Computers and Electrical Engineering 72 (2018) 137–153

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Optimal tuning of 3 degree-of-freedom proportional-integral-derivative controller for hybrid distributed power system using dragonfly algorithm

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ARTICLE INFO

Article history:
Received 25 February 2018
Revised 2 September 2018
Accepted 4 September 2018

Keywords:
Hybrid energy distributed power system
Load frequency control
3DOF-PID controller
Dragonfly algorithm
Battery energy storage system
Probability density function

ABSTRACT

The objective of this paper is to study the dynamic stability of a hybrid energy distributed power system (HEDPS) subject to load and wind power variations. A three degree-of-freedom (3-DOF) proportional-integral-derivative (PID) controller is designed and implemented in the HEDPS to stabilize frequency and power fluctuations after the perturbation. For enhancing system dynamics, the parameters of the 3-DOF PID controller are optimized by using dragonfly algorithm (DA). The results are compared with the results obtained by Zeigler–Nichols tuning and some other well-known meta-heuristic algorithms. The efficacy of proposed DA over different reported algorithms is established in terms of convergence rate, minimum fitness value and dynamic performance of the system. The robustness of the 3-DOF PID-controller is ascertained with time-varying step load perturbation, random wind power perturbation, and under system parameter variation. The robust performance of proposed DA has also been established by performing statistical analysis.

1. Introduction

The deregulation of electrical utility globally unfolds a new roadmap for small power generation, namely distributed generation (DG). In later periods, DG technology has gained more attention from researchers to match variable load profiles, especially in peak hours. Renewable energy in form of a hybrid energy system is cost-effective, environment friendly, reliable and better quality of power generation occurs than non-renewable energy resources [1–3]. This hybrid energy system provides centralized electrical power generation in a local area by combining renewable energy resources with some slack systems and energy storage devices [3]. Owing to their eternal nature, friendliness characteristic, and rapid growth, wind power and solar power are mostly used as a renewable energy resource in DG. However, irregular behavior of wind speed and solar radiation may cause serious stability problems of DG system. To retain system stability, some storage and backup systems are integrated with DG. This structure is called a hybrid energy distributed power system (HEDPS). Battery energy storage system (BESS), flywheel energy storage system (FESS), superconducting magnetic energy storage (SMES), a redox-flow battery (RFB), capacitor energy storage system (CESS), etc. are mostly employed in HEDPS to match peak load demand [1–3]. This helps DG to enhance the system performance, provides good coordination amongst different generators,

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https://doi.org/10.1016/j.compeleceng.2018.09.003

and lowering various operating constraints [2]. The reliable and stable operation of HEDPS is complicated due to continual fluctuations of wind speed and solar radiation. This fluctuation result in mismatch between power generation and load demand, resulting in deviation of frequency from the steady-state level. Thus, to guarantee the stability of the system and to nullify error in frequency, load frequency controller (LFC) is incorporated in HEDPS. LFC continuously monitors variation in power generation with load demand and accordingly takes corrective actions to maintain the stability of HEDPS.

Hitherto, many control algorithms have been applied to HEDPS to enhance the performance after the load and/or wind power variations. Robust H_∞ based LFC for the hybrid DG system has been discussed in [2]. The controller was designed by using particle swarm optimization (PSO) and genetic algorithm (GA). However, selection of weighting function for the design of H_∞ controller is not an easy task. Further, the order of H_∞ controller depends on the plant. Since the power system network itself is a higher order system, hence the implementation of H_∞ controller is not straightforward. A comprehensive review of the optimal allocation of DGs in a power system with different objectives, constraints, and algorithms has been reported in [4]. A renewable energy-based hybrid power system has been examined in [5]. The gains of a PI-controller were selected by the trial-and-error method. Authors in [6] have demonstrated the LFC issue of hybrid wind-diesel power system with and without pitch control technique. In [6], optimum gains of controller parameters were selected by using the integral square error (ISE) criterion. Though, ISE criterion penalizes large error, but unable to improve the settling time of the system oscillations. Serban and Marinescu [7] have presented an aggregated LFC for an autonomous microgrid (MG) with renewable energy resources. A robust proportional-integral (PI) controllable load to stabilize the frequency deviation of a power system is presented in [8]. In [9], PI-controller based small-signal analysis of the hybrid power system was performed. Since PI-controller gains are optimized based on experiences, classical, or trial-and-error methods. Again, it is incapable of attaining better dynamics for a full range of operating conditions. The LFC problem of a wind-diesel micro-hybrid power system has been discussed in [10]. The control strategy for a hybrid renewable energy system, including diesel energy power generator (DEPG), BESS, and FESS was reported in [11]. However, the proposed control algorithm can control the system frequency deviation within the small range. Besides, this paper does not suggest any controller for further improvement of the frequency profile. The authors of [12] have discussed the LFC strategy for MG with electrical vehicle (EV). Application of dish-sterling solar thermal in automatic generation control (AGC) of a hybrid power system is available in [13]. The integral (I), PI, and proportional-integral-derivative (PID) controllers were employed as a secondary controller to regulate frequency and power output of the hybrid system. Gampa and Das have investigated a small isolated power system comprising a wind turbine generator and a diesel generator in [14]. Recently, model predictive control (MPC) algorithm for frequency stabilization was discussed in [15]. However, difficulties with the operation, high maintenance cost, and lack of flexibility can result in fragile controllers that are not profitable.

Competence, controllability, and steadiness of the power system after the integration of renewable energy resources have been measured in terms of fast active compensation. In this perspective, various optimization techniques were reported in literature, which includes GA [8,14], PSO [2,3,14], biogeography-based optimization (BBO) [13], firefly algorithm (FA) [16], ant lion optimization [17], etc. The optimum scheduling problem of microgrid using hybrid differential evolution (DE)-harmony search algorithm (HSA) is presented in [18]. The fuzzy logic based intelligent controller has been successfully used in [19]. An intelligent PSO optimized Sugeno fuzzy controller for PV farms is discussed for the frequency stabilization in a multi-area power system [20]. But, the performance of the fuzzy logic controller is highly susceptible to the selection of the rule base, inference mechanism, fuzzification, and defuzzification strategies. Though, aforesaid algorithms offer a substantial improvement of the system performance, leaving behind some shortcomings. These algorithms are mainly suffered from slow convergence rate, poor local optima avoidance, and require more computation time. Further, there is fuzziness in the selection of algorithm-specific control parameters. For example, the effectual implantation of PSO wants accurate values of acceleration coefficient and the weighting factor for social and cognitive components. Likewise, the performance of DE is entirely reliant on mutation and crossover factors. The algorithmic control parameters of CSA are the scale factor and mutation probability rate. The feasibility and effectiveness of optimization techniques have been further explored in other areas of power system optimization. The solution of optimal power flow (OPF) using an efficient meta-heuristic algorithm-based multi-objective optimization (MOO) technique is reported in [21]. Additionally, the researchers have successfully implemented the cuckoo search algorithm (CSA) [22], clustered adaptive teaching learning-based optimization (CATLBO) [23], enhanced genetic algorithm (EGA) [24], etc. for solving the OPF problem in power system.

Various integral order controllers such as I [13], PI [5,8,9,13,14], and PID [13,14] were extensively used to damp out frequency and power oscillations in HEDPS. However, the conventional controller does not show appreciable results for the HEDPS due to fluctuating behavior of renewable energy resources and the presence of various power system constraints. Furthermore, the conventional feedback controller does not initiate the control action for the disturbance unless the controlled variable deviates from the set-point level.

The objective of this paper is to provide a robust and intelligent computational algorithm for assessing the dynamic stability of HEDPS. To improve system stability, extra two degrees are added to the single-degree-of-freedom (1-DOF) PID-controller called 3-degree-of-freedom proportional-integral-derivative (3DOF-PID) controller. Unlike 1-DOF controller, a 3DOF-PID controller has an excellent set-point tracking ability and provides better regulation for the disturbance input. The controller parameters are optimized by using a stochastic evolutionary algorithm called dragonfly algorithm (DA) [25]. The proposed algorithm is inspired from the static and dynamic swarming behavior of dragonflies. Unlike other aforesaid evolutionary algorithms, the operation of DA is only dependent on the population size and the maximum iteration count. The primary objectives of the present work are summarized below.