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AUTOMATIC GENERATION CONTROL OF MULTI AREA INTERCONNECTED THERMAL POWER SYSTEM CONSIDERING ASYNCHRONOUS TIE-LINES

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ABSTRACT

This paper investigates the effects of HVDC tie-line in parallel with HVAC tie-line on automatic generation control (AGC) problem for a multi-area power system taking into consideration system parameter variations. A fuzzy logic controller is used for five area power system interconnected via parallel HVAC/HVDC transmission link which is also referred as asynchronous tie-lines. The linear model of HVAC/HVDC link is developed and the system responses to sudden load change are studied. Suitable solution for automatic generation control problem of five area electrical power system is obtained by means of improving dynamic performance of power system under study. Robustness of controller is also checked by varying parameters. Simulation results indicate that the scheme works well. The dynamic analyses have been done with and without HVDC link using fuzzy logic controller in MATLAB/SIMULINK. Further a comparison between the two is presented and it has been shown that the performance of the scheme under study is superior in terms of overshoot and settling time.

Keywords: Automatic generation control, fuzzy logic controller, HVAC/HVDC transmission link, generation rate constraint

INTRODUCTION

The automatic generation control is a technical requirement for the proper operation of interconnected power systems. For large scale electrical power systems that normally consist of interconnected control areas representing coherent groups of generators, automatic generation control is very important in power system operation and control for supplying sufficient and reliable electric power with good quality.

In cases of area load changes and abnormal conditions, such as outages of generation and varying system parameters, mismatches in frequency and scheduled tie-line power flows between areas can be caused. These mismatches are corrected by controlling the frequency, which is defined as the regulation of the power output of generators within a prescribed area. The objective of the LFC is to satisfy the requirements such as zero steady state errors in tie-line exchanges and frequency deviations, optimal transient behaviors and in steady state, the power

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generation levels should satisfy the optimal dispatch conditions. Some intelligent controllers have been proposed to solve these problems but considering area interconnection with ac line [1-4]. Also fast-acting energy storage systems e.g. superconducting magnetic energy storage [5], battery energy storage [6], super-capacitor bank [7] etc., can effectively damp electromechanical oscillations in a power system, because they provide storage capacity in addition to the kinetic energy of the generator rotors which can share sudden changes in power requirement. A little attention has been paid to use of HVDC transmission link as system interconnection. Majority of the work carried out earlier is centered on interconnected power systems considering the area interconnection with ac tie lines only. However, there has been a tremendous growth of the HVDC transmission system due to economic, environmental and performance advantages over the other alternatives Hence it has been applied widely in operating a dc link in parallel with an HVAC link interconnecting control areas to get an improved system dynamic performance with greater stability margins under small disturbances in the system [8-12]. A favorable effect on system dynamic performance has been achieved considering such system interconnection. These studies are carried out considering the nominal system parameter values after linearization of the system about an operating condition. In practical cases, system parameters do not remain constant and continuously vary with changing operating conditions. Therefore, a serious concerned should be given to these parameter variation [13-14]. Because of complexity and multi-variable conditions of the power system, conventional control methods may not give satisfactory solutions. On the other hand robustness and reliability makes fuzzy controllers useful in solving wide range of control problems including AGC of interconnected power system [15-20].

In the present paper a fuzzy logic controller is designed and implemented to analyze the dynamic performance of five unequal area thermal power system, interconnected with HVAC/HVDC parallel link taking parameter uncertainties into account. The simulation results are presented to show the effectiveness of the scheme.

FIVE AREA POWER SYSTEM

The five area power system model identified in the present study has the following configuration:

a) It is a five unequal area system of area1: 2000 MW, area2: 4000 MW, area3: 8000 MW, area4: 10,000MW, and area5: 12,000MW.
b) The five areas are interconnected via HVAC tie line in parallel with HVDC link.

The single line diagram of the model under consideration for two areas is presented in Fig. 1 and the block diagram of five area interconnected system with HVDC link is described in Fig. 2. The transmission links are considered as long transmission lines specifically of length greater than break even distance length of HVAC and HVDC transmission lines [8].

The interconnected power system of Fig. 2 consists of five generating areas of unequal area sizes provided with single reheat turbines. Typical generation rate constraint (GRC) of the order of 3% per minute for all areas has been considered as given in the IEEE Committee Report on Power Plant Response [21]. The detailed transfer function models of speed governors and turbines are discussed and developed in the IEEE committee report on dynamic models for steam and hydro turbines in power system studies [22]. An equal bias (B_i) setting is considered for all areas. The step load perturbation (SLP) of 1-10% of the nominal loading has been considered in either of the area for system analysis. The system parameters are given in the appendix.

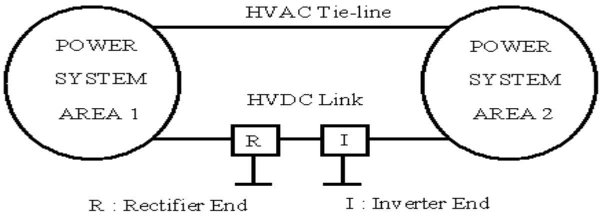

Fig. 1. Single line diagram of two area out of five area power system with HVAC/HVDC parallel tie-line

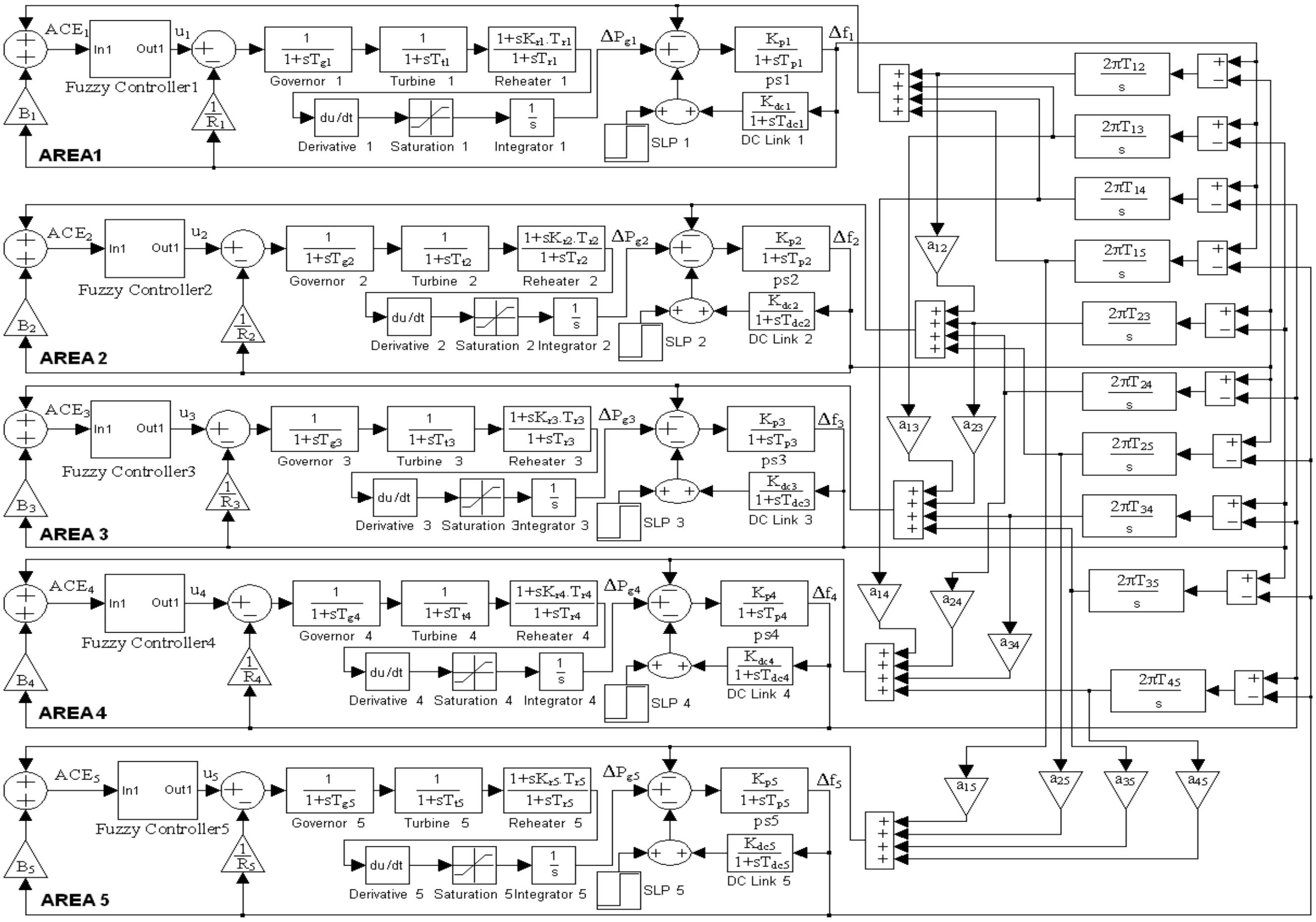

Fig. 2. Block diagram of five area interconnected system

FUZZY LOGIC CONTROLLER

Fuzzy set theory and fuzzy logic establish the rules of a nonlinear mapping [23]. The use of fuzzy sets provides a basis for a systematic ways for the application of uncertain and indefinite models. Fuzzy control is based on a logical system called fuzzy logic which is much closer in spirit to human thinking and natural language than classical logical systems. Nowadays fuzzy logic is used in almost all sectors of industry and science. One of them is automatic generation control.

The main goal of AGC in interconnected power systems is to protect the balance between production and consumption. The fuzzy logic controller designed for the system analysis is shown in Fig 3.

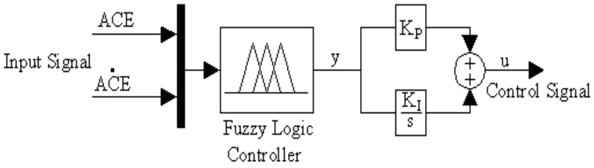

Fig 3. Structure of fuzzy logic controller

In this study derivative of area control error together with area control error (ACE) are fed to the fuzzy logic controller. The fuzzy controller block is formed by fuzzification of ACE and derivative of ACE, the inference mechanism and defuzzification. Therefore, y is a crisp value and u is a control signal for the system. Centroid method of defuzzification and Mamdani fuzzy theory is applied in determining the gains of controller. Table I presents the rules for fuzzy logic controller. There are 7 triangular membership functions considered for inputs (ACE and derivative of ACE) and one output (y). Total 49 rules are designed to get the response. The membership functions used in the fuzzy controller are presented in Fig. 4.

Table I. Rules for the fuzzy logic controller

		d(ACE)/dt						
		LN	**MN**	**SN**	**Z**	**SP**	**MP**	**LP**
ACE	**LN**	LP	LP	LP	MP	MP	SP	Z
	MN	LP	MP	MP	MP	SP	Z	SN
	SN	LP	MP	SP	SP	Z	SN	MN
	Z	MP	MP	SP	Z	SN	MN	MN
	SP	MP	SP	Z	SN	SN	MN	LN
	MP	SP	Z	SN	MN	MN	MN	LN
	LP	Z	SN	MN	MN	LN	LN	LN

LN: large negative, MN: medium negative, SN: small negative, Z: zero, SP: small positive, MP: medium positive and LP: large positive

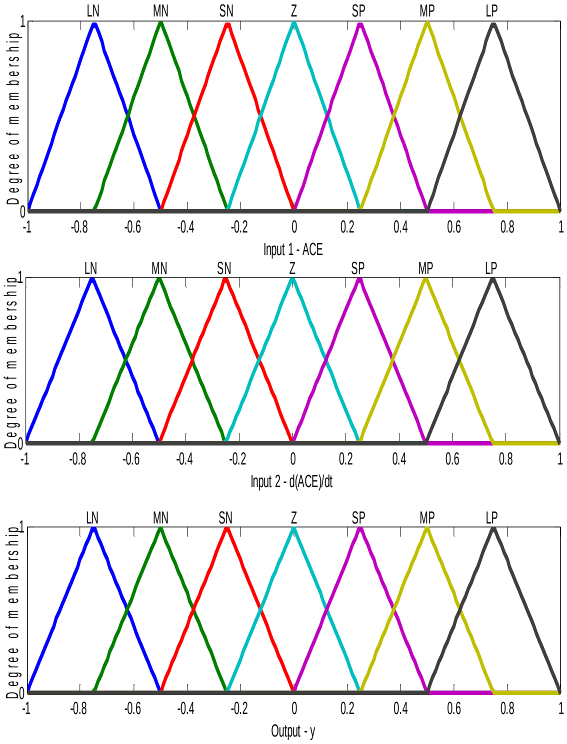

Fig. 4. Membership functions used in the study

SIMULATION RESULTS

In this paper, a fuzzy logic controller has been designed and applied to an unequal five area thermal power system consisting of single stage reheat turbines. The implementation worked with MATLAB-SIMULINK software. The same values of system parameters [8, 9] given in appendix, are used for all simulations to facilitate a comparative study.

The response plots for variables like frequency deviations in area 1 to area 5 and some tie-line power deviations for power system model with and without HVDC link in parallel with HVAC tie-line, in the wake of load disturbance of 1% in area 1, are obtained with the implementation of fuzzy logic controller to analyze the system dynamic performance as shown in Figs. 5 and 6. Fig. 7 shows the frequency deviation of area 1, area 2 and generated power deviations of ΔP_{g2} and ΔP_{g5} with higher values of step load perturbation (SLP) applied in various areas simultaneously (i.e. ΔP_{d1}= 0.1 pu, ΔP_{d2} = 0.02 pu, ΔP_{d3} = 0.03 pu, ΔP_{d4} = 0.01 pu, and ΔP_{d5}= 0.01 pu).

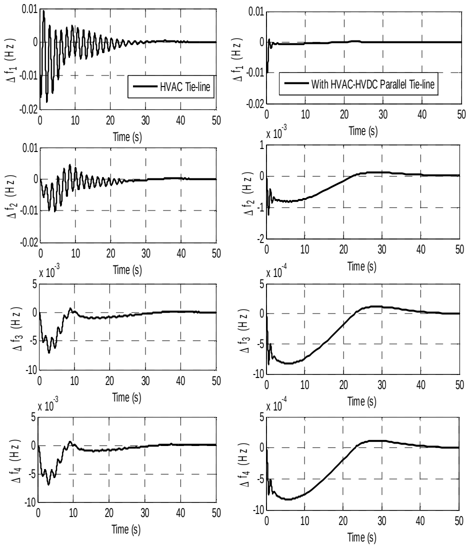

Fig. 5. Frequency deviation of area 1to area 4 with ΔP_{d1} = 0.01 pu

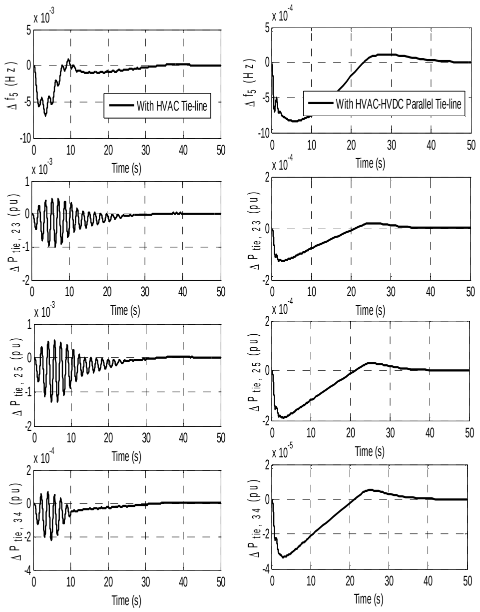

Fig. 6. Frequency deviation of area 5 and tie-line power deviations of $\Delta P_{tie,\,23}$ pu, $\Delta P_{tie,\,25}$ pu, and $\Delta P_{tie,\,34}$ pu with ΔP_{d1} = 0.01pu

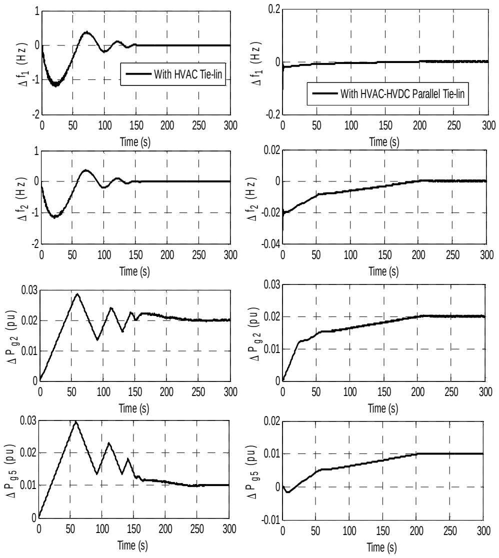

Fig. 7. Frequency deviation of area 1, area 2 and generated power deviations of ΔP_{g2} and ΔP_{g5} with ΔP_{d1} = 0.1 pu, ΔP_{d2} = 0.02 pu, ΔP_{d3} = 0.03 pu, ΔP_{d4} = 0.01 pu, ΔP_{d5} = 0.01 pu

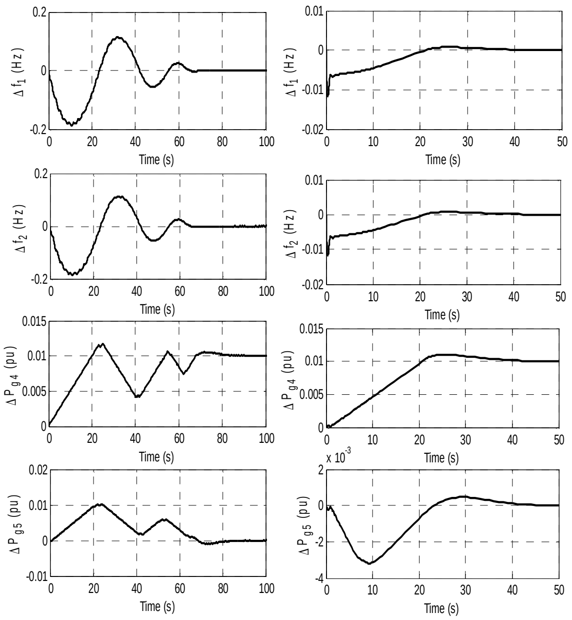

Fig. 8. Frequency deviations of area 1 (Δf_1), area 2 (Δf_2), and generated power deviations of area 4 (ΔP_{g4}), and area 5 (ΔP_{g5}) with +10% of nominal values of B_i, T_{pi} and T_{ij} with $\Delta P_{d1} = \Delta P_{d2} = \Delta P_{d3} = \Delta P_{d4} = 0.01$ pu, $\Delta P_{d5} = 0$ pu

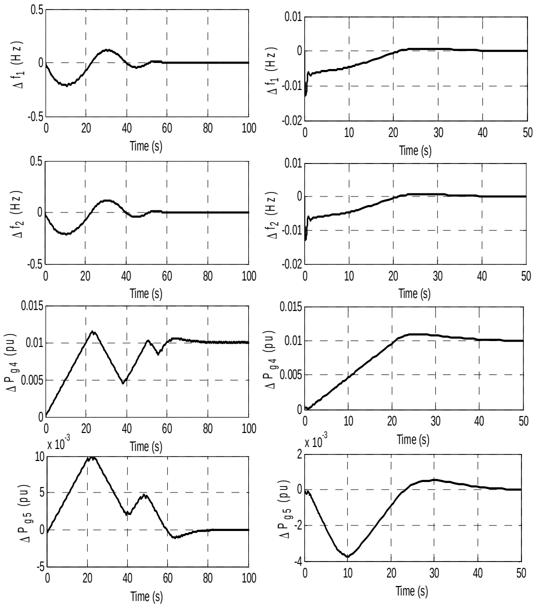

Fig. 9. Frequency deviations of area 1 (Δf_1), area 2 (Δf_2), and generated power deviations of area 4 (ΔP_{g4}), and area 5 (ΔP_{g5}) with ─10% of nominal values of B_i, T_{pi} and T_{ij} with $\Delta P_{d1} = \Delta P_{d2} = \Delta P_{d3} = \Delta P_{d4} = 0.01$ pu, $\Delta P_{d5} = 0$ pu

The settling time and peak overshoots are reduced considerably as shown in Fig. 5, Fig. 6, and Fig. 7 by the use of HVDC link in parallel of existing HVAC tie-line. The simulation results of frequency deviations and tie-line power deviation with fuzzy controller advocates the HVDC link's suitability for AGC schemes.

Other simulations in Fig. 8 and Fig. 9 are carried out for ±10% change in parameter values (mainly B_i, T_{ij} and $T_{pi.}$) of the system. In Fig. 8, the responses are shown with +10% changes in nominal system parameter values at SLP of 1% in area 1 to area 4. It indicates that the changes in frequency in area 1, area 2 and change in generated power of areas 4 and 5 are getting settled down at their steady state values within reasonably good time. Similarly with same amount of disturbance in areas 1 to 4, it is observed that the system is settled down quite fast with ─10% changes in system parameter values as shown in Fig. 9. This justifies the robustness of the fuzzy logic controller which is capable to withstand the changes in dynamic parameters of the five unequal area power system. It also depicts the effectiveness of the HVDC link in parallel with existing HVAC tie-line to suppress frequency, tie-line power, and generated power oscillations under various load perturbations in different areas of the system, as also depicted in Table II. From Table II we concluded that settling time, taken in a 5% band and peak overshoots of the deviation in frequency of area 1 (i.e. Δf_1) drastically reduced in each different operating conditions while using HVDC link in parallel with existing HVAC tie-line.

CONCLUSIONS

In this paper, a fuzzy logic controller is demonstrated to improve the dynamic performance of interconnected unequal five area power system by the use of HVDC link in parallel with existing HVAC tie-line. Five area power system consists of single stage thermal reheat turbines with 3%/minute GRC. The system dynamic performance in the wake of load disturbance in different areas of interconnected power system has been investigated comprehensively by varying system parameters. It has been observed that responses of the system with parallel HVDC link are better in terms of dynamic parameters such as peak overshoot and settling time. Simulation results presented justify the incorporation of HVDC transmission link to supply consumers reliable and quality power.

Table II. Comparison between settling time and peak overshoots under various operating condition for Δf_1

Operating Conditions	**HVAC Tie-line**	**HVAC/HVDC Parallel Tie-line**
Fig. 5		
Settling Time (s)	26.46	10.95
Peak Overshoot (pu)	− 0.0179	− 0.0101
Fig. 7		
Settling Time (s)	>550.00	191.00
Peak Overshoot (pu)	− 1.1844	− 0.1060
Fig. 8		
Settling Time (s)	91.80	32.70
Peak Overshoot (pu)	− 0.1875	− 0.0118
Fig. 9		
Settling Time (s)	76.68	33.36
Peak Overshoot (pu)	− 0.2155	− 0.013

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APPENDIX

Nominal parameters of the five area system under investigation:

P_{r1} = 2000 MW, P_{r2} = 4000 MW, P_{r3} = 8000 MW, P_{r4} = 10000 MW, P_{r5} = 12000 MW;

$R_1 = R_2 = R_3 = R_4 = R_5 = 2.4$ Hz/puMW;
$T_{g1} = T_{g2} = T_{g3} = T_{g4} = T_{g5} = 0.08$ seconds;
$T_{t1} = T_{t2} = T_{t3} = T_{t4} = T_{t5} = 0.3$ seconds;
$T_{p1} = T_{p2} = T_{p3} = T_{p4} = T_{p5} = 20$ seconds;
$K_{p1} = K_{p2} = K_{p3} = K_{p4} = K_{p5} = 120$ Hz/puMW;
$T_{12} = T_{13} = T_{14} = T_{15} = T_{23} = T_{24} = T_{25} = T_{34} = T_{35} = T_{45} = 0.086$ puMW/radian;
$T_{r1} = T_{r2} = T_{r3} = T_{r4} = T_{r5} = 10$ seconds;
$K_{r1} = K_{r2} = K_{r3} = K_{r4} = K_{r5} = 0.5$;
$P_{tie,\ 12} = P_{tie,\ 13} = P_{tie,\ 14} = P_{tie,\ 15} = P_{tie,\ 23} = P_{tie,\ 24} = P_{tie,\ 25} = P_{tie,\ 34} = P_{tie,\ 35} = P_{tie,\ 45,\ (max)} = 200$ MW;
$f = 50$ Hz; $a_{12} = a_{13} = a_{14} = a_{15} = a_{23} = a_{24} = a_{25} = a_{34} = a_{35} = a_{45} = -1$; $K_{dc1} = K_{dc2} = K_{dc3} = K_{dc4} = K_{dc4} = 1.0$;
$T_{dc1} = T_{dc2} = T_{dc3} = T_{dc4} = K_{dc5} = 0.2$ seconds;
Nominal Loading 50%