Journal of Energy Storage 19 (2018) 145–159

Contents lists available at ScienceDirect

Journal of Energy Storage

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

Frequency stabilization of isolated and grid connected hybrid power system models

Somnath Ganguly[a,*], Chandan Kumar Shiva[b], V. Mukherjee[c]

[a] Department of Electrical Engineering, Bankura Unnayani Institute of Engineering, Bankura, West Bengal, India
[b] Department of Electrical and Electronics Engineering, SR Engineering College, Ananthsagar, Hasanparthy, Warangal, Telangana, India
[c] Department of Electrical Engineering, Indian Institute Technology (Indian School of Mines), Dhanbad, Jharkhand, India

ARTICLE INFO

Keywords:
Diesel engine generator
Grid connected hybrid power system
Isolated hybrid power system
Optimization
Superconducting magnetic energy storage
Wind turbine generator

ABSTRACT

This paper investigates the load frequency control (LFC) of two different configurations of power system model. The first one is worked as an isolated hybrid power system (HPS) (IHPS) while the second one is a grid tied HPS (GHPS). In IHPS, the power generating units are diesel engine generator (DEG), wind turbine generator (WTG) and solar thermal power generation (STPG). It is considered in such a way that the generation persists throughout the day with uninterrupted power supply. The energy storage device used in this work is superconducting magnetic energy storage (SMES). The three scenarios considered in isolated mode are (a) HPS with one DEG, one WTG and one STPG, (b) HPS with one DEG and one STPG and (c) HPS with one DEG and one WTG. As concerned to GHPS, a combination of WTG and steam thermal power plant is considered. A conventional proportional-integral-derivative (PID) controller has been used as supplementary control mechanism. The PID controller gains and the tunable parameters of the SMES are tuned by the use of quasi-oppositional harmony search (QOHS) algorithm. Initially, integral of time absolute error based objective function is minimized and, subsequently, three performance indices such as integral of absolute error, integral of square error and integral of time square error are calculated to test the designed efficiency of the proposed QOHS based PID controller. The transient responses of systems pertaining to step and random changes in the load demand are analyzed. The simulated results obtained by the QOHS algorithm reveals that it may be imposed to boost LFC performance of the power system.

1. Introduction

1.1. General

The demand of electrical energy is continuously increasing in physical world due to high population growth and industrial development. At present, the high percentage of electrical energy requirement is met from fossil fuel generating units. However, due to the gradual depletion of fossil fuel and hike in fuel cost, requirement of load demand may not be fulfilled by conventional steam thermal power station (STPG). In this context, renewable energy resource (RES) presents a promising future as it provides clean energy and eliminates dependency on fossil fuels [1]. The electricity and heat generation from solar radiation, wind energy, ocean energy, hydro power, biomass, geothermal resources, biofuels and hydrogen are derived from the clean RESs. Among these RESs, wind energy and solar photovoltaic (PV) generating units have gained popularity due to their inexhaustible environment friendly characteristic as well as fast development in the designed technology. Also, it has a positive implication on financial as well as social growth of the country [2]. Along with the conventional resources, both the reliability as well as the power quality of the generated electricity may be improved, if these RESs are added.

1.2. Literature survey

The increasing concerns on environmental problems as well as the shortage and rising costs of fossil fuels have exhibited interest towards the integration of RESs to the power systems. The power generated by renewable sources is irregular and cannot be easily predicted. This affects the scheduled frequency regulation. To tackle these problems, the concept of distributed generation (also termed as small isolated power system with or without connection to the grid) may be implemented to support and regulate the system frequency at rural application, large commercial areas and process industries. In small isolated power

* Corresponding author.
E-mail addresses: somnath_aec82@yahoo.co.in (S. Ganguly), chandankumarshiva@gmail.com (C.K. Shiva), vivek_agamani@yahoo.com (V. Mukherjee).

https://doi.org/10.1016/j.est.2018.07.014
Received 12 May 2018; Received in revised form 24 July 2018; Accepted 24 July 2018

system, electrical power is supplied by the diesel generators. Additionally, wind and solar radiation based generation have gained increased attention as green energy in most of the isolated power systems [1]. Due to sudden change either in load or in wind speed, the system frequency and, hence, the output power fluctuate. The fluctuating frequency and power seriously affects the stability, control strategy and security of the locally connected grid [3].

A standalone hybrid power system (HPS) consisting of wind turbine generator (WTG), diesel engine generator (DEG), fuel cell and aqua electrolyzer has been used in [4]. In this work, the effect of designed system on the load stabilization has been considered to ensure quality power supply. The development of hybrid PV and fuel cell generation system for stand-alone application has been presented in [5]. The role of this system is the production of electric energy without interruption in isolated places. The modeling, control and power management of hybrid PV fuel cell and battery bank system supplying electric vehicle have been under taken in [6]. It consists of a PV generator, a proton exchange membrane fuel cell and a battery bank supplying an electric vehicle of 3 kW. In another work (see [7]), modeling of a hybrid PV, wind and fuel cells based power system has been presented. The mathematical modeling topology and its power management with battery bank system are significant contributions of this work. In [8], the modeling and the control of HPS are presented by Aissou et al. It comprises of wind and PV sources with battery storage supplying a load via an inverter. Tamalouzt et al., in [9], have highlighted the modeling and simulation of a micro-grid based renewable power system. It comprises of wind turbine, double fed induction generator, PV generator, fuel cell and battery bank.

The generation from RES is stochastic in nature and depends upon the weather condition at any instant of time. This might results in situation where the electrical load is higher than the generation. If there is surplus power available from these RESs, then the energy storage devices (ESDs) may store the excess power for a short period of time and releases them later on to the grid when the load demand is higher than the generation. The most popularly used ESDs are flywheel energy storage system, battery energy storage system, compressed air energy storage system, super capacitor and superconducting magnetic energy storage (SMES) unit. These are being considered to store the surplus energy and deliver the same at the time of peak load demand [10–12]. Among the mentioned storage devices, SMES may be considered to be the efficient for some of its advantages. The SMES gives very high energy storage efficiency, typically 97% for very large systems and comparatively less for small application [13]. This is the device which stores the electrical energy with no loss by a magnetic field of coil comprising of superconducting wire. This storage device is capable of discharging high power within a fraction of cycle to compensate the sudden drop in the line power. Such strategic injection of brief bursts of power plays a crucial role in maintaining the grid reliability. This makes SMES more environmentally beneficial and viable as compared to the batteries [14].

A number of evolutionary computational intelligence based techniques have been developed as well as employed for HPS application. The genetic algorithm (GA) has been applied for the designing of hybrid solar-wind system with battery bank as energy storage (see [15]). To minimize the deviation in frequency, integration of different energy resources along with the energy storage elements has been carried out in [16]. In this work, proportional-integral (PI) controller has been addressed in order to achieve improvements in the deviation of frequency profiles. The tuning of a PI controller using particle swarm optimization (PSO) algorithm for simulation studies in autonomous hybrid energy generation/energy storage system has been dealt with in [17].

In order to improve the utilizing efficiency of renewable energy, a combined PSO and simulated annealing has been used in the literature for hybrid energy storage station as wind-solar generation system (refer [18]). The artificial bee swarm optimization algorithm has been used to optimize the size of HPS model which consists of solar-wind-fuel cell. The simulated work of [19] showed that the designed HPS system is a cost effective one. The hybrid generation systems consisting of WTGs, solar thermal power generation (STPG), PV, DEGs, fuel cells, battery energy storage system, flywheel, ultra capacitors and aqua electrolyzer have been considered for simulation studies in [20]. In this work, GA is used for optimization of controller gains of the hybrid systems. Fractional order fuzzy control of hybrid power system with renewable generation using chaotic PSO has been studied in [21].

The present paper deals with the study and analysis of an isolated and grid connected HPS models. The power generating units like WTG, DEG and STPG form the studied IHPS models. The grid connected HPS (GHPS) is formed by using one WTG and one STPS. Two proportional-integral-derivative (PID) controllers are used in isolated HPS (IHPS) in which one is to control the blade pitch angle of the WTG while the other is to control the speed governor of the DEG. Two more controllers are used in GHPS model to control the blade pitch angle of the WTG and to control the speed governor of the thermal turbine for obtaining better dynamic performance.

1.3. Motivation of present work

Despite of a lot of progress in the field of metaheuristic approaches employed for the optimization problem, there are still possibilities of some more avenues to improve further their searching capabilities and convergence characteristics. In the year 2000, harmony search algorithm (HSA) came into picture (see [22]). In [22], this algorithm was employed to solve the optimization problem of water distribution. Afterwards, this algorithm has found a number of successful applications in different aspects of engineering problems including industry, construction design, information technology, medical science, benchmark function optimization, power system and control system domain (refer [23–25]). A new concept based on opposition based learning (OBL) has been introduced in [26] to enhance the exploration potential of HSA. The work introduced in [27] has showed a new type of population initialization concept and named it as quasi-oppositional based learning (QOBL) concept. It uses random number population with its quasi-opposite number aiming to (a) enhance performance, (b) trounce the premature convergence, (c) improve the diversity of the solution and (d) accelerate the convergence speed of the basic HSA. Due to the increased exploring capability of QOBL, quasi-opposition harmony search (QOHS) algorithm has been used for load frequency control (LFC) problem in [28].

With reference to the above discussions, the main motivation of this paper evolves the utilization of QOHS algorithm to tune the controller parameters for frequency stabilization in different scenarios of the deployed IHPS models and GHPS model subjected to load disturbances.

1.4. Contribution of the present work

The main contributions of this paper are as follows:

(a) The modeling of IHPS embrace of WTG, DEG and STPG is done for handling rural electricity crisis.
(b) The modeling of GHPS comprising of one RES (mainly WTG) and one non RES (popularly STPS) is done for uninterrupted power supply.
(c) For reliable power quality and satisfying the power demand of the local area, SMES has been used in case of IHPS. The benefits of SMES are explored in this case.