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Different methods for controlling the power flow in RERs based power system

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ABSTRACT

Randomness and intermittency are features that characterize renewable energy sources (RERs). Intermittency usually includes both predictable and unpredictable variations. The many drawbacks of intermittency of renewable sources can be overcome by considering some special design considerations. Integrating more than one renewable energy source and including backup sources and storage systems are among the few measures to overcome these drawbacks. These additional design considerations usually increase the overall cost of the renewable system. Furthermore, the presence of more than one energy supply/storage system requires the control of energy flow among the various sources. Therefore, optimizing the size of the components and adopting an energy management strategy (EMS) are essential to decreasing the cost of the system and limiting its negative effects. The energy management strategy is commonly integrated with optimization to ensure the continuity of load supply and to decrease the cost of energy production. Therefore, energy management is a term that collects all the systematic procedures to control and minimize the quantity and the cost of energy used to provide a certain application with its requirements. The energy management strategy usually depends on the type of energy system and its components. Various approaches and techniques have been used to develop a successful energy management strategy. In this paper, a comprehensive review of the approaches proposed and used by authors of many papers is conducted. These approaches include both the standalone hybrid renewable energy systems and the grid-connected hybrid renewable systems. More attention is focused on popularly used techniques to address the features of each system. The selected papers in this review cover the various configurations of the hybrid renewable energy systems for electric power generation only.

Keywords: *Energy management, Renewable energy, Standalone hybrid systems, Grid connected hybrid systems*

I. INTRODUCTION

The past few decades have shown an accelerated global effort in the development of renewable energy sources and the associated technologies that serve them as energy is now recognized as a strategic sector. Governments all over the world have adopted new regulations and policies encouraging the employment of renewable energy technologies. These efforts include promoting renewable energy technologies, improving the efficiency of energy use, and establishing energy conservation plans alongside their related legislative actions [1–5]. The development has covered various renewable energy sources, backup sources, and storage systems. Combining them with conventional sources to supply isolated loads or mini-grids located far from the main grid is the solution to ensure the continuity of supply because of the intermittent nature of renewable sources. An energy system that uses more than one energy source is called a hybrid system. If renewable energy sources are chosen appropriately for each geological location, the need for fossil fuel will be considerably reduced, thus leading to an increase in power supply sustainability, especially in countries that depend on external sources to supply different types of loads [6–9]. Integrating conventional sources with renewable sources can improve the reliability of the electrical power system, especially in difficult environmental conditions, and also reduce the limitations of renewable sources and open markets for investment that otherwise may not exist [10,11].

Nowadays, a significant amount of research is being conducted on hybrid systems and their applications. Different configurations have been analyzed in the literature. An overview of the literature on rural electrification also proves that renewable energy sources are one of the most effective solutions to provide for rural areas located far from the electrical power grid, where delivering high quality and reliable electricity for different applications in these remote areas has also been proven possible [12–14].

Whenever more than one energy source is used to supply a certain load, the need for an efficient energy management strategy (EMS) arises. This strategy guides the flow of energy through the supply system. This need is not only essential for a standalone hybrid system but also for hybrid renewable energy systems that are connected to the main grid. The many roles of this strategy in standalone systems are to ensure continuity of load supply in all conditions, to ensure the maximum utilization of renewable sources, to be integrated with the optimization problem to minimize the cost of energy (COE) production, to protect components from being damaged due to overloading, and to increase stability in the power system. In addition, the role of the energy management strategy in grid-connected systems includes the control of energy flow to and from the grid and metering purposes. The control of energy flow to shift the peak in the load curve or to utilize the periods of low cost tariff is also among these objectives. To conduct any adopted energy management strategy, a central controller should be selected, installed, and programmed to control the system according to an optimized strategy. This controller may be integrated with a monitoring and supervision environment like SCADA.

In the literature, one can find a number of comprehensive review papers on renewable energy systems. In their review paper, Chauhan and Saini [15] presented a comprehensive review on standalone renewable energy systems. The review topics were hybrid system configurations, sizing methodologies, storage options, and control strategies. Three types of control for the flow of energy management were addressed in this review: the centralized, the distributed, and the hybrid of centralized and distributed controls (Fig. 1). Similarly, Bajpai and Dash [16] reviewed the past decade′s research on standalone hybrid renewable energy systems. The reviewed topics were modeling, system sizing, energy management, and optimization. This study reviewed research on energy flow management that analyzed standalone renewable hybrid energy systems. Gu et al. [17] conducted a review on planning, modeling, and energy flow management of combined cooling, heating, and power microgrids. Energy management in terms of control strategies, cogeneration decoupling, and emission reduction was briefly reviewed in their paper. Nehrir et al. [18] reviewed hybrid renewable (photovoltaic (PV), wind, hydro, biomass, and tidal)/alternative energy systems (microturbine and fuel cells). Their paper highlighted a number of important issues, such as system configurations, sizing, and design of hybrid systems and energy management. Similar to what was presented in [15], three types of control for flow of energy management were addressed in this paper: the centralized, the distributed, and the hybrid of centralized and distributed controls. Shivarama Krishna and Sathish [19] presented an overview of various distributed generation technologies and reviewed sizing, energy flow management, and construction of hybrid systems. The feasibility of various types of controllers was also discussed in this paper. Meng et al. [20] summarized the control objectives of supervisory controllers and the adopted energy management strategies for microgrids. The concept of control layers was introduced and their control objectives were classified.

The previous paragraph presented a number of review papers that addressed and reviewed energy management strategies adopted and used for special cases of hybrid systems. Moreover, the literature includes many papers that conducted reviews for various aspects related to hybrid renewable energy systems [21–26].

In the present paper, an extensive review of approaches used by many authors in their papers on adopting energy management strategies is conducted. These strategies include standalone hybrid renewable energy systems and grid-connected hybrid renewable systems as presented in Fig. 2. This review paper aims is to summarize the various strategies adopted for energy management in renewable hybrid systems. The review is conducted for different configurations of standalone and grid-connected hybrid systems to ensure and finally conclude that the energy management strategy that works well and can be adopted for certain renewable energy system may not be the best for other configurations. In some of the reviewed papers, more than one energy management strategy was tested to select the most appropriate one. These cases are addressed in the present study. In Section 2, articles adopting certain energy management strategies in their proposed standalone hybrid renewable energy systems are reviewed. In Section 3, articles adopting energy management strategies for grid-connected hybrid renewable energy systems are reviewed. In Section 4, energy management strategies used in smart grids, including renewable energy sources, are reviewed. In Section 5, articles proposing the use of fuzzy logic to implement the control functions to manage the energy flow in hybrid systems are reviewed

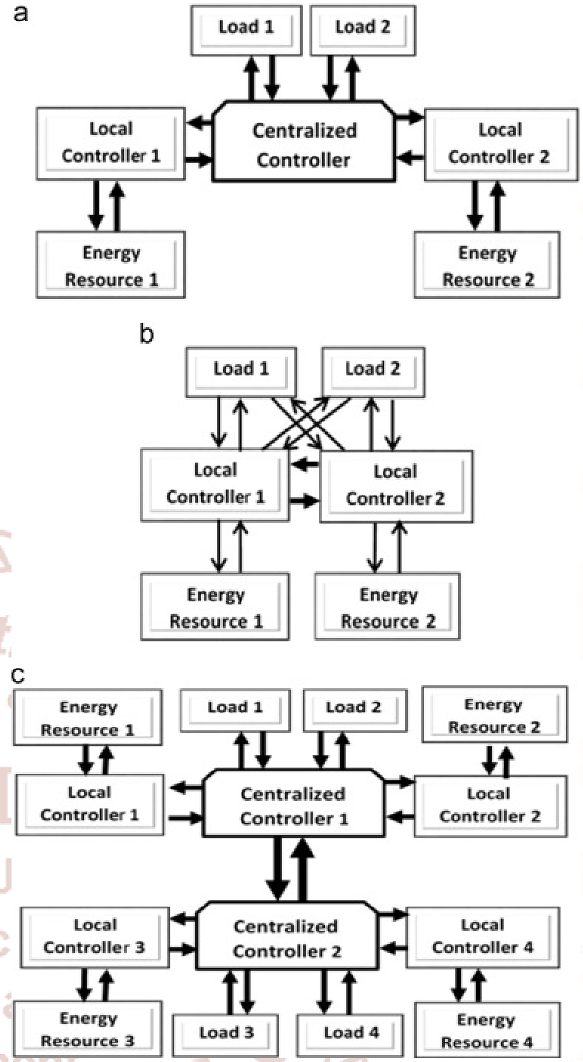

Fig. 1: Energy management control architecture (a) centralized, (b) distributed and (c) hybrid.

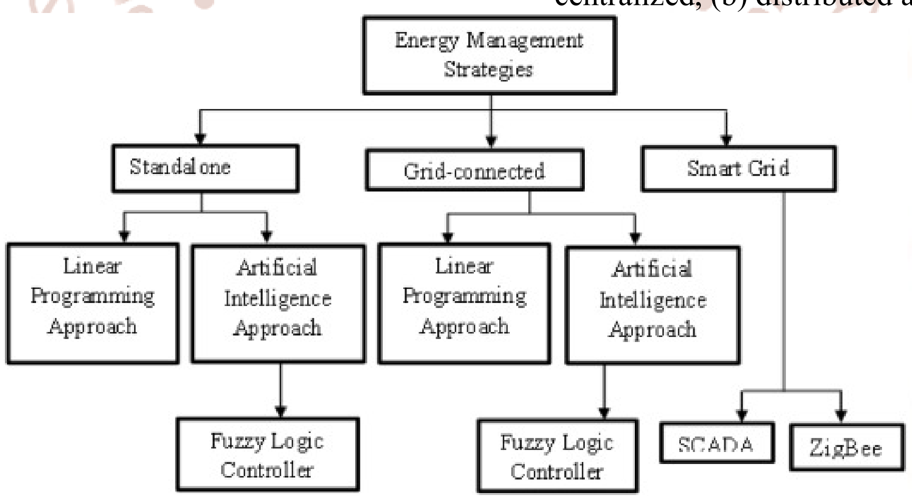

Fig. 2: Classifications of energy management methods

II. Energy management strategies in standalone hybrid renewable energy systems

This section reviews the various energy management approaches used in standalone hybrid renewable energy systems. Some of the reviewed studies in this section used linear programming to implement energy management, and others used intelligent techniques. The following two sections present the reviewed studies that used these two approaches to implement energy management for standalone hybrid systems, respectively.Dursun and Kilic [27] examined the performance of three developed power management strategies for a standalone hybrid power system consisting of PV/wind/PEMFC, where the PV and wind source serve as the main supply and the PEMFC serves as a backup source. The strategies aimed to increase the operation of the fuel cell (FC) membrane and to ensure the continuous flow of energy in the hybrid system. In this study, the authors evaluated battery efficiency using the developed power management strategies in a Matlab/Simulink control algorithm in consideration of the battery state-of-charge (SOC) and the excess power from the main source (wind and PV) after meeting the load demand. In the first strategy, whenever the battery SOC is within the specified limit and excess power from the main source is available, the battery discharges and the excess power is made to run the electrolyzer. However, when the battery SOC is less than the minimum and no excess power from the main source is available, the FC operates to supply the load and charge the battery. In the second strategy, the developed algorithm indicates that when the battery's SOC is within the specified limit and no excess power from the main source is available, the FC is disabled and the battery discharges; however, when the battery SOC is less, the battery charges. The third strategy specifies that when the battery SOC is within the specified limit and excess power is available from the main source, the excess power is made to operate the electrolyzer and charge the battery. However, when the battery's SOC decreases below the limit or when excess power from the main source is available, the FC operates to supply the load and charge the battery.

Table 1: Summary of EMS/control architectures in hybrid renewable energy systems

Controller architecture	Advantages	Disadvantages
Centralized control	• The architecture is best suited for multi-objective energy management strategies in hybrid systems. • Can attain global optimization based on the provided information	• Heavy computation time. • Subject to single-point failure
Distributed controller	• Best solved with artificial intelligent algorithms. • Reduced computation time and single-point failure	• Complex communication within the local controllers
Hybrid centralized and distributed controller	• The optimization is distributed between the central controller and the distributed controllers. • Less computation burden on both centralized and local controllers, • No single point failure problem	

III. Energy management by fuzzy logic controllers

In recent years, many studies have adopted fuzzy logic controllers to perform energy management in standalone or grid-connected hybrid renewable energy systems. Fuzzy logic can effectively manage hybrid energy systems, especially if multi-controls and functions are performed on them. The difficulties in developing and using a precise model for each of the energy sources or storage devices, in predicting the sun radiation or the wind velocity variations, and in predicting the load consumption or the status of the electrical grid make fuzzy logic a well-adapted tool to perform energy management and associated control tasks. The easy adaptability to complex systems, the provision of computational efficiency and robustness in modeling uncertainties, the lack of need for historical data as required by other intelligent controllers (e.g., artificial neural network), and easy drawing of a definite conclusion from vague or imprecise information are additional features of fuzzy logic controllers.

IV. Findings and Disscussion

This review paper provides an intensive review of the strategies used to implement energy management in standalone hybrid renewable energy systems and grid-connected hybrid renewable systems. Special attention has been given to the energy management strategies used in smart grids. The control of energy flow based on fuzzy logic systems have also been addressed in detail.

Adopting a certain energy management strategy is essential to control the flow of energy among the various components (energy sources, storage devices, and loads) comprising the hybrid energy system. One or more than one of the following objectives can be obtained by following a certain energy management strategy:

1. Achieving a high level of system reliability and decreased percentage of occurrence of electricity interruptions.
2. Achieving high operational efficiency.
3. Reducing the cost of energy generated.
4. Increasing the lifetime of the components comprising the hybrid system.

The controller that should be selected to conduct any adopted energy management strategy can be centralized in its functions (Fig. 1a), or the functions are distributed to more than one controller (Fig. 1b). In the distributed arrangement, each source has its own local controller with simple computation requirements. Relatively complex communication capabilities should be available among the local controllers, whereas it is not a requirement in the case of the central controller.

CONCLUSIONS

A review of the strategies and approaches used to implement energy management both in standalone hybrid renewable energy systems and grid-connected hybrid renewable systems was conducted in this study. Special attention was given to the energy management strategies used in smart grids. Energy management strategies based on fuzzy logic systems were also addressed in detail.

The application of energy management strategies in hybrid renewable energy systems is critical in achieving a high level of system reliability and operational efficiency. It has also helped in reducing the cost of energy generated and in increasing the life span of hybrid components, most especially energy storage devices (batteries). As the level of penetration of renewable energy sources increases, the need for a real-time and robust energy management approach becomes important for the hybrid connection of these energy sources together and with the energy storage devices. Therefore, further research should be conducted in this area to improve further the reliability of the entire system.

Some of the features that characterize renewable energy sources are their variability and intermittency. Intermittency covers both the predictable variability and the unpredictable variations. Hybrid systems based on renewable energy sources are usually designed to consider this intermittency, and they aim to increase the reliability of these energy systems and decrease the percentage of occurrence of electricity interruptions. As these considerations are taken into account in the design, renewable sources sometimes generate more energy than the load requirement. This excess energy is usually dumped through the dump load. Developing an energy management strategy that utilizes this excess energy by directing it into certain loads, such as water heating with storage tanks, surrounding heating or air-conditioning, and pumping water, among others, is recommended.

According to this comprehensive review, only a few studies have been conducted on energy management strategy for hybrid renewable energy systems with CHP generation. Most studies are on standalone hybrid systems only. Therefore, developing energy management strategies that control the flow of energy (both heat and electrical) between the sources of the hybrid systems and the load connected directly to these sources or the load connected to grid is recommended. In this case, the way to measure the heat energy generated by the distributed generation sources and the loads should be specified.

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