Retrofitted Hybrid Power System Design With Renewable Energy Sources for Buildings

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***Abstract*—Most of the research on Hybrid Power Systems (HPS) is to provide an economical and sustainable power to the rural electrification. This paper focuses on the design of an HPS for the building which is a part of the urban electrification. In the developing countries, the rate of increase in the demand is more than the rate of increase in the supply, which is a major challenge resulting in very frequent outages. There are number of motives to build integrated and synergistic renewable energy based HPS including environmental, economic, and social benefits. Most of these HPS topologies use inverters to interface the renewable sources to the buildings with an offering of low quality power. Hence, modern sustainability initiatives call for a design for both new HPS and retrofitting of an existing HPS topology. With this aspect, this paper describes the topology of retrofitting HPS with dc Motor-Synchronous Generator set instead of the use of inverter to an existing building power system. This can improve the power quality, reliability of the supply, and ensures stable plant operation. The proposed HPS topology can be used in small-to-medium sized isolated constructions like green buildings, industries, and universities. Different renewable energy sources like Photo Voltaics (PV), Wind Power (WP), and Fuel Cells (FC) are integrated to form HPS. An energy management and control algorithm is proposed to use the energy sources optimally to upgrade these buildings with more reliability and efficiency. The modeling and simulation is done using MATLAB/Simulink.**

***Index Terms*—DC Motor-Synchronous generator (MG) set, energy management and control unit (EMCU), Hybrid Power System (HPS), inverter, island and grid connected operations, power quality.**

I. Introduction

ELECTRICAL energy is essential to everyone's life no matter for whom or where they are. This is especially true in this new century, where people aim to pursue a higher quality of life. It is now a globally accepted reality that electrical energy is fundamental for social and economic development. Unfortunately, still one third of the world's population lives in developing and threshold countries and has no access to electricity [24]. It has been estimated that the world population will reach eight billion by 2020. And this growth is mostly in developing countries [25]. So, to supply the electricity requirements for them, the extension of utility grid is complicated and expensive due to geographical and economical barriers. Besides, the need for unrelenting increment in energy production, diminution in currently reliant fossil fuel resources, and the regulations to reduce the CO_2 emissions is the foremost factor for stipulating the growth of "green energy" generation systems. In such circumstances, an alternative is to use locally available renewable energy sources (e.g., solar, wind, hydrogen, and etc.) and combine to implement modular, expandable, and task-oriented systems known as the HPS. HPS combine two or more energy conversion devices, or two or more fuels for the same device, that when integrated, overcome the limitations inherent in either.

Multi-source HPS with proper control has a higher potential for providing better quality and more reliable power to utilities than a system based on a single resource. These are generally independent of the large centralized utility grid. Generally, HPS use a combination of conventional non renewable energy sources like fossil fuel, hydal energy, nuclear energy, or a combination of renewable energy sources like solar energy, wind energy, etc., and may be a combination of both renewable and non renewable energy sources. The HPS discussed in this paper is a combination of only renewable energy sources like solar cells, fuel cells, and wind energy systems. This is clean and abundantly available in nature. It offers many advantages over conventional fossil fuel based power generation systems, such as low pollution, high efficiency, diversity of fuels, and on-site installation.

Keeping all these in mind, many decentralized HPS have been installed worldwide. One of the major applications of the proposed HPS is to meet the power supply needs of a "green building." On the aesthetic side of green architecture or sustainable design is the philosophy of designing a building that is in harmony with the natural features and resources surrounding the site. These buildings are aimed for optimum usage of energy resources by reducing waste of energy and toxics, pollution free generation, durability, and comfort [8], [26]–[28].

II. Prior Art and Problem Identification

In general, all HPS architectures can be grouped into island mode and grid connected mode layouts [30]–[32]. All these might contain ac diesel generators [11], diesel system, an ac or dc distribution system, loads, energy sources, energy storage, power converters, load management options or a supervisory [20], etc.

These two HPS classifications are as follows:

- Stand-alone/off-grid/Islanding—HPS, which are independent of the utility grid, used to meet the load demands especially at remote places; and
- Grid connected HPS, which are connected in parallel with the central utility power grid and can be used at any location (rural or urban).

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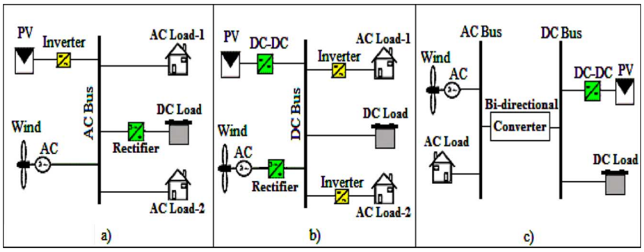

Fig. 1. Different architectures of standalone HPS.

A. Stand Alone/off Grid/islanding HPS

Stand alone HPS are designed and sized to attend specific loads. The power units commonly used are PV panels (dc source), WP and Diesel Generators (ac sources). Batteries are often used for storage and backup. Other power electronics components like rectifiers, inverters, and/or converters are used to match the ac and dc generation source with the voltage and frequency requirements of the load. The control system for HPS configurations should minimize fuel consumption by maximizing power from the renewable sources [29]. There are power fluctuations by the variability of the renewable energy, which cause disturbances that can affect the quality of the power delivered to the load. Fig. 1 shows the basic architectures of standalone HPS.

In centralized ac-bus layout shown in Fig. 1(a), all the energy sources and the loads are connected to an ac bus. DC sources are needed to have the inverters to convert dc to ac before connecting to ac bus. It is more 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.

In centralized dc-bus layout shown in Fig. 1(b), all the energy sources and the loads are connected to a dc bus. All the ac sources needed to have the rectifiers to convert ac to dc before connecting to dc bus. DC loads can be connected directly to the dc bus, which reduces the harmonic pollution from power electronic equipment. The dc bus eliminates the need for frequency and voltage controls of the generation source connected to the bus. This design has a limitation in efficiency because of passing through two stage conversion between source and load in the case where both source and load are operating on ac.

The ac/dc-bus layout shown in Fig. 1(c) has both ac and dc buses. The ac sources and loads are directly connected to ac bus. Similarly, the dc sources and loads are connected to dc bus. Both buses are connected through a bidirectional converter that permits power flow between the two buses. This arrangement increases the system power reliability and supply continuity.

B. Grid Connected HPS

Different grid connected architectures [5], [16], [25] are shown in Fig. 2. Each system has its own advantages and disadvantages. The choice of the layout for particular location depends upon geographical, economical and technical factors.

In centralized ac-bus architecture shown in Fig. 2(a), the sources and the battery are all installed in one place and are connected to a main ac bus bar 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. In this case, the power produced by the PV system and the battery is inverted into ac before being connected to the ac bus.

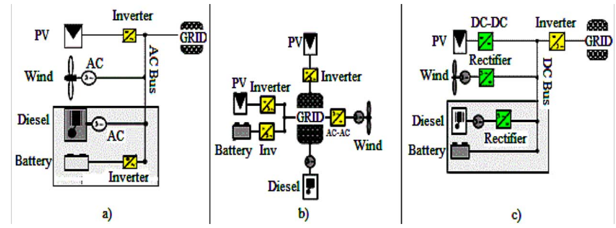

Fig. 2. Different architectures of grid connected HPS.

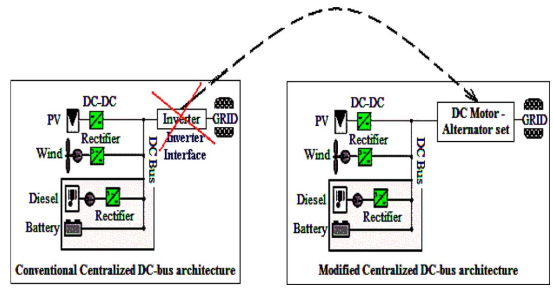

Fig. 3. Comparison of conventional and retrofitted HPS.

In distributed ac-bus architecture shown in Fig. 2(b), 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. The main drawback of this architecture is the difficulty of controlling the system when the diesel generator is in off mode.

The centralized dc-bus architecture shown in Fig. 2(c) utilizes a main centralized dc bus bar. So, the energy conversion systems that produce ac power, namely the WP and the diesel generator, firstly deliver their power to rectifiers to be converted into dc before being delivered to the main dc bus bar. A main inverter takes the responsibility of feeding the ac grid from this dc bus.

C. Cumulative Merits/Demerits of HPS Architectures

The existing HPS architectures have the following constraints as identified from the study in Sections II-A and II-B.

Island mode:

- Centralized ac-bus layout has a more modular configuration, facilitating growth to manage increasing energy needs. It comes with major constraints 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.
- Centralized dc-bus layout reduces the harmonic pollution from power electronic equipment. The dc bus eliminates the need for frequency and voltage controls of the generation source connected to the bus. This design offers an advantage in the fuel consumption, which is 10% to 14% lower compared to the other architectures but with a limitation in efficiency because of passing through a two stage conversion between source and load in the case where both source and load are operating on ac.
- The ac/dc-bus layouts increase the system power reliability and supply continuity, and are associated with the merits and demerits of both centralized ac and dc architectures.