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Operational performance of energy storage as function of electricity prices for on-grid hybrid renewable energy system by optimized fuzzy logic controller

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ABSTRACT

Realization of benefits from on-grid distributed generation based on renewable energy sources requires employment of energy storage to overcome the intermittency in power generation by such sources, while accounting for time-varying electricity prices. The objective of this study is to examine the effects of time-varying electricity prices on the performance of energy storage components for an on-grid hybrid renewable energy system (HRES) utilizing an optimized fuzzy logic controller (FLC). To achieve the objective, FLC membership functions are optimized for minimizing the operational cost of the HRES based on weekly and daily prediction of data for grid electricity price, electrical load, and environmental parameters, including wind speed, solar irradiation, and ambient temperature, using shuffled frog leap algorithm. FLC three inputs include (a) grid electricity price, (b) net power flow as the difference between energy produced and energy consumed, and (c) state of charge (SOC) of battery stack. It is confirmed that accounting for grid electricity price has considerable effects on the performance of energy storage components for operation of on-grid HRES, as the weekly and daily optimized FLCs result in less working hours for fuel cell and electrolyzer and less fluctuations in SOC of battery stack.

1. Introduction

While renewable energy sources (RES) can be used for distributed generation for reducing electricity network distribution losses and environmental emissions, the inherent intermittencies associated with these sources can be overcome by their integration into a hybrid form along with employment of energy storage. For further enhancement of RES performance for meeting varying loads, short and long-term energy storage components such as batteries and hydrogen storage tanks are utilized [1,2]. However, the performance management and power flow control of hybrid RES (HRES) in conjunction with storage require development and proper design of sophisticated controllers with multi-inputs and outputs capabilities, so that the undesirable fluctuations in power production caused by the intermittency of RES are minimized [2–4].

While different aspects of both off-grid and on-grid operation of HRES have been discussed and developed in the literature [5–12], numerous studies have focused on development of controllers for operation management. In one study, fuzzy logic controller (FLC) is used to control an on-grid PV system for meeting an illumination load and the results show that the purchased energy from the network is decreased [13]. Khayamy et al. used the concept of feedback linearization control algorithm to consider the non-linear behavior of an autonomous battery-assisted photovoltaic system providing satisfactory performance and ensuring input–output decoupled control on each of the output variables [14]. FLC is used in another work for maximum power point tracking (MPPT) of an on-grid PV system optimized based on particle swarm optimization (PSO) algorithm [15]. Another use of FLC is developed for smoothing the output of a HRES [16]. Das et al. propose an on-grid HRES which benefits from DC–DC converter for MPPT for supplying continuous power to load [17]. In another study, an un-optimized FLC is examined to determine the appropriate rate of production/consumption of hydrogen storage for an off-grid HRES [18], however, the results show that the system is unable to support a typical residential load for a very long time. Safari et al. [19] performed an optimization by means of PSO algorithm, on the same system used by Bilodeau et al. [18], with focus on determining the optimal

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membership functions (MFs) of FLC that controls the energy storage components of an off-grid HRES. Without consideration for on-grid operation, the results of that study show lower operation and maintenance cost for the off-grid HRES examined.

1.1. Contributions

The review of literature shows that studies on effective utilization of on-grid HRES by means of optimally designed controllers that allow for enhanced performance management of energy storage components using grid electricity price as input, in addition to other varying technical parameters, are lacking. Also, as previous studies have used past data for environmental parameters, it is of interest to determine the effects of the prediction of data on the future performance of on-grid HRES. Further, as the applicability of heuristic optimization algorithms is problem-type dependent, it is necessary to consider different algorithms for achieving better convergence and optimal solution. The objective of this study is to examine the effects of time-varying electricity prices on the performance of energy storage for an on-grid HRES utilizing an optimized FLC. To achieve the objective, a FLC for performance enhancement of energy storage components for a HRES is developed, as shown in Fig. 1, where MFs of FLC are optimized for minimum energy cost of system over a specific period of operation based on weekly and daily prediction of data for grid electricity price, electrical load, and environmental parameters, including wind speed, solar irradiation, and ambient temperature using PSO and shuffled frog leap (SFL) optimization algorithms.

The remainder of this study is organized as follows. In Section 2, on-grid HRES architecture along with components modeling are discussed. Optimization algorithms are summarized in Section 3. The simulation procedure is given in Section 4. Section 5 presents the simulation results and, the conclusions and recommendations are provided in Sections 6.

2. On-grid HRES architecture

In this study, on-grid HRES shown in Fig. 1 is composed of a wind turbine, a PV array, two electrical energy storage components, a FLC, and power electronics devices including converters and inverters for serving a residential type electrical load.

Wind turbine and PV array are intended to serve as the primary energy sources to meet the electrical load and the grid is intended to fulfil the need for backup for situations where the load is not fully met by HRES [10]. The on-grid operation provides for the opportunity to sell the excess energy produced by HRES to the grid for recovering some of the costs for purchased energy. For energy storage, a battery stack is used for coverage of short-term [20] and small scale power flow variations, while a combination of an electrolyzer, hydrogen storage tank, and fuel cell is intended to manage longer term and larger scale variations. The electrolyzer is used for producing and storing hydrogen in the tank, when an excess amount of energy generated by on-grid HRES is available. To complete the electricity-hydrogen-electricity cycle, a proton exchange membrane fuel cell is used to consume stored hydrogen and produce electricity. Note that electricity cannot be purchased from the grid in excess of load for later selling.

The power balance on the DC bus of on-grid HRES in Fig. 1 is described by

$$P_{wind}(t) + P_{pv}(t) + P_{Bat}(t) + P_{fuel-elec}(t) + P_{grid}(t) + \frac{P_{Load}(t)}{\eta_{inv}} = 0 \quad (1)$$

where P_{wind}, P_{pv}, P_{Bat}, $P_{fuel-elec}$, P_{grid}, and P_{Load} are wind turbine output power (kW), PV array output power (kW), battery power

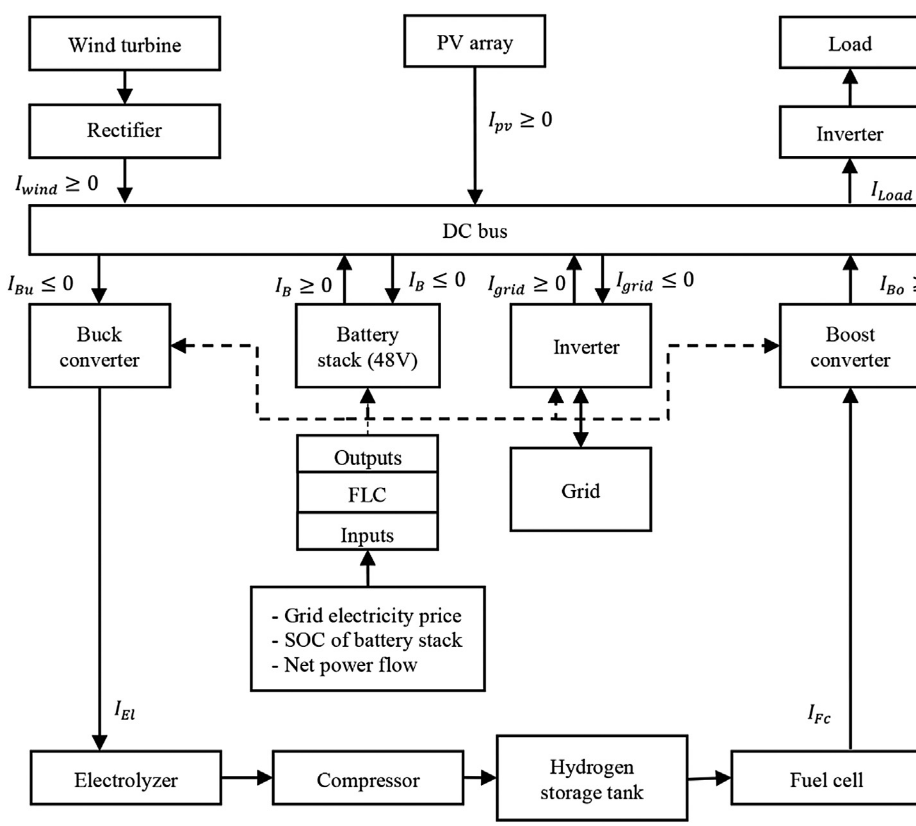

Fig. 1. On-grid HRES architecture with FLC for performance management of energy storage components.