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Cost and size optimization of solar photovoltaic and fuel cell based integrated energy system for un-electrified village

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ABSTRACT

The main aim of designing any energy system is to ensure that maximum energy is generated with minimum capital investment. Also, the cost associated with generating electricity from the system should also be minimum. In order to achieve these aims, integrated energy systems are to be designed and optimized in such a way that the best possible sizing of the components is obtained upon cost and other constraints. This paper gives the details of a solar photovoltaic (PV) and proton exchange membrane (PEM) fuel cell based integrated energy system (IES) proposed in an Indian village. The estimation of the expected load profile of the village and optimization of the system is done using hybrid optimization model for electrical renewable (HOMER) software. The framework adopted for the optimization, the results obtained after simulation and their analysis have been included in detail.

1. Introduction

Renewable resources like solar energy or wind energy are essentially unpredictable and uncertain as far as their availability round the clock is concerned [1]. Owing to their intermittent nature, the reliability and consistency of an energy system involving a single renewable energy source are very less. Also, this would call for elaborate energy storage to ensure uninterrupted supply of power, especially when a stand-alone installation is considered [2]. To address all these issues and to utilize the various renewable resources efficiently, two or more individual renewable energy sources can be combined together to function as an energy generation system. Such a system is called integrated energy systems (IES) and can be deployed to meet the energy demand of rural areas, off-grid communities, and remote applications. The IES under consideration consists of two energy generating units i.e. a solar photovoltaic (PV) system and proton exchange membrane (PEM) fuel cell system. A battery bank is used as a backup source [3,4]. A power conditioning stage consisting of converters and inverters handle the power flow from the sources to the load and the power flow to and from the battery. The simplified block diagram showing the individual components of the proposed IES has been given in Fig. 1.

2. Identification of site

The selected site for the research work is Jhiriya Kheda, which is a small unelectrified village located in Huzur Tahsil of Bhopal district in Madhya Pradesh, India. This site is 23 km from Bhopal, towards Bhopal-Vidisha road (Figs. 2 and 3).

3. Estimation of load profile

For the identified un-electrified village, an integrated energy system based on solar PV and PEM fuel cell have been proposed for reliable power supply. Based on the population of the village and their energy requirement, the load profile is estimated [6]. The energy requirements in such areas can be classified as domestic, agricultural, commercial and street lighting. For domestic purposes, electricity is required for appliances like tube light, compact fluorescent lamp (CFL), fan, radio, television (TV) etc. For agricultural purposes, electricity is mainly required for water pumping system. Commercial applications include CFL, fans, flour mill etc. The street light load is considered to be CFL based.

The energy requirements in the village vary from season to season. Therefore, in this study, yearly data has been divided into three seasons, depending on the demand and energy consumption pattern: winter season (October to January), summer season (February to May), rainy season (June to September). The number of electrical appliances proposed for the electrification of the Jhiriya Kheda village is shown in Table 1.

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Nomenclature

HOMER	Hybrid optimization model for electrical renewable
PV	Photovoltaic
PEM	Proton exchange membrane
CFL	Compact fluorescent lamp
TV	Television
NREL	National renewable energy laboratory
LCC	Life cycle cost
C_{IES}	Cost of the integrated energy system
C_{SPV}	Solar photovoltaic system cost
C_{PEMFC}	PEM fuel cell cost
C_{BAT}	Battery cost
C_{ELECTO}	Electrolyzer cost
C_{PCON}	Power converter cost
C_{HTANK}	Hydrogen tank cost
N_k	Number/Size of integrated energy system component
$CapC_k$	Capital cost integrated energy system component
$RepC_k$	Replacement cost integrated energy system component
NR_k	Number of replacements
OMC_k	Operation and maintenance cost integrated energy system component
DoD	Depth of discharge
NPC	Net present cost
COE	Cost of energy

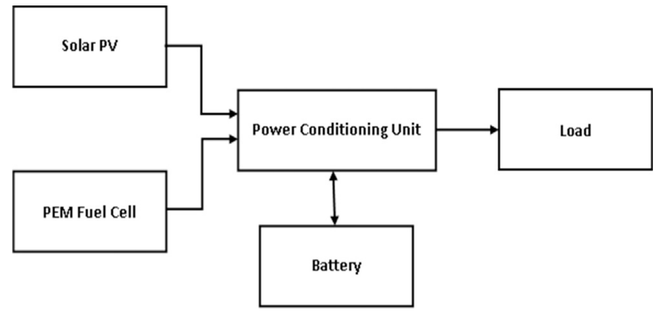

Fig. 1. Block diagram of solar PV- PEM fuel cell based integrated energy system.

Based on the data given in Table 1 and the pattern of the usage and duration depending upon the seasonal variations, the load profile for summer, rainy and winter seasons have been calculated and shown in Fig. 4. From the load profile, it can be depicted that the load demand in the morning and late-night hours is relatively less. The load demand is relatively high during the day time due to the operation of the water pump, flour mill, and domestic load. In the winter season, the demand is less and in the summer season, it is more. Considering component-wise use, it is found that in the winter season, the use of ceiling fan is minimum, but in summer almost all the appliances are put to maximum use and hence displays the highest load demand. The peak requirements of the load dictate the system size and hence the operation of both the water pumps and flour mills are staggered so that, the peak load of the system is 4.7 kW.

4. Solar radiation data and temperature

Solar radiation data for the Jhiriya Kheda village has been obtained from NASA's surface solar energy data set, as per the geographical coordinates of the site. The scaled annual average radiation for this village is 5.264 kWh/m^2/day [5]. The monthly clearness index average is 0.570 and the monthly average radiation is shown in Fig. 5(a). The monthly average ambient temperature for the selected site is shown in Fig. 5(b). and the overall average ambient temperature is 31.9 °C.

5. Optimization of IES using HOMER

The optimal sizing of the components of the proposed integrated energy system has been done using HOMER software (version 2.81). The name HOMER is an abbreviation of a hybrid optimization model for electrical renewable and it is developed by U.S. national renewable energy laboratory (NREL) [1,2].

Simulation, optimization, and sensitivity evaluation are the ternary primary actions run by HOMER. In the simulation process, exceptional energy regulation configurations because every tinkler regarding the 12 months is generated along with their empiric chance or life cycle cost (LCC). In the optimization progression, Optimization software chooses one provision define abroad over all outlines generated within the simulation process so satisfies entire pragmatic constraints and has the lowest LCC. In the sensitivity analysis, multiple optimizations are performed by optimization software on the selected configuration with a range of uncertain input parameters that are assumed to affect the model inputs with time [7].

The objective of this study is to propose an integrated energy generation system which should be optimally designed in terms of economics and consistency events endangered to corporeal and working strategies [20–24]. The cost of the integrated energy system (C_{IES}) becomes the sum of the cost of its individual components i.e. solar photovoltaic system cost (C_{SPV}), PEM fuel cell cost (C_{PEMFC}), battery cost (C_{BAT}), electrolyzer cost (C_{ELECTO}), power converter cost (C_{PCON}) and hydrogen tank cost (C_{HTANK}).

$$C_{IES} = C_{SPV} + C_{PEMFC} + C_{BAT} + C_{ELECTO} + C_{PCON} + C_{HTANK} \quad (1)$$

Cost of each component of integrated energy system,

$$C_k = N_k \times [CapC_k + (RepC_k \times NR_k) + OMC_k] \quad (2)$$

where,

k =Component of the integrated energy system (Solar PV/PEM fuel cell/Power converter/Electrolyzer/Hydrogen tank

N_k = Number/Size of integrated energy system component

$CapC_k$ = . Capital cost integrated energy system component

$RepC_k$ =Replacement cost integrated energy system component

NR_k =Number of replacements

OMC_k =Operation and maintenance cost integrated energy system component

The input information provided to includes electrical loads (one year of load data), renewable energy sources, component technical details, costs, constraints, controls etc. Based on this input information and above-said equations, the designs an optimal energy system configuration to serve the desired loads [8]. This optimization model simulates the process of a system by creation energy equilibrium calculations for each of the 8760 h in a year. For an apiece hour, associates the load demand to the energy supplied by the system in that hour, and calculates the flow of energy to and from each component of the system. Optimization software performs these energy balance calculations and system cost calculations for each system configuration considered [9,10]. Simulation results enlist all the possible system sizes, sorted by net present cost (NPC) [11].