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Fuzzy C-Means clustering for robust decentralized load frequency control of interconnected power system with Generation Rate Constraint

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ABSTRACT

Load–frequency control (LFC) is important in electric power system design and operation moreover, to ensure the quality of the power supply. Literature shows that Fuzzy logic controller, one of the most useful approaches, for utilizing expert knowledge, is adaptive in nature and is applied successfully for power system stabilization control. Fuzzy controller's design depends mainly on the rule base and membership functions over the controller's input and output ranges. The simple and efficient clustering algorithms permit the classification of the data in distinct groups using distance and/or similarity functions. The present paper proposes the generation of optimal Fuzzy rule base by Fuzzy C-Means clustering technique (FCM) for load frequency control. The phase-plane plot of the inputs of the Fuzzy controller is utilized to obtain the rule-base in the linguistic form. The system parametric uncertainties are obtained by changing parameters by 40% simultaneously from their typical values. The performance of the proposed FCM controller is compared with conventional controller and original Fuzzy controller in the presence of Generation Rate Constraint (GRC) in case of two area and three area inter connected power systems.

1. Introduction

With an increasing demand for electric power, the electric power system becomes more and more complicated. Therefore the supply of electric power with stability and high reliability is required. The power system operates in normal state which is characterized by constant frequency and voltage profile with certain system reliability. For a successful operation of power system under abnormal conditions, mismatches have to be corrected via supplementary control [1]. Automatic Generation Control (AGC) or load frequency control [2,3] is a very important issue in power system operation and control for supplying sufficient and reliable electric power with good quality. An interconnected power system can be considered as being divided into control areas. These control areas are connected by the tie lines. In each control area, all generators are assumed to form a coherent group. The power system is subjected to local variations of random magnitude and duration. For satisfactory operation of a power system the frequency should remain nearly constant. The frequency of a system depends on active power balance. As frequency is a common factor throughout the system, a change in active power demand at one point is reflected through out the system [15].

A number of control strategies have been employed in the design of load frequency controllers [2,13,17,19,21–26] in order to achieve better dynamic performance. Among the various types of load frequency controllers, the most widely employed is the conventional proportional integral (PI) controller [9,14,16]. Conventional controller is simple for implementation but takes more time and gives large frequency deviation. A number of state feedback controllers based on linear optimal control theory have been proposed to achieve better performance [11]. Fixed gain controllers are designed at nominal operating conditions and they fail to provide best control performance over a wide range of operating conditions. So, to keep the system performance near its optimum, it is desirable to track the operating conditions and use updated parameters to compute the control. Adaptive controllers with self-adjusting gain settings have been proposed for LFC [16]. Literature survey shows that only a few investigations have been carried out using FLC. The objective of this research is to investigate the load frequency control and inter-area tie power control problem for a multi area power system taking into consideration the uncertainties in the parameters of the system. Power system is a highly non-linear and uncertain system. To take care of these uncertainties many authors have proposed Fuzzy logic based controllers to power systems [1,4,10,13,15,16,20].

Fuzzy logic is a rule-based approach to decision making. This approach is used to handle imprecise knowledge and was developed in the sixties by Zadeh [7]. Such knowledge can be collected

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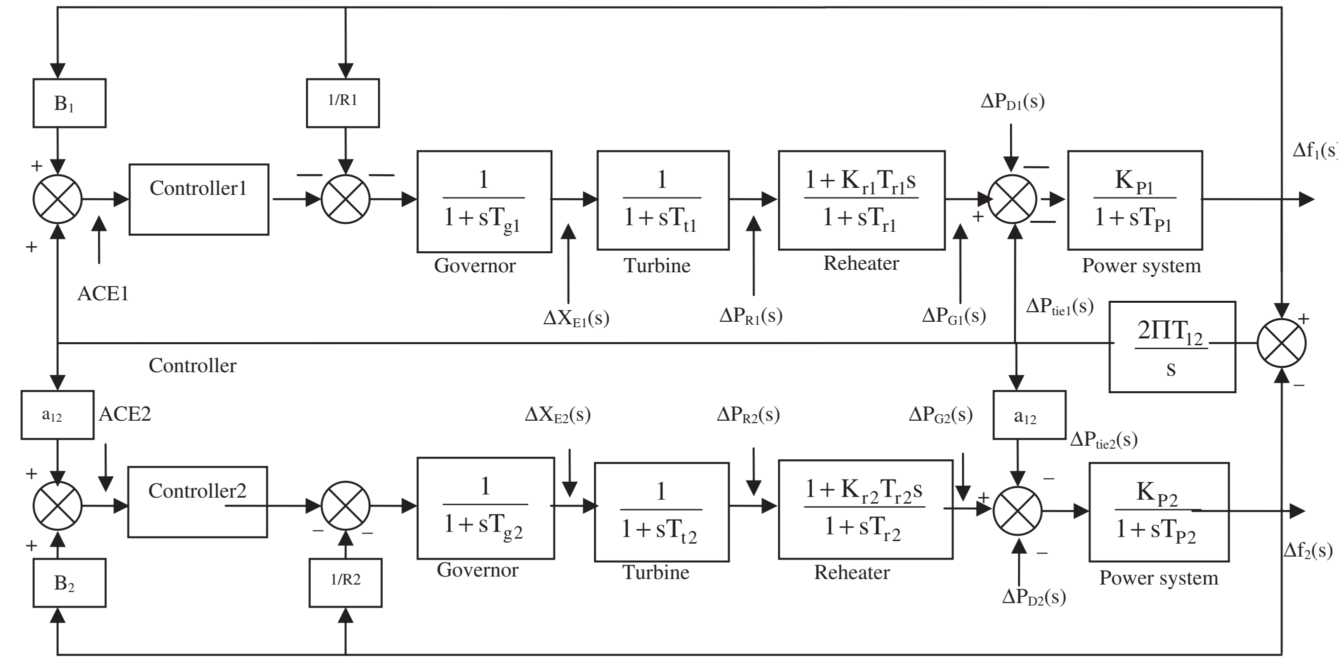

Fig. 1. Block diagram of Two Area Power System.

Table 1
Parameters of the two areas for the operating point-2.

Area-1		Area-2	
T_{G1}	0.042	T_{G2}	0.042
T_{T1}	0.112	T_{T2}	0.112
T_{12}	0.763	T_{12}	0.763
T_{P1}	20	T_{P2}	20
K_{P1}	120	K_{P2}	120
R_1	3.36	R_2	3.36
B_1	0.61	B_2	0.61
Kp	0.6	Kp	0.6
Ki	0.8	Ki	0.8

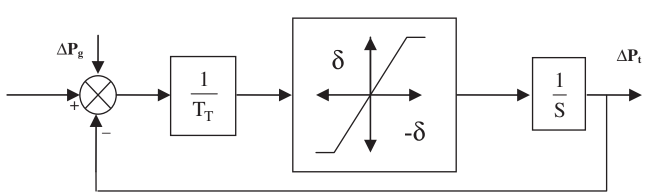

Fig. 2. Non-linear turbine model with GRC.

and delivered by a human expert (e.g. decision-maker, designer, process planner, machine operator, etc.). Fuzzy C-Means (FCM) is a clustering algorithms permit the classification of the data in distinct groups using distance and/or similarity functions. These groups can later be used directly in selecting appropriate fuzzy set boundaries. Also the algorithms can automatically combine similar objects (data entries) in order to reduce the global size of the data. Finally the clustering algorithms let us easily detect potential outliers (clusters containing one or very few data entries). This feature is taken into consideration to design a decentralized fuzzy controller. The phase-plane plot of the input space is formed into clusters with the cluster centers is formed to obtain the required rule-base of the proposed Fuzzy controller. A robust decentralized control scheme is designed using proposed Fuzzy C-Means clustering [8,12]. The proposed controller is simulated for a two area power system in the presence of Generation Rate Constraint (GRC) for different operating conditions and was compared with conventional controller and original Fuzzy controller [4]. Results of simulation show that the FCM controllers guarantee the robust performance for a wide range of operating conditions with lesser rules.

2. System model

Interconnected power systems consist of many control areas connected by tie-lines. The block scheme of a two-area reheat power system is shown in Fig. 1. All blocks are generally nonlinear, time-variant and/or non-minimum phase systems. During the power system normal operation, it reveals only small deviation in the load, so that traditional methods often use linear model to represent the system dynamics around the operating point. In each control area, the generators are assumed to form a coherent group. Loads changing at operating point affect both frequencies in all areas and tie-line power flow between the areas. When there is load disturbance, LFC adjusts the area angular frequency deviation to zero as soon as possible, and control the tie-line power deviation to zero, so that the demand and generation capacity reach a new equilibrium.

The state space equation of the system is:

$$\dot{x} = Ax + Bu + Ld$$
$$y = Cx$$

$$\text{where}: x = [\Delta f_1 \Delta Pg_1 \Delta P_{T1} \Delta X_{e1} \Delta P_{Tie} \Delta f_2 \Delta Pg_2 \Delta P_{T2} \Delta X_{e2}]^T$$

$$u = [u_1 u_2]^T \quad w = [\Delta P_{D1} \Delta P_{D2}]^T$$

$$y = [ACE_1 ACE_2 \Delta f_1 \Delta f_2 \Delta P_{Tie}]^T$$

In Fig. 1, each area of the interconnected power system consists of the following four modules: the governor, the intermediate reheater, the steam turbine and the power system. where: T_{g1}, T_{g2} are governor time constants; T_{r1}, T_{r2} are reheater time constants; K_{r1}, K_{r2} are the reheater gains (pu); T_{t1}, T_{t2} are turbine time