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REVIEW ARTICLE

Modelling of stand-alone photovoltaic systems: a review

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Abstract

The main objective of this paper is to present an overview of various approaches and techniques for sizing of stand-alone photovoltaic (PV) systems and to establish a library of simple mathematical models for each individual element of a stand-alone PV system, namely solar cell, battery, controller, inverter and load. This provides a path to model a PV system that provide good optimization, especially in isolated areas.

Introduction

The global environment conditions are getting worse day by day. The rapidly increasing energy consumption, limited resources of fossil fuel and the soaring cost of fuels increases the need of renewable energy sources. Renewable resources are natural resource. Renewable resources are basically a part of Earth's natural environment and one of the largest components of its atmosphere. Renewable energy is taken or extracted from natural resources such as sunlight, wind, biomass, green energy, tides, and geothermal energy. Common application of renewable energy is electricity generation.

Most renewable energy comes either directly or indirectly from the sun. Sunlight, or solar energy, can be used directly for generating electricity, and also for hot water heating, and a variety of commercial and noncommercial uses. Renewable energy facilities generally require less maintenance than traditional generators. Renewable energy produces zero or a very little amount of waste products such as carbon dioxide or other chemical pollutants, so has minimal impact on the environment. Among all the renewable energy resources, the solar and wind energies have the great potential as a power generating energy source, because of their many advantage like low or zero emission of pollutant gases, low cost, inexhaustible sources and easy availability of these energy sources.

But these systems have some disadvantages also like dependency on weather conditions. One of the major disadvantages with renewable energy is that it is difficult to generate the quantities of electricity that are as large as those produced by traditional fossil fuel generators. So we need to reduce the amount of energy we use or simply find alternated source of energy. The best solution to our energy problem may be to have a balance of many different power sources. Another disadvantage of renewable energy sources is the dependency of supply like sun light or wind etc. Renewable energy often depends on the weather condition for its source of power input. For example a Hydro generator depends on rain to fill dams to supply flowing water. A wind turbine depends on wind to turn the blades to run the turbine, and a solar cell depends on the position of sun to collect heat and make electricity. The supplies from these sources are highly unpredictable and inconsistent. The generation of current from renewable energy technology is also far in excess of traditional fossil fuel generation, this is because it has extremely large capital cost. We can reduce the dependency of solar or wind power system on weather conditions by using some backup supply like batteries.

Stand-alone PV-system

Photovoltaic (PV) applications may offer a promising alternative especially in remote areas as isolated small power generation for the essential electric power. All around the world there are a number of small isolated communities, without access to the grid. Furthermore, in many places due to the remoteness and due to the cost, it is unlikely that main grid connection will be ever established. However, the need for power still exists. Power systems which can generate and supply electricity to such remote locations are differently termed 'decentralized, autonomous or stand-alone'. These may come as individual energy systems (IES) or community energy systems (CES). The technology for power production from renewable energy (REN) resources is available and reliable so the penetration of the technology depends mainly on the economic feasibility and the proper sizing of the components in order to avoid outages as well as ensuring quality and reliability of supply. Several models have been developed, simulating and sizing PV systems using different operation strategies.

The estimation of the excess of energy provided by PV generators using the utilisability method was developed by Liu and Jordan [1]. The excess energy provided by PV systems for an installation having a constant load was also evaluated by Klein [2]. Siegel *et al.* [3] evaluated the monthly average output, the excess of energy and the storage capacity of the batteries. Evans *et al.* [4] described a method to consider the monthly average output of PV fields, Gupta and Young [5]. Clark *et al.* [6] use the average utilisability function.

All these methods are based on the energy balance of the systems studied to determine their storage capacity and output. Other methods estimate the performance of PV systems based on the Load Probability (LLP) technique, defined as the ratio between the energy deficit and the energy demand, both on the load, developed by Bucciareli [7], Klein and Beckman[8], Barra *et al.* [9], and Bartoli *et al.* [10]. These analytical methods are simple to apply but they are not general.

On the other hand, the numerical methods presented by Bucciarelli [11],Groumpos and Papageorgiou [12], Graham *et al.* [13], Aguiar *et al.* [14], Richard and Chapman[15, 16] and Abouzahr [17] present a good solution, but these need a long period solar radiation data record. Egido and Lorenzo [18] reviewed methods for computing capacity of PV arrays and battery storage and suggested analytical model , where it uses more complex methods which allow the improvement of the precision calculation according to the dimension of the PV-array area and the storage capacity. An optimal method for the panel area of photovoltaic system in relation to the static inverter practical results has been developed by Keller and Affolter [19].

The topic of modeling of photovoltaic systems has been well documented by Joyce *et.al.[*33]. A dynamic model of a stand alone PV system has been developed based on model maker having as input characteristics data from component manufacturers. The model has been validated against experimental data and a very good agreement between calculated yields for both simulated and measured values were shown.

The PV 4-parameter and 5 parameter model has been compared by Adel *et.al.*[34]. The comparison was performed using poly crystalline and amorphous silicon solar cells. The results showed that the 4- parameter model can accurately determine the I-V characteristics of single and poly crystalline solar cells. On the other hand the 5-parameter can accurately determine the I-V characteristics of amorphous solar cells.

Nevertheless, a detailed evaluation of the sensitivity of a numerical sizing method developed by Notton *et al.* [21], has shown that the influences of some parameters on the sizing, i.e.,simulation time step, input and output power profile are very important. It is therefore important to have knowledge of the daily profile at least on an hourly basis. The authors have highlighted that optimal solution can be obtained if PV contributes for 75 % of the energy requirements. The cost of electricity generated from a hybrid PV system is also one of the decision-making parameters. Marwali *et al.* [22] developed a methodology for calculating production cost of hybrid PV battery system in which the size of PV system is calculated on the basis of not-met electrical requirement

Chan et.al [35] presents a comparative study of three methods for extracting solar cell parameters of the single diode lumped circuit model. The methods compared are curve fitting method, an iterative method and a recently proposed analytical 5-point method. The 5-point method has been found to be reliable and accurate in situations where the model is a good approximation of cell performance.

The solar irradiation estimation and cloud cover data interpolation techniques have been used by Samini *et.al*.[36] for finding the tilt angle of the modules. The cloud cover data has been then used to estimate the expected number of successive cloudy days in each month with result applied for optimal sizing of battery. An accurate PV module has been presented by Geoff Walker[37] based on the Shockley diode equation. This method has been used to investigate the variation of maximum power point with temperature and insolation levels.

Shrestha and Goel [23] demonstrated a method to find optimal combination of PV array size and battery to meet the refrigeration load, by using statistical models for both solar radiation and the load. The author had designed a stand-alone PV system based on irradiation derived from METEOSAT images. Using a combination of both daily based on WEFAX satellite images and a TAG model, hourly global solar irradiation data on a horizontal plane are synthesized with a good accuracy (RMSE < 80Wh.m-2) [24]. Sidrach-de-Cardona and Mora López [22] have developed a simple model for sizing stand alone PV systems [25, 26].

A new technique for sizing parameters for stand-alone solar-energy systems has been designed by Agha and Sbita [27]. Athanasia *et al.*, reviewed the economics of PV standalone residential households in various European and Mediterranean locations [28]. Benghanem has been developed a suitable methodology based on LLP for sizing PV-system [29].Bhuiyan and Asgar [30] optimized PV battery system for Dhaka, Bangladesh with respect to power output for different tilt and azimuth angle for optimum performance of hybrid PV system.

The model of the charging of a lead acid battery that includes over charging or gas generation is established by Henry et al.[38]. Here a general method for modeling the constant current charging curve of a battery has been adapted. Although the model has been applied to the lead acid battery in particular, the model appears to be generally applicable to other electro chemical systems. The gas evolution process occurring at a constant applied voltage appears as a kinetically controlled gas evolution step. It is independent of the normally occurring gas evolution process on the electrode surface appearing at high voltages.

Per Ekdunge[39] has presented a simplified model, which neglects concentration, potential and current gradients in the porous electrodes. It can be used to simulate the discharge performance of the lead acid battery. The model can predict limitations of the discharge capacity by different phenomena, such as electrolyte depletion in the pores and coverage of the electro active surface by the precipitated reaction product, as determined by the cell geometry and discharge mode. This model can be used for the simulation of dynamic processes

Mellit *et al.*, have presented a simplified methodology for sizing PV-system based on spatial interpolation of optimal sizing PV-system in Algeria [31]. Kaushika *et al.* [32] developed a computational scheme for stand-alone solar PV systems with interconnected arrays have been investigated for optimal sizing of the array and battery bank. A method of sizing standalone PV systems regarding the reliability to satisfy the load demand, economy of components, and discharge depth exploited by the batteries is developed by Balouktsis [38].

The economic analysis of PV stand-alone residential systems verifies the predictions for the brilliant future of PV technology even for this demanding type of application. A new sizing approach is applied to stand-alone PV systems design, which is based on systems configurations without shedding load, is developed by Fragaki and Markvart [39]. The investigation is based on a detailed study of the minimum storage requirement.

Conclusion

The review provides insight into the modeling of a standalone PV system. The model of PV array, Boost converter, Inverter & its control, Variable load is represented. PV cells are approving environmentally friendly source of power that will continue to further photovoltaic research. Photovoltaic advancements in the fields of thin film and nano-crystalline materials will continue to flourish and soon increase PV efficiency to over 35%. As efficiency increases, PV technology will attract a greater number of people, resulting in reduced cost. Because the sun delivers ten thousand times more energy than people currently consume, stand-alone photovoltaic system presents several promising advantages. First, it can convert power for ac utility from relatively low dc voltage sources by itself. Second, it increases output voltage levels without any transformer so that it has higher efficiency and lower weight for the overall system.

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