Efficient Approaches to Protect the Frequency in a Three-Area Interconnected Power System

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***Abstract*—With the rapid development of electrical power systems nowadays, stability and reliability features of the network have to be considered strongly to keep the system under normal working conditions. Because of the complexity of a large-scale or multi-area power system, load disturbances can appear randomly at any point of the network which will cause the deviations of the frequency and tie line power. As a result, the frequency and power generation in the system will be affected. In order to keep the frequency at the nominal value, this work investigates efficient approaches by using advance controllers: PID and fuzzy logic controller. Simulation results will be implemented by using Matlab/Simulink program for a three-area interconnected power system to verify efficiencies of the proposed control schemes.**

***Keywords*-** *Electrical power system; multi-area interconnected power system; tie line; PID; FLC*

I. INTRODUCTION

Power systems came into existence in 1880s and from that time onwards the networks have grown massively in both size and complexity [2], causing big challenges of stability, reliability and protection problems. When load disturbances or random events appear in a multi-area interconnected power network [1], [2], [3], frequency and tie line power will be also changeable, namely deviations of them will not be equal to zero. This leads the instability of the power system. Consequently, to restore the normal working condition of the network, it is necessary to design an efficient control scheme to keep the frequency at the nominal values, such as 50Hz or 60Hz.

Some of literatures have been issued to solve this problem [5], [6], [8], [9], [13], in which both conventional and innovative controllers are used to obtain the desired control performances. The conventional techniques using integral controller have played an important and basic role at the beginning of the solution process. Because of their drawbacks, they have to be replaced by advanced controllers, namely PID (*Proportional, Integral, Derivative*) controller, FLC (*Fuzzy Logic Controller*), ANN (*Artificial Neural Network*) controller, etc. For the practical and efficient aims of the applications, the PID controller [13] and FLC [4] will be chosen to use for a three-area interconnected power system in this study. Simulated results which are implemented by using the Matlab software version 2012a verify that the FLC is the best choice for the load frequency control problem.

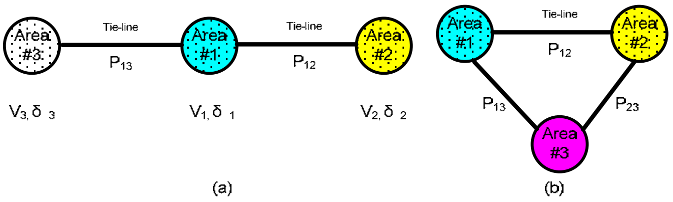


Figure 1. Three-area interconnected power system blocks

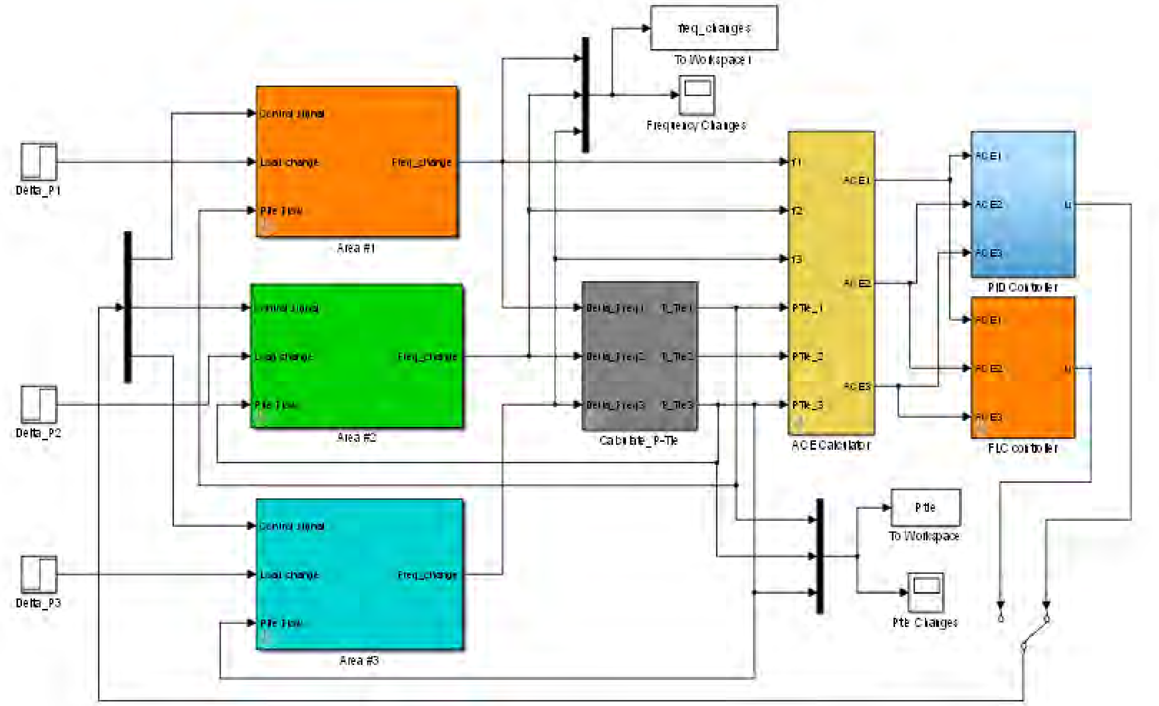


Figure 2. Blocks of the three-area interconnected power system model

II. A THREE-AREA INTERCONNECTED POWER SYSTEM MODEL

A three-area interconnected power system is considered in this work as illustrated in Fig. 1. Here, each area comprises three main components: a governor, a non-reheat turbine, and a generator [2]. In this network, an area is interconnected with each other by a tie line which is used for economy and continuity of power supply [1], [2], [3]. The corresponding model of the three-area interconnected power network will be built in Matlab/Simulink as shown in Fig. 2. Next, area and ACE calculator blocks with the corresponding transfer functions in the Laplace domain [2], [6], are clearly presented in Fig. 3.

The deviations of frequency Δf_i and tie-line power flow $\Delta P_{tie,i}$ of the ith area can be calculated by following equations [2], [3]

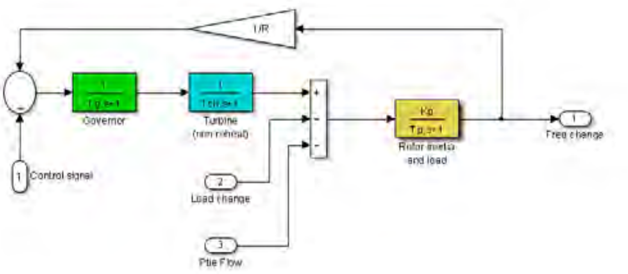
$$\Delta f_i = \frac{1}{2\pi}\frac{d}{dt}\Delta\delta_i \tag{1}$$

$$\Delta P_{tie,i} = \sum_{\substack{i,k=1\\ i\neq k}}^{3} 2\pi T_{ik}^{0}\left(\int \Delta f_i dt - \int \Delta f_k dt\right) \tag{2}$$

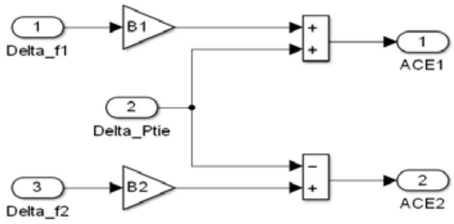
where, the meanings of symbols can be found in the Appendix section of this paper. For the tie-line bias control strategy, the area control error (ACE) for the ith area is computed by (3)

$$ACE_i = \Delta P_{tie,i} + B_i.\Delta f_i \tag{3}$$

where, ACE$_i$, $\Delta P_{tie,i}$, B$_i$, and Δf_i are the control error, tie-line power deviation, area frequency response characteristic, and frequency bias, respectively.



(a) Area #1



(b) Ptie Calculator block

Figure 3. Blocks of the three-area interconnected power system model

III. EFFICIENT CONTROL SCHEMES TO PROTECT THE FREQUENCY

A. PID Controller

The principle of a *PID* controller [13] which is commonly used for the frequency stability of area #i in a multi-area interconnected power system is given by (4)

$$\begin{aligned} u_i(t) &= K_{pi}.ACE_i(t) + K_{Ii}\int_0^t ACE_i(\tau)d\tau + K_{Di}\frac{d}{dt}ACE_i(t) \\ &= K_{pi}\left(ACE_i(t) + \frac{1}{T_{Ii}}\int_0^t ACE_i(\tau)d\tau + T_{Di}\frac{d}{dt}ACE_i(t)\right) \end{aligned} \tag{4}$$

where, K_{Pi}, K_{Ii}, K_{Di}, T_{Ii}, and T_{Di} are proportional, integral, derivative gain factors, integral time, and derivative time constants, respectively.

According to [5], the control properties of a system are affected strongly by the above gain coefficients. The proportional factor K_p calibrates the transient of the ACE, K_I corrects the accumulation of the error, and the derivative factor K_D implements the correction of the present ACE from the previous step. The larger the proportional gain, the smaller the steady state error, however, the loop is also to become unstable. The shorter the integral time, the more impetuous the implementation of an integral is. The larger the derivative coefficient, the more changeable the error becomes. These effects lead the need of the tuning of these factors as investigated in some researches [5], [13].

B. Fuzzy Logic Controller

Because of the non-linear and complicated characteristics of multi-area power networks, a conventional control technique can be replaced efficiently by using an intelligent controller, namely the fuzzy logic controller. In general, a FLC is structuralized by three components: fuzzification unit, rule base unit, and defuzification unit. Details of these components can be found in [4], [10]. In this paper, the FLC which is used as a controller for each area can be indicated in Fig. 4. Here, the ACE and the derivative of ACE, dACE are used as inputs of the FLC. The output of this controller is the control signal, u, which will be taken directly to the corresponding area of the interconnected power system. In this controller, the embedded factors of *Ke*, *Kde,* and *Ku* are used to correct ACE, dACE, and u, respectively. In order to make the better control performance, the multi-level rules can be applied. Table I indicates conventionally a 7-level rule base which is used for our FLC. The fuzzy logic membership functions of FLC's inputs and output are illustrated in Fig. 5.

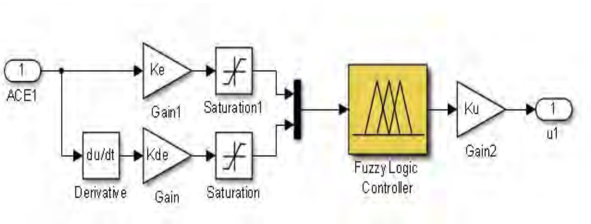


Figure 4. The proposed fuzzy logic controller (FLC) for each area

TABLE I. PROPOSED RULE BASE

dACE	*ACE*						
	BN	**MN**	**SN**	**Z**	**SP**	**MP**	**BP**
BN	BP	BP	BP	MP	MP	SP	Z
MN	BP	MP	MP	MP	SP	Z	SN
SN	BP	MP	SP	SP	Z	SN	MN
Z	MP	MP	SP	Z	SN	NM	MN
SP	MP	SP	Z	SN	SN	MN	BN
MP	SP	Z	SN	MN	MN	MN	BN
BP	Z	SN	MN	MN	BN	BN	BN

IV. SIMULATION RESULTS

To verify efficiently technical performances of the given controllers, simulation results will be implemented by using Matlab/Simulink for a three-area interconnected power system in comparison with the integral controllers. Fig. 6 shows the deviations of frequency in each area by using integral and PID controllers. Fig. 7 illustrates the deviations of frequency in case of using FLC. The deviations of tie line power flow in the three-area interconnected system by using PID controllers are shown in Fig. 8. Table II gives a comparison of different controllers for area #3 which can be used to demonstrate that the FLC is the best choice for the frequency stability problem in the given power system.

V. CONCLUSION

By controlling the deviations of both frequency and tie line power, the stability and reliability of an interconnected power system can be yielded. Through the obtained simulation results, efficient approaches can be clearly verified by using PID controller and FLC, in which the second one is the better choice. It is well known to see that both overshoot and settling time are reduced quickly by using these controllers. As a result, the frequency in the system will be kept at the nominal value with the enough small tolerance. In fact, it is an essential control goal of the protection and stability problem of a multi-area interconnected power system.

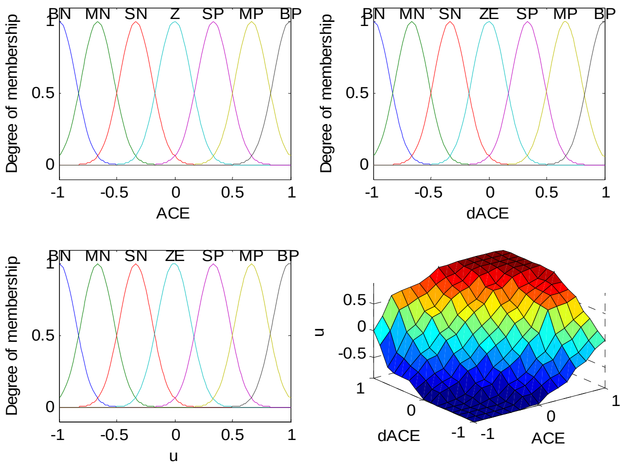


Figure 5. Illustration of given membership functions

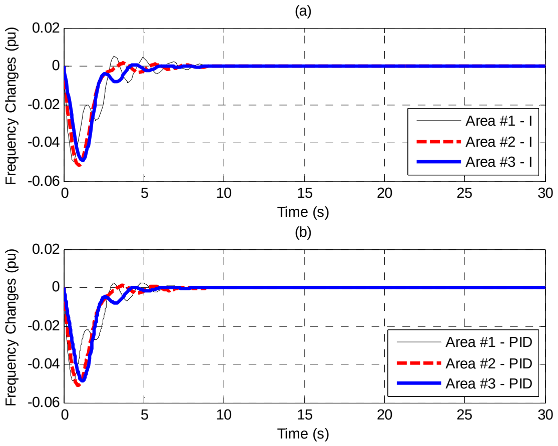


Figure 6. Deviation of frequency in each area using I and PID controllers

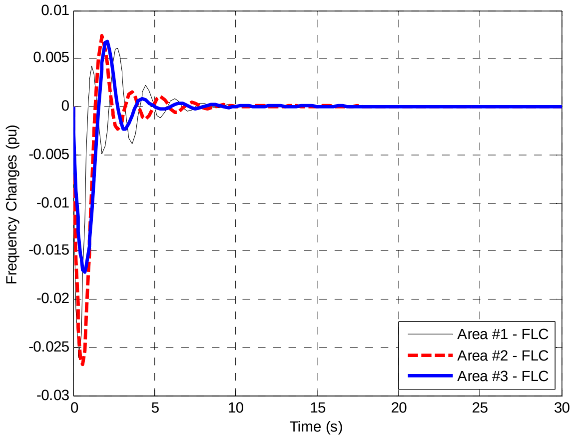


Figure 7. Deviation of frequency in each area using FLC controller

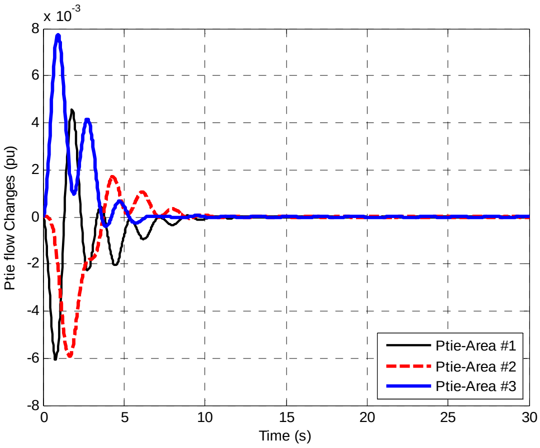


Figure 8. Deviation of tie line power for each area

TABLE II. A COMPARISON OF SIMULATION RESULTS FOR AREA #3

Model	Characteristics	I	PID	FLC
Three-area	First overshoot (pu)	-0.048	-0.042	-0.017
	Settling time (s)	11.3	9.4	8.9

APPENDIX

APPENDIX – A

Nomenclature

i	index of area #i, i = 1, 2, 3
Delta_Pi	load increment, pu
Delta_fi	change of frequency, pu
T_{gi}	time constant of governor, s
T_{chi}	time constant of non-reheat turbine, s
K_{pi}	gain of generator, Hz/pu.MW
T_{pi}	time constant of generator, s
T_{ij}	tie-line time constant, s
$P_{tie,i}$	tie line power flow, pu
B_i	bias factor, MW/pu.Hz
R_i	speed regulation
$K_{Pi,}$ K_{Ii}, K_{Di}	proportional, integral, derivative constant
Kei, Kdei, Kui	error, error derivative, output factors of FLC

APPENDIX-B

Simulated parameters

$T_{g1} = 0.08$, $T_{g2} = 0.1$, $T_{g3} = 0.12$

$T_{ch1} = 0.3$, $T_{ch2} = 0.3$, $T_{ch3} = 0.35$

$K_{p1} = 120$, $K_{p2} = 100$, $K_{p3} = 98$

$T_{p1} = 18$, $T_{p2} = 20$, $T_{p3} = 25$

$T_{ij} = 0.07$

$K_{Pi} = 0.3$, $K_{Ii} = 0.05$, $K_{Di} = 0.02$

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