Levelized cost of electricity for photovoltaic/biogas power plant hybrid system with electrical energy storage degradation costs

Chun Sing Lai a,b,c, Youwei Jia b, Zhao Xu b, Loi Lei Lai a,b,⁎, Xuecong Li a, Jun Cao c, Malcolm D. McCulloch c

a Department of Electrical Engineering, School of Automation, Guangdong University of Technology, Guangzhou 510006, China
b Department of Electrical and Electronic Engineering, The Hong Kong Polytechnic University, Hong Kong Special Administrative Region
⁵ Energy and Power Group, Department of Engineering Science, University of Oxford, 17 Parks Road, Oxford OX1 3PJ, United Kingdom

1. Introduction

Electrical energy storage (EES) plays an increasingly important role in electrical power systems, especially for energy balancing in off-grid systems. With the escalation of energy demand and the pressure to reduce environmental pollution, renewable energy sources such as solar photovoltaic (PV) needs to be adopted [1,2]. For countries located in Africa at the equator, e.g. Kenya, there is an abundant amount of solar insolation throughout the year. In addition, the waste product generated from the large agricultural industry in Kenya makes electrical power generation from biogas power plant via anaerobic digestion (AD) a desirable option [1]. Hence, the optimal hybrid energy system for a rural community in Kenya should consist of solar PV and AD biogas power plant. In this paper, the term AD represents the combination of anaerobic digester and the biogas power plant.

In general, off-grid hybrid renewable energy systems perform better with multiple energy sources compared to a single energy source [3]. This can be explained by the fact that different energy sources have different technical constraints, and may be used to complement each other and to maximise the security of supply. The generation costs could also be potentially reduced. However, the control, design, and optimization of such systems is a complicated matter. In general, many of these systems were designed to with the aim to minimize the total generation cost such as the levelized cost of electricity (LCOE) [3,4].

The operation strategy for a system with an EES and PV generator is relatively simple. Surplus energy is stored in EES and discharges if the load is greater than generation. The interesting questions arise for systems with multiple energy sources. For the case where a dispatchable source such as AD is included, it is required to determine how the EES is charged and which dispatchable source (AD or EES) to use when the load demand is greater than the generation. As mentioned in [4], there are three basic control strategies for a PV-Diesel-EES system. These are known as zero-charge strategy, full cycle-charge strategy and the predictive control strategy. The EES is never charged with the diesel generator in the zero-charge strategy. Diesel generator is used to charge the EES to 100% state of charge (SOC) when the generator is on for the full cycle-charge strategy. Predictive control strategy requires the forecast of renewable generation and load demand to charge the EES.
The advantage of this strategy is that energy wastage in surplus energy production from renewables is reduced. An interesting research question to be answered is to determine the optimal point for the SOC, between 0% to 100% to be charged with AD in order to provide a minimum operational cost [4]. In other words, the strategy will be less of an extreme and is between zero-charge and full cycle-charge.

Scheduling regimes such as rule-based strategies [5] have the advantages in avoiding the need of renewable and load forecasting for optimal operation. Additionally, complexity is further reduced when online optimization is not required. The work did not mention the degradation and costs of EES and have highlighted as a future work.

There are numerous amount of research works in cycle life studies and the costs due to EES degradation for hybrid renewable energy systems [6–9]. However, most do not consider partial charge-discharge cycles and uses depth of discharge (DOD), i.e. only accurate for initial SOC at 100% for EES cycle life calculations. Electrical energy delivered is also used to consider the DOD in some literatures such as [6] and the actual values of the two SOCs may be neglected. Theoretically as an example, the electrical energy output from EES at SOCs of 100% to 80% is also used to consider the DOD in some literatures such as [6] and the actual values of the two SOCs may be neglected. Theoretically as an example, the electrical energy output from EES at SOCs of 100% to 80% is also used to consider the DOD in some literatures such as [6] and the actual values of the two SOCs may be neglected. Theoretically as an example, the electrical energy output from EES at SOCs of 100% to 80% is also used to consider the DOD in some literatures such as [6] and the actual values of the two SOCs may be neglected. Theoretically as an example, the electrical energy output from EES at SOCs of 100% to 80% is also used to consider the DOD in some literatures such as [6] and the actual values of the two SOCs may be neglected. Theoretically as an example, the electrical energy output from EES at SOCs of 100% to 80% is also used to consider the DOD in some literatures such as [6] and the actual values of the two SOCs may be neglected. Theoretically as an example, the electrical energy output from EES at SOCs of 100% to 80% is also used to consider the DOD in some literatures such as [6] and the actual values of the two SOCs may be neglected.
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