Optimization Techniques of Hybrid Renewable Energy System: A Review

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1. Introduction

The term renewable energy is energy derived from a broad spectrum of resources, all of which are based on self-renewing energy sources such as sunlight, wind, flowing water, the earth's internal heat, and biomass such as energy crops, agricultural and industrial waste, and municipal waste. These resources can be used to produce electricity for all economic sectors, fuels for transportation, and heat for buildings and industrial processes [1].

Germany has new targets for renewable energy by 2020: to increase the share of renewable energy in power generation sector from 12% (2006) to 25-30%, in heating sector from 6% (2006) to 14%, in fuel sector from 6.6% (2006) to 17% i.e. from 8% (2006) to 18-19% share of renewable of final energy consumption (FEC) till 2020. Long-term target is 50% share of FEC in 2050 [2]. Renewable energy contributes as much today to US energy production as nuclear power (10%) [1]. The Chinese market has been hosted in anticipation of the country's new Renewable Energy Law, which entered into force 2006. As a result nearly 500 MW of new wind generation capacity was installed in 2005. This brings China up to 1260 MW of capacity, passing the 1000 MW capacity which is often deemed critical for sustained growth [3].

In recent years, hybrid renewable power generating setups i.e. PV (Photovoltaic)-wind-battery or PV-wind-diesel are getting popularity for small remote applications because they give continuous uninterruptable power even in case, that any one of these fail to give power due to some bad environment conditions. Different improvements have been done in all the sectors to improve the overall efficiency of renewable energy setups such as use of sun-tracking system and/or use of reflectors to get maximum amount of light on solar panel, use of variable speed generator to get constant voltage and frequency output from even a fluctuating speed wind turbine, enhancement of power quality by using better battery energy storage system, and/or use of better control algorithm (i.e. Fuzzy logic) [4] and better optimization and simulation software.

This paper reviews optimization technologies to be integrated or embedded into existing and future hybrid renewable energy setups. Thereafter, available power electronic interface solutions for each renewable source, available storage technologies, hybrid operation of renewable sources, various control systems, as well as their requirements will be discussed in detail.

2. Optimization in Hybrid Renewable Energy

PV-diesel, PV-wind, PV-wind-diesel, and wind-diesel hybrid systems with energy storage in batteries have been studied by various authors. These systems have been installed for a number of decades, although their systems would be substantially improved if optimization methods were applied [5]. Figure 1 shows solar wind-battery hybrid system [6].

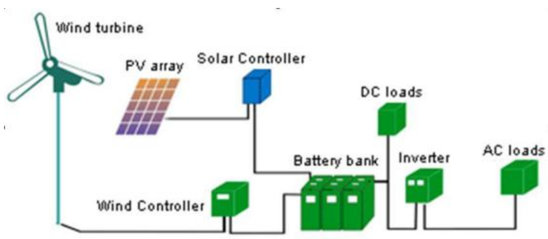
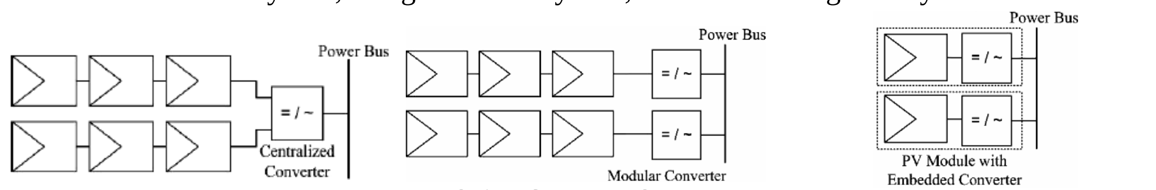


Figure 1: Solar-Wind-Battery Hybrid System

Capital costs for photovoltaic panels have decreased from more than $50/W in the early 1980s to about $5/W today, energy costs have declined from about $0.90/kWh in 1980 to about $0.20/kWh. Although this is still higher than the cost of conventional base load electricity, but different research Laboratories (i.e. NREL) and researchers in government universities, and industry are working together to reduce production costs. Their efforts are focused on developing more efficient semiconductor materials and device designs, while expanding production capacity, increasing production rates, and improving product quality [1]. On the other hand by using solar tracking system and reflectors, maximum energy from sun can be collected [6]. It is estimated that installing roof integrated PV systems and/or Façade integrated PV systems could generate up to 25% of the total electrical energy demand. Consequently, it is expected that building integrated PV capacity will be 50% of world installation by the year 2010 [7].

PV panels are generally connected to the power bus via a power electronic converter. In general, power electronic interface for PV applications are classified into three main groups i.e. centralized converter system, string converter system, and module integrated system.



(a) Centralized Converter System (b) String Converter System (c) Module Integrated Converter System

Figure 2: Power Electronic Interface for PV Applications

In the second approach, each string has its own inverter, and consequently, design flexibility is higher than the first one. Module integrated system is the most flexible and promising topology for PV applications. Here, each PV module is equipped with an embedded converter. Therefore, plug-in operation of this system and future capacity expansion is easily possible. Different converter topologies are suggested for this system. They are generally classified into three groups, in terms of the direct current (DC) link configuration [7]:

- Module integrated converter, with a constant DC link;
- Module integrated converter, with a pseudo DC link;
- Module integrated converter, without DC link.

Wind power systems convert the kinetic energy of the wind into other forms of energy such as electricity. Rapid progress in this technology has reduced costs until they are competitive with those of conventional power. Capital costs have declined from about $2.2/W in the early 1980s to less than $1/W today. Energy costs have decreased from about $0.40/kWh to as low as $0.04-$0.06/kWh today in areas with good wind resources [1]. Power extractable, using a wind turbine, is directly proportional to Power coefficient Cp,

$$P= (Cp*\rho*\pi*R^2*v^3)/2$$

Cp: power coefficient, ρ: air density, R: blades radius and v: wind speed in the direction of turbine. Whereas Cp is non-linear function of tip speed ratio λ. Tip speed ratio is a function of wind turbine angular speed ω. Variable speed utilization of wind turbines introduces the capability of maximum power point tracking (MPPT) operation, by means of controlling the tip speed ratio λ at its optimum value, at the cost of additional power electronics [7].

Reference [3] shows that wind power generation and power consumption during the day are strongly not correlated. To improve the energy storage systems based on compressed air storage can be used to balance the wind profiles. One of the examples of such type of storage is compressed air energy storage (CAES) in Salt Caverns as shown in figure 3 [8]. Today and future tendency is to build adiabatic storage equipment with high compressor outlet temperature and high efficiency. The next stage in the development will be to optimize the overall system together with the tasks of a CAES.

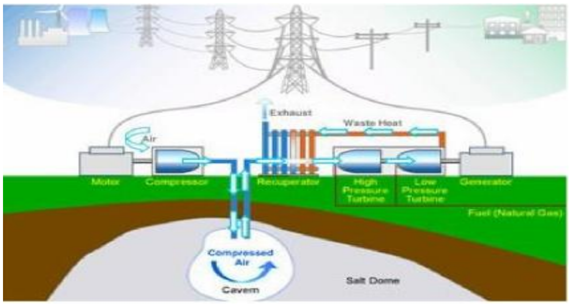


Figure 3: Compressed Air Energy Storage in Salt Caverns

On the other hand, enhancements of power quality by battery energy storage system (BESS) have become promising in the demand side because some industrial products require higher power qualities. They have risks to suffer severe damages by small voltage perturbation. Moreover, preparation against blackout is another quality issue. Similarly, BESS can be a good emergency power supply. Since BESS usually operates daily without noise and emission, smooth and secure startup is ensured, if sufficient energy is stored. Among different types of introduced batteries, NAS (sodium-sulfur) battery seems to be most promising with overall efficiency of 77.8% for 1466 days [9]. The storage of energy in hydrogen is based on the conversion of DC electricity into hydrogen by means of an electrolyzer, storing the hydrogen generated and, whenever necessary, obtaining DC electricity from the hydrogen by means of fuel cells. However, the current cost for this technology, as well as the low energy efficiency (about 25-35% of round trip efficiency compared to about 80% for batteries), still make this storage system economically impractical [5].

Distributed power is modular electric generation from relatively small generating systems ranging from less than a kilowatt to tens of megawatts and located at or near consumer sites. With distributed power, homes and businesses could produce power using technologies such as fuel cells, photovoltaic systems, wind turbines, biomass based generators, micro turbines, engine/generator sets, and electric storage systems. Excess power could be sold to the grid adding to grid capacity and consumers could obtain power from the grid when needed or desired [1].

In hybrid systems with batteries and without diesel generators, the dispatch strategy is very simple. The battery charges if the renewable energy is in excess after meeting the demand, and the battery discharges if the load exceeds the renewable energy. However, the control strategies of a hybrid system can become very complex if the system includes a diesel generator and batteries, as it is necessary to determine how the batteries are charged and what elements (batteries or diesel generator) have priority to supply energy when the load exceeds the energy generated from renewable sources. Different authors used different techniques to control the overall system for example [10] applied neural networks to the control strategies of power PV–diesel systems. In 1996, [11] improved the control strategies introducing new parameters that have become of great importance in the control strategies of the software tools HYBRID2, HOMER, and HOGA. The critical discharge power (Ld) is the value from which the net energy (that demanded by the charges minus that supplied by the renewable sources) is more profitable when supplied by means of the diesel generator than when supplied by means of the batteries (having previously been charged by the diesel generator). The authors propose four control strategies:

- Frugal dispatch strategy: if the net demand is higher than Ld, the diesel generator is used. If it is lower, the batteries are used.
- Load following strategy: the diesel generator never charges the batteries.
- Set point strategy: the diesel generator is on at full power, attempting to charge the batteries until the set point of state of charge is reached.
- Operation strategy of diesel at maximum power for a minimum time (charging the batteries).

Similarly, variable speed operation and direct drive generators have been the recent developments in wind turbine drive trains. Compared with constant speed operation, variable speed operation of wind turbines provides 10-15% higher energy output. In [12] focused on the improvement of overall efficiency in the wind power generation system (WPGS) by restricting the operation of the wind turbine to the optimal efficiency region, using a control strategy based on two chattering-free sliding mode controllers (SMCs). One of the designed SMCs performs wind turbine speed control, while the other controls the generator torque. The control strategy is designed and simulated by using Matlab/Simulink.

3. Simulation and Optimization Tools

Different long term performance and economic analysis software can be used to predict the performance of hybrid power setup. For example HYBRID2 is such type of software based on Probabilistic/time series model. Reference [13] described the latest advances in PV-wind-diesel-batteries hybrid systems, using data from hybrid systems in various locations in the world. They used HYBRID2 tool for their study setups. Reference [14] presented a simulation work, using Simulink, of a real hybrid PV-diesel-battery system located in Alaska, comparing it with a system with only a diesel generator and another diesel-battery system to supply energy for the same load. The result obtained indicates that the system with only a diesel generator had a lower installation cost, but higher operation and maintenance costs; additionally, it was less efficient and released more contaminating emissions than the PV-diesel-battery system. They used HOMER software for comparison of results.

Numerous papers indicate that optimum design can be carried out by minimizing the net present cost (NPC: investment costs plus the discounted present values of all future costs during the lifetime of the system) or by minimizing the levelized cost of energy (LCE: total cost of the entire hybrid system divided by the energy supplied by the hybrid system). Additionally, restrictions are usually included that are applied to reliability, evaluating the same by means of different parameters like loss of load probability (LOLP), loss of power supply probability (LPSP) or unmet load (UL). For example [15] carried out the optimization (minimization of NPC) by means of HOMER in a PV–wind-diesel-battery system in Australia. In addition, simulations of the optimum system are carried out, using HOMER and HYBRIDS for this purpose, comparing the simulations obtained with each of the two programs.

HOMER (Hybrid Optimization Model for Electric Renewables), developed by NREL (National Renewable Energy Laboratory, USA), is the most-used optimization software for hybrid systems [16]. HYBRID2 was developed by the Renewable Energy Research Laboratory (RERL) of the University of Massachusetts [17]. It is hybrid system simulation software. HOGA is a hybrid system optimization program developed by the Electrical Engineering Department of the University of Zaragoza (Spain) [18]. The optimization is carried out by means of genetic algorithms, and can be mono-objective or multi-objective. TRNSYS (Transient Energy System Simulation Program) is energy system simulation software [19], developed in FORTRAN in 1975 by the University of Wisconsin and the University of Colorado (USA). It was initially developed to simulate thermal systems, but over the years, it has also become a hybrid system simulator, including photovoltaic, thermal solar, and other systems. Similarly some other simulation and designing software are also available i.e. INSEL, ARES, RAPSIM, SOMES and SOLSIM.

4. Conclusion

Several independent entities have recently developed scenarios indicating that renewable energy will play a major role in the energy mix for the world, with increasing impacts beginning as early as 2000-2010 and major impacts by 2050. Renewable energy will have most closely the direct impact on rural economy, community planning and lifestyles, international socioeconomic equity, environment. This paper has included the most relevant papers on the design, simulation, control, and optimization of the hybrid systems. Many researches and developments in this area have been done. However the main areas for further development are to get the best efficiency from a wind turbine, aerofoil design optimization for better performance, variable speed generator and power electronics control. Similarly, material development for PV solar panels and optimal design of hybrid system to get maximum energy from the sun throughout the year is necessary. Some design and simulation tools that have been developed over the past few years have been briefly described. By using these software and tools, we can simulate the optimization techniques to achieve better efficiency.

Acknowledgments

The authors would like to thanks Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia for providing facilities and financial support of Research University Operation of Pattern Recognition Research Group No. UKM-OUP-ICT-36-186/2010.

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