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Design of a New Area Control Error Based Load Frequency Controller for a Two-Area Interconnected Power System

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***Abstract*—Successful operation of an interconnected power system requires the matching of total generation with total demand and associated system losses. With time as 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. The two variables are considered for the evaluation of the system performances namely, frequency and tie-line power exchanges. In this two-area symmetrical thermal reheat system with stiff and elastic tie lines are considered for simulation controllers using proportional and integral are designed and the simulated results are analyzed for better performance.**

***Index Terms*—Area Control Error, Load Frequency Control, Settling Time, Stiff tie-line, Elastic tie-line.**

I. Introduction

Recently, the evaluation of control performances of interconnected power systems has become an important issue with respect to individual load frequency controls. In this paper the system performance is evaluated using the settling time based stability criterion in a two-area thermal reheat power system interconnected with elastic and stiff tie-lines. The design of controllers with proportional and integral are implemented and the simulated response for change in output frequency, tie-line power flow and input power are analyzed with the mathematical model developed for a two area symmetrical thermal reheat power system, interconnected with stiff tie-line and elastic tie-lines. The results reveal that the system with elastic tie-line ensures better transient response and less settling time.

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II. Two Area System Models

A. System model with stiff tie-line

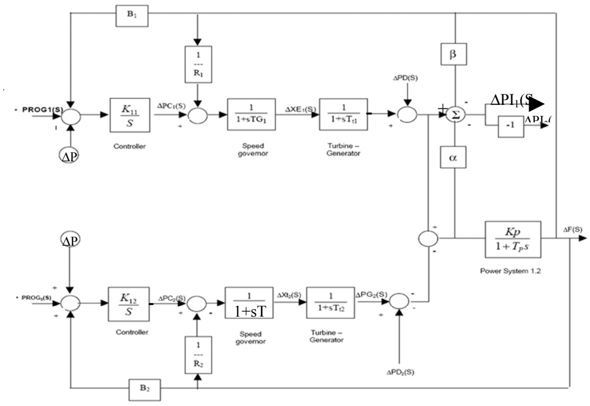

Fig.1. Interconnected with stiff tie-line

This model is based on the assumption that transmission lines within each individual control area, and tie lines between areas, are completely stiff, Then, the whole system can be characterized by a single frequency. That is, all the generators of the system swing in unison [2].

The real power deviation, ΔPI_i, of the interchange between area *i* and the rest of areas in the system, can be obtained from the dynamic equation of the generators and the fact that the overall exchange balance between areas must be zero.

The model proposed in fig.1 can be improved by introducing the load-frequency characteristic of the areas in the dynamic equation of the power system and representing in more detail the speed governor and the turbine-generator of the power plants. Then, assuming neglected line losses, the deviation of interchanged real power can be written as

$$\Delta PI_1 = \Delta PI_2 = (\Delta PG_1 - \Delta PD_1)(1 - \alpha) - (\Delta PG_2 - \Delta PD_2)(\alpha - \beta)\Delta F$$

Where ΔPG_i is the incremental power generation of area i, ΔPG_i is the increment of load consumption in the area, and α, β are coefficients given by

$$\alpha = \frac{H_1 . P_{r1}}{H_1 . P_{r1} + H_2 . P_{r2}} \quad (1)$$

$$\beta = D_1 / (D_1 + D_2) \quad (2)$$

$$\frac{\Delta F(s)}{\sum_{i=1}^{n} (\Delta PG_i \quad \Delta PD_i)} = \frac{K_p}{1 + sT_p} \quad n = 2 \quad (3)$$

$$T_p \triangleq \frac{1}{F^*} \frac{2H_1 . P_{r1} + 2H_2 . P_{r2}}{D_1 + D_2}$$

$$K_p \triangleq \frac{1}{D_1 + D_2}$$

F* being the rated frequency.

B. System model with elastic tie-line

The two-area system model with elastic tie-lines is based on the assumption that transmission lines within each individual control area are strong in relation to ties between areas[2]. So, a whole area can be characterized by a single frequency. This implies that generators belonging to an area swing in unison but on necessarily with generators of the other area.

Neglecting line losses, the increment tie-line power, ΔPI, can be written as

$$\Delta PI_{12} = T_{12} * (\int \Delta f_1 dt - \int \Delta f_2 \, dt)$$

Where $T_{12} * \triangleq \frac{2|V_1||V_2|}{X_{12}} \cos(\delta_1 * - \delta_2 *)$

is the synchronizing coefficient or electrical stiffness of the tie-line; X_{12}, its reactance and $V_i = |V_i| e^{j\alpha i}$ the bus voltage of the line terminal *i*.

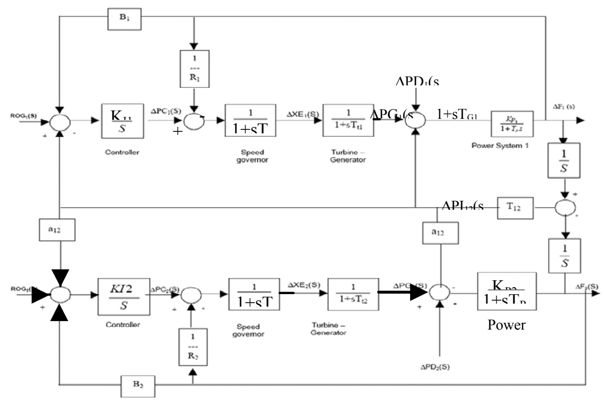

Fig.2. Interconnected with elastic tie-

III. Performance Evaluation

A. Area Control Error (ACE)

Generally, it is assumed that the characteristics of the load fluctuations are the same in the two control areas and there is no correlation between the load fluctuations of each control area, each standard deviation of the load fluctuations is proportional to the square root of the system capacity. If each control area's governor response and LFC contribute equally, the standard deviation of ACE should be proportional to the square root ratio of its capacity divided by the total capacity of interconnected power systems [1].

The permitted values of the standard deviation of ACEs are expressed as given below

$$\sigma_{ACE\ A} \leqslant \sqrt{P_A / P \sigma_{ACE\ (REF\ )}} \quad (4)$$

$$\sigma_{ACE_B} \leqslant \sqrt{P_B / P \sigma_{ACE(REF)}} \quad (5)$$

Supposing the averages of ACE_A and ACE_B are 0, their sample variances will be expressed by the following equations.

$$\frac{1}{N} \sum^{N} ACE_A^2 = \sigma^2_{ACE_A} \quad (6)$$

$$\frac{1}{N} \sum^{N} ACE_B^2 = \sigma^2_{ACE_B} \quad (7)$$

Then the sample variance of ACE of whole system can be expressed as follows.

$$\sigma^2_{ACE} = \frac{1}{N} \sum^{N} (ACE_A + ACE_B)^2$$
$$= \sigma^2_{ACE_A} + \sigma^2_{ACE_B} + 2R_{ACE_{AB}} \quad (8)$$

Where $R_{ACE_{AB}} = \frac{1}{N} \sum^{N} ACE_A ACE_B$

Substituting (4) for (8), (8) and can be expressed as

$$\sigma^2_{ACE} \leq \frac{P_A}{P} \sigma^2_{ACE(REF)} + \frac{P_B}{P} \sigma^2_{ACE(REF)} + 2R_{ACE_{AB}}$$
$$\leq \sigma^2_{ACE(REF)} + 2R_{ACE_{AB}}$$

When there is no correlation between the ACEs, the standard deviation of the ACE of whole system should become less than the permitted value.

IV. Simulation Results

The optimum value of integral controller gains the two-area Interconnected thermal reheat system with stiff tie-line were found to be $K_{i\,stiff\,1} = 0.3; K_{istiff\,2} = 0.3$ and that for two area thermal reheat system. Interconnected with elastic tie-line were found to be $K_{ielastic1} = 0.7; K_{ielastic2} = 0.7$. The frequency and tie-line power responses to step load disturbance in area 1 with elastic tie-line model and stiff tie-line model were simulated. From the output response of the system with stiff and elastic tie-line models it can be found that the system with elastic tie-line model ensures better transient response and less setting time.

Table - I
Controller Design Using ACE.

Identical Area			
Stiff tie-line		**Elastic tie-line**	
$KP_1 = 1.0$	$KI_1 = 0.5$	$KP_1 = 1.2$	$KI_1 = 0.35$
$KP_2 = 1.0$	$KI_2 = 0.5$	$KP_2 = 1.2$	$KI_2 = 0.35$
Settling Time (ts) in secs		**Settling Time (ts) in secs**	
Δf_1=16.57	Δf_2=16.57	Δf_1=25.48	Δf_2=25.48
Δp_{tie}=16.81		Δp_{tie}=28.21	

Table - II
Controller Design Using ACE.

Different Area			
Stiff tie-line		**Elastic tie-line**	
$KP_1 = 1.1$	$KI_1 = 0.55$	$KP_1 = 1.4$	$KI_1 = 0.7$
$KP_2 = 1.1$	$KI_2 = 0.55$	$KP_2 = 1.3$	$KI_2 = 0.6$
Settling Time (ts) in secs		**Settling Time (ts) in secs**	
Δf_1=18.73	Δf_2=18.73	Δf_1=28.23	Δf_2=27.93
Δp_{tie}=17.81		Δp_{tie}=28.23	

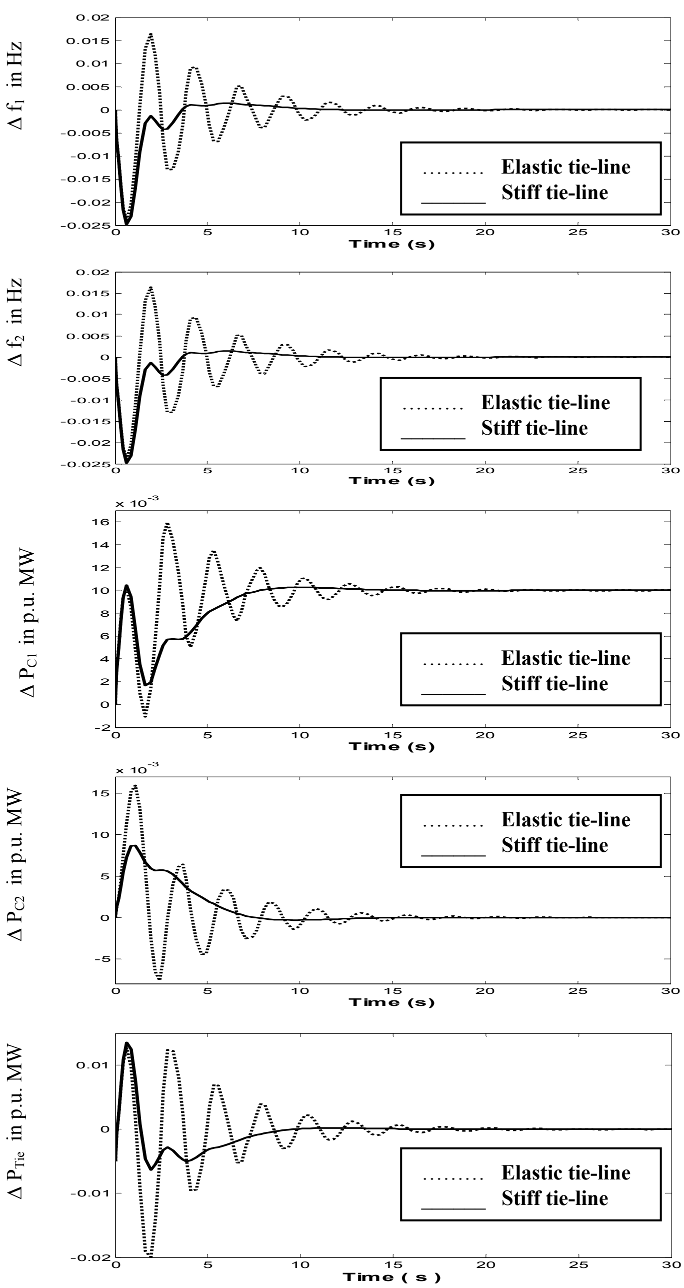

Fig (3). Frequency Deviations, Control Input Deviations and Tie-Line Power Deviation of a Two area Power System(Identical areas) Interconnected with Elastic and Stiff tie-lines for 1% Step Load Change in Area 1.

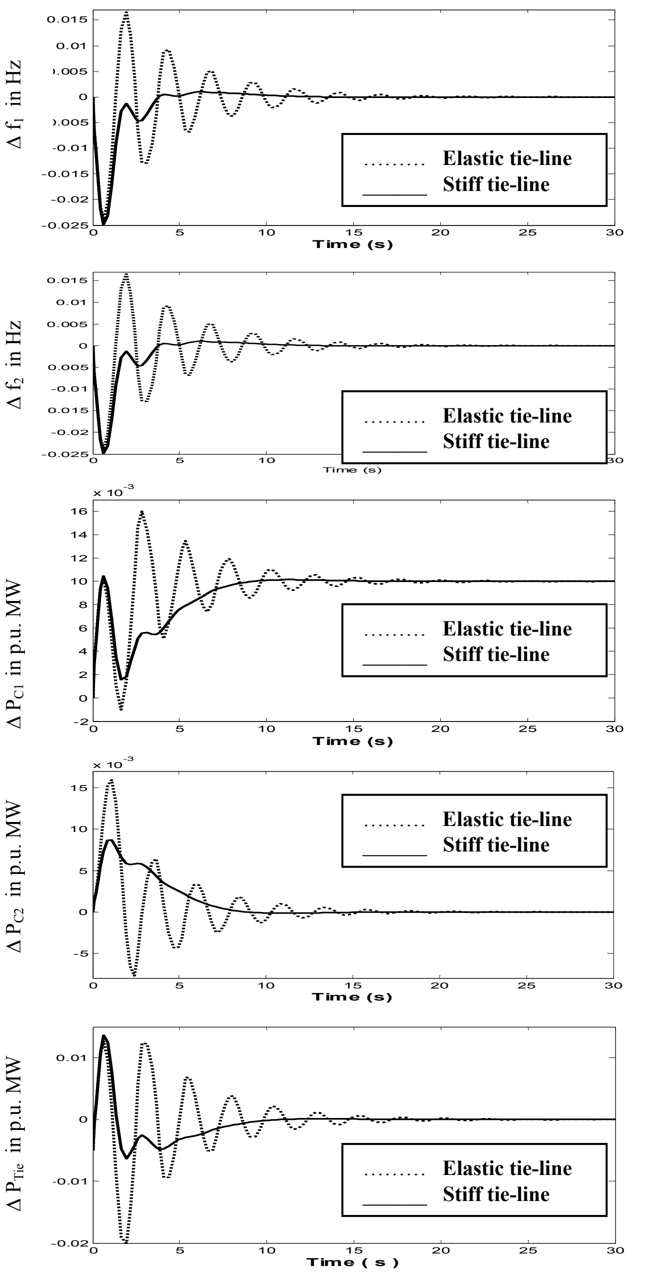

Fig (4). Frequency Deviations, Control Input Deviations and Tie-Line Power Deviation of a Two area Power System(Different areas) Interconnected with Elastic and Stiff tie-lines for 1% Step Load Change in Area 1.

V. CONCLUSION

Load frequency control models of interconnected power system with elastic tie-line representation enables a clear improvement upon models with stiff tie-line. In fact elastic tie-line models provide more detailed information about the system evolution of the frequency of each individual control are and the power interchanged through each tie-line. Evaluation of control performances of interconnected power system of two-area with stiff and elastic tie-lines were simulated by designing the proportional plus integral controllers. Simulated results reveal that better performance can be achieved when the two-area power system inter connected with elastic tie-lines. More over, combination of stiff and elastic tie-lines can also be incorporated to have a better performance in inter area power flow.

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APPENDIX – A

A.1 Data for the interconnected two area(Identical) thermal power system [5]

Rating of each area = 2000MW.
Base power = 2000 MVA.
f^o = 60Hz.
$R_1 = R_2$ =2.4Hz/p.u.MW.
$H_1 = H_2$ =5Sec.
$T_{g1} = T_{g2}$ =0.08sec.
$T_{r1} = T_{r2}$ =10Sec.
$T_{11} = T_{12}$ =0.3sec.
$K_{p1} = K_{p2}$ =120Hz/p.u.MW.
$K_{r1} = K_{r2}$ =0.5.
$T_{p1} = T_{p2}$ =20sec.
$\beta_1 = \beta_2$ =0.425p.u.MW/Hz.
T_{12} = 0.0707 p.u.MW/Hz .
a_{12} = -1.
ΔP_{d1}= 0.01 p.u.MW.
ΔP_{d2}= 0.0 p.u.MW.

A.2 Data for the interconnected two-area(Different) thermal power system [15]

Rating of each area = 2000MW.
Base power = 2000 MVA.
f^o = 60Hz.
R_1 = 2.4Hz/p.u.MW.
R_2 = 5Hz/p.u.MW.
H_1 = 5Sec.
H_2 = 5Sec.
T_{g1}= 0.08sec.
T_{g2}= 0.25sec.
T_{r1} = 10Sec.
T_{r2} = 10Sec.
T_{t1} = 0.3sec.
T_{t2} = 0.25sec.
K_{p1}= 120Hz/p.u.MW.
K_{p2}= 120Hz/p.u.MW.
K_{r1} = 0.5.
K_{r2} = 0.5.
T_{p1} = 20sec.
T_{p2} = 32sec.
β_1 = 0.425p.u.MW/Hz.
β_2 = 0.2083p.u.MW/Hz.
T_{12} = 0.0707 p.u.MW/Hz .
a_{12} = -1.
ΔP_{d1}= 0.01 p.u.MW.
ΔP_{d2}= 0.0 p.u.MW.

NOMENCLATURE

a_{12}	$-Pr_1 / Pr_2$
ACE	Area control error of area
AGC	Automatic Generation Control
D	Area Load Frequency
β_i	Frequency bias constant
β_i	$(D_i + 1/R_i)$ area frequency response characteristics
f	Rated Frequency
H_i	Inertia Constant
KI	Integral gain
K_p	Proportional gain
K_{pi}	$1/D_i$
LFC	Load Frequency Control
ΔP_{Di}	Incremental load consumption in area i
ΔP_{tiei}	Power deviation of the interchange between area i
T_{12}	Synchronising power coefficient (p.u.)

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