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Energy management of remote microgrids considering battery lifetime

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ABSTRACT

Using the example of a two-layer energy management system for remote microgrids, a novel scheduling algorithm is proposed that considers the battery lifetime and is expected to reduce the operational cost of the microgrid. This method combines the objectives of minimizing fuel consumption and battery degradation costs into a single weighted goal.

1. Introduction

Nearly 20% (1.3 billion) of the world's population lacks access to electricity and many people live in remote areas where connection to the grid is not economical or practical (International Energy Agency, 2011). Diesel generators are the primary source of energy in those remote areas due to the low initial investment cost (Pelland et al., 2012). However, due to high fuel procurement, transportation, and storage expenses, the true energy cost can be as high as \$2.5/kWh (Pelland et al., 2012; Witmer and Watson, 2008a). Renewable energy resources such as photovoltaics (PV) and wind can be integrated with the diesel generators to reduce overall fuel consumption. However, the efficiency of a diesel generator decreases with a decrease in load. If not considered, fuel consumption may actually increase when renewables are added (Chalise et al., 2013).

Remote microgrids have loads with high peak-to-average ratios (Wichert, 1997) and generators are typically sized to meet the peak load requirements. Therefore, the generator often operates at low loading, resulting in poor fuel efficiency (Nayar, 2012). In addition, frequent low-load operation below that recommended by the manufacturer (usually 30%) causes wet stacking, carbon buildup, fuel dilution of lube oil, water contamination of lube oil, and damaging detonation (Ashari and Nayar, 1999; Tonkoski, 2014). The addition of PV to the microgrid further reduces the load on the generator and causes even poorer fuel efficiency. Further, PV resources do not always correlate with load demand, and the full potential of the PV resource cannot be achieved. The traditional approach to maintain minimum loading of a generator is to either dump load or, when renewables are included, curtail PV power (Tonkoski, 2014), leading to a loss of energy. Therefore, to overcome the aforementioned issues with the PV-diesel microgrid, a storage system is used (Pelland et al., 2012).

Energy storage systems (typically lead acid batteries due to their low cost per watt (Jenkins et al., 2008)) have been added to microgrids to enable dispatch of the generators to meet load requirements (Pelland et al., 2012). The battery can act as a source to augment the generator or a load to ensure full load operation of the generator. In addition, a battery increases the utilization of PV by storing extra energy. However, the battery represents a significant cost to the microgrid, requires proper disposal or recycling, and has a limited energy throughput (Drouilhet and Johnson, 1997; Jenkins et al., 2008). For the full value of battery throughput to be realized, it must be consumed before the float life has been met (typically 10 years for a lead-acid battery (Homer Energy)). This leads to a tradeoff between battery life and fuel consumption in microgrid operation. For example, generator fuel efficiency can be improved by heavy use of the battery, but this drastically decreases the battery lifetime. Because the battery has a high initial cost and is difficult to transport to remote areas, frequent replacement is impractical. Thus, fuel reduction and battery lifetime improvements are two conflicting objectives of a microgrid energy management system (EMS). The EMS coordinates with microgrid resources and provides an effective means to meet load requirements to achieve both objectives. The EMS is

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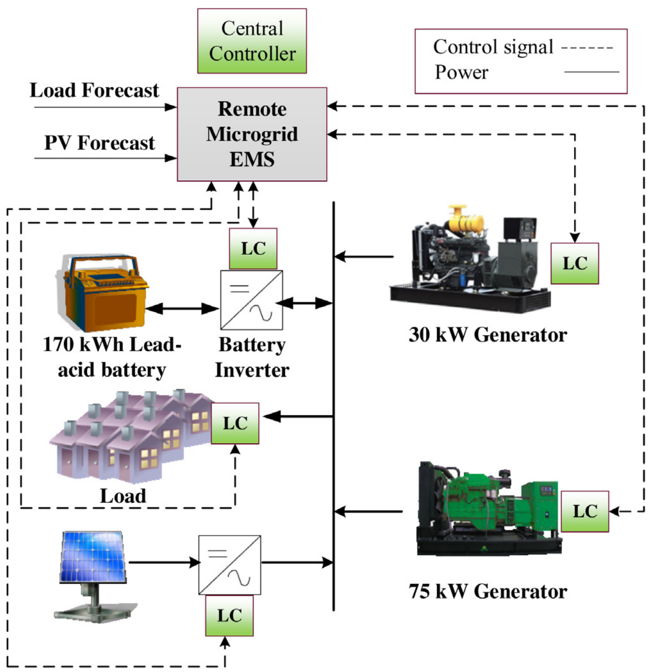

Fig. 1. Remote microgrid layout.

comprised of two distinct modules, day-ahead scheduling and real-time dispatching monitors, which schedule and control the operation of the generators and battery.

Few studies have considered both fuel and battery lifetime objectives during problem formulation and optimization. A recent study presented a multi-objective optimization formulation using a genetic algorithm (GA) to minimize power generation cost and to maximize the useful life of lead–acid batteries (Bo et al., 2013). However, both objectives were assumed equally important and the lifetime assumption was only applicable to the specific battery under consideration. Others (Jenkins et al., 2008; Khasawneh and Illindala, 2014; Su et al., 2014) have used battery throughput cost in an optimization model, but no effort has been made to determine the amount of battery throughput required for economic operation.

This article presents a novel EMS algorithm, considering both fuel consumption and battery lifetime in the operation of remote microgrids. The unique contributions of this article are:

I) Proposed a novel EMS algorithm to minimize the cost of remote microgrid operation while simultaneously extending the battery lifetime and improving battery utilization; and
II) Provided a detailed analysis of the impact on battery lifetime using the Ah-weightage method.

This article is organized as follows: Section 2 presents a brief description of the test microgrid, yearly load and PV profile, and proposed EMS algorithm. The mathematical modeling of the various components and their operational constraints, followed by the battery lifetime cost model and final objective function, are given in Section 3. In Section 4, microgrid operation and component cost are defined. The results and analysis are presented in Section 5, followed by the conclusion in Section 6.

2. Test microgrid system and energy management algorithm

2.1. Microgrid overview

A PV-diesel hybrid remote microgrid similar to that described in (Pelland et al., 2012) was adopted for analysis (Fig. 1). This microgrid consists of 75 kW and 30 kW diesel generators running in isochronous mode, and a 27 kW PV system. Operation of the generators was limited to a minimum of 30% of their rated capacity.

The annual load profile and PV output are as shown in Figs. 2 and 3, respectively. As shown in Fig. 2, the annual peak demand was 64 kW and the average was 25 kW. The peak to average ratio was 2.56. The total load was divided into critical (residential and important commercial loads such as a health clinic) and non-critical loads. The storage system consisted of a 170 kWh lead-acid battery sized to supply an average load for four hours. The battery had an 80% round-trip efficiency and maximum depth-of-discharge (DOD) of 50%. An EMS required to provide necessary control for the efficient operation and optimum utilization of the PV is shown in Fig. 4.

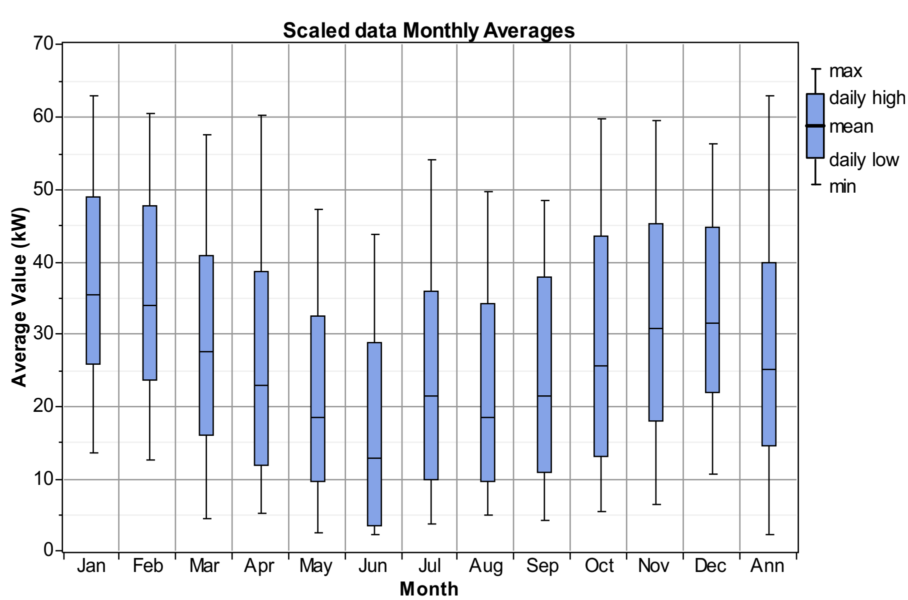

Fig. 2. Yearly load demand.