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A Review of Hybrid Renewable Energy Systems for Electric Power Generation

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ABSTRACT
Integration and combined utilization of renewable energy sources are becoming increasingly attractive. This paper is a review of hybrid renewable energy systems technologies for power generation, important issues and challenges in their design stage. Generation technology selection and unit sizing, System configurations and Energy management and control are discussed. Applications of hybrid energy systems, advantages of hybrid energy systems, issues and problems related to hybrid energy systems and an overview of energy storage technologies for renewable energy systems are presented. This paper also highlights the future trends of Hybrid energy systems, which represent a promising sustainable solution for power generation.
KEYWORD*:* HRES, PV system and fuel cell, HOMER.

I. INTRODUCTION

Nowadays, there is a great concern on dependence on fossil fuel and environmental issues. This has led to more research in the energy sector to reduce the dependence on fossil fuels and to protect the environment. Two strategies that can be followed to reduce dependence on fossil fuel [1]. The first strategy is based on reducing energy consumption by applying energy savings programs. A second strategy is to achieve this goal consists of using renewable energy sources. Moreover, Inaccessibility of the grid power to the remote places and the lack of rural electrification have prompted for alternative sources of energy [SD7]. Renewable resources and clean alternative energy power generation technologies have attracted much attention and concern because they have several advantages such as, less dependence on fossil fuel, availability of the resources which are free of cost, and lower harmful emissions to the atmosphere (i.e. environmental friendly). Renewable energy sources, such as wind, solar, micro hydro (MH), biomass, geothermal, ocean wave and tides, and clean alternative energy sources, such as fuel cells (FCs) and micro turbines (MTs), have become better alternatives for conventional energy sources [2, 3]. However, in comparison to conventional energy sources, renewable energy sources are less competitive due to their uncertainty, intermittency due to dependence on weather, and high initial cost. Recently, extensive research on renewable energy technology has been conducted worldwide which resulted in significant development in the renewable energy materials, decline in the cost of renewable energy technology, and increase in their efficiency. To overcome the intermittency and uncertainty of renewable sources and to provide an economic, reliable, and sustained supply of electricity, a modified configuration that integrate these renewable energy sources and use them in a hybrid system mode is proposed by many researchers. The energy from renewable resources is available in abundance but intermittent in nature, hybrid combination and integration of two or more renewable sources make best utilize of their operating characteristics and improve the system performance and efficiency.

Hybrid Renewable Energy Systems (HRES) are composed of one renewable and one conventional energy source or more than one renewable with or without conventional energy sources, that works in standalone or grid connected mode [1]. Hybridization of different alternative energy sources can complement each other to some extent and achieve higher total energy efficiency than that could be obtained from a single renewable source. Multi source hybrid renewable energy systems, with proper control, have great potential to provide higher quality and more reliable power to customers than a system based on a single source. Due to this feature, hybrid energy systems have caught worldwide research attention.

The applications of hybrid energy systems in remote and isolated areas are more relevant than grid connected systems. In addition, the application of hybrid systems is becoming popular in distributed generation or micro-grids, which recently have great concern. Due to advances in renewable energy technology which have improved their efficiency and reduced the cost, and the advances in power electronic converters and automatic controllers which improve the operation of hybrid energy systems and reduce maintenance requirements, these advance made hybrid systems practical, and economical. Hybrid energy systems are now becoming an integral part of the energy planning process to supply previously unelectrified remote areas [6]. Various hybrid energy systems have been installed [10,11] in many countries over the last decade, resulting in the development of systems that can compete with conventional, fuel based remote area power supplies [12] in many applications.

The design process of hybrid energy systems requires the selection and sizing of the most suitable combination of energy sources, power conditioning devices, and energy storage system together with the implementation of an efficient energy dispatch strategy [6]. The selection of the suitable combination from renewable technology to form a hybrid energy system depends on the availability of the renewable resources in the site where the hybrid system is intended to be installed. In addition to availability of renewable sources, other factors may be taken into account for proper hybrid system design depends on the load requirements such as, reliability, greenhouse gas emissions during the expected life cycle of the system, efficiency of energy conversion, land requirements, economic aspects and social impacts [6, 9]. The unit sizing and optimization of a hybrid power system play an important role in deciding the reliability and economy of the system.

The rest of the paper is organized as follows: Hybrid energy system configurations, unit sizing, and energy storage systems are discussed in Section II. Modelling of hybrid renewable energy systems in section III. Energy management and control are presented in Section IV. Statistics on the current status and future trends of renewable power generation and sample applications of hybrid RE/AE systems and micro grids around the world are given in Section V. Section VI. Presents some critical challenges facing the widespread deployment of RE/AE power generation technologies and vision for future research in this area. Section VII concludes the paper.

II. DESIGN OF HYBRID RENEWABLE ENERGY SYSTEMS

A. technology selection and unit sizing

In this design stage, the system's configuration is synthesized, i.e. which types of generation technologies will be allocated and integrated to build a hybrid system. This is very crucial aspect in the design, since there are usually many alternative possibilities related to which individual components will be included in a hybrid energy system [stand-alone and hybrid wind].

For a given hybrid energy system, this design stage would be to determine:

- The type of renewable energy system to be included.
- The number and capacity of renewable energy units to be installed.
- Whether a back-up unit, such as diesel generator, fuel cell etc. would be included in the system.
- Whether energy storage would be integrated into the system.
- Whether the system is stand-alone or grid connected.

The selection of the technology depends on the availability of renewable resources for particular site where the system is to be installed in which the local weather conditions play an important role for taking decision. Based on the weather statistics (hourly data), a feasibility study for different possible combinations of renewable sources is studied using optimization techniques to get the optimum configuration. Then the number and size of the selected components is optimized in order to get an economical, efficient, and reliable system. Component sizing is important and widely and extensively studied e.g.[13-15]. Several factors or constraints directly influence the sizing of the system components e.g. system economics, greenhouse emission requirements, and system reliability. Over sizing of the components may lead to high system cost and therefore, the system may become economically unviable. On the other hand, under sizing will reduce the initial cost but one has to compromise with system reliability. For a particular load, different criteria constraints may be applied to the set of system components based on the objectives that have to be achieved. Some of the criteria constraints that are mostly considered while designing a hybrid energy system are:

- Reliability criteria: a number of methods are used to analyse the reliability of a hybrid energy systems including, loss of load probability (LOLP), loss of power supply probability (LPSP), and unmet load (UL) [stand alone[16] &[17]
- System cost criteria: system cost criteria may include total energy systems costs, capacity costs and societal costs.
- Operational optimization criteria, which may include fuel savings, emissions reduction, reserve/backup capacity, and elimination of excess power generation.

Design of hybrid energy systems has been extensively studied and numerous optimization techniques, such as linear programming [18], Genetic algorithms [19] etc. have been employed for the optimum economic and reliable design of hybrid systems. Recently, many software packages, such as

HOMER [20], RETScreen [21], Hybrid [22], and HOGA [23], have been developed for the proper selection of suitable generation technologies and their sizes. These software packages have made the study of hybrid systems interesting and easier. Some of studies address only the reliability analysis for the design of hybrid systems [23]&[24-26]while others consider various types and sizes of the available generation resources for the reduction of investment costs, fuel costs, and to improve system operations [27]. Optimization-based approaches that simultaneously minimizes the investment cost (installation and unit cost) and fuel cost while retaining the reliability and emission constraints have been implemented in [28]

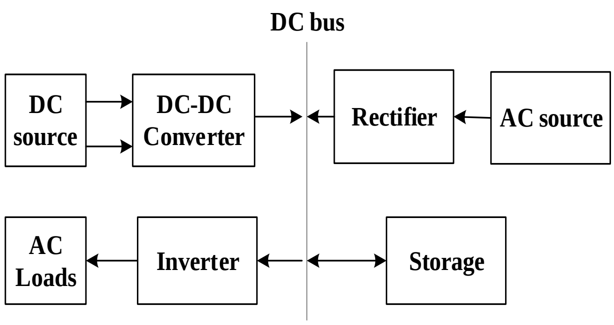
From those studies, one can conclude that the design of such systems is quite complex due to the fact that it has to satisfy several constraints and to achieve several objectives that are conflicting in nature. In addition, the investment costs becomes high, as the reliability constraints subjected to the system are stricter for high degree of reliability. When a lower emission is required, the investment cost becomes high but the fuel cost becomes low.

B. Integration scheme

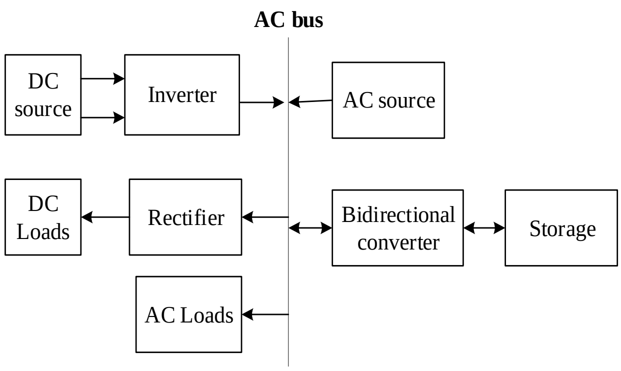
IB.Stand-alone hybrid systems

Various possible configurations may be used for integration of the energy sources that form hybrid system are shown in fig. 1.

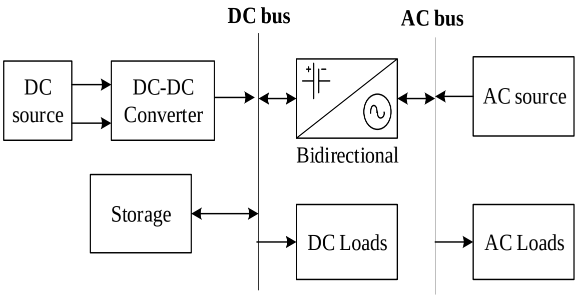
- Series hybrid system, this can be of two forms centralized dc-bus and centralized ac-bus. In centralized dc-bus, all the energy sources, storage devices, and loads are connected to a dc-bus through appropriate electronic devices as shown in fig.1 (a). The dc-bus eliminates the need for frequency and voltage controls of individual sources connected to the bus and the power supplied to the load is not interrupted when diesel generator starts [29] DC loads can be directly connected to the dc-bus which reduces the harmonics from the power electronic devices. DC-bus configuration has low efficiency limitation because in case of both source and load are AC, the power passing through two stage conversions. Another limitation, the inverter must be rated for the peak load requirements and in case of inverter failure results in complete power loss to the load. In centralized ac-bus, all the energy sources, storage devices, and loads are connected to an ac-bus through appropriate electronic devices as shown in fig.1 (b). It is modular configuration, which facilitates the growth to manage the increasing energy needs. It offers major constraint in the synchronization of the inverters and ac sources to maintain the voltage and frequency of the system. The undesired harmonics introduced into the system by the use of inverters increases the level of power quality problems [30].
- Parallel hybrid system, in this configuration the ac sources and loads are directly connected to ac-bus. While the dc sources and loads are directly connected to dc-bus. Bidirectional converter connects both the buses to permit the power flow between them. The inverter rating required is less than that of series configuration and the efficiency is higher. In addition, for the same inverter rating as that used in series configuration, the power supplying capacity of the parallel configuration is much more [Solanki]. Thus, Such configuration arrangement increases the system reliability and ensure the supply continuity [31]. However, synchronization between the output voltage of the inverter and ac bus is needed.
- Switched hybrid system as shown in fig.1 (c), in which the ac sources, such as diesel generator, can directly be connected to the load leading to higher efficiency and synchronization in not needed. This configuration, although popular, has several limitations that only one of the sources is connected to the load at a given instance. Furthermore, during switching between the sources, the power is interrupted.



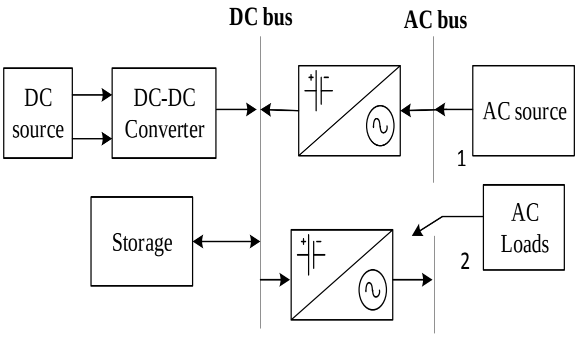
a) DC-Series



b) AC-series



(c) Parallel



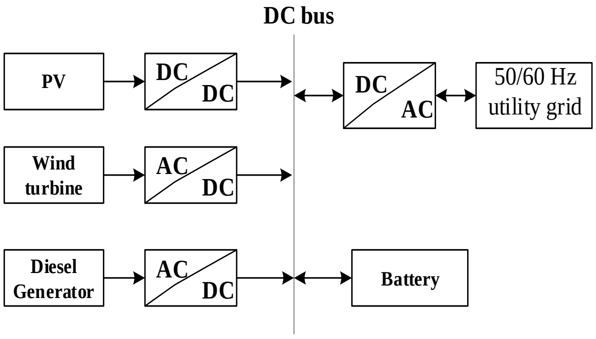
(d) Switched

Fig.1. various stand-alone hybrid system configurations

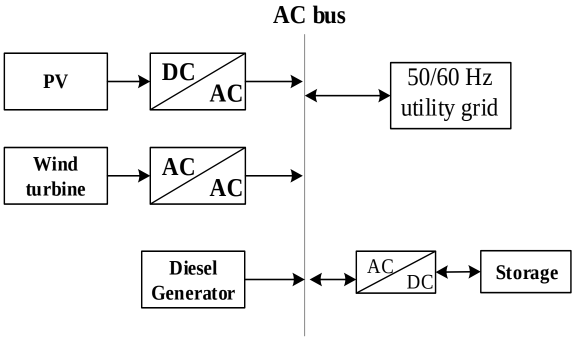
IIB.Grid connected systems

Different grid connected configurations are shown in fig. 2. The choice of the layout for particular location depends upon geographical, economical, and technical factors [ieee 20].

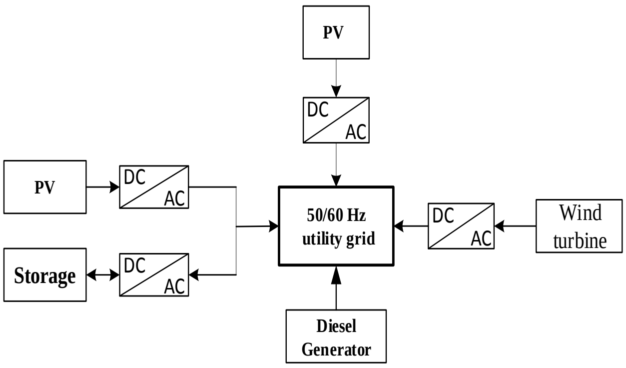
- Centralized dc-bus architecture shown in Fig. 2(a). The ac energy sources, such as wind and diesel generator, firstly deliver their power to rectifiers to be converted into dc before being delivered to the main dc bus bar. An inverter, main,takes the responsibility of feeding the ac grid from this dc bus.
- Centralized ac-bus architecture shown in Fig. 2(b), the sources and the battery all are installed in one place and are connected to a main ac bus bar, through appropriate power electronic devices, before being connected to the grid. This system is centralized in the sense that the power delivered by all the energy conversion systems and the battery is fed to the grid through a single point.
- Distributed ac-bus architecture shown in Fig. 2(c), the power sources do not need to be installed close to each other, and they do not need to be connected to one main bus. The sources are distributed in different geographical locations and connected to the grid separately. The power produced by each source is conditioned separately to be identical with the form required by the grid.



a) Centralized dc-bus



b) Centralized ac-bus



c) Distributed ac-bus

Fig. 2.various stand-alone grid connected hybrid system configurations.

III. ADVANTAGES OF HYBRID SYSTEMS

1- A hybrid energy system can make use of the complementary nature of various sources, which increases the the overall efficiency of the system and improve its performance (power quality and reliability). For instance, combined heat and power operation, e.g. MT and FC, increases their overall efficiency [32]&[33-35]or the response of an energy source with slower dynamic response (e.g. wind or FC) can be enhanced by the addition of a storage device with faster dynamics to meet different types of load requirements[36]&[37-39].

2- Lower emissions: hybrid energy systems can be designed to maximize the use of renewable

resources, resulting in a system with lower emissions.
3- Acceptable cost: hybrid energy systems can be designed to achieve desired attributes at the lowest acceptable cost, which is the key to market acceptance.
4- They provide flexibility in terms of the effective utilization of the renewable sources.

IV. ISSUES WITH HYBRID RENEWABLE ENERGY SYSTEMS

Though a hybrid system has a bundle of advantages, there are some issues and problems related to hybrid systems have to be addressed:
1- Most of hybrid systems require storage devices which batteries are mostly used. These batteries require continues monitoring and increase the cost, as the batteries life is limited to a few years. It is reported that the battery lifetime should increase to around years for the economic use in hybrid systems.
2- Due to dependence of renewable sources involved in the hybrid system on weather results in the load sharing between the different sources employed for power generation, the optimum power dispatch, and the determination of cost per unit generation are not easy.
3- The reliability of power can be ensured by incorporating weather independent sources like diesel generator or fuel cell.
4- The stability issue. As the power generation from different sources of a hybrid system is comparable, a sudden change in the output power from any of the sources or a sudden change in the load can affect the system stability significantly.
5- Individual sources of the hybrid systems have to be operated at a point that gives the most efficient generation. In fact, this may not be occur due to that the load sharing is often not linked to the capacity or ratings of the sources. Several factors decide load sharing like reliability of the source, economy of use, switching require between the sources, availability of fuel etc. Therefore, it is desired to evaluate the schemes to increase the efficiency to as high level as possible.

V. CONCLUSION

This paper provides a summary of available approach and those currently under research for optimal design of hybrid RE/AE energy systems. Different approach for system configuration of hybrid system are presented. Current status and future trends of RE power generation technologies have been discussed. The comprehensive list of references at the end of paper is included at the end of the paper for further research.

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