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REVIEW OF THE OPTIMAL DESIGN ON A HYBRID RENEWABLE GENERATION SYSTEM BY USING INTELLIGENT COMPUTING METHODS

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ABSTRACT: Based on the energy consumption and the availability of renewable energy sources, the wind-solar-diesel hybrid power supply system may be an appropriate choice in several remote sites. That is, it is very suitable to implement an innovative micro-grid hybrid distributed generation system combining several small-scale wind generators, solar photovoltaic panels, battery storage, advanced power electronics equipment and existing diesel generators. In general, hybrid energy systems are really excellent options for supplying small isolated power systems and remote villages where the conventional grid cannot reach due to the technical and economical reasons.

However, wind and solar energy are essentially random energy sources. Many factors should be considered for the configuration of the power supply system. Therefore, this paper will focus on the system planning and operation of hybrid generation systems, and several corresponding topics and papers by using intelligent computing methods will be reviewed. They include typical case studies, modeling and system simulation, control and management, reliability and economic studies, and optimal design on a reliable hybrid generation system.

I. INTRODUCTION

The limited reserves of fuel oils and their unstable prices have significantly increased the interest in renewable energy sources. The alternative energy sources are non-polluting, free in their availability, and continuous. The motivation behind the use of renewable energy sources is the reduction of CO_2 emissions. This is especially true in isolated, standalone, small islands where the access to renewable energy sources is the only solution to meet their energy needs. Today, wind and PV generators are utilized in such applications as water pumping, lighting, electrification of remote areas and telecommunications. For remote systems like radio telecommunication, satellite earth stations, or at sites that are far away from a conventional power system, the hybrid generation systems have been considered as preferred [1]. At present, standalone solar photovoltaic and wind systems have been promoted on a comparatively larger scale; however, these independent systems cannot provide the continuous source of energy. Therefore, energy storage systems will be required for each of these systems in order to satisfy the power demands. Usually storage system is expensive and the size of it has to be reduced to a minimum possible for the renewable energy system to be cost effectively. Hybrid power systems can be used to reduce energy storage requirements [2].

In the world, a significant number of villages may never be connected to the national grid due to their remoteness, or communities are far from the conventional electrical grid due to natural obstacles and environmental constraints. For the people living in these communities, access to renewable energy sources may be the only solution to meet their energy needs. Therefore, the design and the operational experience of hybrid power systems for small micro grids are important.

In order to meet sustained load demands during varying natural weather conditions, different renewable energy sources need to be integrated with one another. Therefore, dynamic modeling of various components in isolated systems and steady-state/transient simulation works are required. Furthermore, an overall control strategy for power management among different energy sources in a multisource energy system is needed. The controller should determine the online operation modes for each generation subsystems and switch from power regulation to maximum power conversion.

Reliability evaluation and economic analysis are also very important in the planning of a hybrid energy system for a particular site. In order to efficiently and economically utilize the renewable energy resources, one optimum sizing method considering system reliability and economical benefit for the hybrid generation system is necessary. The optimum sizing method can help guarantee the lowest investment with full use of the PV array, wind turbine and energy storage system, so that the hybrid system can work in the optimum conditions in terms of investment and system reliability. Different sizing methods, such as probabilistic approach, iterative approach and artificial intelligence method, can be applied to reach a techno-economically optimum hybrid renewable energy system. Whichever sizing and optimization technique are used, they must ultimately search for an optimum combination of the system reliability and cost.

This paper will concentrate on reviewing significant research issues and current state about the hybrid renewable generation system. These topics include several typical case studies of renewable-based micro-grids, modeling and simulation for renewable energy systems, control and management of hybrid renewable energy systems, reliability and economic studies, and optimal design of a reliable hybrid generation system. A number of intelligent computing methods have been utilized in these researches and most of them will be summarized in this paper.

II. CASE STUDY ON SMALL-SCALE HYBRID GENERATION SYSTEMS

In the beginning of designing a small-scale hybrid generation system, the historical power consumption of load, load pattern, solar radiation values, and wind character have to be investigated. The availability of renewable energy resources is an important factor to develop the hybrid power system; that is, weather data are important factors for a pre-feasibility study of renewable hybrid energy system for any particular site. For example, hourly solar radiation, clearness index, wind speed, and wind direction for several years should be collected so that the long-term average annual resource can be evaluated. Moreover, from the above given data, the probability functions of wind speed and solar radiation can be obtained.

Several researches have discussed how to implement an innovative stand-alone hybrid energy system combining small wind turbines, solar photo-voltaic panels, battery storage, advanced power electronic equipment and existing diesel generators. These methodologies include:

- Obtain solar radiation/wind speed data for calculating PV/wind power output potential for specific location.
- Investigate the instantaneous load data.
- Select suitable wind turbine, solar PV system, battery bank and converter as well as small diesel generators for backup purpose.
- Study the environmental impact due to hybrid energy system over the conventional diesel generator.
- Study technical and economic impacts due to the hybrid energy system.

In [3], the design and sizing of a hybrid power system for small-based transceiver stations (BTS) in Indonesia are presented. The combination of wind and solar energy sources are used as the main source, and utility line is used as a backup. The average wind speed in this area is about 4-5 m/s, and the average sunshine hour in this site is between 7 to 8 hours a day during the dry season, and it's between 5 to 6 hours a day during the rainy season. The design of this hybrid generation system includes a 4.8kW PV array, a 2.5kW wind turbine, and a 1200Ah battery. It will provide electricity to a BTS with an average power demand of 4kW. By using this hybrid power system, about 90 per cent of the required power can be supplied by renewable energy sources.

Paper [4] proposes the most feasible configuration of a stand-alone PV/Wind Hybrid Energy System with diesel generator as a backup for cellular mobile telephony base station site in isolated areas of Central India. In this case, the power requirements for the GSM load are about 2kW continuous, and the proposed hybrid system consists of two 7.5kW horizontal-axes type wind turbines, a 5kW Photovoltaic array, a 1kW diesel generator, a 1.83kWh battery bank and a 2kVA Inverter.

Paper [5] proposes a photovoltaic/wind based hybrid power system connected to a common bus with the battery storage and the conventional backup source to supply a 2kW telecommunication load in Malaysia. The hybrid system consists of a 4.5kW PV system, a 2kW wind system, and a 5kWh battery.

Paper [6] also presents an innovative wind/PV/diesel hybrid system implemented in three remote islands in the Republic of Maldives. In this micro-grid system, twenty four 1.8 kW wind turbines are coupled to the micro-grid, and 2.5 kWp of amorphous silicon PV modules are connected to AC grid through the single phase grid connected inverter. This paper [6] undertakes the renewable energy system planning using the software tool HOMER and to analyses the various options paying particular attention to the cost per unit of electricity consumed, fuel saved and initial capital requirements.

In [7], a hybrid system of the pilot project in Lençóis Island located in the north area of Brazil is proposed. It composed of 21kW solar PV power, 22.5kW rated wind power, 120 batteries of 150Ah each, and a 53-kVA/48-kW diesel generator as a backup unit. This paper also addressed the field operation results for this system, including power quality and reliability analyses.

III.MODELING AND SIMULATION OF RENEWABLE ENERGY SYSTEMS

In order to meet sustained load demands during varying natural conditions, different renewable energy sources need to be integrated with one another. In addition, dynamic modeling of various components of this isolated system should be presented. Several papers have described dynamic modeling and simulation results of a renewable energy based hybrid power system. For example, in [8], a detailed dynamic model and simulation of a solar cell/wind turbine/fuel cell/ultracapacitor hybrid power system is developed. Modeling and simulations are conducted, using MATLAB / Simulink software packages to verify the effectiveness of the proposed system. The renewable energy based hybrid power system consists of a 75W solar cell, a 400W wind turbine, a 100W proton exchange membrane fuel cell, an ultra – capacitor, an electrolyzer, and a power conditioner. In paper [8], transient responses of the system to step changes in the load, ambient temperature, radiation, and wind speed in a number of possible situations are studied. In [9], a PV/Wind hybrid electric power system interface with the electric utility for solving modeling and simulation problems by using Matlab/Simulink environment have been proposed, in which detailed modeling, simulation and control of a DC/AC converter connected to electric utility have proposed.

Solar panels are the medium to convert solar power into the electrical power. A number of solar cell models have been developed, but the one diode electrical equivalent circuit is commonly used for cell based or module based analysis. It consists of a diode, a current source, a series resistance and a parallel resistance. The current source generates the photo-current, which is a function of the incident solar cell radiation and temperature [10]. A solar cell is modeled based on the fundamental relationship between the cell voltage and the current output which can be expressed by Eq.1 [11].

$$I_{PV} = I_{ph} - I_0\left(e^{\frac{qV_{pv}}{KT}} - 1\right) \quad (1)$$

Where I_{ph} is photo current (A); I_0 is Diode reserve saturation current (A); q is electron charge; K is Boltzman constant, and T is Cell temperature (K). Solar module is modeled by connecting the cells in parallel or series to meet the real manufacturer specification. In addition, a maximum power point tracker is generally used to extract maximum power from a solar array.

Wind turbines are used to convert the wind power into the electric power. The energy production by wind turbines depends on the wind velocity acting on the turbine. The wind direction is also an important factor. By knowing the predominant wind direction, we can select the ideal spot for wind turbines. Based on the Betz theory, the maximum converting efficiency of a wind generation system is 59%.

The developed wind power can be evaluated at a given wind speed through the power curve of the wind turbine. Power curves are usually provided by the manufacturers of wind turbines, thus allowing easy calculation of the corresponding powers under different wind speeds. The power output equation of a wind turbine can be described in Eq.2:

$$P = \frac{1}{2}\rho\pi C_p V^3(\lambda,\beta)R^2 \quad (2)$$

Where P is wind power; ρ is air density; V is wind speed; R is radius of turbine blades, and C_p is wind power coefficient.

In terms of fuel cell, there are two typical types: low-temperature proton-exchange membrane FC (PEMFC) [12] and high-temperature solid oxide FC (SOFC) [13]. Both of them show great potential in hybrid energy system applications. The PEMFC model is an autonomous model operated under constant channel pressure with no control on the input fuel flow into the FC. The model was validated by experimental data measured from an Avista Labs SR-12 500 W PEMFC stack [12]. The FC will adjust the input fuel flow according to its load current to keep the channel pressure constant.

IV. CONTROL AND MANAGEMENT OF HYBRID RENEWABLE ENERGY SYSTEMS

An overall control strategy for the power management among different energy sources in a multisource energy system is needed. The objectives of the control and management of a hybrid energy system are to satisfy the changeable load power demand and to maintain the state of charge of the battery bank to prevent blackout and to extend the life of the batteries. For these purposes, the controller should determine the online operation modes for each generation subsystems and switch from power regulation to maximum power conversion.

In [14], a comprehensive supervisor control for a hybrid system that comprises wind and photovoltaic generation subsystems, a battery bank, and an ac load is developed. The robust sliding-mode control laws have been considered in this paper to fulfill the different control objectives of the wind and solar subsystems.

Paper [15] proposed an overall control strategy for a hybrid renewable energy system, in which the wind generation system is controlled by a pitch angle controller and a PV electricity generation unit is controlled by a maximum power point tracking (MPPT) controller; furthermore, dynamic models have been used for all the components of the system. At any given time, any excess wind and PV-generated power is supplied to the electrolyzer to generate hydrogen, that is delivered to the hydrogen storage tanks. When there is a deficit in power generation, the fuel cell stack begins to produce energy for the load using hydrogen from the storage tanks.

Paper [16] introduces the hardware realization of the energy management and control subsystem of a grid-connected wind/solar hybrid power system. The system is composed of several modules: programmable logic controller (FBs-40MAT from FATEK), AC multi-function electric power meters, Grid-connection control module, human-machine interface (HMI), dc electric power meters, and RS485/TCP converter to control and manage the operation of multi-source. Communication plays an important role in the system, a safe, reliable and precise operation for a hybrid renewable energy system. In [16], the communication protocol in the subsystem and between subsystems is Modbus RTU, while the communication with computer is implemented by RS485/TCP converters.

V. RELIABILITY STUDY OF HYBRID RENEWABLE GENERATION SYSTEMS

Reliability evaluation is very important in the planning of hybrid energy system for a particular site. The reliability is estimated in terms of the number of the critical load of interruptions over a certain period of time; this choice is because the reliability of a system depends on the complexity of the system itself and not only on the number and the failure rates of its components. Typically, the reliability evaluation methods can be broadly classified into two types namely deterministic and probabilistic techniques [17]. Probabilistic techniques can be further classified into two types. They are analytical and Monte Carlo Simulation (MCS) methods.

Several reliability indices are introduced in literature. Loss of Load Expected (LOLE), Loss of Energy Expected (LOEE) or Expected Energy not Supplied (EENS), Loss of Power Supply Probability (LPSP) and Equivalent Loss Factor (ELF) are some of the most common used indices in the reliability evaluation of generating systems.

In general, the reliability assessment of a hybrid generation system can be done by the following procedure:

- To collect required atmospheric data such as hourly solar radiation, hourly ambient temperature and hourly wind speed.
- To estimate hourly output power available from each type of source by using power generation models and considering outage schedules generated randomly using failure rates of units.
- To obtain total available generation with the reliability index.

The reliability evaluation of the PV/Wind hybrid energy system using well-being approach and Monte Carlo Simulation (MCS) method is discussed in [18], in which the "well-being" approach is implemented by combining deterministic and probabilistic approaches for applying to hybrid energy systems. Furthermore, the effects of different energy types, the effects of changes in peak load, the renewable capacity on system health, and the fuel savings are also studied in that paper. Paper[19] presented an evaluation model and applied it to analyze optimum generation expansion of small isolated systems using PV and wind energy sources. Paper [20] studied reliability and cost implications of PV and Wind Energy utilization in small isolated power systems. A Monte Carlo simulation approach has been utilized to incorporate the numerous random variables and their interactions. Paper [21] developed an analytical method for the well-being assessment of small autonomous power systems having solar and wind energy systems.

VI. OPTIMAL DESIGN OF A RELIABLE RENEWABLE ENERGY SYSTEM

Over the last decades, a large number of algorithms have been developed to solve various optimization problems. The computational drawbacks of existing numerical methods have obligated researchers to trust in heuristic and meta-heuristic algorithms based upon simulations to solve optimization problems. There are many methodologies for sizing and optimization of hybrid energy systems. In paper [22-23], for a given Loss of Power Supply Probability (LPSP), the combinations of a number of PV modules and a number of batteries are calculated, and the choice of the optimum number of PV modules and batteries was based on the minimum cost of the system. Here, The LPSP for a considered period of time T is the ratio of all LPS_t values for that period to the sum of the load demand. This can be defined as:

$$LPSP = \frac{\sum_{t=1}^{T} LPS_t}{\sum_{t=1}^{T} E_{L(t)}} \tag{3}$$

where LPS is the Loss of Power Supply.

In a hybrid energy system, different energy resources are variable to different degrees and some of them are complementary over the annual cycle. A knowledge-based design approach can consider all these factors by proper rules of assignment for resources-needs combinations. In paper [24-25], a knowledge-based design approach that minimizes the total capital cost at a pre-selected reliability level is presented. The reliability level is quantified by the LPSP. The procedure includes some resource-need matching based on economics.

In Paper[26-27], a genetic algorithm is utilized to develop an optimal sizing method for a hybrid wind/solar system that optimizes its configurations with the use of battery banks. The optimal sizing method was then used to calculate optimal system configurations that achieve a given loss of power supply probability (LPSP) while minimizing the annualized cost of the system at the same time.

Paper [28-29] presents the optimal sizing of a wind/photovoltaic/fuel cell hybrid generation system. The function objective is constituted by the costs of the system, and the solution method employed is based on evolutionary computation technique called Particle Swarm Optimizer (PSO). The aim of these works [28-29] is to minimize the total cost of the system such that the demand is met. The PSO algorithm consists of a population continuously updating the knowledge of the given searching space. This population is formed by individuals called particles; each one represents a possible solution. Each particle moves with an adaptable velocity within the search space and retains in its memory the best position it ever encountered. In the global variant of PSO the best position ever attained by all individuals of the swarm is communicated to all the particles.

The hybrid system consists of photovoltaic panels, wind turbines and storage batteries. Considering the complexity of this nonlinear integral planning, a differential evolution algorithm is used to solve this problem in [30-31]. Differential evolutionary is a direct parallel random search algorithm by certain rules of operation. It begins from a randomly generated initial population and continues to iterative calculations. In accord with each individual's fitness, it can retain excellent individual and eliminate poor-quality individual, guide the process of approximation to optimal solution.

Artificial neural network (ANN) techniques are becoming useful as alternate approaches to conventional techniques or as components of integrated systems. They have been used to solve those complicated practical problems in various areas and are becoming more and more popular nowadays. Several papers show the potential of ANN as a design tool for the optimal sizing of PV systems. The advantage of using an AI-based sizing of PV systems is that it provides good optimization, especially in isolated areas, where the weather data are not always available. Paper [32] developed an ANN model for the estimation of the sizing parameters of stand-alone PV-systems. In this model, the inputs are the latitude and longitude of the site, while the outputs are two hybrid-sizing parameters. These parameters allow the designers of PV-systems to determine the number of solar PV modules and the storage capacity of the batteries necessary to satisfy a given consumption. In [33-34], a suitable technique for drawing the iso-reliability curves by using a simplified recurrent neural network is developed. This technique has been applied for Spanish locations. In addition, radial basis function network has been used for identification of the sizing parameters of PV-system in [35].

Several Genetic-Algorithm-based methods for sizing PV systems have been developed in order to select the optimal size of parameters of PV systems in remote areas. GA is inspired by the way that living organisms are adapted to the harsh realities of life in a hostile world. The algorithm imitates in the process the evolution of population by selecting only fit individuals for reproduction. A GA utilizes three principal genetic operators: selection, crossover, and mutation. It is implemented as a computerized search and an optimization procedure that uses principles of natural genetics and natural selection. Paper [36] developed an optimal configuration of power generating systems in isolated islands with the renewable energy using a GA algorithm. This methodology can be used to determine the optimum number of solar array panels, wind turbine generators and battery configurations. The generating system consists of diesel generators, wind turbine generators, PV system and batteries. Using the proposed method, operation cost can be reduced by about 10% in comparison with diesel generators only. A methodology for the optimal sizing of a stand-alone PV/wind-generator system was developed in [37] in which the proposed methodology is based on the GA and compared with linear programming. The simulation results verify that hybrid PV/wind-generator systems feature lower system cost as compared to the cases where either exclusively the wind-generator or exclusively the PV sources are used. A novel strategy, optimized by GA, to control stand-alone hybrid renewable electrical systems with hydrogen storage, is presented in [38]. The optimized hybrid system is composed of renewable energy resources (wind, PVand hydro), batteries, fuel cell, AC generator and electrolyzer.

Linear programming methods were also utilized by several researchers to determine optimal renewable energy systems. In [39], the optimal design of a hybrid wind–solar power system for either autonomous or grid-linked applications is proposed. The method employs linear programming techniques to minimize the average production cost of electricity while meeting the load requirements in a reliable manner, and takes environmental factors into consideration both in the design and operation phases.

The application of the fuzzy logic and the support techniques on the optimal sizing of hybrid generation systems are also proposed in several papers. In [40], an automatic procedure to perform the optimal sizing of a grid connected hybrid solar wind power system based on the fuzzy logic and the multi-objective optimization has been proposed. Both technical and economical objective functions are taken into account in the optimization procedure; the technical objective, related to system reliability, is expressed by the Energy Index of Reliability. In [41], a support technique to help decision makers study the influencing factors in the design of a hybrid solar–wind power system for grid-linked is presented.

VII. CONCLUSIONS

The limited reserves of fuel oils and their unstable prices have significantly increased the interest in the renewable energy sources. At a particular site, it is an important economical task for electrification of those villages in rural areas or telecommunications. Therefore, the design of hybrid renewable power systems has received considerable attention in the last decade. In any hybrid generation system, sizing represents an important part of these system designs, including the optimal sizes of various renewable energy sources and storage systems. This paper has reviewed several typical case studies on hybrid renewable energy systems, including their modeling and simulation, control and management, reliability and economic studies, and the optimal size design by using intelligent computing methods.

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