Hybrid Renewable Energy System: A Review

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Abstract

Renewable energy technologies are suitable for off-grid services, serving the remote areas without having to build or extend expensive and complicated grid infrastructure. Therefore standalone system using renewable energy sources have become a preferred option. This paper is a review of hybrid renewable energy power generation systems focusing on energy sustainability. It highlights the research on the methodology, unit sizing, optimization, storage, energy management of renewable energy system.

Keywords: hybrid energy system, reliability, cost, unit optimization, storage, energy management.

1. Introduction

Rapid depletion of fossil fuels has necessitated an urgent need for alternative sources of energy to cater the continuously increasing energy demand. Another key reason to reduce our consumption of fossil fuels is the growing global warming phenomena. Environmentally friendly power generation technologies will play an important role in future power supply. The renewable energy technologies include power generation from renewable energy sources, such as wind, PV(photovoltaic), MH(micro hydro), biomass, ocean wave, geothermal and tides.

In general, the key reason for the deployment of the above energy systems are their benefits, such as supply security, reduced carbon emission, improved power quality, reliability and employment opportunity to the local people. Since the RE resources are intermittent in nature therefore, hybrid combinations of two or more power generation technologies, along with storage can improve system performance.

Hybrid Renewable Energy System (HRES) combines two or more renewable energy resources with some conventional source (diesel or petrol generator) along with storage, in order to fulfill the demand of an area. An example of PV-wind diesel generator HRES is shown in fig.1.



Fig. 1: PV/wind/battery/diesel generator HRES.

2. Methedology

It is essential to have a well-defined and standardized frame work/steps taken for hybrid system based power generation for rural electrification. These steps are as follows:

- *a.* Demand Assessment: Using accurate load forecasting of remote villages, the load demand can be fetched. Load assessment can also be done by interviewing gram pradhans, school teachers, local people, workers etc. During load survey, following factors may be considered:
- Demand for street lighting,
- Number of houses, schools, health centers, commercial establishment and their energy requirement, number of small scale industries and their energy demand,
- Miscellaneous demand.
- *b.* Resource Assessment: Resource assessment can be done by calculating potential available in wind, MHP, solar, Biomass, Biogas, and other renewable energy resources using meteorological data available.
- c. Barriers/Constraints:
 - Annual electricity demand,
 - Reliability,

- Net Present cost,
- Environmental factors,
- Employment.
- *d.* Demand is fulfilled by Hybrid renewable energy system. This can be done by combining one or more renewable energy sources with conventional energy sources. Some Hybrid renewable system configurations are as follows:
 - PV/Wind/diesel generator HRES,
 - PV/wind/fuel cell HRES
 - Wind/battery HRES
 - Biomass/wind/diesel generator HRES
 - PV/Wind/Biomass/fuel cell HRES
- e. Once the system configuration is selected, optimization is performed with suitable optimization technique.

3. Criteria for Hybrid System Optimizations

In order to select an optimum combination for hybrid system to meet the load demand, evaluation must be carried out on the basis of power reliability and system life-cycle cost.

3.1 Power reliability analysis

Power reliability is considered an important step in hybrid system design process. The hybrid energy system must satisfy the load in the most economical and cost effective way. There are various methods used to calculate the reliability of the hybrid system. Loss of power supply probability (LPSP) [1,2], Loss of Load Probability (LOLP), System Performance Level (SPL) [4], and Loss of Load Hours (LOLH). LPSP is the probability that an insufficient power supply results when the hybrid system is unable to satisfy the load demand. The LOLP is a measure of the probability that the system demand will exceed the system's power supply capacity in a given time period. The SPL is defined as the probability that the load cannot be satisfied [3]. Al-Ashwal and Moghram [4] presented a method for the assessment on the basis of the loss of load risk (LOLR) to decide a proportion for solar and wind energy in a hybrid system.

3.2 System cost analysis

There are several economic criteria for the system cost analysis, such as Net present Cost, Levelised Cost of Energy [5] and life-cycle cost [6]. The Net present Cost is defined as the total present value which includes the initial cost of all the system components, the cost of any component's replacement that occur within the project lifetime and the cost of maintenance. The life of PV modules is generally considered as the life of the system [7].

The Levelised cost of energy is defined as the ratio of the total annualized cost of the system to the annual electricity delivered by the system.

4. Unit Sizing Optimization

Unit sizing of Hybrid RE/AE systems is important and essential task and has been studied extensively in [8,9]. It is basically a method of determining the size of the hybrid system components by minimizing the system cost while maintaining system reliability.

Over sizing the system components will enhance the system cost whereas under sizing can lead to failure of power supply or insufficient power delivered to the load. Sizing optimization can be done in various ways as listed below:

- Software tools
- Probabilistic approach
- Graphical construction method
- Iterative technique
- Artificial Intelligence method

1) Simulation and Optimization software

Simulation tools are the most common tools for evaluating the performance of the Hybrid systems. Optimum configuration can be found by using computer simulations, by comparing the performance and energy production cost of different system configurations. Several software tools are available for designing of the hybrid systems, such as HOMER, HYBRID2, HOGA and HYBRIDS.

HOMER (Hybrid Optimization Model for Electric Renewables) is user friendly software produced by national renewable energy laboratory. It uses hourly simulations and environmental data for the assessment of the hybrid renewable energy system and performs optimization based on Net Present Cost. HOMER has been used extensively in various case studies

HOGA is hybrid system simulation software developed by the Electric Engineering Department of the University of Zaragoza Spain. The simulation is carried out using 1-h intervals.

HYBRID2 is the hybrid system simulation software developed by Renewable Energy Research Laboratory (RERL) of the University of Massachusetts. The simulation is carried out from 10 min-1h intervals.

Hybrids is produced by Solaris Homes, It is Microsoft Excel spread sheet-based assessment application and design tool. Unlike HOMER, HYBRIDS can only simulate one configuration at a time.

2) Optimization techniques

It is important for the designers to find a feasible optimization technique to select optimum system configuration. There are several optimization techniques available for the hybrid system shown in fig.2 such as graphical construction methods, probabilistic approach, iterative technique, artificial intelligence methods, and multi-objective design.

• Graphical construction method: This method has been presented by Borowy and Salameh [10] based on using long-term data of solar radiation and wind speed recorded for every hour of the day for 30 years. Another graphical

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technique has been given by Markvart [11] to optimally design a hybrid solarwind power generation system by considering the monthly-average solar and wind energy values. However, in both graphical methods, only two parameters were included in the optimization process.

- Probabilistic approach: This approach of sizing account the effect of the solar radiation and wind speed variability's in the system design. Bucciarelli [12] proposed a sizing method treating storage energy variation as a random walk. The probability density for daily increment or decrement of storage level was approximated by a two-event probability distribution [13]. Probabilistic approach cannot represent the dynamic changing performance of the hybrid system.
- Iterative technique: Yang et al. [14] proposed a Hybrid Solar–wind System Optimization (HSWSO) model, which utilizes the iterative optimization technique following the LPSP model and Levelised Cost of Energy model for power reliability and system cost respectively. Similarly, an iterative optimization method was presented by Kellogg et al. [15] to select the wind turbine size and PV module number using an iterative procedure to make the difference between the generated and demanded power (DP) as close to zero as possible over a period of time. Furthermore, it usually does not optimize the PV module slope angle and wind turbine installation heights which also highly affect both, the resulting energy production and system costs.
- Artificial intelligence: It is a term that in its broadest sense would mean the ability of a machine or artifact to perform similar kinds of functions that characterize human thought. Artificial intelligence methods, such as Artificial Neural Networks, Genetic Algorithm, Fuzzy Logic, PSO (Particle Swarm Optimization, ACO (Ant Colony Optimization) widely used to optimize a hybrid system in order to maximize its economic benefits. Kalogirou [16] proposed an optimization model as solar systems using Artificial Neural Network and Genetic Algorithm. These methods are most successful methods as they help in finding the global solution of complex problems.

5. Storage

Storage technology is critical and important for ensuring continuous supply of power to the load[17]. There are many types of energy storage that can be used in hybrid renewable energy system for example, compressed air energy storage (CAES), Pumped hydro storage (PHS), hydrogen fuel cells, flywheels, supercapacitors, superconducting magnetic energy storage (SMES) and batteries. The key characteristics of each of the energy storage is shown in table I. It can be seen that SMES is the new technology which has the highest efficiency, but is very expensive due to the use of superconductive wiring in the coil. Hydrogen storage and supercapacitors are not preferred for applications where adequate technical support is not available. For a small power application, the use of PHS is not justified as there is large initial cost involved with the system. CAES is relatively a cheap form of energy storage but the system location needs underground compressed-air storage carvens. Flywheels are efficient and have low cost, but they have a high discharge rate. Batteries are the ideal solution for hres as they are a very mature form of storage and can yield a high energy density and high power density at low cost.

Attributes	Efficiency	Maturity of	Cost	Energy	Power Density
	-	Technology		Density	-
CAES	70%	Mature	High	High	High
PHS	75-85%	Mature	High	Depends on	Depends on the
			initial	the size of	height distance
			cost	reservoir	between
					reservoirs
Hydrogen	50-60%	Early stages of	High	Depends on	Depends on
		maturity		hydrogen	speed on
				reservoir	reaction
Flywheel	80-90%	Mature	Low	Low	High
Super-	80-95%	Immature	High	Low	High
capacitor					
SMES	90-95%	Immature	High	Low	High
Battery	75-85%	Mature	Low	High	High

Table I: Key characteristics of each of the energy storage.

6. Future Trends and Limitations

The renewable technologies have come a long way in terms of research and development. However there are still certain obstacles in terms of their efficiency and optimal use. Following are the challenges faced by the designer.

- The renewable energy sources, such as solar PV and FCs, need innovative technology to harness more amount of useful power from them. The poor efficiency of solar is major obstruction in encouraging its use.
- The manufacturing cost of renewable energy sources needs a significant reduction because the high capital cost leads to an increased payback time.
- It should be ensured that there should be minimal amount of power loss in the power electronic devices.
- The storage technologies need to increase their life-cycle through inventive technologies.
- These stand alone systems are less adaptable to load fluctuations. Large variation in load might even lead to entire system collapse.

7. Conclusion

This paper gives an overview of hybrid renewable energy systems (HRES). Various aspects such as methodology, unit sizing and optimization, storage and energy flow management, are specifically reviewed. Future trends as well as challenges are also presented in the paper. The presented literature review facilitates interested researchers in design and power management of HRES.

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