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Components sizing of photovoltaic stand-alone system based on loss of power supply probability

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ABSTRACT

The Stand-alone Photovoltaic System (SAPS) should be sized optimally since there no steady backup supply connected to it. An optimally sized SAPS should have a low overall cost without compromising the reliability of the system. This paper presents the review of the microgrid and the sizing of the SAPS. The review includes seven type of sizing methods for the microgrid. The sizing of the SAPS combines the Loss of Power Supply Probability (LPSP) and Life Cycle Cost (LCC) using the Iterative Method to determine the optimal size for the SAPS. The reliability of the SAPS is further improved using the Reliability Improvement Method (RIM). The location for the SAPS is at FKE Building, UTM, Johor. The results obtained using the RIM are compared with the results obtained from the LCC Method and the GCM. The GCM does not consider the overall cost of the SAPS throughout the lifetime of the system. The LCC Method consider the overall cost for the SAPS but the LPSP is fixed at 0.812%. While the proposed RIM improves the reliability of the SAPS up to 77.8% from 0.812% LPSP with only 4.9% cost increases.

1. Introduction

Nowadays, the fossil-fuel resources on a worldwide basis have been decreasing tremendously. A study was conducted on the fossil fuel usage in Bhopal, India shows that the oil, gas, and coal reserve will exhaust in 22 years, 30 years, and 80 years respectively. Therefore, it is necessary to find the alternative energy sources such as photovoltaic (PV) and wind energy. These energy sources have a huge potential to meet the continually increasing demand for energy since it is unlimited, pollution-free, and easy to access at any place. Therefore, the uses of renewable sources to fulfil the load demand in a remote location such as radio telecommunications, satellite earth stations, and rural areas are preferable [1,2]. Malaysia has the annual average of 4.21 kW h/m^2 to 5.56 kW h/m^2 of daily solar radiation [3]. The relatively high irradiance level throughout the year creates a potential for the stand-alone photovoltaic system (SAPS). The SAPS is both technically and economically practical for the remote area since the installation of the conventional grid system is not cost effective.

In general, the output power of these renewable sources are unpredictable and non-linear. Therefore, the energy storages such as the battery, the ultracapacitor, and the pumped hydro storage (PHS) are used for a short period of time to meet the peak load demand when there is a shortage of available energy to overcome the load demand [4]. The combination of the renewable energy sources with the energy storage can satisfy the source fluctuations. To optimise the utilisation of the renewable energy sources and the energy storage, a system sizing method is needed [5]. The sizing of SAPS is important in the system design since there is no steady backup supply connected to the system [6]. The optimum sizing can help to reduce the investment cost for installing the SAPS without sacrificing the reliability of PV system [1,5–8].

The optimum sizing that depends on reliability-cost relationship requires both of these components to have the measurable characteristic. The cost can be measured since it is a quantitative data. While the Loss of Power Supply Probability (LPSP) or the Day of Autonomy (DOA) are used to measure the system reliability. The LPSP is the ratio between the energy shortage and the total energy demands of the load for a long period of time [8]. It is also known as the Loss of Load Probability (LOLP), the Loss of Power Probability (LOPP), and the Load Coverage Rate (LCR) [9]. The value of the LPSP ranges from zero to one. A lower value of the LPSP shows a higher system reliability. The reliability results are summarised in a form of a sizing curve called isoreliability line which commonly consists of the sizes of PV arrays and the battery banks [9]. There are two approaches used in designing the SAPS using the LPSP, which are the Chronological Simulation and the Probabilistic Techniques [10]. The Chronological Simulation is done computationally and this method required data spanning for a period of time. The Probabilistic Technique uses the probability of the solar

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radiation and the load demand. The second technique is used if the solar radiation data is not available. The Chronological Simulation is a more precise method compared to the Probabilistic Technique.

There are several Chronological Simulation approaches to determine the optimum configuration for the SAPS. The Numerical Method is used to determine the size of the PV array and the battery story capacity for the SAPS using the hourly mythological data and load profile [11]. The LPSP and DOA concept are used to measure the reliability of the SAPS. The DOA uses the number of days for the SAPS to operate without any blackout [12]. Since Malaysia is not a seasonal country, the DOA is an inadequate concept to measure reliability. While the LPSP is a more suitable reliability measurement concept for the climate condition in Malaysia. The Graphic Construction Method (GCM) is another method for the sizing of the SAPS [1]. The optimum system's configuration is determined by finding the tangent between the partial derivative of a PV array and battery cost with the isoreliability line of the desired LPSP. However, this method does not consider the effect of the interest rate and inflation. A more advanced sizing method based on the LPSP concept is the Artificial Bee Swarm Optimisation (ABSO) for the Hybrid Photovoltaic System (HPVS) [13]. The ABSO is used to reduce the objective function for a complex system and implements the scholastic rules to identify a global solution. An Iterative Method is simple compared to the ABSO method. By using the Iterative Method, the reliability and the total cost of each system's configuration are calculated. A power based Iterative Method is proposed to determine the optimum size for the HPVS [14]. The objective is to determine the minimum different between the power generated and load demand. Another optimal sizing using Iterative Method combines the LSPS and the Levelised Cost of Energy (LCOE) [15,16]. The LCOE of the system's configurations with the desired LPSP is calculated and the lowest LCOE becomes the optimal size for the system.

This paper present the combination of the LPSP concept with the Life Cycle Cost (LCC) analysis to determine the optimal size for the SAPS. The Iterative Method is used to determine the LPSP and LCC of each configuration. The main objective of this work is to determine the system's configuration with a minimum LCC for the criteria of 1% LPSP. The system reliability is further improved by using the Reliability Improvement Method (RIM). This is to identify the maximum reliability improvement with minimum cost increment for the criterion of 1% LPSP. The results from the RIM and the LCC methods are compared with the results using the GCM. The simulation has been conducted using the input parameters from Senai, Johor, Malaysia. The data is based on the hourly solar irradiance and temperature, while the consumption of the FKE Building, UTM is used as the load profile. The simulation is conducted using MATLAB® simulation package. This article is organised as follow: introduction and a review of the sizing method for microgrid system, the available literature and related research in sizing methodology, followed by the system modelling and sizing in Section 3. Then, the results and discussions are described in Section 4 and lastly the conclusion.

2. Review of the component sizing for microgrid system

It is necessary to size the components of microgrid as this ensure the reliable power supply while remaining the economic viable of the system developed. The sizing of renewable energy in the microgrid is a complicated issue since the process of sizing needs to consider the reliability and the cost, which coupled to the uncertainty in demand requirement and energy production. In the microgrid that obtained the energy from renewable energy resources, the power generation depends on the weather conditions including the wind speed, the solar radiation and the ambient temperature. In a grid connected system, the sizing of the microgrid component is less complicated as it only considers the area and time duration to supply energy from the grid. The grid plays the role to ensure the energy demand is satisfied. In comparison, the stand-alone system has a more complex sizing system since it needs to work without disturbances and ensure the quality of power supply. The optimal design of a stand-alone microgrid system has to consider both reliability and cost issues [17]. This means the design of any renewable energy system should meet the load demand at a minimum cost whereby the design of the desired system can be evaluated through its lifetime and emission. The design of optimal size also has a high connection with the energy management strategy that ensures the power flow to meet the demand in the system. The lifetime cost in microgrid usually consists of the operational, the capital, and the maintenance cost. The capital and the maintenance cost are considered as the “fixed cost”. However, the operational cost varies due to the adjustment in how the system works that could minimise the operational cost. The calculation of the lifetime cost and the changes in monetary value due to supply time need to be considered. Hence, the optimal design of the system must ponder the generators type along with the size that results in the lowest lifetime cost and gives a low emission level. In this regards, the goal of microgrid design process is to achieve a reliable power supply under varying atmosphere conditions with a minimum cost of the system. Due to the high requirement in sizing method for microgrid system, numerous articles in the literature discuss the technique used in developing the optimal size for microgrid system. The study on sizing for the stand-alone system seems to be more popular listed in the literature compared to grid connected system. The power management strategy for dispatching energy from the energy source, energy storage and electrical loads require a proper size of the hybrid component system. According to the previous literature, the sizing method for microgrid can be grouped into several techniques including the manually sizing method, the iterative sizing method, sizing using the commercial software tool and the sizing using the optimisation algorithm [18]. The method of manually sizing, sizing using software and optimisation sizing have been discussed by Behzadi in the article [19]. In addition to this three techniques, Upadhyay expanding the alternative to size the microgrid system in the article [20]. The alternatives are grouped into six methods including the Graphic Construction Method, the Probabilistic Method, the Analytical Method, the Iterative Method, the Artificial Intelligence Method and the Hybrid Method. Thus in this review section, the sizing method for the microgrid system is grouped into eight techniques as illustrated in Fig. 1. The description of each method with the related research work given in Table 1.

The manual sizing is being done in previous research by Chedid in [21] where the Analytic Hierarchy Process (AHP) quantify the parameters needed in designing the hybrid solar-wind power system (HSWPS). In this method, the trade-off risk method is used to generate multiple plans under 16 different futures and obtained the corresponding trade-off curves. There are several hierarchical sets up inside this method which includes all factors influencing the size of the developed system. This method is time-consuming since it requires manual calculation to obtain the size of the developed system. Another article by Chasheng in [22] where the researcher first considers the capacity factor of the renewable energy sources used. In this regards, the unit sizing aims to minimise the difference between the generated power (P_{gen}) from the renewable energy sources and the demand (P_{dem}) over a period of time. Although the sizing mechanism has reached the optimum target but the overall results are not feasible since it is not into account the cost effective factor. A manual size method for battery storage and super-capacitor is studied in article [23] where the corresponding calculation is properly done with the aim to increase battery lifetime. There are two methods used to calculate the size of the battery. First, consider the size of the wind turbine and second consider the size turbine and fluctuation generation of wind power due to the unstable wind speed. The mathematical equations for the proper size of the supercapacitor and the battery are available in literature [23] where all the calculations are account subjected to the State of Charge (SOC) of the supercapacitor and battery.

An Iterative Method is introduced in reference [24] where an iterative algorithm is described to determine the wind generator