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A novel optimization method for designing stand alone photovoltaic system

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ABSTRACT

This paper presents a novel optimization method for sizing and design of stand alone photovoltaic systems. Loss of power supply probability analysis is set as a benchmark to determine all possible PV array and battery capacity. Then, the optimum design is proposed based on the lowest levelized cost of energy. The case study, with reference to Malaysia's meteorological data and typical load profile of rural area, has been simulated and compared to selected three past researches.

1. Introduction

Photovoltaic (PV) generating system is the most promising renewable energy resource in Malaysia compared to other alternative energy sources available. Located in the equatorial region, Malaysia naturally has abundant of sunshine and receives an average solar irradiation from 4.21 kWh/m^2 to 5.56 kWh/m^2 per day. The advantages of utilizing PV generation system are that the system is clean, environmental friendly, and this country is blessed with high intensity of solar energy. Besides, it is suitable for decentralization of power generation and off-grid applications [1]. However, solar energy is grossly underutilized despite being endowed with it [2], due to high initial cost and requirement of large space area.

Before PV system installation, it is important to ensure that the recommended system will not oversize/undersize, and designers have to perform early investigation for the system viability in preliminary design. In order to efficiently and economically utilize solar energy, optimization in system sizing is necessary so that the proposed system can operate in optimum condition in terms of investment and power reliability [3]. During system sizing, designers have to forecast electricity consumption and generation, so that the proposed system can overcome the sizing requirement (energy demand). Large self-consumption is desirable, to obtain lowest investment with full use of the PV array and/or battery bank.

Stand alone photovoltaic (SAPV) system is becoming more viable and cost effective to be implemented in remote areas. Many attempts have been made to optimize SAPV system. A study was done to propose a new method for SAPV system sizing in 2009, by using Kuala Lumpur's meteorological data [4]. This study implemented graphical approaches, where two graphs for a given loss of power supply probability (LPSP) were constructed, which were array size versus battery size graph, and partially differentiation of system cost function. The tangent point for both graphs indicated the optimum size for PV array and battery. However, the results are only applicable to the selected site that is Kuala Lumpur. The method used also not appropriate if different load profile is applied and not flexible for different DOD battery. Besides that, the optimization was done using daily irradiation data, whereby the fluctuation effect on generation and system size was not be investigated. In addition, even though the authors considered temperature effect in the PV modeling, the temperature value used was daily average value (temperature average from 0000 to 2400 period). In Malaysia, PV electricity is generated usually from 0700

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to 1900, thus will cause the average temperature to be lower (lowered by temperature at night) compare to the actual value during actual PV generation period. This could limit PV modeling accuracy. Also, the cost function was not included with replacement cost, and cost function for other components, C_{other} was assumed no correlation with battery capacity or PV power (constant).

However, an improved technique to obtain an inclusive sizing for standalone system for five locations in Malaysia has been studied [5]. By using iterative approach, two graphs were plotted to show relation of PV array sizes to loss of load probability (LOLP), and relation between PV sizes and optimum battery sizes, based on average daily meteorological data. By using MATLAB fitting toolbox, two formulas for optimum ratio of PV capacity and battery capacity over specific load value were derived. This research attained average coefficients for different five sites. From the finding, the relation between ratios of PV generated capacity and load demand was exponential with LOLP, while the relationship between PV capacity and battery capacity ratio over specific load demand was linear. The authors also compared their results with those of other findings in Ref. [4]. However, as mentioned in Refs. [6], the limitations for the method used were that the sizing was done based on daily solar meteorological energy and average daily load demand. Other than that, temperature effect was not considered in the PV modeling. In addition, battery size was determined using difference of energy excess towards energy deficit, and the authors neglected battery DOD during battery sizing.

In 2014, a system sizing using conventional method was published, and the result is only suitable in pre-design SAPV, based on a specific load demand. Other parameters included in the design are the optimum size for PV generation, battery capacity to fulfill 2 autonomy days, optimum connection for module and battery, charge controller and inverter rating [7]. However, as mentioned in Refs. [5], the authors did not consider temperature effect on the generated power. Besides, since intuitive method was implemented, only monthly average irradiation data was used to determine PV array and battery size. Hence, LPSP or LOLP value for the proposed system could not be determined. Moreover, battery sizing was calculated using total required capacity needed to cover two autonomous days. Unfortunately, these led to oversized system, and increased system cost.

In the other hand, a method for designing optimum solar cell arrangement (series-parallel) in a single module with respect to site latitude and climate has been published in Ref. [8]. This method has different approached compared to [4,5,7]. Instead of finding optimum PV capacity to supply certain demand at specific location, the author introduces a procedure to find the best way of how solar cell can be arranged in a module at different latitudes and climates. The findings indicate that, sites with higher latitude will have higher parallel string compared to lower latitude. Also to obtain the optimum module dimension of solar cell arrangement the ratio of PV module length over width must exceeds unity for high latitude locations. Hence, this method is the most suitable in obtaining the optimum module dimension prior to optimum sizing of PV system.

In order to overcome current sizing limitations from the published works in Refs. [4,5,7], this paper presents the optimization of SAPV system sizing, not only for solar array and battery size, but also for charge controller and inverter sizing. In addition, this paper also proposes ways to determine detailed configurations for PV and battery connection design. A detailed economic analysis was done for a 25 year period to determine levelised cost of energy for the new proposed system. The obtained results were then analyzed and compared with the previous methods.

2. SAPV System Sizing and Mathematical Modeling

The SAPV system model employed in this analysis is portrayed in this section. Fig. 1 illustrates the proposed system configuration, composed of PV generator, charge controller, battery and inverter. The PV array functions to convert sun radiation into DC power, while the charge controller manages the energy flow in solar electric system, including overcharge protection, deep discharge protection, system power management and user alert. The battery stores excess energy and the inverter converts DC power into AC power to match AC appliances. Sometimes, only AC load is used in the analysis.

2.1. Proposed Optimization Algorithm Flowchart

Fig. 2 shows simplified design steps implemented in this study. The analysis was done via amp-hour method. The main advantage of amp-hour analysis is that it takes the real world behavior of SAPV system components into account. In addition, it is easier to determine charge controller rating [10]. The following section discusses the design process in detail.

2.2. Meteorological Data

In SAPV system, solar panels are the only power source. The hourly energy generation of PV panels depends on the solar irradiation and cell temperature [11]. For this study, meteorological data was imported from Meteonorm 6.1, using PVsyst V6.10 software. PVsyst V6.10 software was mainly used as an analysis, planning, design, and sizing tool. This software has its own Meteo database, and is able to import data from websites. Meanwhile, Meteonorm 6.1 is a comprehensive meteorological reference that has a meteorological forecast model to calculate hourly and minute value from monthly data for any sites. Table 1 shows the average annual global irradiation at horizontal plane and temperature in Malaysia, generated from PVsyst software [12].

2.3. Estimation of Load Demand

For the estimation of hourly load demand, a checklist of all appliances used, as well as their individual load description is required. Energy requirement, E_{req} is determined by calculating the total of hourly DC energy demand, E_{DC} (if existed) and hourly AC energy demand, E_{AC}. Then, hourly system charge requirement, I_{req} (Ah), is calculated using Eqn. (1), where V_{DCbus} is DC bus voltage. Referring to Fig. 3, the designer must determine the DC bus voltage

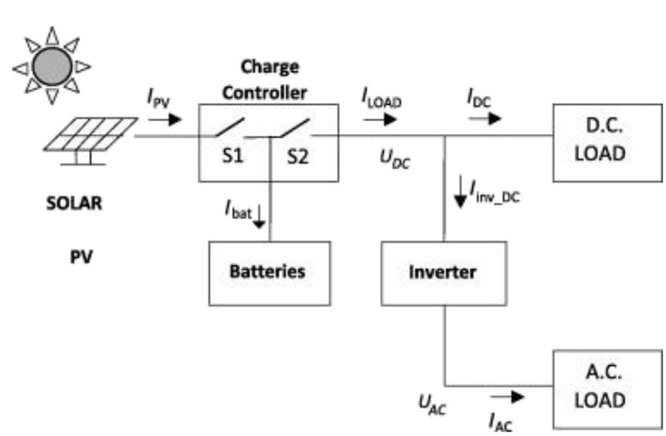

Fig. 1. Stand Alone PV system components [9].