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AGC of two area power system interconnected by AC/DC links with diverse sources in each area

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ABSTRACT

This paper presents a comprehensive study on dynamic performance of a more realistic power system with diverse sources in each area and interconnected via parallel AC/DC transmission links. The power generation in each area is based on diverse sources such as thermal, hydro and gas. To carry out the investigations, optimal Automatic Generation Control (AGC) regulators are designed and implemented by considering an example of a two area power system for 1% step load disturbance in one of the control areas. In order to assess the improvement in stability of this realistic power system with DC link in parallel with AC tie-line as interconnection, eigenvalue study is also conducted. It has been shown that the transient response of power system subject to a step load disturbance is sluggish/poor in the presence of hydro as one of the diverse source in the power system. But an appreciable improvement in system dynamic performance is achieved by considering parallel AC/DC links as interconnection between areas rather than using AC tie lines only.

1. Introduction

Modern power systems consist of a large number of control areas, which generate power to meet the load demand. However, mismatch between generated power and demand causes the system frequency to deviate from the nominal value and it also creates inadvertent exchange of power between control areas. To eliminate these deviations AGC is applied to manipulate the speed changer (set-point) of different power generation plants in each area. Therefore the objective of AGC is to regulate power produced from various sources in each area so that the frequency of power system and tie-line powers are kept within prescribed limits.The main function of control is to ensure that: (i) frequency of various bus voltages and currents are maintained at near specified nominal values; (ii) tie-line power flows among the interconnected areas are maintained at specified levels; and (iii) total power requirement on the system as a whole is shared by individual generators economically in optimum fashion. The first two functions are ensured by designing an efficient AGC regulator. The third function involves another set of control called active power dispatch.

To achieve the objectives of AGC, a large number of studies have been reported for an effective AGC regulator design [1–18], including the pioneering works by Elgerd and Fosha [1,2]. In recent years, following the advent of modern intelligent techniques such as genetic algorithms, fuzzy logic, multi-agent systems, artificial neural networks (ANNs), particle swarm optimization, and hybrid intelligent techniques, some new solutions have been emerged for AGC regulator. By exploiting these artificial intelligent concepts in AGC regulator design many simulation studies are available [6–14], but usually these techniques always not give fix solution to the AGC problem.

It is technical and economically feasible for operating a power system in an interconnected fashion. The various areas (geographical areas with generators connected by strong links) or power pools are interconnected via tie-lines (long transmission lines or weak links). These tie-lines are utilized for contractual power exchange between various control areas and also provide inter-area support in case of abnormal conditions. However, many problems have been identified with AC interconnection between areas in a power system particularly by long distance power transmission. The major problems associated with these lines are: the presence of large power oscillations which can lead to frequent tripping, increase in fault current level and transmission of disturbances from one system to the other deteriorating the overall system dynamic performance. The use of high voltage direct current (HVDC) to transmit bulk power over long distance has received increasing attention in recent years. The reason is that HVDC transmission lines possess attractive features such as fast controllability of power in HVDC lines through converter control, ability to reduce transient stability problems associated with AC lines, and other

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Table 1
Power system data of different parameters/constants for areas $i = 1$ and $j = 2$.

Sr. No.	Name of the parameter/constant	Symbols	Numerical value
1	Bias constant	β_i	0.425
2	Thermal power generation regulation constant	R_{ti}	2.4 Hz/puMW
3	Hydro power generation regulation Constant	R_{hi}	2.4 Hz/puMW
4	Gas power generation regulation constant	R_{gi}	2.4 Hz/puMW
5	Gain of controller	K_{ii}	–
6	Steam turbine governor time constant	T_{gi}	0.08 s
7	Steam turbine time constant	T_{ti}	0.3 s
8	Coefficient of reheater steam turbine	K_{ri}	0.3
9	Steam turbine reheater time constant	T_{ri}	10 s
10	Hydro turbine speed governor transient droop time constant	T_{RHi}	28.75 s
11	Hydro turbine speed governor main servo time constant	T_{GHi}	0.2 s
12	Hydro turbine speed governor reset time	T_{Ri}	5 s
13	Nominal starting time of water in penstock	T_{wi}	1.0 s
14	Gas turbine speed governor lead time constant	X_i	0.6 s
15	Gas turbine speed governor lag time constant	Y_i	1.0 s
16	Gas turbine constant of valve positioner	b_i	0.05
		Ci	1.0
17	Gas turbine combustion reaction time delay	T_{CRi}	0.3
18	Gas turbine fuel time constant	T_{Fi}	0.23
19	Gas turbine compressor discharge volume time constant	T_{CDi}	0.2
20	Thermal power generation contribution	K_{ti}	0.60
21	Hydro power generation contribution	K_{hi}	0.25
22	Gas power generation contribution	K_{gi}	0.15
23	Area size ratio	α_{ij}	−1.0
24	Area control error	ACE_i	
25	Gain constant of power system	K_{Pi}	120.00
26	Time constant of power system	T_{Pi}	20.00 s
27	Tie line power coefficient	T_{ij}	0.0433 MW
28	Inertia constant	H_i	5 MW s/MVA
29	Rated frequency	F_r	60 Hz
30	Power rating of each control area	P_{ri}	2000 MW
31	Frequency deviation of *i*th area	ΔF_i	
32	Tie-line deviation between *i*th and *j*th area	$\Delta Ptie_{ij}$	
33	Deviation in thermal turbine output	ΔP_{Gti}	
34	Deviation in intermediate state of reheat turbine	ΔP_{Rti}	
35	Deviation in steam turbine governor output	ΔX_{ti}	
36	Deviation in hydro turbine output	ΔP_{Ghi}	
37	Deviation in output of mechanical hydraulic governor of hydro turbine	ΔX_{hi}	
38	Deviation in intermediate state of hydro turbine governor	ΔP_{RHi}	
39	Deviation in gas turbine output	ΔP_{Ggi}	
40	Deviation in intermediate state of fuel system combustor of gas turbine	ΔP_{Rgi}	
41	Deviation in intermediate state of fuel system and combustor of gas turbine	ΔP_{FCi}	
42	Deviation in valve positioner of gas turbine	ΔP_{VPi}	
43	Deviation in intermediate state of speed governor of gas turbine	ΔX_{gi}	
44	Deviation in total power output of *i*th area	ΔP_{Gi}	

Table 2
Optimal gain matrices of AGC regulators.

Types of area interconnections	Optimal feedback gain matrix [Ψ^*]													$\mathbf{J}^*$
AC link only	[0.7071	−1.9090	0.1347	6.5018	−0.6386	0.4716	2.3029	1.2136	0.0785	1.0744	0.3240	0.2993	0.3821	329.4511
	1.0599	−0.1606	0.0040	0.2807	0.2841	−0.1373	0.0992	0.0105	0.0009	−0.0003	1.0000	0.0000;		
	0.1347	1.9090	0.7071	1.0599	−0.1606	0.0040	0.2807	0.2841	−0.1373	0.0992	0.0105	0.0009	−0.0003	
	6.5018	−0.6386	0.4716	2.3029	1.2136	0.0785	1.0744	0.3240	0.2993	0.3821	−0.0000	1.0000;]		
AC/DC Links	[0.4297	−0.3205	0.4121	5.7144	−0.5845	0.4564	1.5574	0.9549	0.3017	0.6977	0.2718	0.2917	0.3786	298.4022
	1.8473	−0.2147	0.0192	1.0263	0.5428	−0.3605	0.4758	0.0627	0.0085	0.0031	1.0000	−0.0000	−0.0032;	
	0.4121	0.3205	0.4297	1.8473	−0.2147	0.0192	1.0263	0.5428	−0.3605	0.4758	0.0627	0.0085	0.0031	
	5.7144	−0.5845	0.4564	1.5574	0.9549	0.3017	0.6977	0.2718	0.2917	0.3786	−0.0000	1.0000	0.0032;]	

economical advantages. One of the major applications of HVDC transmission is operating a DC link in parallel with an AC link interconnecting two control areas. Such type of transmission line is called asynchronous tie-line. In this paper, AGC studies have been carried out by considering interconnected power system using AC/DC tie-line between control areas in addition to only AC tie-line.

The AGC study of a two area interconnected power system with parallel AC/DC tie-lines was carried out by Ibraheem et al. with single source of power generation in each area [15–18]. It has been shown that the dynamic performance of a two area hydro-thermal power system improves considerably for a small step load disturbance in real power of the system with AC/DC tie-line [15,16]. The better system dynamic performance is due to addition of two modes by a DC link in the dynamic model. It has also been shown that the dynamic responses of the interconnected power system with hydro areas are sluggish and degraded as compared with other area consisting of reheat thermal power plant [16]. The dynamic performance of a two area power system interconnected