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An Iterative Method for Calculating the Optimum Size of Inverter in PV Systems for Malaysia

Abstract. *This paper presents an iterative method for optimizing inverter size in photovoltaic (PV) system for five sites in Malaysia. The sizing ratio which is the ratio of PV rated power to inverter's rated power is optimized at different load levels using different commercial inverters models. Hourly solar radiation and ambient temperature records are used to develop a Matlab model for a PV array and inverter. The model aims to estimate the inverter's efficiency in terms of PV array output power and inverter rated power. The results showed that the optimum sizing ratios for Kuala Lumpur, Johor Bharu, Ipoh, Kuching and Alor Setar are 1.21, 1.43, 1.31, 1.37 and 1.26, respectively.*

Streszczenie. *W artykule zaprezentowano iteracyjną metodę optymalizacji rozmiaru przekształtnika w systemach fotovoltaicznych na przykładzie pięciu usytuowań w Malezji. Optymalizację przeprowadzono dla różnych obciążeń bazując na komercjalnych modelach przekształtników. Uwzględniono nasłonecznienie dobowe i temperaturę otoczenia. Na przykład dla Kuala Lumpur optymalny stosunek mocy fotowoltaicznej do mocy przekształtnika wynosił 1.21. (**Iteracyjna metoda obliczania optymalnego rozmiaru przekształtnika w systemach fotowoltaicznych na przykładzie Malezji**)*

Keywords: Inverter, optimization of PV systems, sizing PV systems, PV systems, Malaysia
Słowa kluczowe: przekształtnik, systemy fotowoltaiczne.

Introduction

PV system installation has played an important role worldwide based on the fact that solar energy is clean, environment friendly and a secure energy source. However, the drawback of PV system is the high capital cost compared with conventional energy sources. Currently, many research works are carried out focusing on optimization of PV systems so that the number of PV modules, capacity of storage battery, capacity of inverter and PV array tilt angle can be optimally selected [1]. However, the rated power of a PV array must be optimally matched with inverter's rated power in order to achieve maximum PV array output power [2]. The optimal inverter sizing depends on local solar radiation and ambient temperature and inverter performance [3, 4]. For instance, under low solar radiation levels, a PV array generates power at only part of its rated power and consequently the inverter operates under part load conditions with lower system efficiency. PV array efficiency is also affected adversely when an inverter's rated capacity is much lower than the PV rated capacity. On the other hand, under overloading condition, excess PV output power which is greater than the inverter rated capacity is lost [5, 6]. This to say that optimal sizing of PV inverter plays a significant role in increasing PV system efficiency and feasibility.

Research works related to optimization of inverter size can be found in [7-11]. In [7], an analytical method is presented for the calculation of optimum inverter size in grid-connected PV plants at any site in Egypt and Europe. Models for many commercial inverters efficiency curves were developed and the solar energy and ambient temperature records were used to model the PV array output which lead to optimum sizing ratio of inverters. The validity of the analytical model in [7] was tested by comparing the simulation outputs and with measured data. In [8], a simulation approach for inverter sizing based on a single inverter configuration was done for regions in Europe. In the simulation, the PV array and inverter were modeled using the solar energy and ambient temperature records. In [9], inverter sizing strategies for grid-connected photovoltaic (PV) systems are conducted for regions in Germany taking into account site-dependent peculiarities of ambient temperature, inverter operating temperature and solar irradiation distribution characteristics. In this case, 10 s irradiation values were used instead of average hourly irradiation values for sizing inverters since hourly averages hide important irradiation peaks that need to be considered. In [10], optimum PV inverter sizing ratios for grid-connected PV systems in selected European locations were determined in terms of total system output, inverter characteristics and insulation data. The maximum total system output was determined for low, medium and high efficiency inverters of different sizing ratios. In [11], PV inverter sizing is economically optimized by developing a PV module and a PV inverter model in Matlab using real solar irradiation records. The single cost categories of a PV inverter are introduced and discussed with respect to an economically optimized sizing considering reactive power supply. The results showed that the sizing of a PV inverter has to be adapted to the respective reactive power supply methods in order to keep it economically optimized. In this paper, optimal sizing of inverter for PV systems are presented for five sites in Malaysia, namely, in Kuala Lumpur (KL), Johor Bharu (JB), Ipoh, Kuching and Alor Setar (A.L). Hourly solar radiation and ambient temperature records provided by the Solar Energy Research Institute of Universiti Kebangsaan Malaysia were used in the optimization work. The proposed optimization considers the developed inverter efficiency curves and the long term solar energy and ambient temperature records. During the optimization process, the inverter performance is predicted based on the inverter efficiency curves developed from a mathematical model. The optimum inverter size for PV system in Malaysia is then determined by an iterative method.

Modeling of PV array output power

The output power of a PV array depends on the available solar radiation (G) and the ambient temperature (T). The output power of a PV array increases linearly as the solar radiation increases, and decreases as the ambient temperature increases. Thus, the instantaneous output power of a PV array [12] can be given by,

$$(1)\quad P_{pV}\left(t\right)=P_{peak}\left(\frac{G\left(t\right)}{G_{standard}}\right)-\alpha_T\left[T\left(t\right)-T_{standard}\right]$$

where $G_{standard}$ and $T_{standard}$ are the standard test conditions for solar radiation and ambient temperature, respectively and α_T is the temperature coefficient of the PV module power which can be obtained from the datasheet [12].

To extract maximum power from a PV array which is under varying weather and load conditions, maximum power point trackers (MPPT) are used. Such a device ensures maximum power operation of PV array and in this case the PV array is assumed to be operating at maximum power output, P_{peak}.. Based on equation 1, the calculation of PV array output power requires solar radiation and ambient temperature records, and therefore, hourly solar radiation and ambient temperature records for the adopted sites have been obtained. Figure 1 shows a sample of hourly solar radiation and ambient temperature records for five days for Kuala Lumpur. These samples have been taken in the period of (1995-2005).

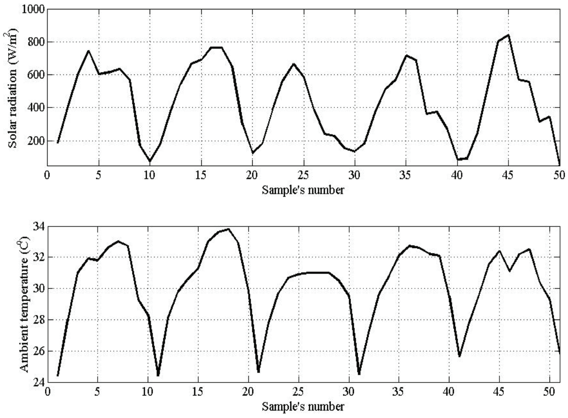

Fig. 1 A sample of the used solar radiation and ambient temperature data

Modeling of inverter efficiency curve

The efficiency of an inverter [12] is calculated by,

$$\eta(t) = \frac{P_{in}(t) - P_{Loss}(t)}{P_{in}(t)} \quad (2)$$

where $P_{in}(t)$ and $P_{Loss}(t)$ are the instantaneous input power and power loss during the conversion.

Ignoring the DC-DC converter efficiency, the input power to the PV system is the output power of the PV module. The P_{Loss} is not constant but depends on many conditions which makes it difficult to be calculated. Thus, an alternative model for inverter efficiency needs to be developed in order to estimate the inverter's output power.

Figure 2 shows an efficiency curve for a commercial inverter obtained from the datasheet. The curve describes the inverter's efficiency in terms of input power and inverter rated power.

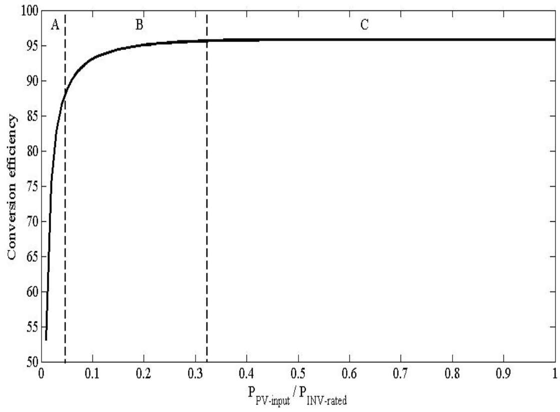

Fig. 2 Typical efficiency curve for an inverter

The efficiency curve can be described by a power function as follows,

$$\left\{ \begin{array}{ll} \eta = c_1 \left(\frac{P_{pV}}{P_{INVR}} \right)^{c2} + c_3 & \frac{P_{pV}}{P_{INVR}} > 0 \\ \eta = 0 & \frac{P_{pV}}{P_{INVR}} = 0 \end{array} \right\} \quad (2)$$

where P_{pV} and P_{INVR} are PV module output power and inverter's rated power respectively while C1-C3 are the model coefficients.

A MATLAB fitting tool can be used for calculating the developed inverter model coefficients, C1-C3. Therefore, samples of the inverter's efficiency curves shown in Figure 2 must be taken for the purpose of curve fitting using the MATLAB fitting tool. Intensive number of samples must be taken for a specific part of the curve as in zone B, less intensive number of samples are taken from the zone A, while few samples are taken from the zone C as described in Figure 3. In this work, three commercial inverters of rated powers, 5 kW, 50 kW and 100 kW are considered. The reason for choosing these inverters is to match the three types of loads, namely, low (5 kW), medium (50 kW) and high (100 KW). Figure 4 shows the efficiency curves which have been constructed based on the model described in equation 3 for the chosen inverters types. Using the MATLAB fitting tool, the developed models coefficients are calculated as shown in Table 1.

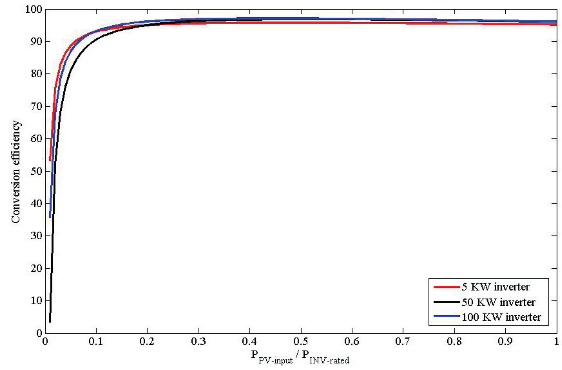

Fig. 2 Efficiency curves for the three chosen inverters

Table 1 Inverter models coefficients

	C_1	C_2	C_3
5 kW	-0.2418	-1.127	96.10
50 kW	-0.5879	-1.105	97.76
100 kW	-0.3253	-1.143	97.49
Average	-0.385	-1.125	97.12

Optimization of inverter size

The optimum size of an inverter is represented by the ratio, R_s which is the PV array rated power to the inverter rated power and it can be descried mathematically as follows,

$$R_S = \frac{P_{pVrated}}{P_{INVrated}} \quad (4)$$

where $P_{PVrated}$ is the rated power of the PV array and $P_{INVrated}$ is the rated power of the inverter.

The objective function of the optimization problem is maximizing the annual average inverter efficiency which is formulated in terms of the daily averages of solar radiation (G), ambient temperature (T) and inverter rated power (P) and is given by,

(5) $$MAX: \eta_{annual} = \frac{\sum_{366}^{1}\eta_{daily}}{366} = \frac{\sum_{366}^{1}\frac{P_{PVinput}}{P_{invR}}}{366} = \frac{\sum_{366}^{1}\frac{P_{Peak}\left(\frac{G(t)}{G_{standard}}\right)-\alpha_T[T(t)-T_{standard}]}{P_{invR}}}{366}$$

The optimization problem is then by using the efficiency curve based optimization which is an iterative method. Figure 4 shows the proposed iterative method for determining the inverter size in which the optimization process starts by obtaining the PV system specifications such as PV array rated power, temperature coefficient and MPPT efficiency. In addition, the hourly solar energy and ambient temperature for the targeted area must be obtained in order to calculate the PV array output power. A set of R_s values is used in the iterative loop, the rated capacity of the inverter is calculated after defining the value of R_s and then the PV array output power is calculated using equation 1. Here, the developed inverter models are used to estimate the efficiency hour by hour through a specific period of time and then the annual efficiency is calculated and stored in an array. This loop will be repeated iteratively until reaching the maximum value of R_s then a search for the maximum efficiency value and its index (optimum R_s) is conducted. However, this process is done for the adopted sites considering low, medium and high loads.

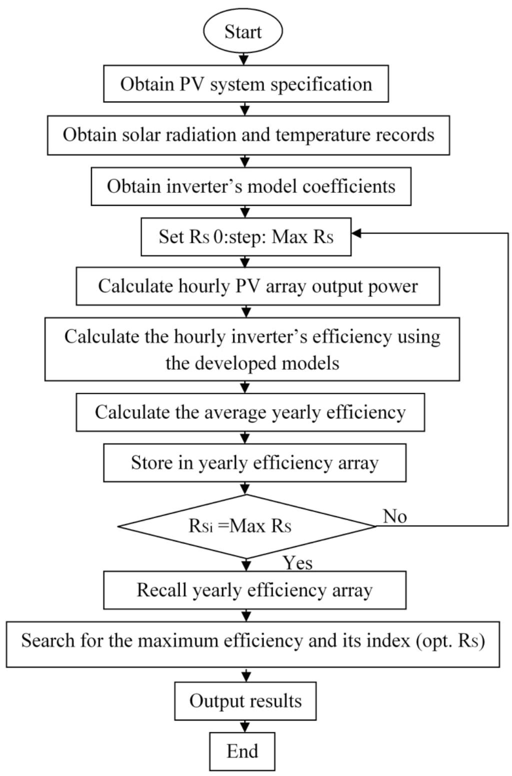

Fig. 3 Iterative method for determining the inverter size

Figure 5 shows an example for searching the optimal inverter size for Kuala Lumpur considering three different loads. It is noted that the values of optimum R_s for the three loads are almost the same except that there are differences in the maximum efficiency value which is due to the nature of the used inverter, and not related to the load nature.
Table 2 shows the optimum inverter size at different locations and load levels in Malaysia. From the tables, it can be concluded that Kuala Lumpur has the best solar energy potential among these regions since the sizing ration Rs is the smallest. On the other hand, all the regions have almost the same Rs and this indicates that these regions have the same potential of solar energy.

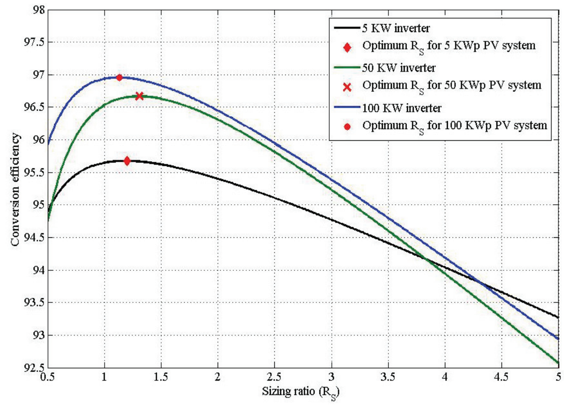

Fig. 4 Searching for the optimum inverter size for Kuala Lumpur

Table 2 Optimum inverter sizes (R_s) for Malaysia

	K.L	J.B	Ipoh	Kuching	A.S
5 kW	1.20	1.41	1.29	1.35	1.20
50 kW	1.31	1.55	1.42	1.48	1.42
100 kW	1.13	1.34	1.23	1.27	1.15
Av.	1.21	1.43	1.31	1.37	1.26

Table 3 shows the annual averages of solar energy and ambient temperature for the five regions. From the table, Kuala Lumpur and Alor Setar have high solar energy average among the other regions with Alor Setar having a slightly higher average than Kuala Lumpur. However, the optimum R_s for Kuala Lumpur is higher than Alor Setar. This may be due to the difference in the average of ambient temperature of the two regions where the average ambient temperature for Kuala Lumpur is lower than Alor Setar by 3.4 C. This result highlights the effect of ambient temperature on the PV system performance and its components size.

Table 3 Annual solar energy and ambient temperate averages for Malaysia

	Solar Energy KWh/m^2	temperature C^o
K.L.	4.90	25.5
J.B	4.57	26.5
Ipoh	4.74	28.8
Kuching	4.61	27.5
A.S	4.96	28.9

Conclusion

Optimization of inverter sizing ratio of PV systems for Malaysia was done. The weather records such as solar energy and ambient temperature for the five sites in Malaysia are obtained and used for developing models for PV array and inverter. The results presented the optimum inverter sizing ratios of 0.21, 1.43, 1.31, 1.37 and 1.26 for Kuala Lumpur, Johor Bharu, Ipoh, Kuching and Alor Setar, respectively. From the results, it is noted that high temperature levels may affect the performance of PV systems negatively.

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