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Original article

Operation of small hybrid autonomous power generation system in isolated, interconnected and grid connected modes

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ABSTRACT

In this paper, the autonomous hybrid power system consisting of wind-turbine generator (WTG), diesel-engine generator (DEG), fuel-cell (FC) and aqua-electrolyzer (AE) is studied. DEG acts as slack generator, whose output power is controlled to have real power balance in the system to keep the frequency deviation within the limit. This paper proposes a new control scheme incorporating PID and PD controllers, to control the output power of DEG to keep real power-frequency balance in the system. PID controller is introduced to make the frequency deviation zero under steady-state, after any disturbance. PD controller is incorporated to damp out the oscillations in system frequency, after disturbance. Detail analysis of the effect of PID and PD controllers on system mode is presented using participation factor. The sensitivity of system modes to the variation of controller parameters is investigated. Simulated responses under isolated operation are presented to show that the proposed control strategy is capable of maintaining power-frequency balance in the system, following any disturbance. The mathematical model of the interconnected system is developed. One feedback loop is added to the existing PID controller in each area to reduce the tie-line power loss. Grid-connected and distribution system connected operation of the hybrid power system are also investigated.

1. Introduction

Last few decades, a huge amount of fossil fuel of the earth have been consumed and polluted the environment, particularly the global warming and harmful effects of carbon emissions are the major issues. These have created a new demand for clean and sustainable energy sources for producing electrical energy. A mix of renewable sources along with diesel generator (DEG) may be a good option to supply an isolated load. Hence, the aim of this work is to provide clean environment-friendly power to the isolated load and to reduce the dependency of power generation on fossil fuel, in the isolated area.

Renewable power generation system such as photovoltaic (PV) and wind power (WP) produce clean electrical energy. But the energy produced by the PV generation system is costly and it has low energy conversion efficiency as compared to WP generation system. Now-a-days, the advancement in technology has made the WP generation cheaper. In last few years, fuel-cell (FC) power generation system have attracted a lot of attention by the researchers [1–5]. The FC power generation system may generate electric energy with less pollution, higher efficiency, onsite installation, utilization of exhaust heat and water and diversity of fuels as compared to other power generation system [3–5].

The renewable energy sources can be combined with the DEG as a standby generation to form a hybrid power generating system. The output power from the different components of the hybrid power system should be effectively controlled and coordinated to supply the quality power to the load in the isolated system. Several types of research have been conducted on the operation, control and different aspects of the hybrid power system by the previous researchers. Many researchers have carried out the suitability studies for wind-diesel hybrid power generation system [6–13]. The effect of intermittency nature of WP generation, due to variation in wind speed, on the system frequency variation was studied in [14,15]. The operation of hybrid power generation systems, employing different configurations to supply power to the loads was reported in [16–18]. In [16], the authors have studied the performance of a standalone hybrid power generation system consisting of WP generation system, diesel engine generator (DEG) system, fuel-cells (FC) and aqua-electrolyzers (AE), considering PI controller. In [16], instead of using battery and dump load, AE has been used to absorb the fluctuating power of WP generation.

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Nomenclature

P_g	total generated power
P_w	wind power
P_{wt}	output power of the wind generator
K_{wt}	gain of the wind generator
T_{wt}	time constant of the wind generator
K_u	ratio of the wind power used in the aqua-electrolyzer to the total generated power by the wind generator
P_{ae}	output power of the aqua-electrolyzer
K_{ae}	gain of the aqua-electrolyzer
T_{ae}	time constant of the aqua-electrolyzer
P_f	output power of the fuel-cell
K_f	gain of the fuel-cell
T_f	time constant of the fuel-cell
P_{dg}	output power of the diesel generator
K_{dg}	gain of the diesel generator
T_{dg}	time constant of the diesel generator
T_d	time delay of the diesel generator
K_{p1}	proportional gain of the PID controller
K_{d1}	derivative gain of the PID controller
K_{i1}	integral gain of the PID controller
K_{p2}	proportional gain of the PD controller
K_{d2}	derivative gain of the PD controller
Δf	frequency deviation
$MAXG$	peak value of wind gust (m/s)
$MRWS$	peak value of ramp wind (m/s)
V_w	net velocity of wind (m/s)
V_{WB}	constant speed component of the wind (m/s)
V_{WG}	gust wind(m/s)
V_{WR}	ramp wind (m/s)
V_{WN}	random noise component of wind (m/s)
T_{GS}	starting time of gust wind (seconds)
T_{GF}	gust maximum time (seconds)
T_{RS}	ramp starts time (seconds)
T_{RF}	ramp maximum time (seconds)

In [17,18], the authors have studied the performance of a hybrid power generation system consisting of DEG, PV, battery energy storage system (BESS), flywheel energy storage (FESS) system, FC, and AE, without considering any controller. A control method, employing the fuzzy logic controller to solve the frequency variation problem of the hybrid power system consisting of micro-turbine along with FC and AE, was proposed in [19]. The power control strategy under the multimode operation of a grid-connected hybrid power system consisting of PV, WP generation, and battery was discussed in [20]. Dynamic modeling and simulations of hybrid power station consisting of different generating components were carried out in [21–23]. In [24,25], sizing of different components of hybrid power system consisting of the wind-turbine, tidal turbine, micro-turbine and battery were carried out considering economic analysis for optimal use of the renewable energy. A derivative-free meta-heuristic method has been applied for optimal control of system frequency and power deviation in a wind-diesel system in [26,27]. Performance study of the different controllers for controlling system frequency of a hybrid power generating station consisting of the solar-wind-diesel-fuel cell was presented in [28–30]. System frequency control of hybrid power system of different configurations using the conventional controller with gain parameters tuned using artificial intelligence technique (quasi-oppositional harmony search algorithm) was studied in [31–33]. The use of different flexible AC transmission system devices for tie-line power flow control has been described in [32].

In view of the above literature survey, it is found that previous literature [17] did not consider any controller, for frequency control in hybrid power system and the controller parameters are not optimized in [16]. In [16,17], only the time domain simulated results were presented and no frequency domain analysis [19–33], showing the effect of the controller on the system mode, and hence, on the system performance, was presented. Other researchers [30–33] have considered PID controllers for system frequency control, but, wind speed model was not considered. The interconnected operation of the hybrid power system was also not carried out by the previous researchers. In view of these, the motivations of this work are: a control strategy to control the output power of DEG may be developed and the analysis, on the effect of controller on system mode can be presented, interconnected and grid-connected operation of the hybrid power system may be studied, the effect of connecting the hybrid power system to a distribution network can also be studied.

Hence, the main contributions of this paper are: a new control strategy incorporating PID (to keep the frequency deviation zero at steady-state and improve dynamic performances after any disturbance) and PD (to damp out the oscillations in system frequency following a disturbance) controllers to control the output power of DEG to keep the system frequency within limit, is proposed. PID and PD controllers may be very well known techniques, but the contribution of this work is the demonstration of the effect of controllers on the system modes and hence on the system performance, using participation factor technique. Simulated responses are presented to show the applicability of the proposed control technique. From the responses, it can be concluded that the proposed control is capable of maintaining power-frequency balance in the system. The interconnected operation of the hybrid power system is also studied. The mathematical model of the interconnected system considering tie-line reactance as well as resistance is developed. A feedback loop (tie-line power signal) is introduced to reduce the tie-line power loss in case of any disturbance. The responses of the interconnected system are presented to show the viability of the control technique. System performance is also investigated under grid-connected mode. The effect on node voltage and power loss, after connecting the hybrid power system under study to a distribution network is also investigated.

The rest of the paper is organized as follows: Section 2 presents the mathematical modeling of the hybrid system under study and wind disturbance. In Section 3, the suitability of the adopted control strategy for the hybrid power generating system is analyzed using frequency domain approach. In Section 4, simulated responses of the isolated system are presented to show the applicability of the control method. The interconnected operation is investigated in Section 5. Grid-connected and distribution system connected operation are shown in Section 6. In Section 6, it also shows the effect of connecting the isolated and interconnected hybrid system to the distribution network. Section 7 concludes the paper.

2. Modeling of hybrid power generation system

In this paper, a hybrid power generation system consisting of wind turbine generator (WTG), diesel engine generator (DEG), fuel-cell (FC) and aqua-electrolyzer (AE) is considered. Fig. 1 shows the hybrid WTG–DEG–FC–AE generation system. A portion of the power generated by WTG system is utilized by AE to generate