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A new design of dual mode Type-II fuzzy logic load frequency controller for interconnected power systems with parallel AC–DC tie-lines and capacitor energy storage unit

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ABSTRACT

A new design of dual mode Type-II fuzzy logic load frequency controller (DMT-IIFLC) for interconnected power systems with parallel AC–DC tie-lines and capacitor energy storage unit (CES) is proposed in this paper. Any optimum controller selected for load frequency control of interconnected power systems should not only stabilize the power system, but also reduce the system frequency and tie-line power oscillations and settling time of the output responses. In general proportional plus integral controllers are used for loadfrequency control but it does not eliminate the conflict between the static and dynamic accuracy. This dispute may be broken up by using the principle of T-IIFLC to utilize expert knowledge and being adaptive in nature. The dual-mode concept is incorporated in the proposed controller to improve the system performance. A DC link is connected in parallel with AC tie-line to stabilize the frequency of oscillations. In summation, the CES unit is found to be advantageous for secondary control in the power system and keeps the power quality with the distributed power resources. The CES, which are not aged to the frequent charging and discharging, has been a quick response and outstanding function during overload conditions. The system performance of the proposed controller have improved significantly when compared with PI and T-IFLC. It is also found to be less sensitive to the changes in the system parameters and also robust under different operating modes of the system.

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Introduction

The interconnected power system encounters a great challenge in power system design and operation. The load–frequency control (LFC) problem has gained much importance because of the size and complexity of modern interconnected power systems. The objective of LFC is to regulate the output power of the regulating plants so that the frequency of the power system and tie-line power is kept within prescribed limits [1–3]. Many control strategies for LFC, of power systems, have been investigated and proposed by many researchers over the past several years [4,5]. The application of control strategy to the LFC problem has found wide acceptance because of its role in eliminating most of the problems associated with other multilevel control strategies. The proportional and integral (PI) controller is most widely applied for the LFC scheme [6].

It is a well-accepted fact that the classical conventional solution of this problem has been one of the first practical applications for the LFC problem. The advantage of using the PI controller lies in their simplicity, easy realization, low cost and robust and decentralized nature of the control strategy [7,8]. However, the conventional controller reduces the steady-state to zero but it exhibits poor dynamic performance and does not reach high performance. Furthermore, the settling time of the system frequency and tie-line power deviations are also relatively long. Recently, conventional PI controllers have been replaced by fuzzy logic controllers (FLC). FLC has received an important role in power systems [9].

An FLC, described completely in terms of Type-I fuzzy sets, (T-IFS) is called a Type-I fuzzy logic system or Type-I fuzzy logic controller (T-IFLC). Fuzzy logic is a logical system for formalization of approximate reasoning, and is used synonymously with fuzzy set theory, systems introduced by Zadeh and investigated further by many researchers [10–12]. Since it is able to model human decision making process and represents vague and uncertain data, fuzzy set theory is a theory about vagueness and uncertainty. This theory provides a methodology that allows modeling of the systems that are too complex or not well defined by mathematical

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Nomenclature

A	Type-I fuzzy set
$\tilde{A}$	Type-II fuzzy set
T-I FLC	Type-I fuzzy logic controller
T-II FLC	Type-II fuzzy logic controller
DMT-II FLC	dual-mode Type-II fuzzy logic controller
FOU	footprint of uncertainty
$\overline{\text{FOU}}$	upper bound of FOU
$\underline{\text{FOU}}$	lower bound of FOU
J_x	interval $\subseteq [0,1]$.
U	Universe of discourse = [0,1]
X	input variable (crisp input)
X	Universe of discourse (x domain)
χ	state vector
μ	Type-I membership function
$\mu_{\tilde{A}}$	Type-II membership function
$\underline{\mu}_{\tilde{A}}$	Type-II lower membership function
$\bar{\mu}_{\tilde{A}}$	Type-II upper membership function
b_i	frequency bias constant in p.u. MW/Hz
R_i	steady state regulation of governor in Hz/p.u. MW
T_{Gi}	time constant of steam turbine governor mechanism in seconds
K_{Ri}	reheat coefficient of the steam turbine
T_{Ri}	reheat time constant of the steam turbine in seconds
T_{Ti}	time constant of the steam turbine in seconds
K_{Pi}	gain constant of power system
T_{Pi}	time constant of power system
K_{dc}	gain constant of rectifier and converter unit
T_{dc}	time constant of rectifier and converter unit
a_{ij}	area size ratio
T_{ij}	tie-line power coefficient
K_p	proportional constant
K_i	integral constant
ΔX_{Ei}	Governor valve position in p.u. MW
ΔP_{THi}	deviation in intermediate state of reheat turbine in p.u. MW
ΔP_{Gi}	deviation in thermal turbine output in p.u.MW
ΔF_i	frequency deviation of ith area in Hz
ΔP_{tieij}	tie-line deviation between ith and jth area
ΔP_{di}	deviation in demand in pu-power
ε_i	switching limit
$K_{d,ei}$,	electric governor derivative constant
$K_{p,ei}$,	electric governor proportional constant
$K_{i,ei}$	electric governor integral constant
S	laplace frequency variable.
N	number of interconnected areas
Δ	incremental change of a variable
LFC	load frequency control
PI	proportional and integral
AC	alternating current
DC	direct current
FLC	fuzzy logic controller
ACE	area control error
ISE	integral square error
CES	capacitor energy storage

Superscript
Transpose of a matrix

Subscripts

i, j	area indices ($i, j = 1,2,\ldots,N$)

formulation. Therefore, T-IFLC becomes nonlinear and adaptive in nature, having a robust performance under parameter variations with the ability to get desired control actions for complex, uncertain, and nonlinear systems without the requirement of their mathematical models and parameter estimation [13,14]. The general framework of fuzzy reasoning handles much of uncertainty; a Fuzzy system uses T-IFS, which represents uncertainty by numbers in the range [0,1]. When something is uncertain, like a measurement, it is difficult to determine its exact value. However, it is not reasonable to use an accurate membership function for something uncertain, so in this case we need another type of fuzzy sets, those that are able to handle these uncertainties, the so-called Type-II fuzzy logic control (T-IIFLC) [15–17]. Thus, the amount of uncertainty in a system can be reduced by using T-IIFLC because it offers better capabilities to handle the linguistic uncertainties by modeling vagueness and unreliability of information [18].

A T-IIFLC is characterized by a fuzzy membership function, that is, the membership grade for each element of this set is a fuzzy set in 0,1 unlike a T-IFS where the membership grade is a crisp number in the range 0,1 [19–21]. Such sets can be used in situations in which there is an uncertainty about the membership grades themselves, for examples, an uncertainty in the shape of the membership functions or in some of its parameters [21,22]. To achieve the best system configuration possible, it is important to take into account the design of the energy storage system.

The energy storage unit is an attractive alternative to augment demand side management implementation. A quick-acting energy storage system, in accession to the kinetic energy of the generator rotors, provides adequate control to mute out the frequency oscillations. The problems such as low discharge rate, increased time required for power flow reversal and maintenance requirements have lead to the evolution of a energy storage devices for their applications in load frequency stabilizers [23,24]. By using energy storage systems, a low-cost source of electricity can be efficiently supplied to satisfy the peak requirement [25].

The capacitor energy storage (CES) system is suggested as energy storage unit for improving the dynamic behavior of LFC for two area power systems. The CES will, in addition to load levelling, a function conventionally assigned to them, have a wide range of applications such as power quality maintenance of decentralized power supplies [26–28]. The CES is excellent for short-time overload output and the response characteristics possessed in particular. The effect of generation control and the absorption of power fluctuation needed for power quality maintenance are required. In this survey, a two area power system with CES unit is taken to control power flows [28]. In each control area, all the generators are assumed to form a coherent group.

In the recent days, high-voltage DC transmission system has witnessed unprecedented development in the power system because of its performance, economy and environment friendly nature over the other options. By implementing a DC link in parallel with an AC link, the dynamic performance of the system can be improved with greater stability margin under small disturbances in the system [29,30].

An important design concept of the dual mode is used in the proposed controller because it improves the system performance and makes it flexible and applicable to actual systems [31,32]. The computer simulation results of the application of the proposed controller with interconnected power systems proved that the proposed controller is effective and provides significant improvement in the system performance. Moreover, it has likewise been discovered that the proposed controller is less sensitive to system

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