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Multi-criteria decision analysis for renewable energy integration: A southern India focus

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A B S T R A C T

In recent days, sustainability is considered as an important mechanism due to contemporary increase in demands and worldwide limited resources. This paper presents the possibility of integrating a renewable energy system with an existing grid to meet electrical energy demand of institutional buildings located in Indian state of Tamil Nadu. Currently, the Tamil Nadu state electric-grid power is not surplus and experiencing 40% short fall in generation. In this present paper a modern approach for the optimum planning of electric power system (EPS) is proposed based on the Analytic Hierarchy Process (AHP). An intertwined analysis on energy management and techno-economic optimization of grid connected renewable energy system is proposed. The prospects of different fixed tilt solar panels and peak load shifting based energy management are performed through HOMER Energy® simulation. The AHP multi-criteria decision analysis reveals that annual optimum tilt grid connected photovoltaic system is the optimum configuration for study location. The effectiveness of the AHP approach is evaluated with best-worst method and stochastic multi-criteria acceptability analysis for prioritizing the renewable energy system options in order to select best EPS. In addition, the optimum configuration is implemented in the institutional buildings and performance is analyzed under varying climatic conditions.

1. Introduction

Electrical energy has been universally accepted as one of the most essential aspects for human development and economic growth. The availability of uninterrupted power supply is important for a fast development of a country. There are many barriers in unleashing the full potential of India's power sector. Hence, the country needs electricity to improve the growth of every organization, be it large scale or small scale, manufacturing, service, education and healthcare sector. Due to increased cost of imported coal, Coal India Ltd (CIL) has restricted the supply of coal around 65% of actual coal requirement for coal based thermal plants [1]. This has led to an increase in power generation costs. To overcome this energy crisis, the Indian government is also laying a lot of emphasis on demand side management (DSM) and energy efficiency. The power generation sector is required to take action for energy crises. Due to the global concern over carbon emissions from conventional power generation sources, many countries are pushing for the integration of renewable energy (RE) sources into the power generation mix. The solar photovoltaic (PV), wind and their combinations in hybrid system is deemed to be the perfect solution. As they are available at free of cost, zero pollution as well as their modularity [2,3]. Basically two approaches namely, hybrid renewable energy systems (HRES) and integrated renewable energy systems (IRES) are used to harness available renewable sources [4].

Over the years, research has been focused on different technological approach to meet the ever-increasing demand for high quality and reliable power supply [5]. The efficient utilization of locally available renewable sources, including techno-economic feasibility and optimum planning of the system with lowest cost of energy (COE) is an important criterion for the location of interest [6,7]. Currently, Tamil Nadu state electric-grid power is not surplus and experiencing 40% short fall in generation. Thus, the available grid power to these remote areas has only 10 h a day [8].

Alireza et al. [9] analyzed the PV, wind and diesel generators in a standalone HRES for rural electrification of three villages and to decide on the most suitable one from the economic perspectives. Tawil et al. [10] analyzed the sizing and rough optimization of hybrid combination of wind, tidal with backup facility of pumped hydroelectric storage and diesel generators in a standalone system

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for marine context. Hassan et al. [11] evaluated the performance of different tracking system in grid-connected photo-voltaic (GCPV) configuration in Makkah location in Saudi Arabia using HOMER simulation. The study reported that PV system with two axis tracker have 34% higher than fixed tilt system. In terms of economic point of view, the tracking systems needs sophisticated mechanical parts and increased system cost of 400% more than fixed tilt system. The study not concentrated on annual optimum tilted PV system. The hybrid solar-wind system is superior when compared to single solar/wind systems. Munuswamy et al. [12] conducted a cost comparison analysis of fuel-cell based systems and grid supply systems for rural healthcare centre (RHC) in India using HOMER simulations. The results reported that the grid electric supply is more cost-effective than standalone system if it is beyond 44 km distance. All these case studies in the literature has incorporated only the basic rural community-needs but not considered the productive energy usage.

In practice, the actual performance of PV systems is affected by various parameters such as daytime ambient temperature, humidity and solar irradiation [13]. Similarly, PV performance depends on the technology used [14], geographical location of the study [15], different tilt angle of PV panels [16] and dust accumulation on the PV panels [17]. These studies have not considered the temperature co-efficient on PV panel's performance in the HOMER simulation. In this present study, the temperature co-efficient of $-0.5\%/^{\circ}C$ is considered in the entire study. Chauhan and Saini [18] considered techno-economic analysis using energy management for IRES to fulfill the energy demand of a group of villages in Indian state of Uttarakhand for the complete year rather than considering the seasonal changes.

Almost all the case studies carried out in the literature focused more on the electrification of remote villages, rural areas and Islands using locally available energy sources for standalone systems. There is no comprehensive work on Analytic Hierarchy Process (AHP) evaluation for decision making in upgrading the existing electric power system (EPS). The AHP evaluation considers the technical, economical and environmental parameters. Clustering the institutional hostel buildings for HRES configuration has not been reported so far by the researchers. The peak load shifting based DSM strategy has a major gap in previous literature. The HOMER simulation allows only single objective for minimizing total net-present cost (TNPC) and cannot be formulated for multi-objective problem.

Considering all these circumstances, the present paper is focused on the multi-criteria decision analysis for renewable energy integration in the study area which is located in the Indian state of Tamil Nadu. Further, techno-economic optimization is analyzed with and without DSM strategy for different seasonal changes in the study area in order to seek the best configuration through AHP approach. This study aids the results of AHP approach is validated with other multi-criteria decision making approaches like best-worst method and stochastic multi-criteria acceptability analysis. The suggested GCPV system is implemented in hostel buildings in the study area through net-metering (FiT) approach and the performance is analyzed for three days under varying climatic conditions.

2. Methodology adopted for case study investigation

Methodology used in the present work includes survey about study area on resource and demand assessment of various energy consumption sectors. A detailed load pattern is made; a load shifting DSM approach has been suggested for peak load reduction and to minimize the system size and electricity cost. The annual optimum tilt (AOT) angle for PV system is determined for study location. With the application of hybrid optimization tool, the calculated AOT angle for PV panels, meteorological and demand data of case study is fed in to the simulation. The simulation is modeled for both grid connected systems with and without DSM strategy. A modified approach for the optimum planning and decision making AHP in the upgrade of existing EPS is proposed. The proposed system has been analyzed in three days under clear sunny day, partially-clear day and cloudy day.

2.1. Analytic hierarchy process (multi-criteria decision analysis)

The objective of AHP decision making approach is to assess and priorities the list of alternative solutions which satisfies the objective of the complex decision problem [19–21]. The key steps concerned in the present case study are:

Step 1 Structuring the decision problem

In the first step, the complex problem is decomposed and represented as a hierarchical structure, shown in Fig. 1. The lowest level surrounded with a set of decision alternatives. In this stage, the objective function and its associated constraints are developed in order to identify the best EPS configuration for hostel buildings. The present study considered with two scenarios, which are peak load shift DSM and different tilted PV systems. In the combination the present study holds five different configurations with an existing utility grid only system.

Step 2 Evaluating the decision criteria

At the next intermediate level, the decision criteria subdivided into a cluster of sub-criteria. The knowledge by past experience, a decision maker judges the relative value of the element that belongs to the pair-wise fashion. This comparison utilizes the Saaty scale for their order of importance [22,23]. The Saaty scale table is given in supplementary document as Annexure 1. This step produces *n x n* judgment matrix [A], which holds the largest real Eigen value (λ_{max}) and corresponding normalized Eigen vector (w_i), said to be local-priority vector.

Step 3 Decision alternatives

During the evaluation, the consistency index (C_i) is utilized to check the consistency of each judgment matrix, given in Eqs. (1)–(3). The consistency ratio (C_R) is the measure of consistency, calculated by Eq. (4). According to the size of the matrix, the random consistency index (R_i) is varies. These details are given in supplementary document as Annexure 2. At the end of this step, if the consistency ratio (C_R) is less than 0.1, then the judgment matrix is said to be consistent. Otherwise, the decision makers have to perform the same practice to give a consistent level.

$$\begin{bmatrix} 1 & a_{12} & a_{13} & \dots & a_{1n} \\ 1/a_{12} & 1 & a_{23} & \dots & a_{2n} \\ 1/a_{13} & 1/a_{23} & 1 & \dots & a_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & 1/a_{3n} & \dots & 1 \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \dots \\ w_n \end{bmatrix} = \lambda \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ \dots \\ r_n \end{bmatrix} \tag{1}$$

$$w_i = \left(\frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \right) \quad i = 1, 2, 3, \dots n. \tag{2}$$