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Energy dispatch strategy for a photovoltaic–wind–diesel–battery hybrid power system

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Abstract

In this paper, an energy dispatch model that satisfies the load demand, taking into account the intermittent nature of the solar and wind energy sources and variations in demand, is presented for a solar photovoltaic–wind–diesel–battery hybrid power supply system. Model predictive control techniques are applied in the management and control of such a power supply system. The emphasis in this work is on the co-ordinated management of energy flow from the battery, wind, photovoltaic and diesel generators when the system is subject to disturbances. The results show that the advantages of the approach become apparent in its capability to attenuate and its robustness against uncertainties and external disturbances. When compared with the open loop model, the closed-loop model is shown to be more superior owing to its ability to predict future system behavior and compute appropriate corrective control actions required to meet variations in demand and radiation. Diesel consumption is generally shown to be more in winter than in summer. This work thus presents a more practical solution to the energy dispatch problem.

Keywords: Energy management; Disturbance; Intermittent nature; Hybrid energy system; Optimization scheme

1. Introduction

Renewable energy (RE) and autonomous hybrid energy systems have become attractive energy supply options in many countries because of global environmental concerns and access to electricity, as well as the depletion and rising cost of fossil fuel resources (Deshmukh and Deshmukh, 2008). Diesel generators (DGs) have traditionally been favored solutions for off-grid applications because of their low initial capital cost. They however exhibit high operational and maintenance costs and have negative environmental impacts. Solar photovoltaic(PV) and wind supplies are free and environmentally friendly, but because of their intermittent nature they cannot provide continuous uninterrupted power. Incorporation of battery storage can improve supply reliability but it is often necessary to oversize both the storage and RE systems excessively, resulting in high capital costs and inefficient use of the system. PV–wind–diesel–battery (PWDB) hybrid power systems offer great opportunities by overcoming the above problems, providing environmentally friendly, reliable systems that reduce DG running costs and are considered as a cost-effective way to meet energy requirements of areas not easily accessible for grid connection (Elhadidy and Shaahid, 1999; Datta et al., 2009).

Hybrid energy systems have been used to power satellite earth stations, rural communities, radio telecommunications and other off-grid applications (Belfkira et al., 2011). In Central Africa, in countries such as the Congo,

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Nomenclature

$P_1(k)$	control variable representing energy flow from the diesel generator to the load at the kth hour [kW]
$P_2(k)$	control variable representing energy flow to and from the battery at the kth hour [kW]
$P_3(k)$	control variable representing energy flow from the PV array at the kth hour [kW]
$P_4(k)$	control variable representing energy flow from the wind generator at the kth hour [kW]
$P_L(k)$	control variable representing the load at the kth hour [kW]
A_c	the PV array area [m^2]
$P_{pv}(k)$	the hourly energy output from a PV generator of a given array area at the kth hour[kW h/m^2]
$P_{wind}(k)$	the hourly energy output from a wind generator at the kth hour [kW]
η_{pv}	the PV generator efficiency
η_{pv}	the PV generator efficiency
η_{WG}	the wind generator efficiency
η_B	the battery round trip efficiency
$SOC(k)$	the current state of charge of the battery bank

many mines are operating on DGs and RE hybrid systems can be useful in such industrial applications. The main challenge is the design of an optimal energy management system that satisfies the load demand, considering the variable nature of the RE energy sources and the real-time variations in demand. Considerable research effort has been made to optimize hybrid system components and operations, using various methods (Dufo-Lopez et al., 2011; Barley and Winn, 1996; Kamaruzzaman et al., 2008; Elaiw et al., 2012). However, these do not solve the problem in real-time in order to analyze the actual performance of the system, hence the application of a receding horizon strategy in the performance analysis of the hybrid system in this work. Unlike most similar works, this work focuses on the optimal dispatch of the various powers while minimizing operation cost and maximizing the utilization of renewable energy sources while considering battery life improvement by minimizing the charge–discharge cycles of the battery. Model predictive control (MPC) is employed in this work owing to its advantages over the open loop approach and its capability to handle constraints of the system explicitly using a user-defined cost function (Lee and Yu, 1994). Closed-loop models automatically adjust to changes in the outputs due to external disturbance, measures states and give feed back to the optimization model repeatedly and hence the optimal solution is updated accordingly (Kaabeche and Ibtiouen, 2014; Vahidi et al., 2006). The open loop model is unable to compensate for disturbances occurring from external sources owing to the absence of a feedback mechanism. When compared with the open loop optimization approaches, MPC results in reduced dimensions, easier computation, convergence and robustness which are well demonstrated by its application to power economic dispatching problems with a six-unit system (Kaabeche and Ibtiouen, 2014; Xia et al., 2011; Zhang and Xia, 2011). The MPC approach has been applied to a building heating system in order to analyze the energy savings that can be achieved (Siroky et al., 2011). Implementation of the receding horizon in controlling a single conventional power plant output to balance the demand has been explored by Gallestey et al. (2002). However, the work done so far does not specifically apply the on-line methodology to PWDB hybrid power supply options. A few researchers have applied this approach to the analysis of electric energy systems that incorporate intermittent resources (Xie and Ilic, 2008).

This work follows up on previous work presented in Tazvinga et al. (2013). The major addition is the wind generator and the application of the receding horizon technique to the optimal energy management strategy of a PWDB hybrid power supply system. The paper presents a more practical model when compared with the open loop model making it more favorable for real-time applications. The optimal control model for the PWDB hybrid system is an open loop approach and there is no feedback of system states. Absence of feedback might render the system vulnerable to disturbances in both load demand and RE (solar and wind) energy. In this paper, the MPC technique is applied to the open loop model for a PWDB hybrid power supply system with the aim of minimizing fuel costs, minimizing use of the battery and maximizing use of RE generators. The paper considers the effect of daily energy consumption and RE variations on the system by introducing disturbances in the demand profiles and RE output for both winter and summer seasons. The multi-objective optimization used in this work enables designers, performance analyzers, control agents and decision-makers who are faced with multiple objectives to make appropriate trade-offs, compromises or choices. Although an MPC strategy might be too sophisticated for individual domestic applications, it is certainly useful for institutional and industrial applications. The paper is organized as follows: in Section 2, the hybrid system configuration is briefly described. In Section 3, the MPC formulation for the PWDB hybrid system is described. In Section 4, the simulation results are discussed and the last section is the conclusion.

2. Hybrid system configuration

The PWDB hybrid power supply system considered in this paper consists of the PV system, wind generator (WG) system, battery storage system and the DG, as