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Improving Dynamic Performance of Automatic Generation Control of Interconnected Power System by Combing Parallel EHV AC/ HV DC link

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Abstract: This paper deals with load frequency control of 2 area interconnected Thermal power systems with EHVAC/HVDC links when subjected to small step load perturbations. For the present study, power system model consists of two areas thermal power plants having identical capacity. The system interconnection is considered namely (I) EHVAC transmission link only (II) EHVAC in parallel with HVDC transmission link. The HVDC link is considered to be operating in constant current control mode. To carry out the investigations, optimal AGC regulators are designed using proportional-plus-integral control strategy and implemented on the system under consideration in the wake of 1% step load perturbation in thermal area. The system responses will be simulated in Mat lab. Responses of deviation in frequencies, deviation in tie line power and integral of area control errors are plotted. By comparing the responses of the two model developed, one by using HVDC link and another without using HVDC link, the frequency deviation and settling time is lesser than without using HVDC link. Therefore by combining the transmission line by using HVDC link provides better dynamic performances in terms of overshoot and settling time.
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Keywords: Interconnected power systems; System dynamic performance; EHVAC//HVDC transmission link, MATLAB

I. INTRODUCTION

Large scale power systems are normally divided into control areas based on the principle of coherency. The coherent areas are interconnected through tie-lines which are used for contractual energy exchange between areas and provide inter-area support during abnormal operations. The successful operation of interconnected power systems requires the matching of total generation with total load demand and associated system losses. With time, the operating point of a power system changes, and hence, these systems may experience deviations in nominal system frequency and scheduled power exchanges to other areas, which may yield undesirable effects. There are two variables of interest, namely, frequency and tie-line power exchanges. Their variations are weighted together by a linear combination to a single variable called the ACE. During the last few decades, considerable generation controllers for interconnected power systems[1-5]

Electric power systems consist of a number of control areas, which generate power to meet the power demand. However, poor balancing between generated power and demand can cause the system frequency to deviate away from the nominal value and create inadvertent power exchange between control areas. To avoid such situation, load frequency controllers are designed and implemented to balance generated power and demand in each control area automatically. Frequency control as a major function of automatic generation control is one of the important control problems in electric power system design and operation, and is becoming more significant today because of the increasing size, changing structure, emerging new uncertainties, environmental constraints and the complexity of power systems. In the last two decades, many studies have focused on damping control and voltage stability and the related issues, but there has been much less work on the power system frequency control analysis and synthesis. While some aspects of frequency control have been illustrated along with individual chapters, many conferences and technical papers, a comprehensive and sensible practical explanation of robust frequency control in a book form is necessary[6-7].

This paper provides a thorough understanding of the basic principles of power system frequency behavior in wide range of operating conditions. It uses simple frequency response models, control structures and mathematical algorithms to adapt modern robust control theorems with frequency control issue and conceptual explanations.

The objective of the present work is as follows:

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i) To develop the model of single area and two area interconnected power system combining EHV AC/ HV DC link.
ii) To design different controllers and implement it in two area interconnected power system.
iii) To simulate and investigate the performances of each controllers with and without HV DC link.

II. LOAD FREQUENCY CONTROL IN TWO AREA POWER SYSTEM

Automatic Generation Control (AGC) is used in real-time control to match the area generation changes to area load changes in order to meet tie-line flows and keep frequency at nominal value. By processing frequency and tie line deviations, AGC can determine whether the load changed in its own area or in its neighbor's area. If the former, the generations of units under AGC is adjusted until the deviations becomes zero. The AGC problem of interconnected system is not only to see that the generation balances the demand but also to allocate generation between various systems, so that the total system operation schedules are kept up. Thus in interconnected system either executed manually or automatically, the function of AGC is to reallocate the generation changes to pre-selected machines after an initial random accommodation of the load by governor action. It is necessary to obtain much better frequency constancy than obtained by speed governor itself. To accomplish this we must overcome speed changes in accordance with some suitable control strategy. In practice different conventional control strategies are utilized for AGC viz., Proportional and Integral (PI), Proportional, Integral and Derivative (PID) and Optimal control. The PI controller improves steady state error simultaneously allowing a transient response with little or no overshoot. A**s** long as error remains, the integral output will increase causing the speed changer position, attains a constant value only when the frequency error has reduced to zero. So it introduces oscillations into the system. The PID controller improves the transient response so as to reduce error amplitude with each oscillation and then output is eventually settled to a final desired value.

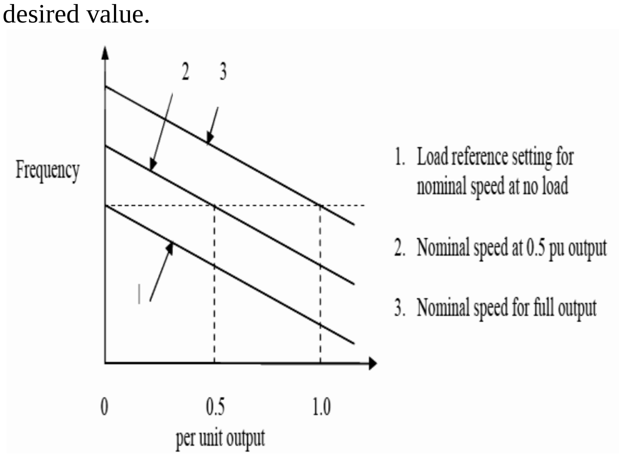

Fig. 1 Variation of frequency with p.u output

Governor characteristics point. By adjusting this set point on each unit a desired unit dispatch can be maintained while holding system frequency close to the desired nominal value. R is equal to p.u change in frequency, divided by p.u change in unit output. That is,

$$R = \frac{\Delta\omega}{\Delta P} \quad p.u \tag{1}$$

Model of system frequency:

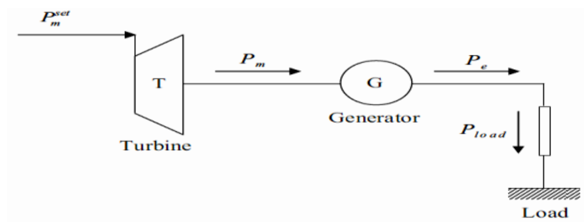

Fig. 2 Simplified representation of a power system consisting of single generator connected to the same bus as the load.

Suppose that this generator experience a step increase in load,

$$\Delta P_L(s) = \frac{\Delta P_L}{s} \tag{2}$$

The transfer function relating the load change Δ PL, to the frequency change Δω is

$$\Delta\omega(s) = \Delta P_L(s)\left[\frac{\frac{-1}{Ms+D}}{1+\frac{1}{R}\left(\frac{1}{1+sT_G}\right)\left(\frac{1}{1+sT_{CH}}\right)\left(\frac{1}{Ms+D}\right)}\right] \tag{3}$$

The steady state value of Δω(s) may be found by:
steady state = lim [s Δω(s)]

$$\Delta\omega \text{ steady state} = \frac{-\Delta P_L}{\frac{1}{R}+D} \tag{4}$$

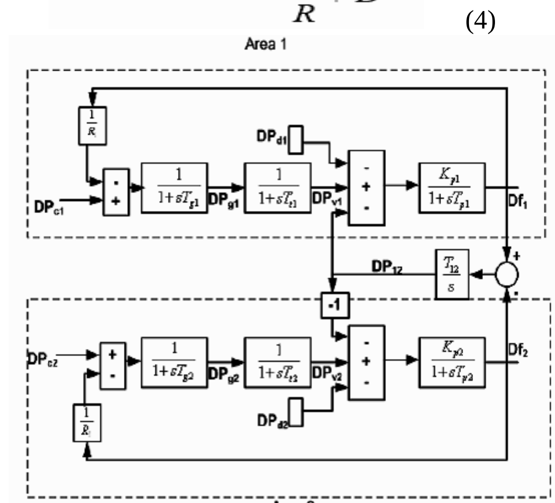

Fig. 3.Transfer function model of two-area thermal system

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Automatic Generation Control (AGC) or Load Frequency Control is a very important issue in power system operation and control for supplying sufficient and reliable electric power with good quality. An interconnected power system can be considered as being divided into control area, all generators are assumed to form a coherent group. In the steady state operation of power system, the load demand is increased or decreased in the form of Kinetic Energy stored in generator prime mover set, which results the variation of speed and frequency accordingly. Therefore, the control of load frequency is essential to have safe operation of the power system. Automatic generation control (AGC) is defined as, the regulation of power output of controllable generators within a prescribed area in response to change in system frequency, tie-line loading, or a relation of these to each other, so as to maintain the schedules system frequency and the established interchange with other areas within predetermined limits. Therefore, a control strategy is needed that not only maintains constancy of frequency and desired tie-power flow but also achieves zero steady state error and inadvertent interchange. Among the various types of load frequency controllers, the most widely employed is the conventional proportional integral (PI) controller. The PI controller is very simple for implementation and gives better dynamic response.

III. TIE-LINE MODELLING

From power flow equation:

$$P_i = \sum_{k=1}^{n} |V_i||V_k|B_{ik} \sin(\theta_i - \theta_k) \quad (5)$$

Approximate at normal operating condition, we have

$$P_i \approx \sum_{k=1}^{n} B_{ik}(\theta_i - \theta_k) \quad (6)$$

Then, for small change,

$$\Delta P_i \approx \sum_{k=1}^{n} B_{ik}(\Delta\theta_i - \Delta\theta_k) = \sum_{k=1}^{n} T_{ik}(\Delta\theta_i - \Delta\theta_k) \quad (7)$$

Where T_{ik} is called stiffness or synchronizing power coefficient

From the equation, $$\Delta P_i = \sum_{k=1}^{n} T_{ik}(\Delta\theta_i - \Delta\theta_k) \quad (8)$$

And $$\Delta\theta = \frac{1}{s}\Delta\omega$$

We have, $$\Delta P_i = \sum_{k=1}^{n} \frac{T_{ik}}{s}(\Delta\omega_i - \Delta\omega_k) \quad (9)$$

IV. AREA CONTROL ERROR: TIE-LINE BIAS CONTROL

In reality a control area is interconnected not with one tie-line or to one neighbouring area but with several tie-lines to neighbouring control areas, all part of the overall power pool. Consider the i_{th} control area. Its net interchange equals the sum of megawatts on all m outgoing tie-lines. As the area control error ACE_i ought to be reflective of the total power it should thus be chosen of the form

$$ACE = \sum_{j=1}^{m} \Delta Pij + Bi\,\Delta fi \quad (10)$$

- Use ACE is to adjust setting control power of each area.

- To drive ACE in all area to zero.
-To send appropriate signal to setting control power,

- Use integrator controller so that ACE goes to zero at steady state.

Steady state is reached when frequency is back at the operating point and generator in area 2 takes its own load.

A. INTEGRAL CONTROLLER

This mode represents a natural extension of principal of floating control in the limit of infinitesimal changes in the rate of controller output with infinitesimal changes in error. This mode is also referred to as reset action. It involves integration of the error signal over a period of time. The rate of change of correcting signal is proportional to the error.

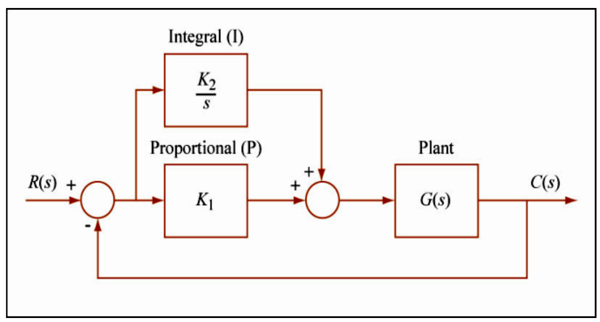

Fig. 4 Block diagram PI controller

The transfer function of this controller is

$$G(s) = Kp + \frac{Ki}{s}$$

And,
I = $(1/K_i)$ $E_p(t)$ dt + P_o
Where,
K_i = integral time.
$1/K_i$ = reset rate.
E_p = error.
P_o = controller output at t = 0.

In this mode, the controller will continue to take the control action as long as the control error exists and any offset error, caused by load changes, is eliminated. The above equation can be simplified as:-

$$I = (E_1/K_i) + (E_2/K_i) + (E_3/K_i)$$

$$I = 1/K_i \left(\sum_{n=1}^{N} E_n \right)$$

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We see that faster rate provided by K_i causes a much greater controller output at a particular time after the error is generated.

V. RESULT AND DISCUSSION

The following configurations are identified for power system model:

(i) EHVAC link is used as a system interconnection.

(ii) EHVAC link in parallel with HVDC link is used as a system interconnection.

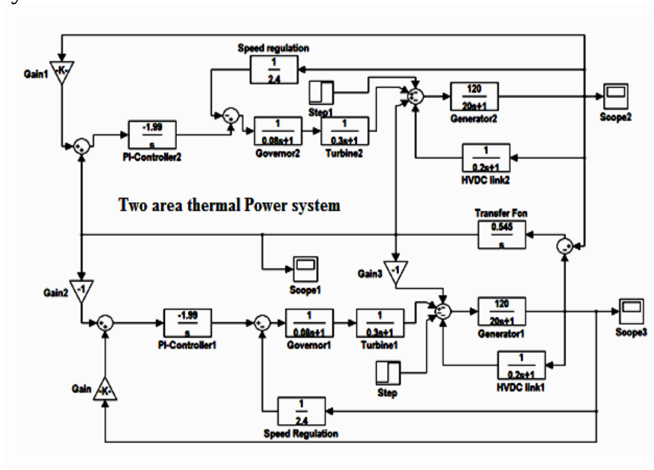

Fig.5 MATLAB model of the interconnected thermal power system by using HVDC link and tie line

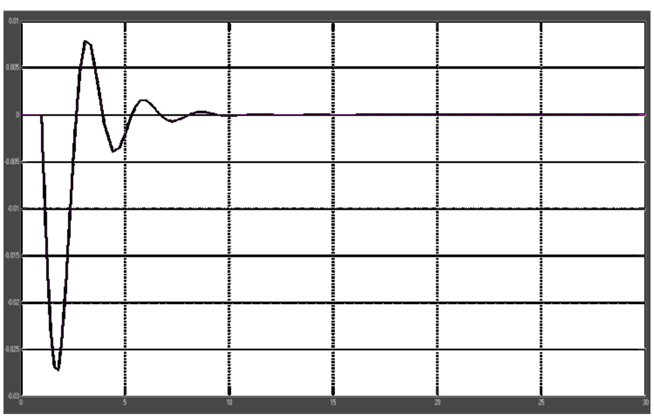

Fig.6 Response of change in frequency interconnected thermal power system without using HVDC link

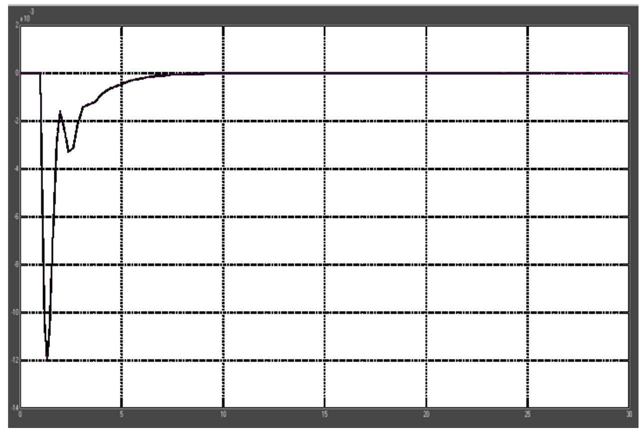

Fig. 7 Response of change in frequency interconnected thermal power system with using HVDC link

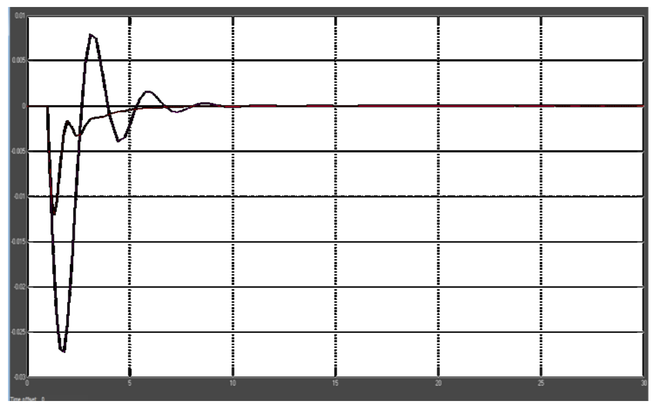

Fig.8 Combined Response of change in frequency of the interconnected thermal system by using HVDC link and without using HVDC link.

TABLE: 1. COMPARATIVE STUDY OF SETTLING TIME

Configuration	Area 1 (sec)	Area 2 (sec)	Steady error
With EHV AC Ink	12	12	Zero
With EHV AC/DC link	08	08	Zero

TABLE: 2. COMPARATIVE STUDY OF PEAK OVERSHOOTS

Configuration	Δf Area 1 (pu)	Δf Area 2 (pu)	Steady State error
With EHV AC Ink	-0.025	-0.025	Zero
With EHV AC/DC link	-0.012	-0.012	Zero

VI. CONCLUSION

Two cases have been studied for 2-area interconnected thermal power system. One without HVDC link and another by combining EHV AC/ HV DC link. By comparing table 1 and table 2, it is inferred that (i) with EHVAC links, deviation in frequencies, and integral of area control errors

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have large overshoot & settling time subjected to 1% step load disturbance in thermal area. (ii) With parallel EHVAC/HVDC links, all responses have been improved in terms of settling time, overshoot & steady state error subjected to 1% step load disturbance.

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APPENDIX A

NOTATIONS:

i =Subscript referring to area (i=1, 2)

ΔXgi=Incremental change in governor valve position of ith area

ΔPci= Incremental change in speed changer position of ith area

ΔPgi= Incremental change in power generation of ith area

ΔPdi= Incremental change in load demand of ith area (p.u. MW/Hz)

ΔFi= Incremental change in frequency of ith area

ΔPtiei =Incremental change in tie-line power flow of ith area (MW)

ΔPdci= Incremental change in DC link power flow of ith area

ΔPri= Incremental change in reheat turbine output of ith area

fo= Nominal system frequency (Hz)

Hi =per unit inertia constant of ith area (sec)

Di= Load frequency constant of ith area (p.u. MW/Hz)

Ri=Speed regulation parameter of ith area (Hz/p.u. MW)

Bi= Frequency bias constant of ith area (p.u. MW/Hz)

Kgi= Speed governor gain of ith area

Tgi =Speed governor time constant of ith area (sec)

Kri= Reheat turbine gain

Kdc =DC-Link gain

Tdc= DC-Link time constant (sec)

Pri= Rated power output of ith area

Δi= Power angle of ith area

P max = Maximum rated power

T12= Synchronizing coefficient of AC link

a12= Area size ratio coefficient

ACE= Area Control Error

IACEi= Integral Area Control Error of ith area.

AGC= Automatic Generation Control

LFC= Load Frequency Control

MW =Mega Watt

EHVAC= Extra High Voltage Alternating Current

HVDC =High Voltage Direct Current

PI= Proportional Integral Control

APPENDIX B:

Numerical data

For Thermal Plant

Pr1 =Pr2= 2000 MW; D1 =D2= 0.00833 p.u. MW/Hz; M1=M2=0.167pu MW/Hz; R1 =R2= 2.4 Hz p.u.MW; B1 =B2= 0.425 p.u.MW/Hz; Tg1 =Tg2= 0.08 Sec; Tt1 =Tt2= 0.3 sec; a12 = -1;
ΔPd1 = 0.01; ΔPd2 = 0.00; Kr1 =Kr2= 0.5; Tr1=Tr2= 10 Sec;

AC& DC Link Pmax = 200 MW (10% of RatedPower);
2*pi*T12=2*pi*T23=2*pi*T31=0.545
a = δ1- δ2 = δ2- δ3 =δ3- δ1 = 30°;
Kdc1=Kdc2=Kdc3=1.0;Tdc1=Tdc2=Tdc3 = 0.2Sec;

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