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A Review on Unit Sixing, Optimization and Energy Management of HRES

Dipti
M.Tech Scholar, Electrical Engineering Department,
E-Max School of Engineering and Applied Research, Gadhauli, Ambala, Haryana, India

ABSTRACT
It has become imperative for the power and energy engineers to look out for the renewable energy sources such as sun, wind, geothermal, ocean and biomass as sustainable, cost-effective and environment friendly alternatives for conventional energy sources. However, the non-availability of these renewable energy resources all the time throughout the year has led to research in the area of hybrid renewable energy systems. In the past few years, a lot of research has taken place in the design, optimization, operation and control of the renewable hybrid energy systems. It is indeed evident that this area is still emerging and vast in scope. The main aim of this paper is to review the research on the unit sizing, optimization, energy management and modeling of the hybrid renewable energy system components. Developments in research on modeling of hybrid energy resources (PV systems), backup energy systems (Fuel Cell, Battery, Ultra-capacitor, Diesel Generator), power conditioning units (MPPT converters, Buck/Boost converters, Battery chargers) and techniques for energy flow management have been discussed in detail. In this paper, an attempt has been made to present a comprehensive review of the research in this area in the past one decade.

Keywords: *Battery energy storage systems, photovoltaic, renewable, solar, proportional integral regulator, power quality.*

I. INTRODUCTION

The rapid industrialization over the past three decades due to globalization, inventions in new technologies and increased household energy consumption of the urban population has resulted in the unprecedented increase in the demand for energy and in particular electricity. This has led to a huge supply–demand gap in the power sector. The scarcity of conventional energy resources, rise in the fuel prices and harmful emissions from the burning of fossil fuels has made power generation from conventional energy sources unsustainable and unviable. It is envisage that this supply–demand gap will continue to rise exponentially unless it is met by some other means of power generation. Inaccessibility of the grid power to the remote places and the lack of rural electrification have prompted for alternative sources of energy. The renewable energy resources, such as wind, sun, water, sea and biomass, have become better alternatives for conventional energy resources. Hybrid Renewable Energy Systems (HRES) is composed of one renewable and one conventional energy source or more than one renewable with or without conventional energy sources, that works in standalone or grid connected mode [1]. HRES is becoming popular for stand-alone power generation in isolated sites due to the advances in renewable energy technologies and power electronic converters which are used to convert the unregulated power generated from renewable sources into useful power at the load end. The important feature of HRES is to combine two or more renewable power generation technologies to make best use of their operating characteristics and to obtain efficiencies higher than that could be obtained from a single power source. Hybrid systems can address limitations in terms of fuel flexibility, efficiency, reliability, emissions and economics. A generalized model of HRES is illustrated with a block diagram in Fig. 1, where either one or both of the renewable sources (solar PV/wind) can be used in combination with back up devices, such as FCs, batteries, UCs or DG sets. Solar PV and wind systems are the primary sources of energy. This energy is available in abundance, but is intermittent in nature and site specific. To overcome this drawback, back up energy devices (secondary sources) are introduced into the system to supply the deficit power and to take care of transient load demands. The primary and secondary sources are connected to the dc bus through dc–dc converters to obtain regulated power output from the sources and to maintain a constant voltage at the dc bus. The converters for PV/wind system are usually a cascade of two dc–dc converters, one used for maximum power tracking and the other for voltage regulation. Similarly, dc and ac loads are connected to the dc bus through dc–dc and dc–ac converters respectively. This ensures regulated power supply to the loads throughout operation. The batteries and UCs are connected to the dc bus via bi-directional dc–dc converters for effective charging and discharging. DG sets are connected by means of ac–dc converters. The FC stack and electrolyzer need individual dc–dc converters for regulated power output and conversion. The entire system has one master controller and several slave controllers for different sources. The master controller operates in close co-ordination with all energy sources and slave controllers. It controls the switching action between the primary and back up energy sources depending on availability of power and prior set control logic. The voltage and current measurement of an individual power source are taken locally by respective slave controller and is relayed back to the master controller at each sampling instant. The slave controller also generates PWM signals for the dc–dc converter under its control and hence monitors the power regulation. The solid black arrows indicate the flow of energy from the sources to the dc bus and from dc bus to loads. The dotted arrow lines indicate the control action and information flow between the sources and controllers. This HRES ensures continuous and effective delivery of power to the loads. Solar Photovoltaic (PV) and wind energy which are renewable, site-dependent and non-polluting are potential sources of alternative energy. Nonetheless, standalone PV/wind systems can meet the load demand only for the time during which sunshine/cut-in wind speeds are available. Hence, HRES invariably includes backup energy storage systems to meet the load demand at any point of time. The elements of backup energy storage systems are either fuel cell (FC) or battery or diesel generator (DG) or ultra-capacitor (UC) or a combination of these sources. While batteries are most commonly used for this purpose, they typically lose 1–5% of their energy content per hour and thus can store energy only for short period of time [2]. The various possible hybrid system configurations can be designed based on availability of primary energy sources (PV and/or wind) onsite. Backup energy sources are complimentary in nature due to difference in capital and operating costs, power and energy characteristics and fuel flexibility. However, this review is focused mainly on PV based HRES due to space limitations. PV technology is a relatively new field of renewable energy that is rapidly expanding. The amount of power generated by a PV array depends on the operating voltage of the array and the maximum power point (MPP), which vary with solar insolation and temperature. MPP specifies a unique operating point on PV characteristic at which maximum possible power can be extracted. At the MPP, the PV operates at its highest efficiency. Therefore, many methods have been developed to track the MPP [3]. The output power of the solar module is highly affected by the sunlight incident angle and its efficiency can be improved if the solar module is properly installed at the optimum angle. Chen et al. [4] calculated the optimum installation angle for the fixed solar modules based on the genetic algorithm (GA) and the simulated-annealing (SA) method. Significant research on economic and environmental aspects of integrating the PV system with DG has been reported [5–8]. The DG backup for PV systems has gained popularity for quite long time as it is capable of supplying electric energy for 24 h, at low capital cost. However, increased fuel prices, intensive maintenance and harmful carbon emissions from DG sets have made them unsustainable and unattractive [9]. Moreover, the whole system efficiency decreases drastically when the DG has to be run lower than the rated output. UCs have also been suggested as back up devices for offering high energy density as compared to ordinary capacitors and high power density than batteries [10,11]. They also have high round trip efficiency (greater than 90%) and can support greater number of charge/discharge cycles. Over the time, FCs is replacing the DG as an alternative backup energy resource in the integrated PV systems. The major problems associated with FCs are the high cost of the membrane and catalyst as well as fuel availability [12]. However, the combination of the FC and the renewable energy source can provide a multifold benefit [13]. First, fossil fuel consumption would be reduced because of higher FC efficiency than DG, and second benefit would be reduction of power losses, since the FC power plant can be placed at or near the load center to take advantage of its low noise and emissions. Another important advantage in using FC is its fuel flexibility. However, the most common fuel used is hydrogen. Hydrogen can be derived from natural gas, ethanol, methanol, biogas, and coal gas, propane, naphtha or other similar hydrocarbons through reforming. This type of hybrid system is particularly useful in spaceship, transportation and stationary applications. Hydrogen prices are likely to drop in future to about double price of natural gas as hydrogen is becoming a commodity. The decisive economical factor is the effective cost per kWh. Today's FCs is already competitive in comparison to DG, offering a huge up-side potential with the expected cost decrease in hydrogen and cost increase in diesel. If the whole system is properly designed, then FC results in reduced maintenance effort and cost compared with a DG [14]. The review article discusses four main aspects in the subsequent sections, i.e. unit sizing and optimization of the HRES, modeling of the major components used in hybrid PV systems with FC, DG, Battery or UCas backup, modeling of power conditioning units, optimal energy flow management and at last the challenges faced by HRES and future trends that can help in improving the system. The sizing and optimization study is essential before setting up or installation of a HRES. It gives a fair idea of the size of the individual components and hence plays an important role in the initial capital investment. The modeling of components is highly significant in understanding the physical mechanisms and power generation ability of the components. It is useful for simulation studies. The optimal energy flow study devises techniques and schemes to operate the system at minimum cost but with high reliability. Lastly, the challenges bring forward the gaps in research areas and the discussion on future trends is vital for improving the overall technology of the HRES.

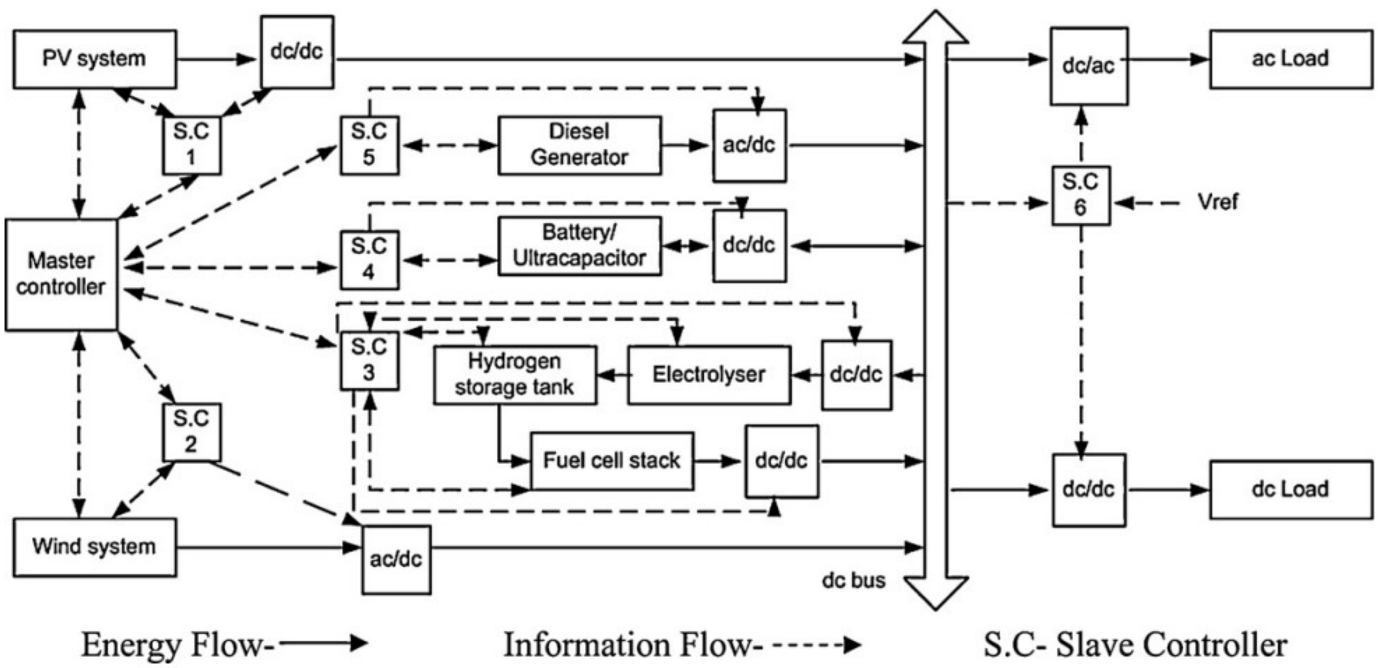

Fig.1. Generalized model of block diagram of hybrid renewable energy system

II. Unit sizing and optimization

Renewable energy sources essentially have random behavior and cannot have accurate prediction. Continuous sunny days give abundant PV power because of which the battery banks or hydrogen tanks are underutilized. On the other hand, cloudy days with continuous rain can discharge the batteries and hydrogen storage tanks well beyond the lower discharge limit. Therefore, the number of PV modules to be installed, the size of the FC, battery bank and hydrogen storage tanks need to be calculated carefully considering all extreme weather conditions. Unit sizing and optimization is basically a method of determining the size of the hybrid system components by minimizing the system cost while maintaining system reliability. Optimum resource management in a hybrid generation system is crucial to achieve acceptable cost and reliability level. These design objectives are usually conflicting with one another and thus a reasonable tradeoff between them is desirable. Over sizing the system components will increase the system cost whereas under sizing can lead to failure of power supply. Thus, sufficient care should be taken to design a reliable system at minimum cost. A classification chart that groups and classifies the various sizing procedures is illustrated in Fig. 2. This broad classification is based on the availability and non-availability of weather data, such as irradiance, clearness index and wind speed [15]. When weather data is available, conventional sizing approaches are used and are classified on the basis of concept of energy balance and reliability of supply. However, conventional techniques need long term meteorological data for sizing of PV systems, which may not be available in remote isolated sites. Thus, non-availability of weather data in remote sites has urged the researchers to look into Artificial Intelligence (AI) techniques, such as Artificial Neural Networks (ANN), Fuzzy Logic (FL), Genetic Algorithms (GA) or a hybrid of such techniques [16]. Conventional sizing methods are in use for more than two decades and give accurate results when actual weather data is available. One of the simple ways of sizing components is based on the concept of energy balance. The daily average available energy from the sun and the daily average load demand are balanced to determine the number of modules needed. The available energy from the sun can be determined from solar irradiance data. Sizing based on energy balance takes into consideration the path losses and efficiencies of the source, converters and controllers. Li et al. [17] proposed an algorithm to determine the minimal system configuration using an iterative technique based on energy balance. The optimal sizes of the system components for a hybrid PV/FC/Battery system producing onsite hydrogen were determined in [18]. Sizing of batteries were done by carefully choosing the days of autonomy, a vital parameter in battery sizing. FC and electrolyzer sizing were done taking marginal safety. Some of the sizing procedures in the literature consider the reliability of electricity supply as an important factor. This reliability is determined by estimating the loss of load probability (LOLP) which is the ratio between estimated energy deficit and the energy demand over the total time of operation [15]. Other similar concepts are loss of power probability (LOPP), loss of power supply probability (LPSP) and load coverage rate (LCR). Such sizing techniques are used in applications where a high degree of reliability is required. Ardakani et al. [19] used a reliability index called equivalent loss factor (ELF) for optimizing the size of the components in a hybrid wind/PV/Battery system. Xu et al. [20] proposed a strategy to minimize the total system cost subject to the constraint of LPSP using GA. Moriana et al. [21] also used LPSP as a reliability index for sizing the storage unit in a wind/PV system. Nelson et al. [22] considered an LPSP less than or equal to 0.0003 which corresponds to a loss of power of 1 day in 10 years for sizing the PV modules and hydrogen tanks in a wind/PV/FC system. In remote inaccessible sites, weather data collection is difficult. Hence researchers devised AI based techniques to size the PV systems. Mellit et al. [16] discussed various AI methods for sizing of PV systems. Some of the AI techniques are ANN, FL, GA or a hybrid of such methods. These methods can tolerate certain degree of error in the input data; generate fast results once trained from examples and model complex non-linear processes with ease. ANN is a collection of interconnected processing units where each incoming connection has an input value and a weight attached to it. The output is a function of the summed units. ANNs can then be trained with respect to data sets, and once trained, new patterns may be presented to them for prediction or classification. FL allows the application of a 'human language' to describe the problems and their fuzzy solutions. When input parameters are highly variable and unstable, fuzzy controllers can be used as they are more robust and cheaper than conventional PID controllers. Hybrid methods use a combination of two or more AI techniques for sizing the system. Mellit et al. [23] considered the latitude and longitude of the site as inputs and estimated two outputs based on an ANN model for sizing the PV system. The output parameters allowed successful sizing of the number of PV modules and batteries with a relative error less than 6%. Similar applications of various AI techniques in sizing and optimization of HRES are listed in Table 1. Sizing of the components is generally accompanied by optimizing the system components or other parameters, such as investment cost, output energy cost or consumption of fuel [29]. Optimization is generally carried with the objective of minimizing the Net Present Cost (NPC) or by minimizing the Levelized Cost of Energy (LCE) [30]. Wang and Singh [31] proposed a constrained mixed-integer multi objective particle swarm optimization (PSO) method to minimize the system cost and simultaneously maximize the system reliability. The unit sizing and optimization by minimizing the NPC using HOMER for a hybrid PV-Wind-Diesel-Battery system and hybrid PV-Diesel-Battery system has been carried out in [32] and [33], respectively. Ashok [34] used non-linear constrained optimization techniques to minimize the annual operating cost for a hybrid PV-Wind-Diesel-Battery system including a micro-hydro. The renewable energy fraction was calculated to be 100% and the need for DG was hence eliminated. Several simulation tools are readily available today in order to model, size and optimize the hybrid system. An overview of such simulation and/or optimization tools is discussed in [29, 30]. A brief description of a few popular simulation tools is listed in Table 2.

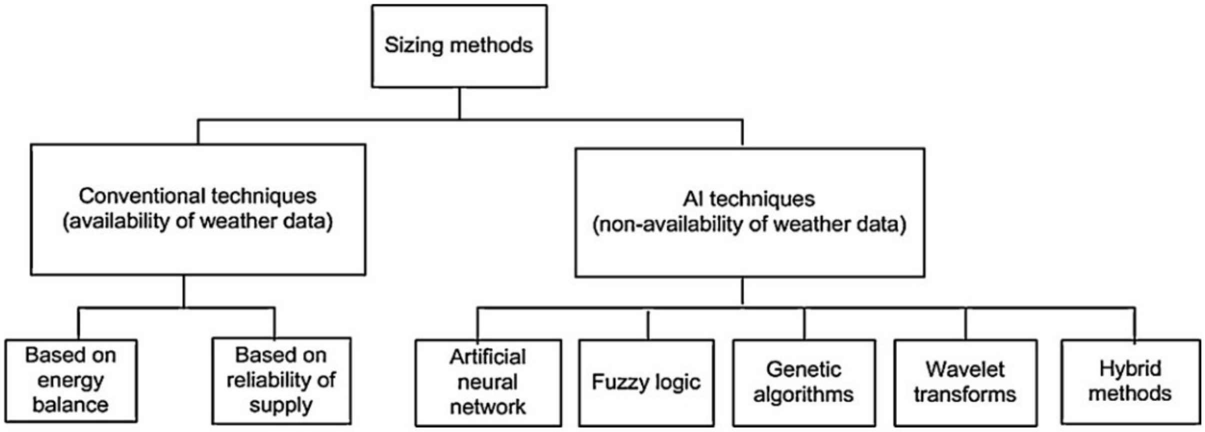

Fig.2. Classification of hybrid system sizing methods.

Table 1 Artificial intelligence (AI) techniques used in sizing of HRES

Sr. no	AI technique used & references	Brief description
1	Genetic Algorithms (GA) [20,24,25]	Optimal sizing of standalone hybrid wind/PV systems and wind/PV/DG systems
2	Artificial neural network (ANN) [23,26]	Sizing PV systems using adaptive ANN
3	Hybrid methods a) Combination of neural network and wavelet transform [27] b) Combination of neuro-fuzzy and GA [28]	Sizing of standalone PV system using neural network and wavelet techniques. Using neuro-fuzzy and GA for sizing standalone PV systems

Table 2 Simulation tools and their features used in HRES

HOMER	NREL [35]	Simulation and sizing of HRES based on optimization of NPC, considering wind turbines, PV modules, batteries, small hydro and many other components
HYBRID2	NREL and University of Massachusetts [36]	Long term performance and economic analysis of HRES
PV SOL	Valentin Energy Software [37]	Designing, planning of both stand-alone and grid-connected systems and analysis of electricity consumption and its costs
RAPSIM	MUERI in a project funded by ACRE [38]	Simulation of HRES including PV, wind, diesel generator
TRNSYS	Solar Energy Laboratory, University of Wisconsin-Madison [39]	Simulation of solar thermal systems, solar PV, wind and several other components without optimization

III. Optimal energy flow management in hybrid systems

The An optimal energy flow management among the various energy sources in HRES is necessary since, the power output from renewable sources is intermittent and dependent on several uncontrolled conditions. The dynamic interaction between various energy sources and the loads often requires a careful study of the transient response of such systems. The energy management strategy should ensure high system efficiency and high reliability with least cost. The main objective of the technique should be to supply the peak load demand at all times. In hybrid PV systems, FCs serve as long term energy storage option and are in demand because of multiple advantages. However the slow dynamics of FCs and its degradation due to frequent start-up and shut down cycles is a major disadvantage. Hence batteries are used in such hybrid systems to take care of power deficits and to act as a short term energy storage medium. The combination of FCs and batteries along with PV helps in ensuring uninterrupted power supply to the load. The key parameters that influence or help in deciding the optimal energy management strategy have been summarized as follows:

- Useful electrical energy available from the primary renewable energy sources, such as solar PV and wind turbines.
- Capital cost, operating cost, lifetime and days of autonomy of storage devices, such as batteries, ultra-capacitors and FCs.
- State of charge of storage devices or the pressure level of hydrogen tanks in case of hydrogen energy systems.
- The number of start-up and shut down cycles for FCs and electrolyzer.
- Fuel price in case of hybrid systems involving DG.

The literature on energy management schemes is quite extensive and includes various configurations of the hybrid systems involving solar PV. Ipsakis et al. proposed three power management strategies (PMS) for a hybrid PV/Wind/FC/Battery system with hydrogen production using electrolyzers. The PMSs are compared based on a sensitivity analysis by considering several parameters such as SOC of batteries and output power from FC. The key decision factors in the PMSs are the power delivered by the renewable energy sources and the SOC of the batteries. These PMSs strongly affect the lifetime of various subsystems, mainly the FC and electrolyzer. Three stand-alone hybrid PV systems (PV/Battery, PV/FC, PV/FC/Battery) using different energy storage technologies are discussed, analyzed and compared in [17]. The energy management strategy here is based on the system energy balance throughout the year and a trade-off between maximum system efficiency and minimum system cost has been implemented. The PV/FC/Battery hybrid system was found to have higher system efficiency with lower cost and also required lesser number of PV modules as compared to the other two configurations. Kang and Won suggested a PMS for a PV/FC/Battery hybrid system based on the cost of battery and FC. The authors have aimed at reducing the number of change over between FC and battery by introduction of measuring and time delay elements to the conventional strategy. Jiang presented an effective energy management strategy and simulated in virtual test bed (VTB) environment for a PV/FC/Battery system connected to the dc bus through appropriate dc–dc power converters and controls. The PV-Battery subsystem was controlled in two modes, namely the MPPT mode and the bus (battery) voltage limit (BVL) mode. The BVL mode prevents the battery from overcharging and the MPPT mode draws maximum power from the PV module.

IV. Conclusions

This review article presents comprehensive overview of hybrid renewable energy systems (HRES) with emphasize on solar photovoltaic based stand-alone applications. Various significant aspects of such systems, such as unit sizing and optimization, modeling of system components and optimal energy flow management strategies, are specifically reviewed. Different sizing techniques have been reviewed under classification based on availability of weather data. Developments in research on modeling of hybrid energy resources (PV systems), backup energy systems (fuel cell, battery, ultra-capacitor, diesel generator) and power conditioning units (MPPT converters, buck/boost converters, battery chargers) have been reviewed. The equivalent models including several physical mechanisms of these system components have been extensively discussed with a broad classification in modeling section. The section on energy flow management has covered significant references on various methods for optimal operation and control of HRES. The issues on economic viability and grid interconnection are the major challenges to make the HRES adaptable and sustainable. The high capital cost and low demand in solar photovoltaic and fuel cells had slowed down the large scale implementation of such hybrid systems in the past. However, recent global boost to renewable energy markets has dramatically encouraged research and development in this sector. Future trends include cutting edge technology development to increase the efficiency of such hybrid systems and encouragement in terms of its implementation. HRES has an immense potential to meet the load demand of remote, isolated sites and can contribute significantly to both rural as well as urban development. This in turn reduces the central generation capacity and increases overall system reliability. These units can supply uninterrupted power at zero emission level which is the major advantage of such systems. The widespread use of hybrid renewable energy systems will not only solve the energy issues but also ensure a green and sustainable planet.

References

1. Lazarov VD, Notton G, Zarkov Z, Bochev I. Hybrid power systems with renewable energy sources types, structures, trends for research and development. In: Proc of International Conference ELMA. 2005. p. 515–20.
2. Nayar CV. Stand alone wind/diesel/battery hybrid energy systems. Wind Energy 1997;21(1):13–9.
3. Salas V, Olias E, Barrado A, Lazaro A. Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems. Sol Energ Mater Sol Cells 2006;90(11):1555–78.
4. Chen YM, Lee CH, Wu HC. Calculation of the optimum installation angle for fixed solar-cell panels based on the genetic algorithm and the simulatedannealing method. IEEE Trans Energ Convers 2005;20(2):467–547.
5. Rehman S, Al-Hadhrami LM. Study of a solar PV-diesel-battery hybrid power system for a remotely located population near Rafha, Saudi Arabia. Energy 2010;35(12):4986–95.
6. Yamegueu D, Azoumah Y, Py X, Zongo N. Experimental study of electricity generation by solar PV/diesel hybrid systems without battery storage for offgrid areas. Renew Energ 2011;36(6):1780–7.
7. Wichert B. PV-diesel hybrid energy systems for remote area power generation – A review of current practice and future developments. Renew Sust Energ Rev 1997;1(3):209–28.
8. Hrayshat ES. Techno-economic analysis of autonomous hybrid photovoltaicdiesel-battery system. Energ Sustain Dev 2009;13(3):143–50.
9. Solano-Peralta M, Moner-Girona M, van Sark W GJHM, Vallve X. 'Tropicalisation' of Feed-in Tariffs: a custom-made support scheme for hybrid PV/diesel systems in isolated regions. Renew Sust Energ Rev 2009;13(9):2279–94.
10. Onar OC, Uzunoglu M, Alam MS. Dynamic modeling, design and simulation of a wind/fuel cell/ultra-capacitor-based hybrid power generation system. J Power Sources 2006;161(1):707–22.
11. Burke A. Ultracapacitors: why, how, and where is the technology. J Power Sources 2000;91(1):37–50.
12. Erdinc O, Uzunoglu M. Recent trends in PEM fuel cell-powered hybrid systems: Investigation of application areas, design architectures and energy management approaches. Renew Sust Energ Rev 2010;14(9):2874–84.
13. Rahman S, Kwa-sur T. A feasibility study of photovoltaic-fuel cell hybrid energy system. IEEE Trans Energ Convers 1988;3(1):50–5.
14. Esser T. Fuel cells enabling renewable off-grid solutions. In: IEEE 30th International Telecommunications Energy Conference, INTELEC. 2008. p. 1–2.
15. Markvart T, Castaner ˜ L. Practical handbook of photovoltaics: fundamentals and applications. Elsevier; 2003.
16. Mellit A, Kalogirou SA, Hontoria L, Shaari S. Artificial intelligence techniques for sizing photovoltaic systems: a review. Renew Sust Energ Rev 2009;13(2):406–19.
17. Li C-H, Zhu X-J, Cao G-Y, Sui S, Hu M-R. Dynamic modeling and sizing optimization of stand-alone photovoltaic power systems using hybrid energy storage technology. Renew Energ 2009;32(3):815–26.
18. Zhou K, Ferreira JA, de Haan SWH. Optimal energy management strategy and system sizing method for stand-alone photovoltaic-hydrogen systems. Int J Hydrogen Energy 2008;33(2):477–89.
19. Ardakani FJ, Riahy G,AbediM. Design of an optimum hybrid renewable energy system considering reliability indices. In: 18th Iranian Conference on Electrical Engineering (ICEE). 2010. p. 842–7.
20. Xu D, Kang L, Chang L, Cao B. Optimal sizing of standalone hybrid wind/PV power systems using genetic algorithms. Canadian Conference on Electrical and Computer Engineering 2005:1722–5.
21. Moriana I, San Martiˇın I, Sanchis P. Wind-photovoltaic hybrid systems design. In: International Symposium on Power Electronics

Electrical Drives Automation and Motion (SPEEDAM). 2010. p. 610–5.

22. Nelson DB,NehrirMH,WangC. Unit sizing of stand-alonehybrid wind/PV/fuel cell power generation systems. In: IEEE Power Engineering Society Gen Meet. 2005. p. 2116–22.
23. Mellit A, Benghanem M, Hadj Arab A, Guessoum A. Modelling of sizing the photovoltaic system parameters using artificial neural network. In: Proc. of IEEE Conference on Control Applications CCA, vol. 1. 2003. p. 353–7.
24. Senjyu T, Hayashi D, Yona A, Urasaki N, Funabashi T. Optimal configuration of power generating systems in isolated island with renewable energy. Renew Energ 2007;32(11):1917–33.
25. Koutroulis E, Kolokotsa D, Potirakis A, Kalaitzakis K. Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms. Sol Energy 2006;80(9):1072–88.
26. Hontoria L, Aguilera J, Zufiria P. A new approach for sizing stand alone photovoltaic systems based in neural networks. Sol Energy 2005;78(2):313–9.
27. Mellit A, Benghanem M, Hadj Arab A, Guessoum A, Moulai K. Neural network adaptive wavelets for sizing of stand-alone photovoltaic systems. Proc of 2nd International IEEE Conference on Intelligent Systems 2004;1:365–70.
28. Mellit A. ANFIS-based genetic algorithm for predicting the optimal sizing coefficient of photovoltaic supply (PVS) systems. In: Proc. of the Third International Conference on Thermal Engineering: Theory and Applications. 2007. p. 96–102.
29. Notton G, Lazarov V, Zarkov Z, Stoyanov L. Optimization of hybrid systems with renewable energy sources: trends for research. In: First International Symposium on Environ Identities and Mediterranean Area, ISEIMA. 2006. p. 144–9.
30. Agustin JLB, Lopez RD. Simulation and optimization of stand-alone hybrid renewable energy systems. Renew Sust Energ Rev 2009;13(8):2111–8