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Effective utilization of excess energy in standalone hybrid renewable energy systems for improving comfort ability and reducing cost of energy: A review and analysis

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ABSTRACT

One of the features that characterize renewable energy sources is their variability and intermittency. Intermittency covers both the predictable and unpredictable variations of their power outputs and uncertainty in the power availability. To overcome the drawback of intermittency, special design considerations should be taken into account. These additional design considerations increases the overall cost of the renewable energy systems. Adding storage system and/or backup source to the renewable sources is one of the measures used to guarantee the continuity of power supply to the loads, and therefore improve the reliability of the renewable energy systems. The operation of renewable energy systems results in the creation of surplus energy, which is the energy generated by renewable energy systems, but is not consumed by the loads in standalone power systems. Effective utilization of this excess energy has the potential to decrease the cost of energy (COE) production by these hybrid renewable energy systems. In this paper, a review of the literature will be carried out in order to provide further insight into the approaches suggested in the literature on how to deal with the utilization of excess energy. Furthermore, various possible configurations of hybrid systems will be analyzed in detail for the effective utilization of the excess energy produced by hybrid systems. This is done in order to evaluate the effectiveness of utilization of excess energy by various means, especially for improving the living space comfort ability and decreasing the COE. Case studies will be carried out to demonstrate the proposed configurations for the effective utilization of the excess energy, and the results will be presented.

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1. Introduction

Great efforts are made to develop new and renewable energy technologies along with energy storage systems and encourage their entry to the market of electric industry. These technologies can be operated as standalone sources, as part of hybrid systems, or as distributed generation connected to a microgrid or a distribution grid. These sources include photovoltaic systems, wind energy systems, diesel engines, fuel cells, microturbines, and different other renewable sources and storage systems.

These efforts are seeing a marked increase recently due to the fact that different types of fossil fuel that conventional sources of energy depend on are going to be depleted. When this is taken into consideration, along with the fact that high levels of global warming gases are emitted as a result of combustion of these fossil fuels, this encourages different institutions and authorities worldwide to invest in local generation from renewable energy sources [1–3]. This involves finding substitutes, or at least reducing the dependency on fossil fuels. Furthermore, an overview of the literature on rural electrification proves shows that renewable energy sources are one of the most effective solutions to provide power to rural areas that are located far from the electrical power grid. Delivering high quality and reliable electricity for different applications in these remote areas were also proven to be feasible [4–6].

Renewable energy sources are non-depleted, non-polluting, and location dependent. Recently, utilization of renewable sources has become more attractive, cost effective, and significant. However, because renewable sources are variable and intermittent, a need for a storage system and/or backup source arises to ensure continuity in supplying the load [7–9].

Hybrid energy systems are systems that combine two or more energy conversion sources (electricity/heat generation and/or storage devices), and when combined, will overcome any inherent limitations [10–14]. If one of these energy sources is renewable, this hybrid system can be treated as a hybrid renewable energy system.

When hybrid systems operated effectively, they increase the overall efficiency of the system and become a more reliable energy supply. Moreover, hybrid renewable energy systems can significantly reduce the cost of generation and the environmental impacts. Utilization of hybrid systems that combines renewable sources with backup sources and energy storage reduces the limitations of renewable sources, and open up markets for investment that might not otherwise exist. Hybrid systems take the best features of differing, but complementary resources in its construction [15,16].

For systems with more than one energy sources used to supply a load, a criterion to manage the power flow between these sources should be specified. This management strategy should define the priorities to dispatch the energy between the different sources. For the system considered in this study, the priority is to maximize the utilization of energy generated by the renewable sources (e.g. PV panels) and the energy stored in the battery bank. In case of inability of these sources to cover the load demand, one or more non-renewable (e.g. microturbine or diesel generator) or renewable but schedulable (biomass) standby resources can be used to counteract demand-generation mismatch in these standalone hybrid systems. For the case where the generated energy exceeds the load requirement and the battery, if available in the hybrid system, is not able to store anymore as it is full, an excess energy that should either be dumped or utilized for ancillary service (or other purpose) to maintain a power balance in the system. Fig. 1 shows the flowchart guiding the management strategy to achieve energy balancing for this situation.

Different configurations can be followed in designing standalone hybrid systems to effectively utilize the available renewable energy sources and to serve the customer loads. Any combination of renewable sources is possible, but it may require an optional backup source and/or storage system. To select the most appropriate configuration for a specific site, a feasibility study considering the meteorological data of this site and based on life cycle cost analysis should be done.

One of the drawbacks of the renewable energy systems is their high capital cost compared to conventional ones. Using hybrid systems that combine more than one energy source and the size optimization of each of the components constructing these systems are some of the measures that can be taken to reduce their capital costs. Effective utilization of any excess energy that hasn't been consumed by the load or used to charge the battery in standalone hybrid systems can be considered as one of the approaches used to decrease the cost of energy (COE) production for these hybrid systems.

Actually, this excess energy, if not dumped, may damage the battery due to the fact that it might result in an overcharge. It may also cause over voltages in the standalone hybrid systems that, in turn, may adversely affect the equipment connected to the system. The traditional way to overcome this excess energy is through using dump loads to consume it. Resistors are usually used for this purpose, and a controller usually diverts the extra power away from the battery banks and directs it into the designated (dedicated) dump load when the desired voltage of the battery bank is reached. Values of these resistors should be selected in order to allow enough current to pass through. The diversion control circuit may be included in the charger regulator circuit, in the inverter circuit, or in the rectifier circuit, as most of the manufacturers of these power electronic interfaced renewable energy systems usually include these diversion control circuits within their products [17].

Instead of dumping the excess power through a dump load, other alternatives to deal with this excess power have been suggested by many researchers, and can be found in the literature. To the best of the authors' knowledge, a detailed analysis to evaluate the effectiveness of utilization of the excess energy has not been previously carried out. In this paper, a review of the literature will be carried out in order to assess approaches being suggested to deal with the excess energy produced but not used either to supply the load or charge the batteries. Furthermore, hybrid system configurations will be analyzed in detail in order to evaluate the effectiveness of utilization of excess energy by various means, especially for improving the living space comfort ability without any additional cost.

2. Quantification of excess energy in hybrid renewable energy systems—A review

In this section, a review of various studies carried out in different locations around the world will be presented. The purpose of this review is to indicate the percentage of the excess