include flat frequency control (FFC), tie-line bias control (TBC) and flat tie-line control (FTC). In FFC, Some areas act as load change absorbers and others as base load.

The advantage is the higher operating efficiencies of the base load as they run at their maximum rated value at all times. But the drawback here is the reduced number of areas absorbing load changes which makes the system more transient prone. In FTC load changes in each area are controlled within the area, thereby maintaining tie line frequency constant. The most commonly used method is

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the tie-line load bias control in which all power systems in the interconnection aid in regulating frequency regardless of where the frequency change originates. In this project, the power system considered has a Thermal system with four thermal areas, a Hydro plant and a wind farm.

III. MODELING OF THERMAL AREAS

The thermal areas have been modelled using transfer function. Speed governor, turbine and generator constitute the various parts namely the speed governing system, turbine model, generator load model [7].

A. Speed Governing System

The command signal ΔPC initiates a sequence of events-the pilot valve moves upwards, high pressure oil flows on to the top of the main piston moving it downwards; the steam valve opening consequently increases, the turbine generator speed increases, i.e. the frequency goes up which is modelled mathematically.

$$\Delta Y_E(S) = [\Delta P_C(S) - \frac{1}{R}\Delta F(S)] \times (\frac{ksg}{1+TsgS}) \qquad (1)$$

B. Turbine model

The dynamic response of steam turbine is related to changes in steam valve opening ΔYE in terms of changes in power output. Typically the time constant T_t lies in the range 0.2 to 2.5 sec.

C. Generator Load Model

The increment in power input to the generator-load system is related to frequency change as

$$\Delta F(S) = [\Delta P_G(S) - \Delta P_D(S)] \times (\frac{kps}{1+Tps}) \qquad (2)$$

D. Entire thermal area

Typical values of time constants of load frequency control system are related a $T_{sg} < T_t << T_{ps}$ shows in the required block diagram below.

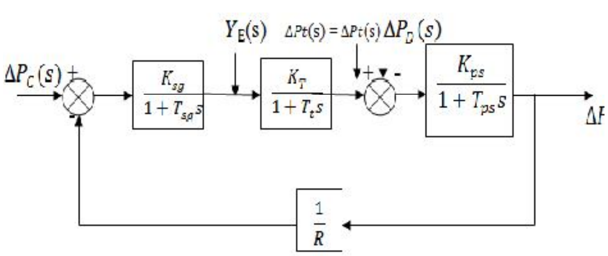

Fig.1 Block Diagram of Thermal

A complete block diagram of an isolated power system comprising turbine, generator, governor and load is easily obtained by combining the blocks.

Table no.1 Parameters of Thermal Areas

Area	Rated power	D(puMW/HZ)	Per unit inertia constant H(s)	Kps	T_{ps}
T_p1	2000	.01	6	100	24
T_p2	1000	.02	5	50	24
T_p3	600	.033	4	30	5.3
T_p4	2500	.008	6	125	30

IV. MODELING OF HYDRO AND WIND AREA

The representation of the hydraulic turbine and water column in stability studies is usually based on certain Assumptions. The hydraulic resistance is considered negligible. The penstock pipe is assumed inelastic and water incompressible. Also the velocity of the water is considered to vary directly with the gate opening and with the square root of the net head and the turbine output power is nearly proportional to the product of head and volume flow. [3]

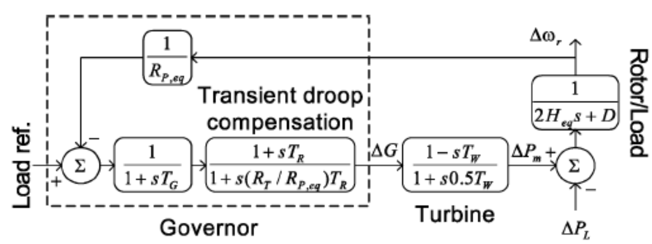

Fig.2 block diagram for hydro system

Hydro plants are modelled the same way as thermal plants. The input to the hydro turbine is water instead of steam. Initial droop characteristics owing to reduced pressure on turbine on opening the gate valve has to be compensated. Hydro turbines have peculiar response due to water inertia; a change in gate position produces an initial turbine power change which is opposite to that sought. For stable control performance, a large transient (temporary) droop with a long resettling time is therefore required in the forms of transient droop compensation as shown in Fig.2 The compensation limits gate movement until water flow power output has time to catch up. The result is governor exhibits a high droop for fast speed deviations and low droop in steady state.

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B. Modelling of wind farm

The wind power plant of nominal rating of 35 MW is also connected in the three area network and the transfer function model is developed for the wind power plant assuming a constant speed of wind [16].The second order dynamics of wind energy conversion system is given by choosing the proper natural frequency ω_n and damping factor ζ which further gives the controller parameters.

$$T_i = \frac{2\zeta}{\omega_n} - 1/\omega_n^2 T_{pt} \quad (3)$$

$$K_p = \left(\frac{T_i T_{pt}}{K_{pt}}\right)\omega_n^2 \quad (4)$$

A high value of Kpensure the better tracking performance but control effect limitation arises ,so the Kpmust be limited .The increase in overshoot is compensated by first order filtering of the reference signal. The dynamic behaviour of Wind Energy Conversion System (WECS) can be given by two- pole- one -zero transfer function as given below:

$$H_{pt}(S) = \frac{K_{pt}(T_Z S+1)}{(T_\Sigma S+1)(T_{pt}S+1)} \quad (5)$$

T_{pt} and T_Σ are main and parasitic time constant respectively. The closed loop structure of WECS with PI control is as shown in Fig 3.

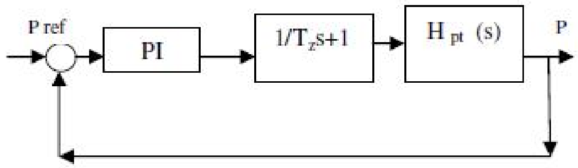

Fig.3 Wind Energy conversation system

The wind farm parameters are given in Table-III Recently the active power control of the variable speed

Wind turbines are becoming more mature with the advanced power electronic technology. The inertial and speed-droop controls of wind turbines for frequency response are widely used. The developed control loop within the wind turbine is like the speed governor which automatically adjusts power output in response to a frequency drop. However, due to the wind variability, the speed-droop control has its own Limitation. Because wind power is an intermittent motive source which differs from the source applying to the traditional plants, the control of wind turbine output is much more challenging[14].An appropriate coordination between stability and controllability of active power in wind turbines should be maintained.

V. LFC FOR A MULTI-AREA SYSTEM

An extended power system can be divided into a number of load frequency control areas interconnected by means of tie lines. The control objective now is to regulate the frequency of each area and to simultaneously regulate the tie line power as per inter-area contacts. As in case of frequency, proportional plus integral controller will be installed so as to give zero steady state error in the tie line power flow as compared to the contracted power. It is conveniently assumed that each control area can be represented by an equivalent turbine, generator and governor system. Symbols used with suffix 1 refer to area 1 & those with suffix 2 refer to area 2 and so on. Incremental tie line power out of area 1 given by [5].

$$\Delta P_{tie,1} = 2\pi T_{12}\left(\int \Delta f_1 dt - \int \Delta f_2\, dt\right) \quad (6)$$

Similarly, the incremental tie line power output of area 2 is given by

$$\Delta P_{tie,2} = 2\pi T_{21}\left(\int \Delta f_2 dt - \int \Delta f_1 dt\right) \quad (7)$$

Where T_{12} = synchronizing coefficient
f1 & f2 represent frequency of the respective area.

$$\Delta P_{tie,2}(S) = \frac{-2\pi a_{12} T_{12}}{s}[\Delta F_1(S) - \Delta F_2(S)] \quad (8)$$

This has been represented by fig.4

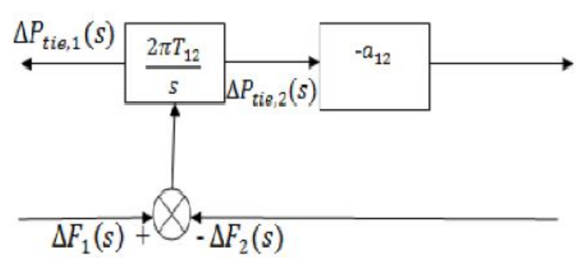

Fig.4 Tie Line Power Diagram

With the primary LFC loop a change in the system load will result in a steady state frequency deviation, depending on the governor speed regulation. In order to reduce the frequency deviation to zero we must provide a reset action by introducing an integral controller to act on the load reference setting to change the speed set point. The integral controller increases the system type by 1 which forces the final frequency deviation to zero. The

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integral controller gain must be adjusted for a satisfactory transient response. It is seen from the above discussion that with the speed governing system installed on each machine, the steady load frequency characteristic for a given speed changer setting has considerable droop, from no load to full load .system frequency system specifications are rather stringent and,therefore so much change in frequency cannot be tolerated. In fact, it is expected that the steady change in frequency will be zero. While steady state frequency can be brought back to the scheduled value by adjusting speed changer setting, the system could undergo intolerable dynamic frequency changes with changes in load. It leads to the natural suggestion that the speed changer setting be adjusted automatically by monitoring the frequency changes.

For purpose, a single from Δf is fed through an integrator to the speed changer resulting in block diagram configuration shown .the system now modifies to a proportional plus integral controller, which is well known from control theory, gives zero steady state error.

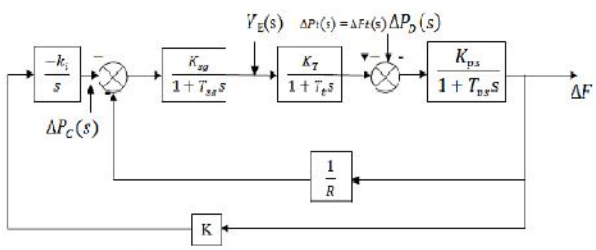

Fig.5 Diagram for Proportional plus Integral Load frequency Control

$$\Delta F(S) = -\frac{K_{ps}}{(1+T_{ps}S)+(\frac{1}{R}+\frac{K_i}{S})\times\frac{K_{ps}}{(1+T_{sg}S(1+T_tS))}} \times \frac{\Delta p_D}{S}$$

VI. SIMULATION AND RESULTS

A. LFC for thermal system two area without wind

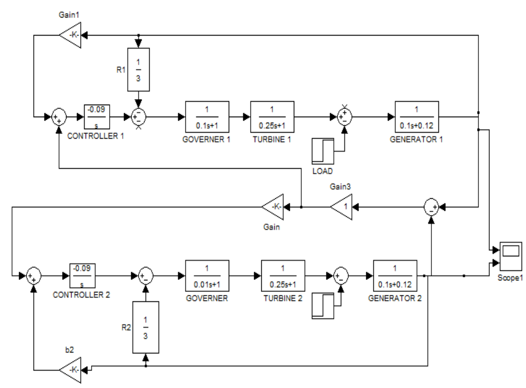

Fig: 5Two area thermal without wind

The two thermal systems have been combined and the composite block diagram is simulated in Simulink or mat lab R2010 as shown above figure 5

Response for two area thermal without and with wind are shown below.

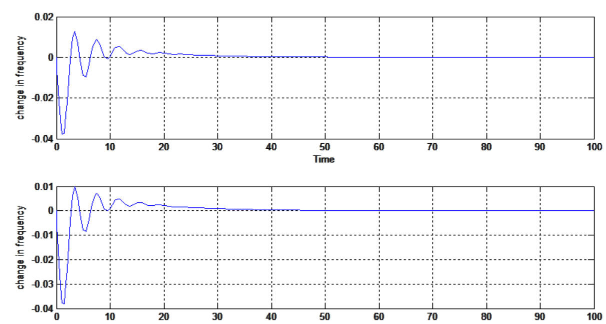

Fig: 6 Responses for two areas without wind

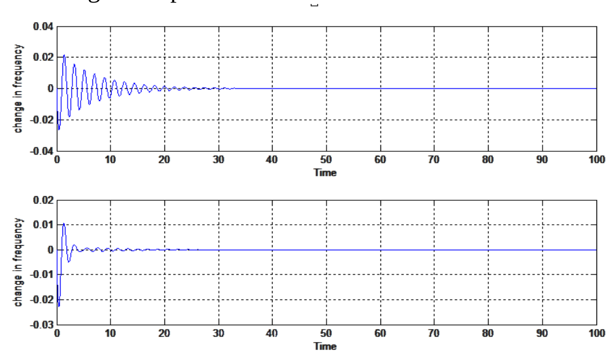

Fig: 7 Response for two areas with wind integration

Let the loads ΔP_{D1} to ΔP_{D2} be simultaneously applied in control areas 1 to 2 respectively. The system parameters of two area system are given table I. The frequency deviation versus time scale of two thermal areas for step load change is shown in figure 6. From the

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response it is evident that frequency deviation for thermal system is within tolerance limits. And when wind area integrated to thermal the steady state error becomes zero faster than without wind as shown in fig 7.

B. LFC for Thermal and Hydro System (multi area)

The four thermal systems along with hydro unit are combined and composite block diagram is simulated as shown in figure.8

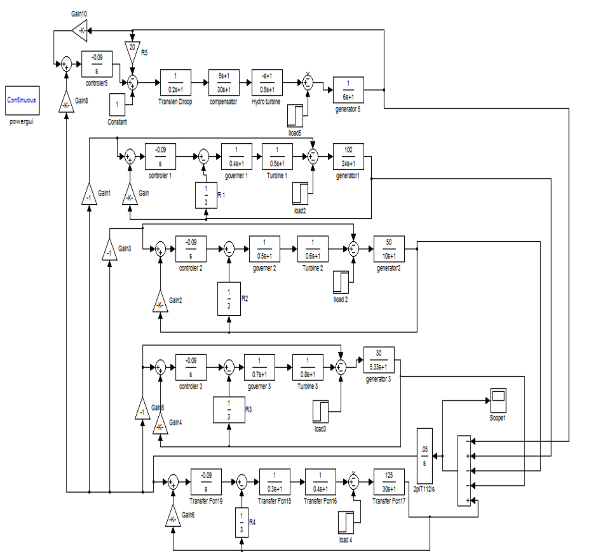

Fig.8 Hydro and thermal systems

Frequency Deviation (Hz) Vs Time (s) for Hydro & Thermal system with p controller

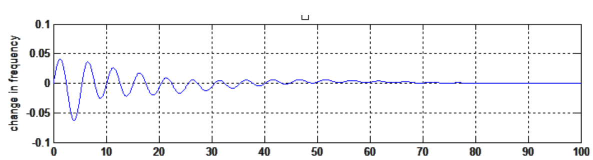

Fig.9 response of hydro thermalwith pi controller

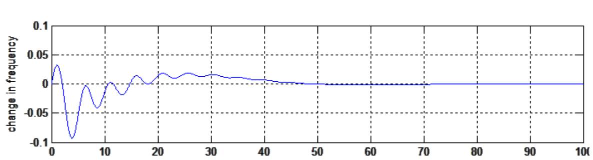

Fig.10 response of hydro thermal with pid controller

Frequency deviation versus time for integrated thermal and hydro system for step load change with pi and pid controller is shown in fig.9and fig.10 from the response it can be concluded that penetration of hydro energy (renewable) does not affect the system frequency adversely as the frequency deviation is well within limits.

C. LFC for Thermal, Hydro and Wind system

To compensate the intermittent nature of renewable, grid connection of the same is imperative for reliable power generation. It is possible to divide an extended power system into sub areas in which the generators are tightly coupled together so as to form a coherent group, i.e. all the generators respond in unison to changes in load or speed changer settings. Such a coherent area is called control area in which frequency is assumed to be same throughout in static and dynamic conditions. For the purpose of developing a suitable control strategy, a control area can be reduced to a single speed governor, turbo generator and load system consisting of four thermal areas, a hydro area and wind farm is controlled by a controller. By a batch control, the load is divided amongst various power plants in the ratio of their capacities by control system. This entire power system is modelled as shown in fig.10

The four thermal areas and the hydro unit are combined together in thermal & Hydro subsystem which is same as the model shown in fig.11 .the output ΔF of this subsystem gets reflected in grid voltage.

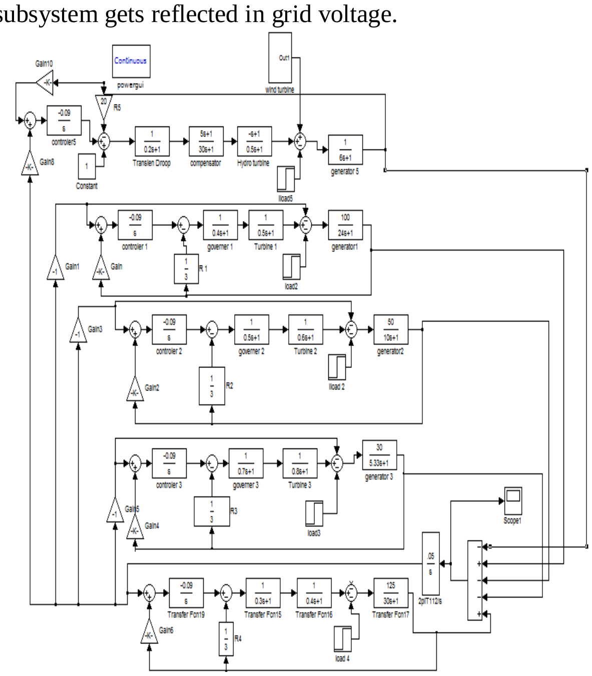

Fig.11LFC for Thermal, Hydro and Wind system

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The output of wind farm is sent to the central control system
To calculate the load distribution over thermal station.

Response for fixed load in four area thermal and hydro system

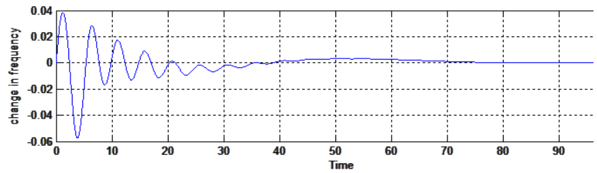

Fig.12 Response of multi area with wind pi controller

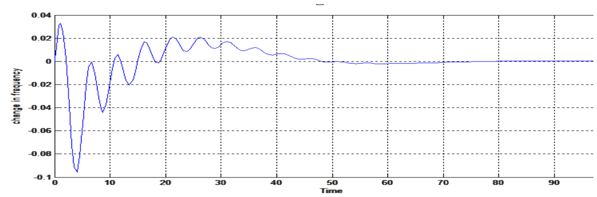

Fig.13 Response of multi area with wind pid controller

Frequency deviation versus Time for Integrated Thermal, Hydro and Wind system for step load change with pi and pid controller is shown in Fig.12and fig.13. From the curves, it can be concluded that in an integrated system with high penetration of renewable, frequency deviation has increased. Nevertheless, it is within limits thereby making renewable energy sources desirable.

VII. CONCLUSION

Load frequency control becomes more important, when a large amount of renewable power supplies like wind power generation are introduced. In this paper Load Frequency Control with considerable penetration of renewable has been analysed in the presence of Thermal, Hydro and Wind Systems with pi and pid controllers. It is observed that frequency deviation is low when wind system is introduced into the actual thermal systems, and it is within the tolerable limits for fixed load variations. The loads are distributed among different units using Tie Line Bias Control method of LFC as it gives minimal frequency deviation. When compared to pi controller pid controller gives steady state error zero in less time is observed.

TABLENO.2 NOMINAL PARAMETERS OF WIND POWER PLANTSIMULATED

Density of air =1.25kg/m^3 Gear ratio =70	$T_{pt = 10.055}$
Radius of Turbine blade=45m	$K_{pt = 0.12}$
Average wind velocity=7m/s	$T_{i = 3s}$
H=5sec	T_p =20s

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