ハイブリッド電力システムにおける系統周波数制御と有効電力平滑化に関する研究

Abstract

In most remote and isolated areas, electric power is often supplied by diesel generators. However, diesel generators cause serious impacts on the environment as every liter of diesel releases about three kilograms of CO2. Also, diesel is expensive because transportation to remote area adds extra cost. Moreover, diesel generators are inherently inefficient when operating at a low load factor (below 40%-50% of their rated capacity). Due to these environmental and economic influences of the diesel generator, interest in alternative cost-effective, sustainable, and clean energy sources has grown significantly. Wind, solar, sea, biomass, and geothermal powers are sustainable and clean sources. Wind and solar attracted a lot of attention nowadays and became the most widely utilized renewable energy sources in power systems. Also, fuel cell (FC) has the ability to be considered as one of the green power sources of the future. However, hybrid power system, especially in isolated systems with renewable energy sources such as WTG and PV, faces some stability problems because the power supplied by these sources is not constant, diverges quickly and cannot be easily predicted. So, these oscillations in the renewable power sources can produce instantaneous mismatch in the vital balance between generation and demand. Consequently, continuous variations in frequency and voltage levels usually appear which negatively affect the electric power system stability. Therefore, a continuous control for the supplied power by these renewable sources is required to ensure robust performance of the hybrid power system.

Nowadays, energy storage systems (ESS) are integrated with the renewable sources to maintain the safe operation of the power system and balance the supply and demand sides. These serve as backup devices and store excess power when the generation is more than demand and release power to the system when the demand is more than generation. This action helps in maintaining a steady flow of power irrespective of the load and generation power levels fluctuations. As a result, it guarantees acceptable levels of systems frequency deviations.

In this thesis, five frequency control and active power leveling schemes are implemented for hybrid power systems including renewable energy sources and ESS. In the first approach, robust control approach of hybrid wind-diesel power system is discussed. Proportional-Integral-Derivative (PID) controller is designed in the blade pitch system of wind turbine to improve the system dynamic performance. Furthermore, to minimize the system oscillations, super-conducting magnetic energy storage (SMES) with first order lead-lag controller is implemented to supply and absorb active power quickly trying to reach power generation /demand balance and thereby control system frequency. Minimization of frequency and wind output power deviations are considered as two objective functions for the PID controller of wind turbine. Also, mitigating frequency and diesel output power deviations are presented as two objective functions of the lead-lag controller of SMES. Modified version of non-dominated sorting genetic algorithm (NSGA-II) is used to tune the controllers' parameters to get an optimal response.

In the second scheme, optimal multi-objective design of PID controller's parameters for a small power system using epsilon multi-objective genetic algorithm (ε-MOGA) has been presented. The small power system includes a wind turbine generator (WTG), a diesel generator, a battery energy storage system (BESS) and a load. The proposed scheme is applied for controlling the pitch angle system of the WTG to minimize the wind turbine mechanical blades stress, reduce the wind output power deviation, control the system frequency and decrease the size of BESS by regulating its charging level. The deviations of input wind power are considered in a frequency domain. The low-frequency component is reduced by the pitch angle control system of WTG, while the high-frequency component is mitigated by the charge/discharge of the BESS, respectively. The input of the pitch angle control system of WTG is determined according to the low-frequency component of the input wind power deviation and the BESS state of charge. The output power of BESS is determined according to its state of charge, the high-frequency component of the input wind power deviation and the frequency deviations.

A new frequency control scheme for a hybrid power system to ensure supplying a high-quality power

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in isolated areas is applied in the third methodology. The proposed power system consists of WTG, solar photovoltaic (PV), aqua-electrolyzer (AE), FC, BESS, flywheel (FW) and diesel engine generator (DEG). Also, plug-in hybrid electric vehicle (EV) is implemented at the customer side. A full-order observer is utilized to estimate the supply error. Then, the estimated supply error is considered in a frequency domain. The high-frequency component is reduced by BESS and FW. While, the low-frequency component of supply error is mitigated using FC, EV, and DEG. Two PI controllers are implemented in the proposed system to control the system frequency and reduce the supply error. ε-MOGA is applied to optimize the controllers' parameters.

A novel polar fuzzy (PF) control scheme for hybrid power system is proposed in the fourth approach. The proposed control technique remedies the issues of system frequency and continuity of demand supply caused by renewable sources uncertainties. The hybrid power system consists of WTG, PV, solar thermal power generator (STPG), DEG, AE, FC, ultra-capacitor (UC), and FW. Furthermore, due to the high cost of BESS, a new idea of vehicle-to-grid (V2G) control is applied to use the battery of EV as equivalent to large-scale energy storage units instead of small batteries to improve the frequency stability of the system. In addition, EV customers' convenience is taken into account. A minimal-order observer is used to estimate the supply error. Then, the area control error (ACE) signal is calculated in terms of the estimated supply error and the frequency deviation. ACE is considered in a frequency domain. Two PF approaches are utilized in the proposed power system. The task of each one of these controllers is to mitigate one frequency component of ACE. The responsibility for ACE compensation is shared among all parts of the system according to their speed of response.

In the fifth approach, new methodology for controlling system frequency and power is analyzed. Two decentralized fuzzy logic-based control schemes to a high penetration no storage wind-diesel system are addressed. First one is implemented in the governor of conventional generators to damp frequency oscillation. While, the other is applied to control the pitch angle system of wind turbines to smooth the wind output power fluctuations and enhance the power system performance. Genetic algorithm (GA) is employed to tune and optimize the membership function parameters of the fuzzy logic controllers to get optimal performance. The effectiveness of the suggested controllers is validated by time-domain simulation for the standard IEEE 9-bus 3 generators test system, including three wind farms.

The effectiveness and robustness of the proposed schemes are verified by the numerical simulations in MATLAB® / SIMULINK® environment under various scenarios.

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