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Energy management system for stand-alone diesel-wind-biomass microgrid with energy storage system

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ABSTRACT

An energy management system for stand-alone microgrid composed of diesel generators, wind turbine generator, biomass generator and an ESS (energy storage system) is proposed in this paper. Different operation objectives are achieved by a hierarchical control structure with different time scales. Firstly, the optimal schedules of the diesel generators, wind turbine generator, biomass generator and ESS are determined fifteen minutes ahead according to the super short-term forecast of load and wind speed in the optimal scheduling layer. Comprehensive analysis which takes the uncertainty of load and wind speed into account is conducted in this layer to minimize the operation cost of the system and ensure a desirable range of the state of charge of the ESS. Secondly, the operation points of each unit are regulated dynamically to guarantee real-time power balance and safety range of diesel generation in the real-time control layer, based on which the response capability when suffering significant forecast deviation and other emergency issues, e.g. sudden load-up can be improved. Finally, the effectiveness of the proposed energy management strategy is verified on an RT_Lab based real-time simulation platform, and the economic performances with different types of ESS are analyzed as well.

1. Introduction

Power supply in remote areas and islands far from the utility grid has been a huge challenge. However, electricity shortage is a paradox in some of these areas with abundant renewable energy. Therefore, it is of great potential to meet the power demand by employing renewable energy sources such as PV (photovoltaic), WTG (wind turbine generator) for power generation [1–4]. Recent developments in power electronics technologies make it an effective approach to solve the power supply problems in these areas to integrate various DGs (distributed generators), ESS (energy storage system) and local load as a microgrid [5–7].

Due to the limited coverage of utility grid, microgrids in remote areas and islands always operate in islanded mode, which need higher requirement on real-time power balance compared with those connected to the utility grid. In general, sources with reliable power supply capability (e.g. diesel generators) usually operate as the main unit to control the system voltage and frequency and balance the power generation and consumption. However, the intermittent nature of power supplied by WTG and PV brings significant challenges to the stability of such systems [8–11]. Therefore, ESS has been adopted to improve the system stability and flexibility [12–14]. EMS (Energy management system), which is used for the coordinated control of diesel generators, DGs based on renewable energy and ESS, has played a key role to achieve high reliability of power supply and low operation cost in stand-alone microgrid simultaneously. Many related technologies in this field were studied. As an energy storage technique with low cost and high power density, CAES (compressed air energy storage) was applied in a hybrid wind-pneumatic-diesel system in Ref. [15]. Several control strategies of CAES were compared in terms of the fuel economy performance and the impacts of storage capacity and wind power penetration were analyzed in the paper. In Refs. [16], a knowledge based system controller was used to schedule a wind-diesel-ESS isolated microgrid an hour ahead so that the diesel generator power and fuel cost can be both minimized. An optimal model predictive control-based strategy for a multi-objective

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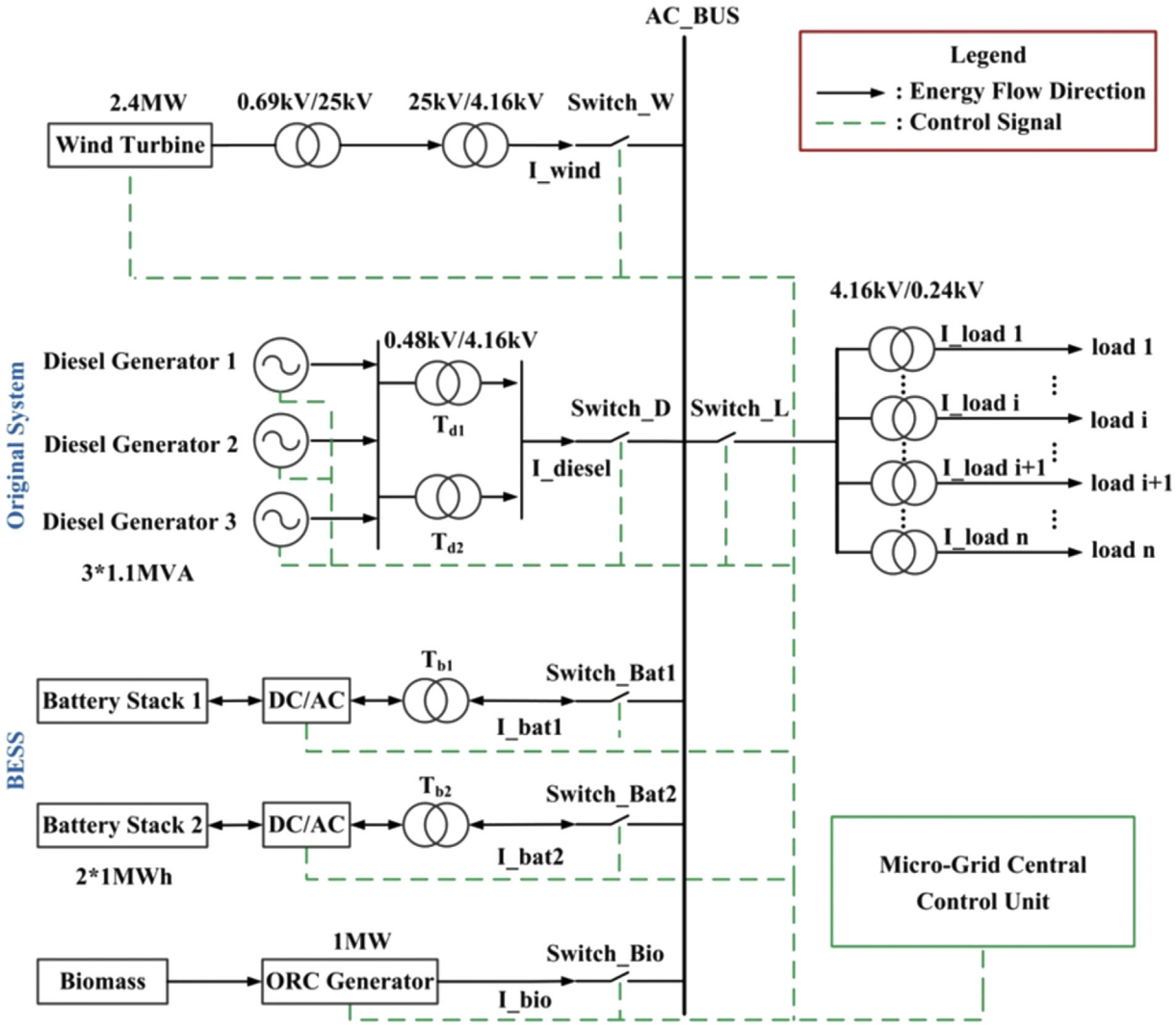

Fig. 1. Configuration of the microgrid.

Table 1
Efficiency characteristics of diesel generators.

Load factor (%)	Efficiency (%)
25	92.4
50	94.84
75	95.33
100	95.02
110	94.77

optimization problem was proposed with the goals of minimizing fuel costs and changes in power output of diesel generators, minimizing costs associated with low battery life of ESS, and maximizing the ability to maintain real-time power balance during operation [17]. Considering different components of wind power disturbances, a wind-diesel hybrid system was studied and the interactions of sources were analyzed in Ref. [18]. The battery and ultracapacitors were used to compensate the medium frequency and high frequency components respectively to smooth the wind power, improve the performance of the system and reduce the fuel consumption.

In areas with abundant solar source, PV has great potential for power generation. To supply electricity and water to an isolated small village in Nigeria, a PV-pump hydro energy storage system was proposed in Ref. [19]. Both the device size and plant management were optimized to achieve the best economic performances via the particle swarm theory. In a solar photovoltaic-diesel-battery hybrid system, “continuous” and “ON/OFF” operation strategies for the diesel generator were proposed to minimize the operation cost, which considered the intermittent solar resource, battery SOC (state of charge) and load demand fluctuation [20]. Meanwhile, the performance of fuel saving and operating time of diesel generator under these two strategies were analyzed. For a stand-alone PV/wind hybrid system studied in Refs. [21], a two layered cooperative control strategy was proposed. The primary control includes voltage and frequency control of the ESS, and the secondary control of MMS (microgrid management system) regulates the power output of the ESS to be nearly zero to ensure enough capacity margin. A renewable-based microgrid with PV, WTG, diesel generator and ESS was studied in Ref. [22]. A novel EMS based on a rolling horizon strategy was proposed, and a mixed integer optimization problem based on forecasting models was solved to determine the optimal dispatching plan.

EMS should be tested before engineering application. The aforementioned strategies were verified based on simulation or