Electrical Power and Energy Systems 96 (2018) 261–273

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Optimal planning of renewable energy resource for a residential house considering economic and reliability criteria

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ARTICLE INFO

Keywords:
Techno-economic analysis
System reliability
Hybrid renewable energy system
Optimal planning
Reserve system
HOMER

ABSTRACT

In this century, problems such as the scarcity of fossil fuel resources and related environmental contamination have led to the emergence of new energy systems based on renewable energy resources. In this paper, an optimal planning approach is proposed based on 100% renewable energy system (RES) for a residential house. In respect to renewable resources potential in the site location and electrical demand, the best combination of resources is chosen based on minimum energy supply cost and maximum reliability. Furthermore, different scenarios are suggested by considering different levels of capacity shortage (CSH) and unmet electricity load (UEL) percentage. As a case study, the real electricity consumption data for a single family household is considered in Hesarak, Tehran, Iran. The final optimal solution for this 100% RES with the objective function of cost minimization and reliability constraint include 4 kW PV, 2 kW wind turbine, 4 kW converter and 6 battery strings. This scenario with CSH of 1.1% and UEL of 0.9% has the net present cost of 20,527 $ that while having low cost, the reliability of this system is also good compared to other scenarios.

1. Introduction

To meet the growing demand for energy with a cost-effective method with respect to the environmental issues and social priorities, there is a need for a sustainable energy system [1]. Such a system provides the possibility to move toward sustainable development and reaching all people of the world to effective, accessible, clean and safe energy. Today, about 1.3 billion people (mainly in developing countries and rural areas) do not have access to electrical energy [2]. This is due to various reasons for instance lack of resources, inadequate infrastructures and long distance from the utility grid. In order to solve these problems and increasing access to the electricity in remote locations, there are two solutions. The first solution is the increasing of the electricity production by conventional methods and developing distribution and transmission networks to remote areas. And the second solution is the implementation of on-site generation systems. The first option because of many problems such as high investment costs, low efficiency of energy conversion, high losses in transmission and distribution lines and especially a lot of environmental pollutions is not a good choice for power supply of future energy systems [3]. Distributed generation (DG) sources and in particular renewable energy resources (RER) in many parts of the world have become a viable and desirable option to replace with traditional systems.

Each of RER has merits and demerits. Despite the fact that RER provides many technical, economic and environmental advantages, their intermittent nature leads to uncertainty in the prediction of power generation and resulting in decreased reliability of the system [4]. These weaknesses can be overcome with the integration of RER with each other or with conventional power sources in the form of hybrid renewable energy systems (HRES). Hybrid systems for power supply have lower costs, lower storage capacity, higher efficiency and reliability than systems which use only one source for power supply [5].

Large-scale renewable energy systems such as solar and wind farms mostly are connected to the grid and are used to supply the power of urban areas. In these systems, the main electricity grid is used as a backup system in the case of power deficit. Also in the case of excess power production, it can be sold to the main grid. In addition to the mixing of energy sources, the use of equipment such as diesel generators and energy storage systems (ESS) as a backup system is conventional and leads to higher system reliability in remote areas [6]. The use of this storage systems provides the possibility for 100% renewable power generation in remote areas [7]. At the situation that 100% demand must be met by RER, the most important issue in the implementing of HRES is optimal planning of these systems [8]. This planning process requires a detailed assessment of the potential of existing resources, related environmental, economic and technical

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http://dx.doi.org/10.1016/j.ijepes.2017.10.017
Received 31 March 2017; Received in revised form 9 September 2017; Accepted 13 October 2017
0142-0615/

Nomenclature

$L_{res,AC}$	required operating reserve on the AC bus
$L_{res,DC}$	required operating reserve on the DC bus
r_l	input operating reserve as a percent of hourly load
$L_{l.AC}$	hourly average AC primary load
$L_{l.DC}$	hourly average DC primary load
r_{pl}	input operating reserve as a percent of annual peak load
$L_{pl.AC}$	highest hourly average AC primary load experienced by the system during the year
$L_{pl.DC}$	highest hourly average DC primary load experienced by the system during the year
r_{wind}	input operating reserve as a percent of wind power output
$P_{wind,AC}$	hourly average AC wind power output
$P_{wind,DC}$	hourly average DC wind power output

constraints as well as the reliability of the system. So far, several works have been done in the literature for optimal planning and management of HRES.

A review of the literature in the field of optimal planning methods and tools, control and operational optimizing of HRES in remote areas has been done by Bernal-Agustín and Dufo-López [9]. Kaundinya et al. [10], compared and evaluated the various aspects of decentralized power supply systems in both grid-connected and off-grid modes. Different planning and evaluation methods of off-grid power supply systems can also be found in Ref. [11]. Erdinc and Uzunoglu [12], reviewed various methods such as the commercial software or various optimization methods such as heuristic methods in the field of the optimal planning of HRES. Evaluation of HRES in remote areas focusing on PV-based systems in terms of optimal sizing methods, component modeling, control and optimization of operational procedures have been studied by Bajpai and Dash [13]. Mahesh and Sandhu [14], reviewed the PV/wind/battery energy systems in terms of optimal sizing, the design of the converter, component modeling and operational optimization in both grid-connected and off-grid modes. Reviews on the HRES usage in the micro-grids in various aspects of the planning, optimization tools and methods taking into account the role of different ESS studies in terms of optimal planning and management can be found in literatures [15,16]. Also, a review of the main features of rural and remote areas energy systems in terms of energy consumption, different methods of planning, case studies, techno-economical, policy and sustainability evaluation can be found in Ref. [2]. Also examples of reginal HRES assessment can be found in [17,18].

Sinha and Chandel [5], studied simulation tools for planning, optimization, and evaluation of HRES. The results of their study show that HOMER due to the possibility of sensitivity analysis on the input data, evaluating the technical, economic, environmental and reliability criteria as well as fast and easy evaluation of a large number of system components, has the most applications among simulation software. Bahramara et al. [19], reviewed and classified the different research carried out by HOMER in the field of optimal planning and management of HRES. Their study results show that most investigation by using HOMER have been focused on off-grid systems and economic and environmental criteria. Also, it shows that there are a few numbers of studies, which focused on 100% RES and technical, economic, environmental and reliability indices simultaneously.

In studies related to the HRES planning, paying attention to the trade-off between economic and reliability indicators is the most important task [20]. The use of backup systems such as diesel generators or ESS can lead to higher reliability of the system. In addition, designing a proper reserve system, especially for 100% RES, can lead to higher system reliability while resulting in lower costs and optimal use of the resources. On the other hand, since the reserve system is mostly intended as a percent of demand or production of resources in the planning process, the impact of the reserve system should be considered in optimization results. Despite the importance of this subject, so far limited works have paid attention to the impact of reliability indices and reserve system on the planning and the optimization process.

Adding wind turbines to an energy system based on diesel power plants in a village has been studied in Ref. [21]. Authors have intended the reserve system as a percent of the hourly load and hourly wind turbine output power, however, its effect on system performance has not been discussed. They also concluded that due to a large amount of demand and high contribution of diesel generators in power generation changes the maximum annual capacity shortage (MACS) has no impact on the optimum combination of systems elements. Hrayshat [22], has performed the planning of a power supply system based on PV, diesel generators, and batteries as an off-grid system for a house in a remote area. Sensitivity analysis has been carried out in different levels of solar radiation, diesel prices, reserve system on PV energy output, MACS and the minimum share of renewable energy. But they did not report any conclusion about MACS and operational reserve in the sensitivity analysis. A similar work by adding a wind turbine to the previous combination has been implemented in Ref. [23]. Reserve system has been considered as a percent of the hourly load and power output of the wind turbine. However, the impacts of reserve system and different amounts of MACS on the optimal combination of systems and optimal performance results, have not been discussed. Türkay and Telli [24], designed and evaluated an HRES includes PV, wind turbine along with the using of the fuel cell and hydrogen storage tank. They examined the impact of various system components costs and the amounts of MACS on the off-grid system performance. Hafez and Bhattacharya [25], evaluated the various combination of RER, diesel generators and grid for providing the power of a micro-grid. They studied the effects of diesel prices, distance from the main grid and unmet load on the optimal performance of the system. But the effects of the reserve system and unmet load on the optimal planning process and performance of the proposed scheme have not been investigated. Rawat and Chandel [26], investigated an HRES based on PV and wind turbine installed on an institutional building and other optimal options were offered to replace with the existing system. Various features of the optimal system in the presence of different amounts of the MACS and their effects on the net present costs and excess electricity generation were studied. Although the effects of reserve system on the optimal performance and reliability of the system has not been investigated.

In this paper, an optimal planning approach is proposed based on 100% RES for a residential house by HOMER software. The best combination of resources is chosen with respect to RER potential in the study area and electrical load demand. The home is off-grid and RER should provide all of the power demand. The results for different modes of operating reserve and unmet electric load are discussed and various suggestions are classified based on cost and reliability requirements. Eventually, the optimum combination of an HRES is suggested based on the minimum net present cost of the system. But unlike previous studies, the effect of relevant reserve systems has been intended in this process and the optimum values for the capacity shortage and unmet load has been determined. As a case study, a real electricity consumption data for a single family household has been considered in Hesarak, Tehran, Iran.

The rest of this paper is categorized as follows: In Section 2, methods, basic definitions and mathematical relationships are explained. Section 3 contains a description of the system, its essential assumptions and study parameters. In Section 4, simulation results are described and discussed and finally in section 5 conclusion of the study is illustrated.