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Optimum Design of a Stand-alone Hybrid Power System with Demand-Side Management

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Abstract

Hybridising renewable energy sources improves the reliability of renewable energy systems for stand-alone applications. However, the high system cost is one of the setbacks that contribute to the slow growth of renewable energy development. The system cost can be reduced by optimal system design. This paper presents hybrid system design strategies that minimize the system capital cost. The design concept considers integration of demand-side management (DSM) strategy in the system design process. In this strategy, the residential load is divided into three categories and prioritized two of them. This reduces the peak load, in effect reduces the system design capacity. A traditional design method was used to design a hybrid system to meet a specific daily load profile of a typical 3-bedroom residential facility in Tema, Ghana. The system capacity, system capital cost, net present cost, capacity shortage and excess generation of the system were considered as hypothesis. The algorithm of the proposed design strategy was used to design an optimal system for the same daily load profile. Upon comparison of the two systems, the following observations were made; the system capacity reduced from 8.4 kW to 4.3 kW, the initial cost and the net present cost of the optimal system reduced by 48% and 41.5% respectively, system capacity shortage was slightly improved from 9.5% to 8.8%. The costs of energy (COE) improved from 0.793 kWh to 0.742 kWh, 6.4% reduction. The results indicate that, the proposed design method reduces the system capacity by almost half which significantly reduced the system initial cost by 41.5 percent.

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Keywords: Design method, Demand-side Management, Hybrid system;

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1. Introduction

The deployment of renewable energy resources such as photovoltaic (PV) and wind energy system has rapidly grown in electric power systems due to the environment-friendly nature of these resources on one hand and the increasing cost of conventional energy sources on the other. The clean energy resources are considered to be the solution to the current energy crises in sub-Saharan region. Apart from the unavailability of natural grid network in the remote communities in the region, the residents in the urban communities show great interest in renewable energy due to power shortage and the escalating cost of energy in the region. Due to the intermittent generation nature of the renewable energy resources, it is not a reliable source of energy when used in stand-alone application. To improve the reliability, there are other alternative energy sources which are readily dispatchable. The slow growth of renewable energy system development is as a result of the current high system cost. The factors that contribute to the high system cost has been grouped into three categories; energy resource availability, cost of system components and design methodology system cost is a dependant of system capacity, whereas system capacity also depends on the load, energy source availability and the design method.

The paper presents a strategic method of designing an optimum hybrid power system using load management strategy. The peak load of a particular load profile is considered to be a stand-alone hybrid power system. Amongst the factors that influence the system design capacity is the design peak load. Managing the load to reduce the peak load will eventually reduce the system capacity. The paper first presents demand-side management strategy of typical 3 – bedroom residential facility in Tema, Ghana. It further presents two system designs, one with demand-side management strategy and the other without DSM strategy.

Nomenclature

P_{Load}	Daily consumption in KW
P_{t1}	Load at time t1 in KW
P_{t2}	Load at time t2 in KW
t_1	First hour of the day
t_2	Second hour of the day
T_{12}	Time difference between t1 and t2 in hour

2. State-of–the–Art – a Brief Overview

Several studies relating the use of Hybrid Power System as an alternative solution for the conventional energy are presented in many literatures. Yang, et.al. [1], proposed methodology for sizing an optimum hybrid solar-wind system with battery bank. Genetic algorithm was used to estimate the optimum system configuration that could achieve the clients required loss of power supply probability with minimum annualized cost of systems.

Saeid et. al. [2] proposed the use of imperialist competitive algorithm in designing a stand-alone hybrid solar-wind-diesel power generation. The objective of the study was to minimize the net study present cost of hybrid system for life-time of project by considering reliable supply of load and loss of power probability index. The study compared the use of imperialist competitive algorithm, to the particle swarm optimization and ant colony optimization. The investigation revealed that the imperialist competitive algorithm is considered to be faster and more accurate than others and has more certain design in comparison to PSO and ACO algorithms. Since the study considers load management strategy to reduce peak demand of a specific load profile, it is essential to review research reports on demand-side management. DSM application improves grid flexibility and supports intermittent renewable energy utilization. It is widely used in micro grid networks. Little research work is done on integrating demand-side management in stand-alone hybrid power systems for residential facilities.

Ben Christopher [3], proposed control strategies for balancing the dynamic demand in a grid connected hybrid system. His study aimed to enhance the greatest use of solar and wind power by maintaining uninterrupted power to the customers, guided by system operating cycle. In this strategy, sound energy storage unit was used to control the power mismatch. The reliable power supply in the whole system is opted through exact technical control using energy conservation and valley filling methods.