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Robust H-infinite loop shaping controller based on hybrid PSO and harmonic search for frequency regulation in hybrid distributed generation system

Soumya R. Mohanty [a], Nand Kishor [a,*], Prakash K. Ray [b]

[a] Electrical Engineering Department, Motilal Nehru National Institute of Technology, Allahabad, India
[b] Department of Electrical and Electronics Engineering, International Institute of Information Technology, Bhubaneswar, India

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ABSTRACT

This paper presents a study on frequency regulation in isolated hybrid distributed generation (DG) system. The hybrid DG system consists of wind turbine generator (WTG), photovoltaic (PV), aqua-electrolyzer (AE), fuel cell (FC) and diesel engine generator (DEG) along with storage like flywheel energy storage system (FESS), battery energy storage system (BESS) and ultra-capacitor (UC). H-infinite loop shaping based on particle swarm optimization (PSO) as well as hybrid particle swarm optimization and harmonic search (PSOHS) controller is proposed to minimize the frequency deviation. The controller performance is analyzed under wide-band range of wind speed based on Van-der Hoven model, random load demand and non-linear solar-radiation variation which are considered as disturbances into the system. Also, the controller robustness is tested for changes in parameter up to ±30% of its nominal value. The simulated results under different operating scenarios demonstrate minimum frequency deviation in hybrid system, being achieved by the proposed controllers with use of UC as storage combination along with FESS in comparison to a simple PSO tuned PID controller.

Introduction

The deregulation of electricity markets worldwide bring new perspectives for small power generation known as distributed generation (DG). In the past few years, DG technologies have attracted in providing energy solutions to some customers that are more cost-effective, environmental friendly and provide better power quality or reliability over conventional power generation options. Though, DG comprises a relatively small fraction of the total capacity; however, the penetration level is expected to increase in future [1]. Among the renewable resources, wind energy and solar photovoltaic have gained popularity due to their inexhaustible environmental friendliness characteristic and fast development in the technology. Additionally, fuel cell (FC) also offers alternate energy resource; both electricity and heat to its customer. However, the intermittency in wind speed and solar radiation characteristics tend to serious operating problem, thereby stability of isolated DG system, which is already a weak system. As a matter of fact, these resources need to be integrated along with some storage systems to form HS for improved performance and better co-ordination, thereby minimizing individual operating limitations [2]. Among the storage systems; battery energy storage system (BESS), flywheel energy storage system (FESS), superconducting magnetic energy storage (SMES), compressed air energy storage (CAES) are popularly being considered to store the surplus energy and supply the peak-load demand [3–5]. However, BESS suffers from the problems associated to low-discharge rate, increased time required for power flow reversal and maintenance requirements, while FESS suffers from low energy density. Similarly, SMES is expensive and requires a continuously operating liquid helium system and CAES has low efficiency and adverse environment impact. Therefore, as an alternative storage, double layer capacitor or ultra-capacitor (UC) offers another option to complement the slower power output of the main resources and meet load demand because of its fast power response, flexible and modular structure [6,7].

In fact, a reliable and stable operation of isolated hybrid renewable energy system is more complex, unlike those with grid connected. The fluctuations in both wind speed and solar radiation lead to mismatch between the power generation and load demand resulting into deviation in system frequency and voltage from the nominal value. These undue disturbances if allowed to exceed beyond the tolerance limit may lead to undesired performance and

* Corresponding author. Tel.: +91 532 2271412.
E-mail addresses: soumyaigit@gmail.com (S.R. Mohanty), nand_research@yahoo.co.in (N. Kishor), pkraymnnit@gmail.com (P.K. Ray).

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result into damage of the connected devices/equipments. Therefore in order to minimize the deviations, various research studies have been reported in literatures [8–16].

Integration of renewable energy resources and energy storage in HS is discussed in [8]. The authors [9] have discussed their study on PI controller based isolated island HS consisting of wind, diesel engine generator (DEG), aqua-electrolyzer (AE) and FC. Several simulation case studies of such system including battery storage are presented. Recently, Ray et al. [10] have presented the problem of minimizing frequency deviation in HS that included BESS, FESS, SMES and UC. A comparison among these storage systems is reported. However, PI controller suffers from the heuristic variation of its gain which may cause undesired performance. In this context, considering the uncertainties in the system parameters, random load change and fluctuations in wind speed and solar radiation, robust control techniques like H-infinite based on linear matrix inequalities (LMI), loop shaping and (H_∞) using droop characteristic have been thus discussed by some researchers [11–13]. But these controllers were designed based on heuristic selection of its parameters. Thus, in order to obtain a robust performance, this paper proposed H-infinite loop shaping and PID controllers whose parameters/gains being optimized by particle swarm optimization (PSO) [14,15] and hybrid particle swarm optimization and harmonic search (PSOHS). Controllers are designed in presence of the system uncertainties, stochastic variation in wind and solar power and variation in load demand. The normalized coprime factorization technique [13,16] is applied to represent all unstructured uncertainties in the system. The performance and stability of the hybrid distributed generation system were studied with incorporation of H_∞ loop shaping method being optimized by PSO and PSOHS.

This paper is organized as follows; section "DG system modeling" describes the modeling of different resources and controllers employed in considered HS, section "Proposed controllers" describes the proposed controller, the integration topology of the formulated HS in section "Integration topologies of isolated hybrid system", followed by the time-domain and frequency-domain analysis based simulation results under various operating conditions in section "Simulation results and analysis". Finally, conclusions are drawn in section "Conclusion".

DG system modeling

The various energy resources are integrated along with energy storage systems to formulate different HS combinations for an improved power quality and reliability. However, the intermittency of sources like wind and PV due to unpredictable variation in wind speed and solar radiation may reduce the capacity of the energy storage systems. Hence FC is integrated with such resources along with the energy storage systems like BESS, FESS, etc. to overcome the stability related issues. Further, the fuel cell-ultracapacitor (FC–UC) combination is incorporated in the system to compensate the slow dynamics of fuel cell. In addition, conventional PID, PSO tuned PID (PSO-PID) and H-infinite loop shaping controller based on PSO (PSO loop shaping) are incorporated in the individual resources in order to control the respective power output and to obtain improved performance of the hybrid system. Prior to the detailed study of the integrated hybrid systems, the modeling and characteristics of the different components are carried out and presented in the subsequent sub-sections. In the modeling part, the system non-linearities and convertors have not been taken into account and the systems are simulated in simplified form as linear first order transfer functions [8,17]. The configuration of the proposed renewable energy and energy storage system based hybrid system is shown in Fig. 1.

Wind power generation

The below subsection describes a brief modeling aspects in wind system.

Large band modeling of wind speed

A Van der Hoven model [18] is considered to model wide-band variation in wind speed. The power spectrum of the horizontal wind speed is calculated in a range from 0.0007 to 900 cycles/h, i.e., more than six decades. Such a frequency range contains the

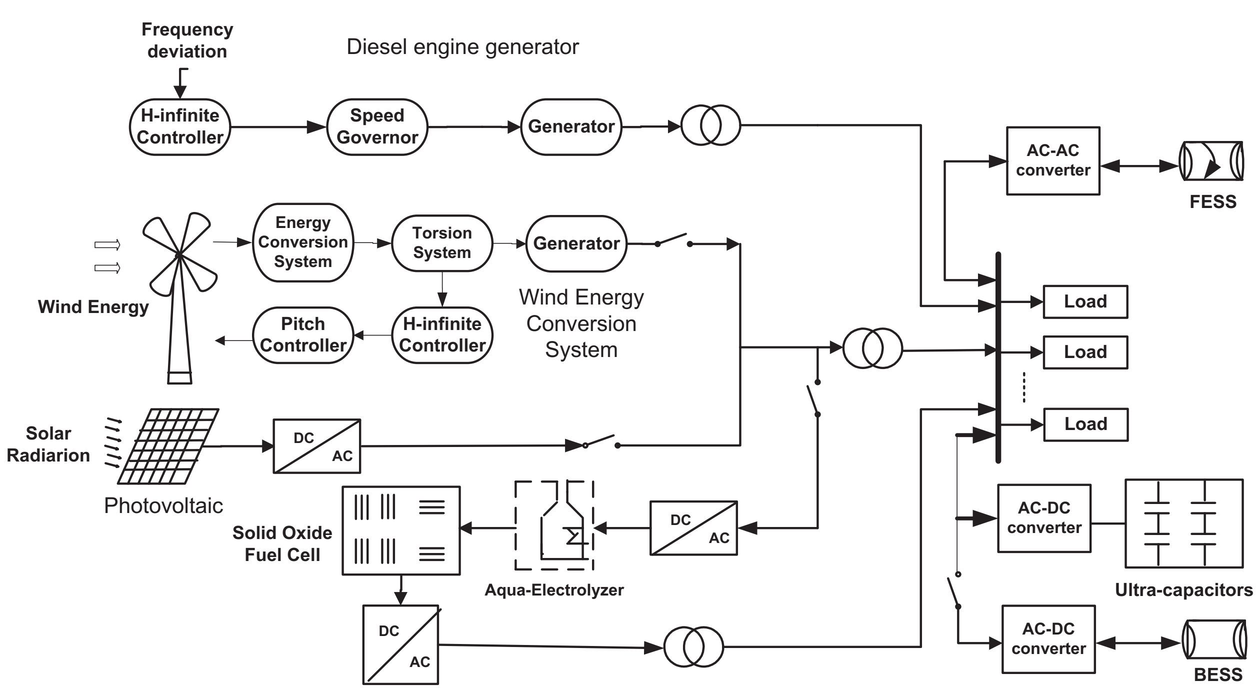

Fig. 1. Configuration of the hybrid system.