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A hybrid DE–PS algorithm for load frequency control under deregulated power system with UPFC and RFB

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Unified Power Flow Controller (UPFC);
Redox Flow Battery (RFB)

Abstract In this paper, a Modified Integral Derivative (MID) controller is proposed for Load Frequency Control (LFC) of multi-area multi-source power system in deregulated environment. The multi-source power system is having different sources of power generation such as thermal, hydro, wind and diesel generating units considering boiler dynamics for thermal plants, Generation Rate Constraint (GRC) and Governor Dead Band (GDB) non-linearity. The superiority of proposed hybrid Differential Evolution and Pattern Search (hDE-PS) optimized MID controller over GA and DE techniques is demonstrated. Further, the effectiveness of proposed hDE-PS optimized MID controller over Integral (I) and Integral Derivative (ID) controller is verified. Then, to further improve the system performance, Unified Power Flow Controller (UPFC) is placed in the tie-line and Redox Flow Batteries (RFBs) are considered in the first area. The performance of proposed approach is evaluated at all possible power transactions that take place in a deregulated power market.

1. Introduction

The main objective of power system control is to maintain continuous supply of power with an acceptable quality, to all the consumers in the system. The system will be in equilibrium, when there is a balance between the power demand and the power generated. There are two basic control mechanisms used to achieve reactive power balance (acceptable voltage profile) and real power balance (acceptable frequency values). In an interconnected power system a sudden load change in one area causes the deviation of frequency of all the areas. This change in frequency is to be corrected by Load Frequency Control (LFC) [1,2]. Nevertheless, the users of the electric power change the loads randomly and momentarily. It is impossible to maintain the balances between generation and load without control. So, a control system is essential to cancel the effects of the random load changes and to keep the frequency at the standard value [3].

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Nomenclature

apf	ACE participation factor
a_{12}	$-P_{R1}/P_{R2}$
ACE_i	area control error of area i
B_i	Frequency bias parameter of area i (p.u.MW/Hz)
cpf_{mn}	contract participation factor between mth $GENCO$ and nth $DISCO$
CR	crossover probability
DPM	$DISCO$ participation matrix
F	nominal system frequency (Hz)
FC	step size
G	number of generation
GDB	governor dead band
GRC	generation rate constraint
i	subscript referred to area i (1, 2)
K_{diesel}	gain of diesel unit
K_{ri}	steam turbine reheat constant of area i
K_{RFB}	gain of Redox Flow Battery
K_{PSi}	power system gain of area i (Hz/p.u.MW)
N_P	number of population size
P_{Ri}	rated power of area i (MW)
t_{sim}	simulation time (s)
T_{ri}	steam turbine reheat time constant of area i (s)
T_{Gi}	speed Governor time constant for thermal unit of area i (s)
T_{GHi}	hydro turbine speed governor main servo time constant of area i (s)
T_{PSi}	power system time constant of area i (s)
T_{RFB}	time constant of Redox Flow Battery (s)
T_{RHi}	hydro turbine speed governor transient droop time constant of area i (s)
T_{RSi}	hydro turbine speed governor reset time of area i (s)
T_{Ti}	steam turbine time constant of area i (s)
T_{UPFC}	time constant of UPFC (s)
T_{Wi}	nominal starting time of water in penstock of area i (s)
T_{12}	synchronizing coefficient between areas 1 and 2 (p.u.)
ΔF_i	incremental change in frequency of area i (Hz)
ΔP_{D_i}	incremental step load change of area i
ΔP_{Tie}	incremental change in tie-line power between areas 1 and 2 (p.u.)
$\Delta P_{Tie,12}^{actual}$	change in actual tie-line power (p.u.MW)
$\Delta P_{Tie,12}^{error}$	change in tie-line power error (p.u.MW)
$\Delta P_{Tie,12}^{scheduled}$	change in scheduled steady state tie-line power (p.u.MW)

In a traditional power system configuration, generation, transmission and distribution of an electrical power are owned by a single entity called as Vertically Integrated Utility (VIU), which supplies power to the customers at regulated tariff. In an open energy market, Generating Companies (GENCOs) may or may not participate in the LFC task as they are independent power utilities. On the other hand, Distribution Companies (DISCOs) may contract with GENCOs or Independent Power Producers (IPPs) for the transaction of power in different areas [4]. Thus, in deregulated environment, control is greatly decentralized and Independent System Operators (ISOs) are responsible for maintaining the system frequency and tie-line power flows [4,5].

The researchers in the world over are trying to propose several strategies for LFC of power systems under deregulated environment in order to maintain the system frequency and tie-line flow at their scheduled values during normal operation and also during small perturbations. Recently, Parmar et al. [6] have studied the multi-source power generation in deregulated power environment using optimal output feedback controller. Debbarma et al. [7] have proposed AGC of multi-area thermal power systems under deregulated power environment considering reheat turbines and GRC, where the fractional order PID controller parameters are optimized employing Bacterial Foraging (BF) optimization technique and the results are compared with classical controller to show its superiority. Demiroren and Zeynelgil [8] have suggested AGC in three area power system after deregulation and used GA technique to find the optimal integral gains and bias factors. A four area power system in a deregulated environment has been examined in [9]. Hybrid particle swarm optimization is used to obtain optimal gain of PID controller. However, in the above literatures the effect of physical constraints such as Generation Rate Constraint (GRC) and Governor Dead Band (GDB) nonlinearity is not examined which needs further comprehensive study.

Several classical controllers structures such as Integral (I), Proportional–Integral (PI), Integral–Derivative (ID), Proportional–Integral–Derivative (PID) and Integral–Double Derivative (IDD) have been explored in [10]. Tan and Zhang [11] have been proposed Two Degree of Freedom (TDF) Internal Model Control (IMC) method to tune decentralized PID type load frequency controllers for multi-area power systems in deregulated power environments. Liu et al. [12] have been suggested optimal Load Frequency Control (LFC) under restructured power systems with different market structures. It is found from the literature survey that, most of the work is limited to reheat thermal plants, hydro plants and relatively lesser attention has been devoted to wind, diesel generating units. Due to insufficient power generation and environmental degradation issues, it is necessary to make use of wind energy in favorable locations [13]. Keeping in view the present power scenario, combination of multisource power generation with their corresponding participation factors is considered for the present study.

Flexible AC Transmission Systems (FACTS) controllers play a crucial role to control the power flow in an interconnected power system. Several studies have explored the potential of using FACTS devices for better power system control since it provides more flexibility. Unified Power Flow Controller (UPFC) is one of the most versatile FACTS controllers which is connected in series with the transmission line or in a tie-line to improve the damping of oscillations [14]. Redox Flow Batteries (RFBs) are an active power source which can be essential not only as a fast energy compensation