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ORIGINAL ARTICLE

Performance of optimal hierarchical type 2 fuzzy controller for load–frequency system with production rate limitation and governor dead band

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Fuzzy Mamdani;
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Non-linear system

Abstract Controlling load–frequency is regarded as one of the most important control-related issues in design and exploitation of power systems. Permanent frequency deviation from nominal value directly affects exploitation and reliability of power system. Too much frequency deviation may cause damage to equipment, reduction of network loads efficiency, creation of overload on communication lines and stimulation of network protection tools, and in some unfavorable circumstances, may cause the network collapse. So, it is of great importance to maintain the frequency at its nominal value.

It would be useful to make use of the type 2 fuzzy in modeling of uncertainties in systems which are uncertain. In the present article, first, the simplified 4-block type-2 fuzzy has been used for modeling the fuzzy system. Then, fuzzy system regulations are reduced by 33% with the help of hierarchy fuzzy structure. The simplified type-2 fuzzy controller is optimized using the Cuckoo algorithm. Eventually, the performance of the proposed controller is compared to the Mamdani fuzzy controller in terms of the ISE, ITSE, and RMS criteria.

1. Introduction

Maintaining system frequency within a nominal range as load vacillates up and down has long been considered as a crucial task for system operators. This issue is of even greater significance today, taking into account radical growth in size and complexity of present power systems.

Any imbalance in generation and consumption of electrical energy in power system causes the system to deviate and thus the rate of the programmed exchange power changes [1]. Responding to lack of balance in actual power of power systems is known as load frequency control (LFC) [2].

A well-designed power system is generally represented by high power quality standards, nearly-fixed and stable frequency as well as wisely-regulated voltage [36]. As such, small breeze in active power (demand) will nonlinearly spur the frequency of the system while its voltage may be perturbed if the

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Nomenclature

Tt_i	time constant of turbine
Tp_i	time constant of power system
Kp_i	efficiency of power system model
Tg_i	time constant of governor
R_i	multiple of regulation of area i
ΔF_i	frequency deviation of area i
ISE	Integral Square Error
ITSE	Integral Time Square Error
RMSE	Root Mean Square Error
T2FH	Type-2 Fuzzy Hierarchical
T2FHC	Simplified 4 Blocks Optimal Type-2 TSK Fuzzy Hierarchical Controller
OHTSKF	Optimal Hierarchical TSK Fuzzy

reactive power (VAR) absorption keeps changing in the grid. To curb the frequency oscillations, Load Frequency Control (LFC) loop was developed in interlocking the power and frequency to the nominal values subject to time variation instances in operation. Given a number of interconnections among neighboring utilities, controlling load frequency required paying a great deal of attention.

Minimal deviations in the real power are tantamount to Rotor Angle (δ) variation, which is technically construed as frequency deviation in system. On the other hand, any change in active power will vibrate system frequency and re-shape the main parameters of the system performance. Therefore, an additional controller is needed to regulate the frequency of system instantaneously along with tighter accuracy.

To design a real-time load frequency controller, deviations in Rotor Angle ($\Delta\delta$) must be monitored. In other words, frequency and real power variations can be recorded so that error signals Δf, and ΔP_{tie} are established which are then consolidated to cast real power ΔP_v variable. Such power is in turn fed into primary stimulator to increase the input Torque. Hence, primary stimulator changes generator output as much as ΔP_g, and accordingly adjusts the amount of Δf and ΔP_{tie} on a predefined basis.

Following are three major purposes of load frequency control system:

(1) Keeping frequency within the permissible and acceptable level.
(2) Distribution of load among generators.
(3) Controlling load transmission in the tie-line.

In Refs. [1–19], several methods for frequency load control have been presented. Among these, PI and PID classic controllers, which have attracted more attention in the industry, use optimization algorithms to obtain the optimized values of classic controllers in nominal conditions. Although they are optimized methods, they have some deficiencies. This makes an actual power network to obtain some types of uncertainties causing the system parameters to be changed and modeling faults to occur. In addition, work point of the power system is changed during the day. So, a LFC optimized based on the nominal parameter of the system is not appropriate for the issue of frequency load control, and implementation of this frequency adjuster is deemed to be inadequate to reach the target performance.

Among other disadvantages of classical controllers are having large fluctuation and being robust against nonlinear factors cited as governor dead band.

In most studies carried out so far on the issue of frequency load control, centralized control approach has been most widely used. The most important limitation on centralized control is the fact that it is needed to transfer data between several areas which cover a wide range of geographical area. This may lead to increase in data information and their process volume, causing a decrease in the reliability [1]. In order to overcome these problems, use of decentralized control is recommended. Because of this, the system under control is divided into some control areas.

Linear optimal control [10] is a technique proposed with smooth controlling outfit. Though it is still constrained for further application due to its impracticality and lack of complete system information, yet the linearity characteristics of the controller itself may procure inaccurate and faulty control actions [10]. Ref. [11] shows a hierarchical optimal robust controller implementation in power system LFC model. However, simulations were carried out in two hierarchical levels (one follows another consecutively) consisting of system optimization and control system robustness verification levels.

Due to the increase in complexity of modern power systems, some advanced control systems have been recommended to be used in this regard. For instance, it is possible to use self-adjusting and adaptive control [3], predictive model-based controls [4,5], and smart controls [6,7]. Using advanced control method makes it possible to improve the efficiency rate. For this purpose, it is needed to have information on network status as well as an online effective identifier which makes their implementation hard.

According to technical literature, most of the proposed techniques have merely introduced controlling load frequency in a system with an unclear picture on how to determine system stability in practice. Since power systems commonly experience perceptible and large number of fluctuation and disturbance during operation, therefore, most of the studied literature has not provided adequate tools that maintain system stability measures within numerically cumbersome and technically arduous senses.

In load–frequency system, there is always disturbance. Thus, the final control chosen for system must be robust against disturbances. On the other hand, type 2 fuzzy controllers are inherently robust and contain all the properties of type 1 fuzzy controllers. Also, they are based on real world modeling. Therefore, for this paper, type 2 fuzzy controller has been used [43–45].

In this paper, a LFC controller is developed by means of fuzzy controller. Fuzzy controller can be utilized to overcome the plants with unexpected complex dynamics and external disturbances [18,31–33]. Moreover, LFC controller

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