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Review Article

Renewable Energy Systems for Power Generation-A Review

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Abstract: Energy is an imperative contribution for social and commercial growth. In recent years the energy demand has been increased rapidly with wide-ranging activities in domestic, agricultural, industrial sectors. For various reasons, the demand is particularly more in the developing countries. As the fossil fuel is getting exhausted day by day, it has become necessary for the power and energy engineers to look out for the renewable energy sources such as sun, wind, ocean, biomass and geothermal as sustainable, environmental friendly and cost effective. The renewable energy resources like geothermal and ocean are not cost effective and not viable to transport the produced energy to farther distances. The possible renewable energy resources are sun and wind, but they are not available all the time-throughout the year which causes problems in generating power. In order to overcome this, we concentrate on the area of hybrid renewable energy systems which sustain lower cost and higher reliability. The main aim of this study is to review the research on the unit sizing, energy management and optimization of the hybrid renewable energy systems.

Keywords: Control strategy, hybrid energy, optimization, solar, wind

INTRODUCTION

Increased industrialization and household energy utilization has resulted in the demand of energy mainly electricity. The lack of non-renewable energy resources increase the fuel cost and dangerous emission from the burning of fossil fuels from power generation is unsustainable. Energy is a fundamental constitute of economical development and also essential for increasing population. Hybrid electricity generation system is far more reliable than a single source of energy. Isolated power systems using renewable energy sources like sun, wind, hydro, biomass etc. can be used to supply electricity for unreachable locality where the grid connection is not possible and they can be cost-effective in the long run.

The GA based optimization with two point estimate method is used to optimize the size of the wind, PV and battery storage hybrid power system. A smart grid is developed for matching the renewable energy with HVAC load with higher efficiency and lesser cost (Arabali *et al*., 2013). A hybrid wind-PV-battery power generation system is developed with the aid of a new sizing procedure. The main aim of this procedure is to find optimal number of wind turbines, PV panels together with optimum battery capacity at minimum cost with good accuracy (Hacaoglu *et al*., 2009).

A combination of PV, electrolyzer, batteries and fuel cell hybrid system was designed. The system components were optimized by HOMER software. The comparison result shows the different load profile can manage the demand with minimum cost (Silva *et al*., 2011). A stand-alone hybrid PV, wind and battery system was designed by applying elitist genetic algorithm. The optimization method is to be applied for sizing of the system components, which can satisfy the total electric demand with reasonable cost (Abbes *et al*., 2013). A small autonomous renewable power generation system was designed by using hybrid TS and SA optimization method. From this method, the optimal sizing components were found like PV, wind turbine, biodiesel generator, diesel generator, fuel cell and battery size. The performance of the system can be investigated by applying the hybrid TS-SA method as well as individual SA and TS method. The result has been found in terms of convergence and quality with low cost (Katsigiannis *et al*., 2012). The novel methodology has been introduced based on the process of integration principle. Using optimal design configuration, the minimum battery capacity of the system has to be found at minimum cost with high reliability (Sreeraj *et al*., 2010).

The combination of PV panels, wind turbine generators and battery storage system is designed based on multiple criteria which includes reliability, emission and cost. The improved particle swarm optimization

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algorithm is developed for different design scenarios (Wang and Singh, 2008). The renewable energy system based micro grid mainly focuses on the sizing, planning, operation and optimal design of a hybrid system. Four special types of power systems were compared and evaluated based on performance, environmental emission and cost. The analysis is carried out using HOMER software. The result shows the grid connected micro grid is economical than other energy systems (Hafez and Bhattacharya, 2012).

A stand-alone hybrid renewable energy system is more reliable and economical than a single energy system in remote areas. The different types of control strategies, optimization techniques, design and simulation of the hybrid systems were discussed (Bernal-Agustin and Dufo-Lopez, 2009). The hybrid solar-wind power system with battery storage system was employed with optimal sizing method based on genetic algorithm. The performance has been analyzed by applying power for a telecommunication relay station. The result demonstrates the performance of the system were good with minimum ACS (Yang *et al*., 2008).

This study aims to revise the researches that have so far been done on hybrid energy systems. It also focuses mainly on the unit sizing, energy management and thus optimizing the hybrid energy renewable systems.

OPTIMIZATION TECHNIQUES AND CONTROL STRATEGIES FOR RENEWABLE POWER SYSTEMS

Solar power generation systems: The PV system with MPPT techniques were employed to make maximum utilization of PV array. A modified variable step size incremental algorithm is used to track maximum output power with high speed and more accuracy (Liu *et al*., 2008). The large photovoltaic arrays were tracking maximum global power using novel algorithm combined with dc-dc converter under partially shaded state. Comparing with the conventional controller the tracking time is awfully less (Patel and Agarwal, 2008).

The parallel connected photovoltaic system with maximum power point tracking system is to be used for stand-alone applications. To reduce the power converter losses and improve the efficiency of the system, a bi-directional dc-dc converter was introduced (Gules *et al*., 2008). A stand-alone PV system is operated based on a fuzzy logic and dual maximum power point tracking controller. It can keep the system at maximum power operating point. This control scheme reduces the steady state oscillation and attains stable operation of the system (Nabulsi and Dhaouadi, 2012).

The PV system with distributed MPPT was introduced to overcome the drawbacks of partial shading and module mismatching. The stability and steady state behavior were analyzed from a small signal ac and dc model which promises high efficiency and more reliability of the PV system (Femia *et al*., 2008). The PV system is connected to the grid based on single phase three level diode clamped inverter topology with free of output transformer, which not only reduces the size, cost and weight, it can also improve the overall efficiency of the system (Gonzalez *et al*., 2008). The transformerless photovoltaic inverter technology was introduced based on a new ac by-pass circuit with H-bridge. This technology has been used to reduce the leakage current and improves the efficiency of the system. It can be proved by comparing the existing technologies (Kerekes *et al*., 2011). The PV system with solar tracking is to reduce the losses by applying optimization of the variables. The different types of algorithms have been applied to design the optimal PV system. Using these algorithms the performance of the system has been tested. The obtained result shows the differential evolution is the best optimization technique for PV system (Gomez-Lorente *et al*., 2012).

A stand-alone PV system with battery is designed with optimum capacity solar array by genetic algorithm. It can improve the performance of the system with high reliability and more economy (Ling and Son, 2010). The PV modules are connected in the sequence, under non ideal conditions the degradation of system performance have been discussed. A suitable structure of an individual power interface for photovoltaic module has improved the performance of the system (Xiao *et al*., 2007).

Wind power generation systems: A Genetic algorithm based optimization technique is proposed for a large DC offshore wind farm to find optimum network design for minimizing the cost and increasing the reliability (Zhao *et al*., 2004). The inverter based wind power generation system can extract maximum wind power using Advanced Hill climb searching method. The intelligent memory method is used with an on-line training process to control the inverter for maximum wind extraction (Wang and Chang, 2004). The performance of the wind turbine is to be evaluated by three different objectives like vibration of tower, drive train and wind power output. The evolutionary strategy algorithm can solve the multi objective optimization problems (Kusiak *et al*., 2010). The wind turbine blades are optimized by genetic algorithm to yield maximum energy at minimum cost, where the two different sizes of wind turbines were analyzed (Eke and Onyewudiala, 2010).

The variable frequency wind generators were designed using frequency control strategy based fuzzy logic control. A fuzzy logic supervisor is to control the generator torque and reduce the computation time of the system (Mokadem *et al*., 2009). A variety of wind power systems with different generators, power electronic converters were discussed and also special features were compared. The possible methods for improving the performance of the wind turbine systems using power electronics technologies have been discussed (Chen *et al*., 2009).

A variable frequency transformer with a PID damping controller can be used to reduce power fluctuation for off shore wind farm which is connected with onshore power grid. The frequency and time domain based models were subjected to disturbance conditions and evaluate the effectiveness of the control scheme (Wang and Chen, 2011). A suitable control strategy has been introduced for both variable and fixed speed wind turbine systems. The fully controlled frequency converter is able to control the reactive power which can provide maximum power to the grid. A real wind speed data is used to evaluate the performance of the system (Muyeen *et al*., 2010). The MPPT controller with an adaptive compensation control has been introduced for a micro scale wind system. This control system is used to capture more wind power during variation of wind velocity and also improves the dynamic response of the system. The MPPT controller is used to increase the efficiency, instead of two-stage converter (Pan and Juan, 2010). The matrix converter based wind power system can adjust the terminal frequency and also reactive power to regulate the power factor. The MPPT algorithm has been used to control the shaft speed to capture maximum power from wind (Barakati *et al*., 2009).

Hybrid power generation systems: The current status of optimization, control technologies and simulation for stand- alone wind-solar hybrid power system with battery storage were reviewed. The research and development endeavor in this area is still required for improving the performance of the system (Zhou *et al*., 2010). The stand-alone ac linked photovoltaic/wind/fuel cell hybrid power system was designed for power management strategy of different energy sources and also the performance has been verified using real weather data and practical load demand (Wang and Nehrir, 2008). Large wind farms can be integrated with battery energy storage system for smooth output power. The control strategy is developed for optimal battery energy storage system. The actual wind farm data is used to test the effectiveness of the system (Teleke *et al*., 2009). Photovoltaic power generation system is combined with BESS can be absorbed and delivered real and reactive power to improve system stability and can also be economical. The real time control modes contain power factor correction, frequency droop response, output leveling, solar time-shifting and ramp rate control are also discussed (Hill *et al*., 2012). The combination of Photovoltaic, diesel with different battery backup has found an optimal solution which minimizes the energy cost. The sensitivity analysis shows the hybrid system is more economical than a diesel only system (Rehman and Al-Hadhrami, 2010). The solar-wind-hydro hybrid power system is used as a fuzzy optimization approach for solving the generation scheduling problem. The optimal generating schedule for each unit can be obtained by fuzzy set notations under an uncertain environment (Liang and Liao, 2007).

The recent research developers are using optimization algorithms for control problems, planning and design in the area of sustainable and renewable energy. Some researchers are using pareto-optimization techniques for solving multi-objective problems have been reviewed (Banos *et al*., 2011).

A stand-alone wind/solar/diesel hybrid power system with an intelligent power controller has been achieved fast and stable response for real power control. The improved ENN can control the pitch angle of wind turbine and solar system can be controlled by RBFN to achieve maximum power point tracking of the system (Lin *et al*., 2011). A new hybrid wind-solar power generation system was planned for isolated and remote areas. On line flux control is used to capture maximum wind power from the wind and draws maximum power from the solar by changing the duty cycle. With the use of MPPT the hybrid system can obtain high efficiency (Liu *et al*., 2010).

The combination of wind turbine, photovoltaic and battery storage system regulates power generation of each component by supervisory control. The dynamic performance is to be evaluated under the planned modes of operation (Kim *et al*., 2008). The hybrid solar-wind power system is modeled with the optimal sizing of the components by optimization methodology of ANFIS. This algorithm is compared with HOGA and HOMER software. This system can satisfy the LPSP and also meet the load requirement with lowest cost (Rajkumar *et al*., 2011). A small autonomous wind-solar-hydro power system was developed for remote areas. The optimal sizing of the system components were developed with the help of biogeography based algorithm. This method gives an excellent convergence property and also requires less computational time with minimum total cost of the system (Bansal *et al*., 2013). The solar-wind-SC hybrid power generation system with optimization of energy storage system was designed to minimize the operation cost and one-time investment cost using improved simulated annealing particle swarm algorithm. This algorithm is faster than the conventional one (Zhou and Sun, 2014).

Three different types of hybrid systems were introduced. The sizing optimization of these systems have been performed by using energy storage technology, where all the systems were compared and the result shows PV/Fuel Cell/Battery hybrid system configuration has reduced the cost and has increased the efficiency (Li *et al*., 2009). The hybrid PV with super capacitor storage power system was modeled for high power applications. The stabilization, robustness and dynamic problems can be controlled by reduced order mathematical model, which can improve the efficiency as well as power quality of the system (Thounthong, 2011). To improve the smoothing performance of the hybrid wind/PV/BESS a suitable control strategy has been introduced. A novel adaptive power control method for wind/PV power system and power allocation method for BESS can reduce the power fluctuations and can also regulate the output power of the system (Li *et al*., 2013). A combination of stand-alone PV/diesel/battery hybrid power system was introduced for reduce the LCC and also CO2 emission of the system. A computer language 'C' has been developed for analyzing the system components (Agarwal *et al*., 2013).

Table 1: Publications on cost minimization through optimal components sizing of hybrid systems

Authors	Year	PV	Wind	Battery	Hydro	Diesel	Fuel cell	Algorithm	Control strategy
Kim *et al*.	2008	✓	✓	✓					✓
Yang *et al*.	2008	✓	✓	✓				✓	
Hocaoglu *et al*.	2009	✓	✓	✓					✓
Li *et al*.	2009	✓		✓			✓	✓	
Teleke *et al*.	2009		✓	✓					✓
Liu *et al*.	2010	✓	✓						✓
Sreeraj *et al*.	2010	✓	✓	✓	✓				✓
Rajkumar *et al*.	2011	✓	✓	✓				✓	
Lin *et al*.	2011	✓	✓			✓			✓
Hong and Lian	2012	✓	✓			✓		✓	
Hill *et al*.	2012	✓		✓					✓
Johromi *et al*.	2012	✓	✓					✓	
Bansal *et al*.	2013	✓	✓		✓			✓	
Li *et al*.	2013	✓	✓	✓					✓
Abbes *et al*.	2013	✓	✓	✓				✓	
Agarwal *et al*.	2013	✓	✓	✓				✓	

Table 1 shows the Publications on Cost Minimization through Optimal Components Sizing of Hybrid Systems. The combination of PV/wind/battery energy system can be designed by modified steepest descent algorithm, which can find the optimal parameters with minimum total life cycle cost (Hennet and Samarakou, 1986). The elitist non-dominated sorting genetic algorithm has been employed for a stand-alone wind/PV power system for optimal sizing of the system components. The matching between supply and demand has been estimated which can maximize the CC and minimize the IC (Jahromi *et al*., 2012). A stand-alone PV/wind/diesel hybrid system was developed by Markov model based GA to determine the best size of the system component, which reduces the investment cost as well as CO2 emission of the power system (Hong and Lian, 2012).

CONCLUSION

The number of research papers that use single and multi-objective optimization methods to solve renewable energy problems has increased multifold in the recent years. This is mainly because of the energy demands and the ways to meet them in a natural, economical and unpolluted ways. This study provides a summary of the latest research on the development and the use of optimization algorithms for design and modeling of the components in the field of renewable and sustainable energy. Based on the collected weather data, the modeling of energy system components and battery storage system has been reviewed. The immense potential of hybrid renewable energy could meet the energy demand that increases the overall system reliability. Hybrid energy system can possibly solve not only the energy issues, but it can also ensure a green and sustainable planet.

Nomenclature:

ACS	= Annualized Cost of System
ANFIS	= Adaptive Neuro-Fuzzy Interference System
BESS	= Battery Energy Storage System
CO_2	= Carbon-dioxide
CC	= Correlation Coefficient
ENN	= Elman Neural Network
GA	= Genetic Algorithm
HOMER	= Hybrid Optimization Model for Electric Renewable
HOGA	= Hybrid Optimization by Genetic Algorithm
IC	= Inequality Coefficient
LCC	= Life Cycle Cost
LPSP	= Loss of Power Supply Probability
MPPT	= Maximum Power Point Tracking
PV	= Photovoltaic
RBFN	= Radial Basis Function Network
SA	= Simulated Annealing
SC	= Super Capacitor

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