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REVIEW ON RENEWABLE ENERGY BASED MODELING AND CONTROL STRATEGIES

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ABSTRACT

Renewable energy resources is regarded as an alternative for future energy demand in India. The exploitation of RES is increasing exponentially. As per Ministry of New and Renewable Energy (MNRE) data, the present contribution of RES in the installed capacity is more than 12.5% and the share of RES would increase in the near future. However, the power generated from RES is fluctuating in nature particularly in solar photovoltaic and wind energy conversion systems. In view of aforesaid, various control strategies have been used by researchers and available in the literature. This paper presents the various issues related to grid integration of renewable energy sources and their control strategies.

Keywords: Renewable Energy Sources (RES); Control Strategies; Modelling; Optimization

I. INTRODUCTION

The increasing concerns on air pollution and global warming, the clean green renewable sources of energy are expected to play more significant role in the future of global energy [W. EI Khattam et al (2004), N. Jenkins et al (2000), H. L. Willis et al (2000)]. Most of them are environmentally benign and free from the atmospheric pollution, acid rain, and global climate warming. Furthermore, due to public support and government incentives over recent decades, they are growing rapidly, not only in technical performance, but also in the breadth of applications. The public attention has remained focused on these renewable technologies as environmentally sustainable and available alternatives. In recent years, tremendous amount of work came into notice in the area of renewable energy sources. It is seen that most of the researchers worked on two broad categories, i.e, design of hybrid energy system and performance of the hybrid energy power system.

A number of research papers related to modelling and control strategies are available in literature. In this paper, renewable energy based hybrid models and control strategies are taken into consideration. In addition, various issues related to hybrid modelling are also addressed. It has been found that the researchers have worked to achieve two broad results as mentioned above.

This paper is organized as follows: the approaches and methods adopted by different researchers to achieve an optimal hybrid design are presented in Section 2. Various performance optimization strategies have been discussed in Section 3. Section 4 presents the research gap and conclusion of the paper is given in Section 5.

II. DESIGN OPTIMIZATION

As discusses earlier, the researchers worked under two broad optimization objectives. One such category is the design of an optimal sizing of hybrid energy sources. This includes the selection of proper renewable energy sources with proper sizing, so that an optimized hybrid energy system could be developed, depending on the availability and feasibility of renewable energy power required of each source. Some of the key methodologies and approaches adopted are as follows:

2.1 Using Simulation Programs

Optimum sizing is necessary to obtain economical power output from an efficient renewable energy based system thereby reducing the investment with full utilisation of the system component [W. Zhou et al. (2010)]. It has been found that simulation programs are the most common tools used for optimization of hybrid systems, among which, Hybrid Optimization Model for Electric Renewable (HOMER) has been used extensively [NREL: HOMER]. Later, researchers developed HYBRID2, with very precise simulation, as it can define time intervals ranging from 10 min to 1 hour. Similarly, HOGA is developed incorporating an optimization program by means of Genetic Algorithms. It is seen that all these simulation programs can only simulate one configuration at a time, but not designed to provide an optimised configuration .

2.2 Using Meteorological Year Data

Work was then focused on reducing the complexity of the problem by the selection of proper data details. Researchers used typical meteorological year data long period meteorological data [U. Merter et al. (2000), Q. Zhang et al. (2002), H. X. Yang et al. (2004), E. Koutroulis (2006)] and worst month scenario data to solve sizing problem [M. A. Egido et al. (1992), C. Protogeropoulos et al. (1997), T. R. Morgan et al. (1996)]. Some have used a combination of these data, introducing two sizing methods which for stand-alone hybrid wind-solar energy systems are reported in the literature [C. Protogeropoulos et al. (1997)]. It is proposed to used yearly average data firstly for the optimization and then the worst-months data for more precise sizing. Similar method by using only worst month data is also presented [T. R. Morgan et al. (1996)]. Aiming towards more precise calculations, researchers used time-series simulation methods which usually have a resolution of 1 hour interval. It has been found that long-term hourly data and peak load demand data can be used to optimize hybrid systems [B. S. Borowy et al. (1994)]. Incremental time-scale data have been used by some researchers at incremental step time, 1 hour or 1 minute but this method requires significant computational effort [E. I. Baring-Gould (2002), G. Notton et al. (1996)]. Many efforts, like the development of predictive algorithm, has been conducted to decrease the simulation time and/or reduce the number of variables used. Using this technique, researchers could estimate the system performance using simple parameters and thus eliminating the necessity for time-series hourly data. Monthly-average values have been also used to develop a predictive algorithm [A. Celik (2003)]that in the form of stochastic and dynamic optimization models, incorporating uncertainties in demand, component failure and weather behaviour were also presented [M. Muselli et al. (1999), R. J. Kaye (1994)].

2.3 Graphical Approach

Various graphical optimization techniques have been reported in the literature. Graphical construction technique to calculate the optimum combination has been presented using long-term data [H. X. Yang et al. (2008), H. X.

Yang et al. (2007), B. S. Borowy et al. (1996)]. Another graphical technique is used to optimally design a hybrid solar–wind power generation system by considering the monthly-average solar and wind energy values [T. Markvart (1996)]. However, in both graphical methods, only two parameters are included in the optimization process, while some important factors are completely neglected.

2.4 Probabilistic Approach

Probabilistic approaches have also been opted for sizing hybrid system, as it accounted for the effect of renewable sources variability in the system design. Sizing method treating storage energy variation as a random walk and the probability density for daily increment or decrement of storage level approximated by a two-event probability distribution is presented [A. D. Bagul et al. (1996)]. The method is further extended to account for the effect of correlation between day to day radiations values [L. L. J. Bucciarelli et al. (1986)], then modified by J. M. Gordon (1987) and Bagul et al (1996) , in whose works, the storage energy transitions were approximated by three-event probabilistic approach to overcome the limitations of conventional two-event approach in matching the actual distribution of the energy generated by hybrid systems. Probabilistic approach is based on the convolution technique to incorporate the fluctuating nature of the resources and the load, thus eliminating the need for time-series data, to assess the long-term performance of a hybrid solar wind system for both stand-alone and grid-connected applications [G. Tina et al. (2006), S. H. Karaki et al. (1999)]. It has been noticed that the major limitation of this probabilistic approach is that it cannot represent the dynamic changing performance of the hybrid system.

2.5 Iterative Approach

Many researchers have used iterative methods to solve the problem. An iterative optimization technique for power reliability and system cost is presented [H. X. Yang et al. (2007)]. Similarly, an iterative optimization method is also presented to select the RES size [W. D. Kellogg (1998)]. For iterative optimization method, minimization of the system cost is implemented either by linearly changing the values of the corresponding decision variables or employing linear programming techniques, resulting in suboptimal solutions and increased computational effort requirements. But, it usually does not optimize other controlling parameters, which also highly affect both, the resulting energy production and system costs. Several other optimization techniques like simulated annealing and Tabu search have been applied to solve the optimized sizing problem. Hybrid SA-TS have also been tested and found advantageous as compared to individual SA and TS methods [A. Yiannis et al. (2012)].

2.6 Artificial Intelligence Approach

Artificial intelligence methods such as Genetic Algorithms, Artificial Neural Networks and Fuzzy Logic, have also been widely used to optimize a hybrid system. In such cases, Genetic Algorithm has been widely used as compared to other artificial intelligence techniques because of their capability to handle complex problems with linear or non-linear cost functions [E. Koutroulis (2006), H. X. Yang et al. (2008), G. C. H. Seeling et al. (1997)]. Genetic Algorithms address the problems of uncertain renewable energy supplies, load demand and the non-linear characteristics of some components by incorporating past and future demand [A. Soteris et al. (2004)]. GA is also widely used in conjunction with Artificial Neural Networks [Ying-Yi Hong et al. (2012)].

New design variables/constraints including cost minimization, and both reliability and CO2 emission are taken as constraints [Lingfeng Wang et al. (2009)]. Markov-based GA is introduced for the determination of optimal sizes of renewable energy sources units. It is found that Markov-based GA can help to reduce CPU time greatly and provide competitive cost.

In all the above mentioned approaches, the system is taken to be independent to either grid or grid uncertainties. Later, Lingfeng Wang et al. investigated both design scenarios, i.e., grid-linked hybrid generation systems without and with uncertainties consideration for the design of hybrid generation system [I. Serban et al. (2008)]. Hybrid system is designed using Particle Swarm Optimization for the minimisation of total cost ($/year) including initial cost, operational and maintenance (OM) cost for each type of power source, and the salvage value of each equipment. For the grid-linked system design, the annual cost for purchasing power from the utility grid is considered. Reliability and pollutant emission are taken as additional design objectives, under constrained variables.

2.7 Performance Optimization

As discussed, only system sizing is not the matter of concern for the researchers. An installed system also requires optimized dynamic variables for an optimized performance. Hybrid system must be able to deliver a purely sinusoidal output voltage at a fixed frequency. As well the system must be able to cope up with the power requirements. Thus, hybrid renewable energy systems need to be designed and controlled for the proper functioning of the system.

Controllers can be designed for the power system stability improvement, power flow control, transients control of the system. Such controllers are responsible for the functioning of RES at maximum power point, improvements in power quality, uninterrupted power supply, reduced internal losses and efficient cost effective power sharing among renewable energy sources in a hybrid system. Such control is extremely important because any fluctuation in power produced by any renewable energy resources considerably affects the power system operation, which can lead to frequency oscillations [I. Serban et al. (2009), C. Dufour et al. (2004)], and/or violations of power lines capability.

2.8 Real Time or Online Control Design

Real-time simulators are a complementary tool to conventional offline simulation programs for power system studies [L.-F. Pak et al. (2006), V. Dinavahi et al. (2004), C. Dufour (1996), D. Hercog et al. (2007), F. Gao et al (2010), Y. Li et al. (2004), Wei Qi et al. (2011)]. With much more computational power, real-time simulators are able to simulate very complex and large models in real-time or faster. The simulation time step of a real-time simulator can be as low as tens of microseconds at the CPU, and tens of nanoseconds at the field-programmable gate array (FPGA). Real-time enables hardware-in-the-loop (HIL) simulation. As only low power signals are exchanged between a prototype controller and a simulated plant, it is called signal HIL simulation.

The real-time simulator is the most suitable research tool for studies of the integrated wind ESS system as the nature of the renewable energy resources is stochastic and the developed hybrid model is complex since the characteristics of the equipment are highly nonlinear, and the battery storage performance is very dependent on previous operating conditions.

2.9 Operating Point Control

Effort has also been done in controlling the operating point of the system keeping the system to work at maximum power point. A cost-effective control technique for maximum power point tracking from the photovoltaic array and wind turbine under varying climatic conditions without measuring the irradiance of the photovoltaic or the wind speed has been developed [Paolo Maffezzoni et al. (2009)]. Predictive control has also been used to [Paolo Maffezzoni et al. (2009)] to compute the operating points of the wind subsystem and of the solar subsystem together to generate enough energy to satisfy the load demand. In addition to this, supervisory control have also been used to optimize the operating points so as to reduce the peak value of surge currents. Predictive control has also been extensively used by other researchers [C. Rodriguez et al. (2007)]. It is shown that the temperature profile can be predicted as a function of the cooling strategy for a solar-module. It is found that the I–V electrical characteristic of the whole module can be derived from this information, thereby identifying those average parameters that mainly affect the solar-module behaviour,thus facilitating the prediction on the current and voltage levels that can be sustained by the solar panel as well as the maximum suppliable power [M. Fortunato et al. (2008)]. All of these aspects are a key to the proper design of the electronic control interface that tracks the maximum power point [N. Femia et al. (2005), N. Femia et al. (2008), G. R. Walker et al. (2004), P. K. Goel et al. (2011)]. Such control techniques have been applied to control different types of hybrid systems to maintain constant voltage, constant frequency, MPT, neutral-current compensation, harmonics elimination, load balancing and the highest efficiency optimization [Sylvain Lemofouet et al. (2006), M. Shahid Khan et al. (2008)].

2.10 Converter Control

The operating conditions of the renewable energy based system could be regulated by controlling the converter parameters. Optimized operating conditions can be achieved by controlling the converter parameters. A fast acting hybrid control of voltage sourced converter (VSC), can manage and ensure continuous operation of the system in the presence of temporary single line to ground faults on the utility feeder without the need for a storage provision. It also limits reactive fault current contribution by the converter, and therefore, avoiding problems associated with over current protection of the feeder [Yasser et. al. (2009)]. Thus converter side control extremely improves the system performance. For fast load changes and fast voltage disturbances, work has also been done to control grid-connected PWM voltage source inverters (VSIs). A control strategy for voltage source converter based on positive and negative symmetrical components can be used to investigate the voltage sag in [Amin Hajizadeh et al. (2010), Zhe Zhang et al. (2012)]. Phase-shift angle and duty cycle can be used to control a bidirectional isolated dc–dc converter for the hybrid energy system [M. Komori, et al. (2001)]. Similarly, a Lyapunov-based neuro-fuzzy controller has also been designed to ensure the proper working of HES when a voltage disturbance occurs in distribution system [M. Komori, et al. (2001)].

2.11 Hybrid Energy Storage System Control

Power quality can be increased by the proper selection and control of Hybrid Energy Storage System. A miniature flywheel energy storage system for energy storage with a pair of hybrid magnetic bearings (HMBs); consisting of both superconducting magnetic bearings (SMBs) and active magnetic bearings (AMBs) applied with H-infinity control method and zero bias method has also been developed [J. R. Miller (1995)]. It is seen that by using the HMBs the radial displacement of the rotor is much smaller than that with SMBs thus improving the dynamics of the ESS.

Hybrid power sources that combine advanced batteries with ultra capacitors can be operated for longer times [L. P. Jarvis et al. (1999), L. P. Jarvis et al. (2000), R. A. Dougal et al. (2002)]. Peak power can be greatly enhanced, internal losses can be considerably reduced, and that discharge life of the battery is extended using ultra capacitors [A. Yoshida et al. (1992)]. The greatest benefits can be seen when the load pulse rate is higher than the system eigen-frequency and when the pulse duty is small.

Ultra capacitors are also increasing interest because of their high-energy density (compared to conventional capacitors) and high-power density (compared to batteries and fuel cells) [A. F. Burke et al. (1995), B. E. Conway (1999), R. Kötz et al. (2000), S. M. Halpin et al. (1996)]. The use of ultra capacitor in power distribution and in utility electronic apparatus has shown improvements in power quality, uninterrupted power supply, and memory backup [K. Harada et al. (1998), P. Pillay et al. (1995), R. L. Spyker et al. (2000), L. Zubieta et al. (2000), M. G. Molina et al. (2007)].

Also, superconducting magnetic energy storage (SMES) has been utilized for better power quality by many researchers. With the appropriate topology of the power conditioning system (PCS) and its control system design, the SMES unit has been found capable of simultaneously performing both instantaneous active and reactive power flow control [Marcelo Gustavo Molina et al. (2011), Toshifumi Ise et al. (2005)]. Fuzzy control scheme has also been used for the optimized performance of a hybrid energy storage system composed of a superconducting magnet [Carlos Andrés et al. (2009)].

Due to the emergent technology of fuel cells, much amount of research has also been focused on it.

PEMFC control strategy has been developed to produce the power, minimize the fuel consumption and also provide a regulated dc bus voltage to the load [Xin Kong et al. (2009)]. This is done by controlling the voltage of air pump of FC for the control of fuel cell current through a dc/dc switching converter. The control results, fuel consumption, and fuel cell protect against oxygen starvation phenomenon.

To incorporate some non linear structures, the development of an ANN based fuel-cell model within the hybrid model of a FC stack not only improves accuracy but also allows the model to adapt itself to operating conditions; giving a good estimate of the relationship between current and temperature and making the system work on maximum power condition [Li Wang et al. (2010)]. Other types of fuel cells have also been suggested in HESS for the minimization of hydrogen rate using the output dc current of the SOFC or the current magnitude of the ac load [Chad Abbey et al. (2010)].

The topology of ESS is also suggested by the researchers for better power quality. A two level ESS has been proposed, where the battery is paired with a fast-acting low-power -capacity ESS [Ke Jin et al. (2009)]. The controller minimizes dump load, limits the intra-hour diesel ramp rates, and maximizes ESS utilization. In addition, the operation of charging and discharging of ESS can be managed by controlling the bidirectional converter operated under buck boost or shut down mode according to the operation condition of the fuel cell and battery [Phatiphat Thounthong et al. (2010)]. Fatness properties for a FC/super capacitor could also be used in designing a better control law [J. L. Bernal-Agustın et al. (2008)].

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2.12 Power Management Control

Effective energy management of hybrid energy systems is necessary to ensure optimal energy utilization. The energy management system (EMS) is complex and needs to find solutions quickly and continuously, in a given intermittent environment. For such fast dynamics, conventional optimization techniques are too slow to be used for the optimization of multi-objective and multi-constraint energy management problem. As a result, researchers have focused on the application of intelligent control not only for unit sizing but also for energy utilization of hybrid energy systems [Hanane Dagdougui et al. (2010), V. Miranda et al. (2005), C. L. Chen (2007), B. C. Ummels et al. (2007), C. Chun- Lung (2008), J. Hetzer et al. (2008), F. A. Mohamed et al. (2007), C. A. Hernandez-Aramburo et al. (2005), Jorge L. Duarte et al. (2007)].

It is seen that voltage regulation is affected mostly by the balance of reactive power and the time constant of the generator excitation system which also affects the frequency variation in the system. Thus a proper power balance and time constant are required for a stable operation. Therefore, apart from system sizing and performance control, researchers also have paid attention to the selection of renewable energy sources and energy storage system for an optimized hybrid energy system. Much more attention has been paid to the power shared by each renewable source.

A suitable three-port, galvanic isolated, bidirectional power converter has been proposed to control the power flow [Eduard Muljadi et al. (2002)]. Many topologies have been developed in this regard. Work has also been focused on the dynamic interaction among renewable power sources and loads [Torbjorn Thiringer et al. (2001)].

It is also required that the renewable energy sources must try to keep unity power factor as long as the voltage on the grid does not exceed a nominal voltage limit. Researchers have used supervisory control to order the respective components so as to maintain the voltage/frequency level [F. Valenciaga et al. (2005)]. Supervisory control system has also been used to satisfy the load power demand and to maintain the state of charge of the battery bank to prevent blackout as energy storage system also plays an important role in deciding the hybrid topology and power sharing between them [Tomonobu Senjyu et al. (2005)].

Another techniques like sliding mode control have also been applied for a proper power sharing so as to satisfy total instantaneous power demand in highly uncertain environment [Francisco Jurado et al. (2003)].

It is seen that conventional control depends on the mathematical model of the plant controlled. Since, energy storage model is uncertain, adaptive controller promises better performance. An adaptive minimum variance controller is found robust enough to stabilize different disturbances [F. Valenciaga et al. (2001)].

Control of different types of fuel-cell hybrid systems, including SOFC, and their applications have been proposed [Kaushik Rajashekara (2005), Caisheng Wang et al. (2008)]. In case of fast fluctuating load demand, fuel cells must be used with an auxiliary power source. This is because fuel cell is a slow dynamic system and a fluctuating load profile will cause a high voltage drop in a short time. Many of the researchers used hybrid fuel cell/battery system to improve the slow transient response of a fuel cell stack.

Except fuel cells, researchers used electrolyser in their hybrid system to compensate the extra power developed. An ac-linked hybrid wind/PV/FC for stand-alone applications has been developed and power management strategy has been proposed for wind and PV as the primary power sources of the system, and an FC-electrolyzer combination as a backup and a long-term storage system.

III. VISION OF THE FUTURE

It is found that researchers have taken various control objectives for the development of hybrid energy system. Work has been done in system designing featuring system sizing so as to generate a cost effective green energy. Performance, stability and power quality control have also been taken as the control objectives by various researchers. It is seen that large amount of work is done using conventional control techniques or power convertor control methods. Still lots of work could be done if the system could be designed using soft computing techniques.

IV. CONCLUSIONS

This paper provides a summary of available approaches and those currently under research for optimal control techniques and objectives considered in the design of hybrid renewable energy systems. Different approaches and techniques for system control of hybrid systems are presented. Current status and future possibilities in system control have been tried to discuss. The comprehensive list of references at the end of the paper is aimed to help interested researchers in the design including system sizing, performance control and power management of hybrid renewable energy systems.

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