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Conventional load frequency control of an interconnected multi-area reheat thermal power systems using HVDC link

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Abstract—This work presents Load Frequency Control (LFC) of multi -area interconnected thermal power systems incorporate with reheat turbine. Area 1, area 2 and area 3 are interconnected using normal HVAC tie line. In this investigation HVDC link is connected in parallel with HVAC tie line and performance of AC/DC tie line is compared with ordinary HVAC tie line. The dynamic performance of the system is observed with conventional PI controller. Optimal values of proportional and integral controller gain values are tuned using Integral Time Absolute Error (ITAE) performance indices technique. Time domain simulation is utilized to study the behavior of system with 1% of step load disturbance given in either area of the system. Finally, simulation result indicates that the system with HVDC link yield better controlled response in terms of settling time, overshoot and damping oscillations.

Index Terms—Area control error, interconnected power system, Load Frequency Control (LFC), Parallel HVAC/HVDC link, Performance indices, Proportional –Integral (PI) controller, Time domain analysis.

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1 Introduction

Energy is important, which is used in our day to day life from ancient days. Different kinds of energies used are mechanical, thermal, electrical etc. Out of all energies electrical energy is preferred due to various advantages. Because electrical energy can be easily transported from one place to another, easily converted into other forms of energy, easily controlled and regulated to match requirements and also the losses during transportation is minimum. Due to the advancement in technology the power consumption is increasing continuously and power demands on the power system are never steady and it varies continuously [9-11]. Change in active power affects the system frequency and variation in reactive power causes the changes in magnitude value of voltage. Therefore to maintain the steady state operation of power system is necessary to control both active and reactive power.

Load frequency control (LFC) method is used to control the frequency of large interconnection of power system [9-11]. This provides reliable electric power with good quality to consumers. Because quality and reliability of power is very much important for sensitive loads such as hospitals, processing plants (semiconductor, food, rayon and fabrics) and data processing. To produce more power, power systems are interconnected. Here thermal power plants are interconnected. Generally thermal plants respond to rapidly changing loads with out difficulty and this plant, not only produces electric power, but also generates steam for different industrial purposes. It occupies less space compared to Hydro- electric plants. Interconnection of power plants provides maximum advantages over individual power plant operation. The interconnection between power systems can highly improve the continuity, security and integrity of power supply, reduce the cost of energy per unit and improves the reliability of supply to the consumers. Due to increased size of power system, the complexity is increased. So the stability of the power system should be maintained. In this paper, stability of the power system is maintained by the conventional PI controller. In addition to the HVAC tie line HVDC link is connected in parallel. Due to this parallel HVAC tie line and HVDC link the settling time and oscillations are reduced and the system performance is improved [3-6].

The main objectives of the present work are:

- To model the simulink model of three area interconnected thermal power systems with reheat turbine.
- To study the effects of HVDC link parallel with HVAC tie line in multi-area thermal power systems.
- To optimize the integral and proportional controller gains using integral time absolute error technique with and without HVDC link.
- To compare the dynamic performances of reheat thermal power systems with and without HVDC link

2 Three Area Power Systems

The LFC investigated system consists of three generating units of equal size, area 1, 2 and 3 comprising a reheat thermal power system. Here conventional PI controller act as a supplementary controller. The block diagram representation of three area power systems with PI controller is shown in fig.1. [1-2,5-6]. MATLAB version 7.5(R2007b) has been used to obtain the frequency deviation in area1, area3,

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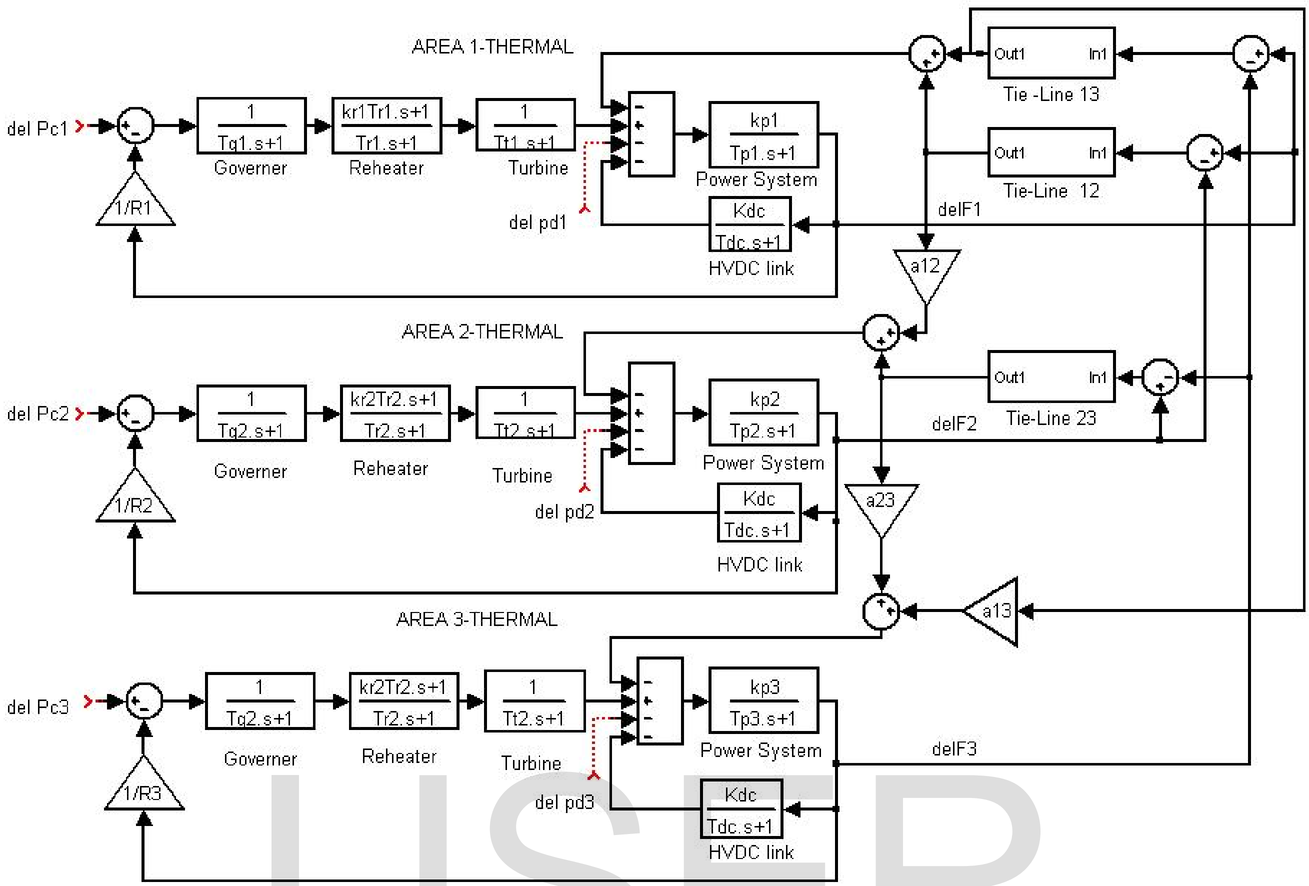

Fig. 1. Transfer function model of three area interconnected thermal power system with HVDC link.

tie line power flow deviation in area 1, area 3 and area control error in area 3 with 1% of step load perturbation in area 1.

2.1 HVDC link

HVDC link is used to transmit electric power for long distance. With HVDC system the elimination of the effect of line reactance and no charging current makes it possible to have stability without any consideration of the line length [5]. HVDC is also preferred for underground and submarine cable transmission over long distance at high voltage. In case of AC cable the temperature rises due to charging current forms a limit for loading. That is beyond certain limit AC cable can not be used due to thermal limit and the HVAC interconnection between the power systems produces many problems particularly in case of long distance transmission [3, 7-8]. By the use of HVAC lines, large oscillations are produced which make frequent tripping and increases fault current level. These problems reduce the overall system dynamic performance.

When the HVDC link is used in parallel with the HVAC line, the above problems are reduced and the dynamic performance of the system is also improved. The important features of HVDC transmission lines are fast controllability of line power and improvement of transient stability in HVAC lines. HVDC system has three basic parts such as AC to DC converter station, transmission line and DC to AC converter station. Converters used in both ends are much expensive and HVDC transmission system is economical for long distances and also converters produce a lot of harmonics which may cause interference with communication lines requiring filters which increase the cost. The transfer function model of HVDC link is given by

$$\frac{\Delta P_{dc}}{U_{dc}} = \frac{K_{dc}}{1+sT_{dc}} \qquad (1)$$

Where

K_{dc} - Gain associated with DC link

T_{dc} -Time constant of DC link

3 Optimal Gain Setting of PI Controller

In the LFC, improved dynamic performance is achieved by the use of conventional PI controller. The block diagram of conventional PI controller is shown in fig.2. Integral controller provides zero state error in frequency deviation and tie line power flow. Proportional controller reduces the peak overshoot in the damping oscillations of system response. In load frequency control nominal parameters of system is achieved with the generation of proper control signal (u). Control signal generated by the PI controller is given by

$$u(t) = K_p e(t)dt + \frac{K_p}{T_i}\int e(t)dt \qquad (2)$$

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where
u(t)-control signal
Kp-Proportional controller gain
Ki-Integral controller gain
E(t)= Error signal

Area control error is defined as “linear combination of change in tie line power and frequency deviation”. It is expressed as follows

$$ACE_i = \Delta P_{tiei} + B_i \Delta f_i \quad (3)$$

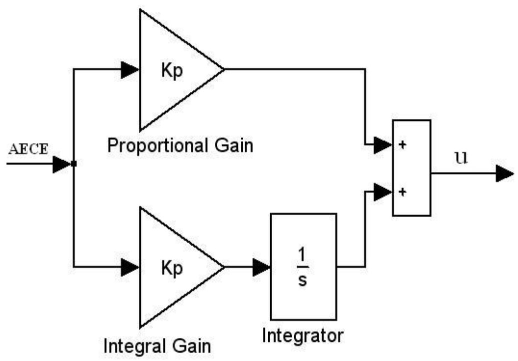

Fig. 2. Block diagram of conventional PI controller

The optimal gain values of both integral and proportional controllers are obtained using Integral Time Absolute Error (ITAE) performance criterion [6]. The cost function is expressed as follows

$$J = \int_0^\infty t \, |\{\Delta f_i + \Delta P_{tiei-j}\}| \, dt \quad (4)$$

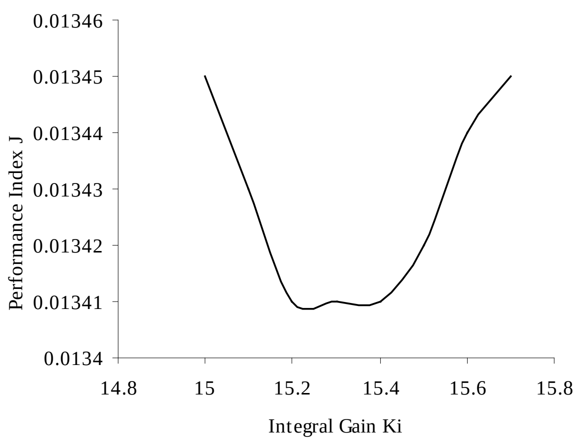

Fig. 3. IATE Performance indices curve (Ki vs J) with HVDC link

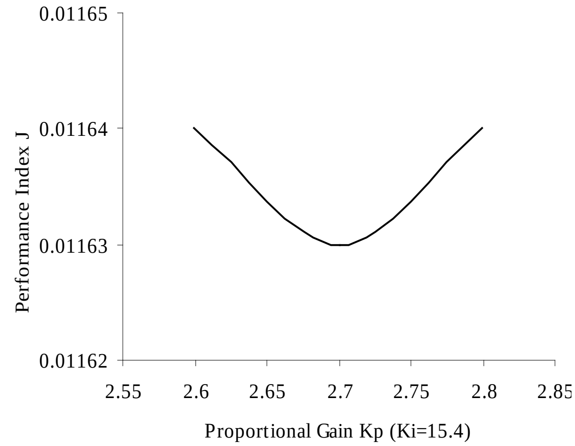

Fig. 4 IATE Performance indices curve (Kp vs J) with HVDC link

Fig.3&4 shows the variation of the performance indices with respect to the Integral controller gain (Ki) and proportional gain (Kp) values with 1% step load perturbation in the thermal area 1. The optimal gain values of conventional controllers are given in table 1 with and without HVDC link.

TABLE 1
OPTIMAL GAIN VALUES OF CONVENTIONAL PI CONTROLLER WITH AND WITHOUT HVDC LINK

	Optimal controller gain values	
	Integral controller(Ki)	***Proportional controller(Kp)***
With out HVDC link	0.58	0.06
With HVDC link	15.4	2.7

4 SYSTEM PERFORMANCES AND DISCUSSIONS

In this work, conventional PI controller based three area reheat thermal power systems were designed. Simulations were performed with help of conventional controller and the effect of HVDC link is analyzed in the interconnected power systems. The designed simulink model of system incorporate with three equal sizes of reheat thermal power system and all the areas are interconnected with HVAC/DC line. Fig.5 shows the open loop frequency deviation response comparisons and fig.6 shows the tie line power deviation comparisons with 1% of step load perturbation in thermal area 1.

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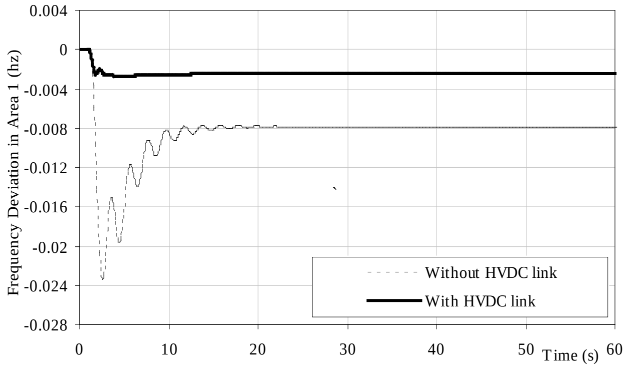

Fig. 5. Open loop response (Δf_1)

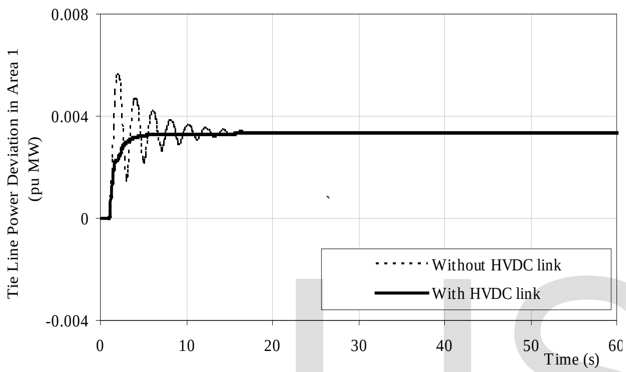

Fig. 6. Open loop response (ΔP_{tie1})

Examining these open loop responses; it clearly indicates that without controller action, the system yields steady state error with damping oscillations. In order to conquer this problem, conventional PI controller is implemented and designed in section II. From this, the values of controller gains are (Ki=15.4; Kp= 2.7).

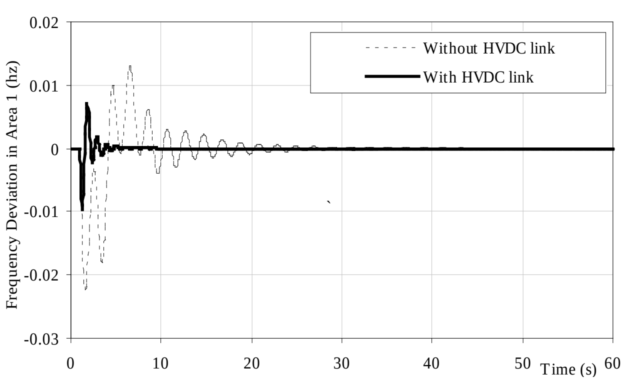

Fig. 7. Response with and without HVDC link (delF$_1$)

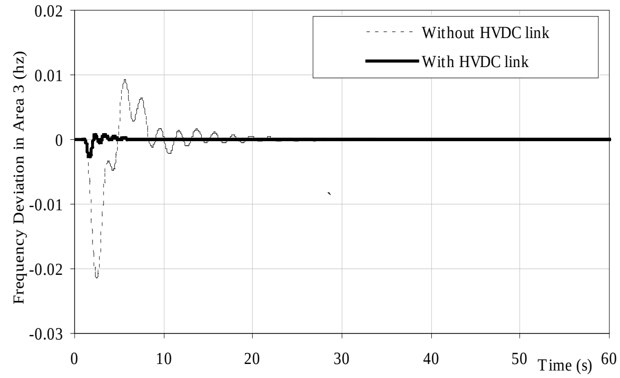

Fig. 8. Response with and without HVDC link (delF$_3$)

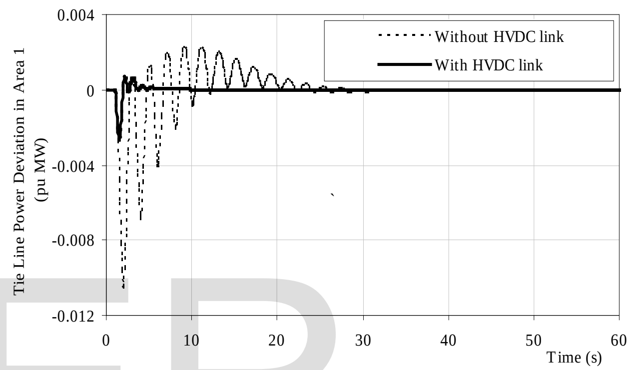

Fig. 9. Response with and without HVDC link (delP$_{tie1}$)

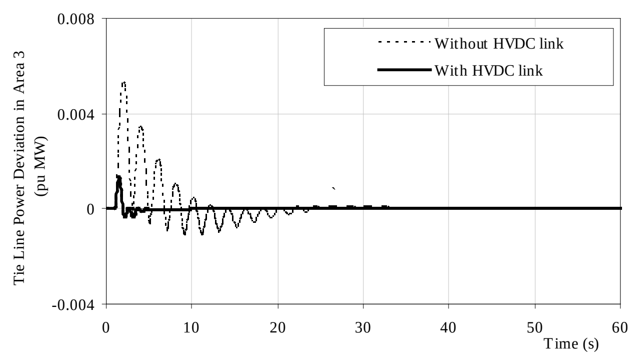

Fig. 10. Response with and without HVDC link (delP$_{tie\ 3}$)

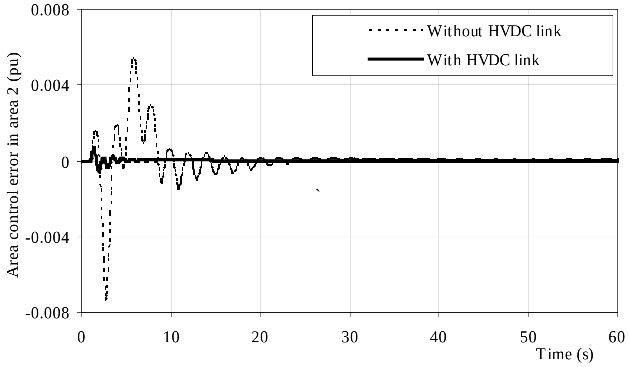

Fig. 11. Response with and without HVDC link (ACE_2)

Fig. 7 and Fig. 8 show the comparison of frequency fluctuations in area 1 and 3 with and without considering the effect of HVDC link. Fig. 9 and Fig. 10 show the comparison of tie line power flow fluctuations in area 1 and 3 with and without considering the effect of HVDC link. Fig. 11 show the comparison of area control error in area 2 with and without considering the effect of HVDC link

It is observed from the responses, that the HVDC link having capability to minimize the peak over shoot, settling time and damping oscillations with fast settled controlled response compared without considering HVDC link. Table 2 shows the performance comparison of thermal power system with and without presence of HVDC link.

TABLE 2
PERFORMANCE OF THERMAL POWER SYSTEM WITH AND WITHOUT HVDC LINK

Time domain specification	Frequency deviation in area 1	
	Without HVDC link	*With HVDC link*
Peak over shoot	0.008960	0.00004127
Settling time(sec)	44.76	14.3430
Peak time(sec)	5.756	2.472

5 CONCLUSIONS

. The following summaries are the noteworthy contribution of this work:

- In this work simulink model of three area inter connected power system is modeled and performance of system is obtained with 1% of step load disturbance given in area 1.
- The proposed model of HVDC link is implemented in the interconnected reheat thermal power systems.
- The optimal conventional controller gain values are obtained by using ITAE performance criterion with and without considering HVDC link.
- Investigation reveals that, the system yields more controlled and fast settled response when HVDC link is taken into an account.

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