Different Configurations and Technologies in PV-Wind based Hybrid Power System

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ABSTRACT

The wind and solar energy are omnipresent, freely available, and environmental friendly. The wind energy systems may not be technically viable at all sites because of low wind speeds and being more unpredictable than solar energy. The combined utilization of these renewable energy sources are therefore becoming increasingly attractive and are being widely used as alternative of oil-produced energy. Economic aspects of these renewable energy technologies are sufficiently promising to include them for rising power generation capability in developing countries. A renewable hybrid energy system consists of two or more energy sources, a power conditioning equipment, a controller and an optional energy storage system. Research and development efforts in solar, wind, and other renewable energy technologies are required to continue for, improving their performance, establishing techniques for accurately predicting their output and reliably integrating them with other conventional generating sources. The aim of this paper is to review the current state of the design, operation and control requirement of the hybrid energy base power systems with conventional backup source i.e. diesel or grid. This Paper also highlights the future developments, which have the potential to increase the economic attractiveness of such systems and their acceptance by the user.

Keywords: Solar energy; Wind energy; Hybrid renewable energy system

I. Introduction

One of the most promising applications of renewable energy technology is the installation of hybrid energy systems in remote areas, where the grid extension is costly and the cost of fuel increases drastically with the remoteness of the location [1]. Recent research and development in Renewable energy sources have shown excellent potential, as a form of supplementary contribution to conventional power generation systems [2]. In order to meet sustained load demands during varying natural conditions, different energy sources and converters need to be integrated with each other for extended usage of alternative energy. The field of solar–wind has experienced a remarkable growth for past two decades in its widespread use of standalone to utility interactive solar–wind systems [3].

However, a drawback, common to solar and wind options, is their unpredictable nature and dependence on weather and climatic changes, and the variations of solar and wind energy may not match with the time distribution of load demand. This shortcoming not only affects the system's energy performance, but also results in batteries being discarded too early. Generally, the independent use of both energy resources may result in considerable over-sizing, which in turn makes the design costly. It is prudent that neither a stand-alone solar energy system nor a wind energy system can provide a continuous power supply due to seasonal and periodical variations for stand-alone systems. Fortunately, the problems caused by the variable nature of these resources can be partially or wholly overcome by integrating these two energy resources in a proper combination, using the strengths of one source to overcome the weakness of the other.

Autonomous wind systems (in spite of the maturity of state-of-the-art) do not produce usable energy for a considerable portion of time during the year. This is primarily due to relatively high cut-in wind speeds (the velocity at which wind turbine starts produces usable energy) which ranges from 3.5 to 4.5 m/s. In decree to overcome this downtime, the utilization of solar PV and wind hybrid system is urged. Such systems are usually equipped with diesel generators to meet the peak load during the short periods when there is a deficit of available energy to cover the load demand. Diesel generator sets, while being relatively inexpensive to purchase, are generally expensive to operate and maintain, especially at low load levels. [4,5]. The significant characteristics of HRES are to combine two or more renewable power generation technologies to make proper use of their operating characteristics and to obtain efficiencies higher than that could be obtained from a single power source [6]. Fig. 1 presents a basic component of solar–wind hybrid renewable energy system.

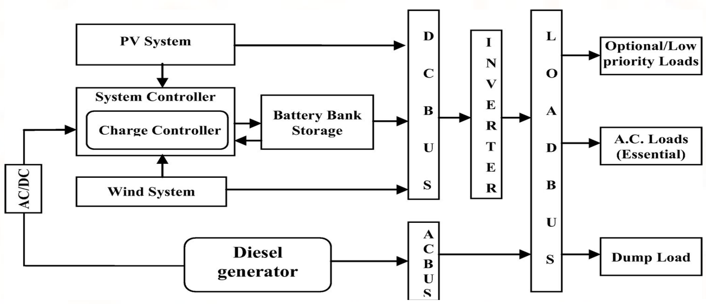

Fig. 1. Basic component of solar–wind hybrid renewable energy system.

II. Modelling the components of HRES

Literature review reveals that over the last decades, HRES applications are growing rapidly and HRES technology has proven its competitiveness for remote area applications. It is observed that approximately 90% of studies reported are on design/economic aspects of HRES. However, fewer studies were reported on control of HRES. It is expected that within the next few years HRES becomes competitive with utility grid power for wide spread distributed applications. Hence, there is a need to investigate potential and performance of PV and wind energy system to calculate level of penetration in existing networks of developed or developing countries in order to improve quality of power supply. Many researchers work on different mathematical modeling for wind energy conversion. Arifujjaman, Iqbal, Quaicoe, and Khan (2005) has worked on small wind turbine by controlling horizontal furling scheme. In this section modelling of different components of HRES system is described.

A. Modelling of Wind System

The mathematical modeling of wind energy conversion system includes, wind turbine dynamics and generator modeling. Considered here for review a three-blade, horizontal-axis, and maintenance free wind electric generator is installed. It converts wind energy into electrical energy. The wind power generation from the turbine can be predicted from the wind power equation discussed here as under.

The wind turbine is characterized by non-dimensional performance as a function of tip speed ratio. The output of mechanical power captured from wind by a wind turbine can be formulated as

$$Pa = \frac{1}{2}\rho\pi r^2 \mathrm{C_p}(\lambda, \beta)\mathrm{V_w^3} \qquad (1)$$

where, πr^2 is the rotor swept area, $\mathrm{C_p}$ is the power co-efficient, λ is the tip speed ratio, β is the pitch angle while $\mathrm{V_w}$ being the wind speed. The tip speed ratio λ can be described as:

$$\lambda = \frac{r\Omega}{V_w} \qquad (2)$$

Using this model the system response to a recorded wind gust is investigated by calculating the generator current, the rectifier current, the load current, the battery charging current, and the battery voltage.

B. Modeliing of PV System

Solar energy conversion system depends upon the solar cell and photovoltaic module. The mathematical modeling of solar–photovoltaic system is discussed here as under.

The ideal equivalent circuit of a solar cell consists of a current source in parallel with a diode. The output terminals of the circuit are connected to the load. Ideally the voltage current equation of the solar cell is given by

$$I = I_{PH} - I_D - I_{SH} \qquad (2)$$

I_{PH} (photo-generated current) is also called as I_L (light current) which refers to direct current generated by photovoltaic effect. Whereas I is the output current of the cell.

From Shockley's diode equation;

$$I_D = I_0\left[\exp\left(\frac{V + IR_S}{nV_t}\right) - 1\right] \quad (3)$$

Where;

$$V_t = \frac{kT}{q} \quad (4)$$

The power–voltage (P–V) characteristic of a photovoltaic module operating at a standard irradiance of 1000 W/m and temperature of 25 °C shown in Fig. 2.

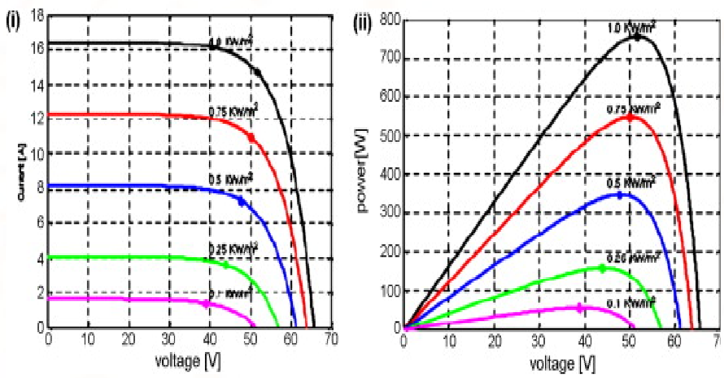

Fig. 2. (i) *I–V* characteristics of PV module and (ii) *P–V* characteristics of PV module.

C. Modelling of Diesel Engine

To attenuate shortfalls in energy production during periods of poor sunshine, photovoltaic systems require a backup diesel generator for increased system availability and minimum storage requirements. The choice of diesel generator depends on type and nature of the load. To determine rated capacity of the engine generator to be installed, following two cases should be considered:

1. If the diesel generator is directly connected to load, then the rated capacity of the generator must be at least equal to the maximum load, and

2. If the diesel generator is used as a battery charger, then the current produced by the generator should not be greater than CAh/5 A, where CAh is the ampere hour capacity of the battery.

Table 1 gives summary of modeling method of HRES.

Table – 1: Summary of modeling method of solar wind HRES

Author	Objective	Technique	Conclusions
Marchetti [42] **Consoli [43]**	Mathematical moldelling of HRES Long term modelling of HRES	Analytic Method MATLAB Simulink	Gave a mathematical approach to the environment statistical factor. 1. The system integrates different kind of generator and by traditional electric energy plant. 2.Estimated the long term performances of hybrid system for electric energy production 3. Model result shows a fuel consumption reduction of 64% in case of full DC configuration and about 72% in AC configuration
Rahman and Chadid	Optimal design of hybrid wind-solar system	Linear programming	1. Reduce the average production cost of electricity while meeting the load constraint 2.Environmental factors are considered both for the design and operation phases.
Ghali	Model of HRES based on LPSP	Loss of power supply probability	1. The probability density function of the storage is obtained and battery size is calculated the system

			reliability. 2. Changing the number of PV modules is not much effective in dropping the storage capacity required
Kellog	Generation unit sizing and cost analysis for PV/ wind system	Numerical Algorithm	1. Optimum generation capability and storage required is determined for a stand-alone, wind, PV, and hybrid wind PV system for an experimental site in Montana with a typical residential load 2. The hybrid combination of wind and solar generation makes the system more reliable
Gupta	Modeling of HRES for off grid electrification of cluster of villages	LINDO software version 6.1	Based on demand and potential constraints cost function is minimized.

III. Optimum sizing of HRES

Before setting up or installation of a new HRES, it is essential sizing using intuitive method of the individual components to obtain the initial capital investment cost and feasibility study [7]. Unit sizing is basically a method of determining the right practical sizing of the HRES components by minimizing the system cost [8] while maintaining system reliability. The correct sizing is to determine the wind generator capacity (size and number of wind turbines), the number of PV panels and number and capacity of battery banks needed for the standalone system. Note that it is important to maintain optimum resource management in a hybrid generation system in order to avoid wrong sizing. Over sizing the system components will increase the system cost whereas under sizing can lead to failure of power supply to fulfill the load requirements [8].

Optimization techniques for PV–Wind HRES in general, are used to provide the best system sizing with minimum cost.

Many techniques are used for this purpose, but the most popular models are revised in this chapter, namely Graphic Construction, Probabilistic, Iterative and Artificial Intelligence optimization techniques.

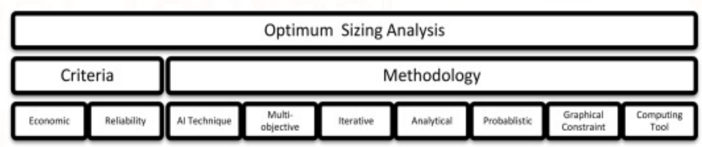

Fig. 4. Optimum sizing analysis of solar wind hybrid renewable energy system HRES.

Fig. 4. Shows the different optimum sizing analysis of solar wind hybrid renewable energy system HRES. Some of the important sizing techniques are to be discussed in the following sub section.

IV. Optimization Technique Based on Software Technology

There are many software tools that are capable to assess the renewable energy system performance for pre-defined system configurations. These include HYBRID 2, PVSYST, INSEL, SOLSIM, WATSUN-PV, PV-DESIGNPRO, RAPSIM, PHOTO, SOMES, HOMER, RAPSYS, RETScreen, ARES, and PVF-chart. Out of all these software tools only two (SOMES and HOMER) are exactly relevant to this investigation, because these two software are capable of providing optimal design of hybrid system. Furthe there are some artificial techniques are used to find the optimum size of the HRES system. These are:

A. Particle swarm optimization.

The particle swarm algorithm was first presented by Kennedy and Eberhart (1995) as an optimization method to solve non-linear optimization problems. This procedure is inspired by certain social behavior. For a brief introduction to this method, consider a swarm of p particles, where each particle's position represents a possible solution point in the design problem space D. Every single particle is denoted by its position and speed; in an iterative process, each particle continuously records the best solution thus far during its flight.

Sensitivity study is also carried out to examine the impacts of different system parameter on the overall design performance. Sizing of solar–wind renewable energy system is done by Sanchez et al. [47] and evolutionary computation technique called PSO is used with the cost of system as an objective function. PSO algorithm is used by Ardakani et al. [48] for optimal sizing of system's component. As a result the optimum number of pv modules, wind turbine and battery along with inverter capacity is obtained.

B. Linear programming method

This is a well-known popular method used by number of researchers to find the optimum size of renewable energy systems. A very good explanation and insights into how linear programming (LP) method can be applied to find the size of wind turbine and PV system in a PV–wind hybrid energy system is detailed out in Markvast (1997). The method employs a simple graphical construction to determine the optimum configuration of the two renewable energy generators that satisfies the energy demand of the user throughout the year. It is essential to note that method does not include battery bank storage and diesel generator. LP method was used in Swift and Holder (1988) to size PV–wind system, considering reliability of power supply system. The reliability index used is defined as the ratio of total energy deficit to total energy load. Other applications of this method are available in Chedid and Rahman (1997) and Ramakumar, Shetty, and Ashenayi (1986).

C. Genetic algorithms

Genetic algorithms are an adequate search technique for solving complex problems when other techniques are not able to obtain an acceptable solution. This method has been applied in Tomonobu, Hayashi, and Urasaki (2006), Dufo-Lopez and Bernal-Augustin (2005), and Shadmand and Balog (2014). The works reported in these papers use the hourly average metrological and load data over a few years for simulation. In reality, the weather conditions are not the same every day and in every hours of the day. Therefore, under varying every hour and every day weather conditions, the optimum number of facilities to use the hourly average data may not be able to be supplied without outages over a year. In such situations, the use of genetic algorithm method has been found most suitable.

D. Neural

Neural network is an interconnected group of artificial neurons that uses a mathematical model or computational model for information processing based on a connectionist approach to computation. Fidalgo et al.applied artificial neural network (ANN) based approach for applying preventive control strategies for a large hybrid renewable energy system. ANNs are an essential part which is better than customary statistical methods in the dynamic security pattern class and also evaluates the degree of security. Jifang et al. proposed a neural network control strategy for multi-energy common DC bus hybrid power supply by analyzing the distinctiveness of solar energy, wind energy. Levenberg–Marquaret algorithm linked to neural network is used and momentum factor is introduced in the training. Duang et al. develop a hybrid model for an hourly forecast of PV wind renewable energy system and used computational intelligence of PSO for computing different definitions of the forecast error.

V. Conclusions

The hybrid energy systems are recognized as a viable alternative to grid supply or conventional, fuel-based, remote area power supplies all over the world. The literature review reveals that, renewable energy based low emission hybrid systems are not cost competitive against conventional fossil fuel power systems. However, the need for cleaner power and improvements in alternative energy technologies bear good potential for widespread use of such systems.

Moreover, the rural households in industrialized and less developed countries attach high value to a reliable, limited supply of electricity. Community facilities such as rural hospitals, schools, telecommunication and water pumping stations can contribute significantly to the welfare of people and rural development. While it is recognized that technology can only be one aspect of community development, the renewable energy systems have demonstrated the potential to provide support in some of the basic infrastructure needs in remote and urban areas for different application.

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