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SciVerse ScienceDirect
Energy Procedia 14 (2012) 1134 – 1142
Energy Procedia

2nd International Conference on Advances in Energy Engineering,2011

An improved algorithm for photovoltaic system sizing

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Abstract

A decision on the system requirements of a photovoltaic (PV) power plant is becoming critical as its components are very costly. An accurate and optimum sizing is in demand. This study proposes some modification to the existing approach of PV sizing by incorporating the battery rate factor into the sizing process. This new approach helps in eliminating the excess battery requirements without affecting the existing load demand. The results of the proposed algorithm is compared and validated with the system data for two existing PV power plants. An analytical methodology is developed for evaluating the sizing for varying rate factors. A new limit is defined for the battery charging hours to avoid the need for additional battery bank units. The knowledge of minimum battery charging rate is a useful input, for a system designer, in selecting the charge controller ratings. The code is developed in MATLAB based on the mathematical models proposed in the algorithm.

Keywords: PV sizing; Rate factor; Battery sizing;Battery charging rate

1. Introduction

The need for capturing solar energy capture is at its highest and the Government of India has already made the Green policy, as one of their key agendas. With the growing energy demand, attention is concentrated in increasing the number of solar energy devices. Among this, PV is one of the best options. However, PV sizing decisions are based on the past experiences with the system.

Earlier many researchers have proposed various sizing algorithms to get a near accurate system requirements. A analytical method [1-2], in an earlier work, characterize the system design based on loss of load probability and number of system failures. In another approach [3] on PV system design a new method incorporating the effect of daily solar radiation, instead of monthly average solar radiation, is discussed. The simulation model [4] for sizing the stand alone PV systems for an interconnected array based on loss of load probability(LPSP) method present the surplus and deficit of energy as a function of LPSP. Functional relationship between different variables involved in sizing is studied in some earlier

doi:10.1016/j.egypro.2011.12.1066

works using analytical [5-8] approach. The rate factor of a battery is one of the key performance parameter. The charging and discharge rate of battery decides the long term ampere hour capacity of the battery[9].

A model [10] for lead acid battery performance is developed which explains the process of peukerts law. The faster discharge rates causes decrease in ampere hour capacity of the battery. Inversely for slower discharge the ampere hour capacity of battery improves. None of the previous studies, is not considering the effect of this rate factor in the battery sizing. This study aims at incorporating the effect of rate factor into the PV system sizing and hence developing an improved sizing algorithm. There are possible reasons for higher charging current when the number of bright sunshine hours is higher. The higher charging rate can effect the battery capacity and hence the performance. A limit defining the minimum charging hours for battery is derived that will limit the excess battery requirements and also controlling the higher charging current to the battery. Also, the sizing recheck is developed to check the limits of battery for charging and discharging rates. The results of the algorithm are compared to the system requirements of two existing PV power plants installed in the state of Kerala, India. The effect of rate factor on the decision of number of battery bank units is also discussed.

Nomenclature

A_h Rated ampere hour of the battery at standard discharge rate

A_{hy} Ampere hour of the battery at discharge rate of y hours

$C_{r,y}$ Battery charging rate in hours

E_i Efficiency of inverter

h Number of hours of bright sunshine

I_{hd} Total daily ampere hour demand

I_{hdc} Daily DC ampere hour demand

I_m Current of PV module at maximum power

K_1, K_2, K_2' Constants

n Number of days of battery storage required

N_b Total number of batteries

N_m Total number of modules

N_{bp} Number of batteries in parallel

N_{mp} Number of modules in parallel

p,q Coefficients of battery charging

P_{inv} Inverter power output

R Rate factor

V_{dc} System voltage (Inverter input voltage)

Wh_{ac} Total AC watt hour demand

W_{ac} Total AC connected load in watts

2. Background

The main components of a PV system include, a PV module, a battery bank, the power conditioning units (inverters and controllers). A schematic of the PV system is as shown in Fig. 1. The sizing of the PV components derives the specification required by the module and battery bank to feed the rated load demand. The total number of modules required is a function of the daily ampere hour demand of the load, number of bright sunshine hours, system voltage and the constant K_1.

$$N_m = f\ (I_{hd}, h , V_{dc}, K_1) \tag{1}$$

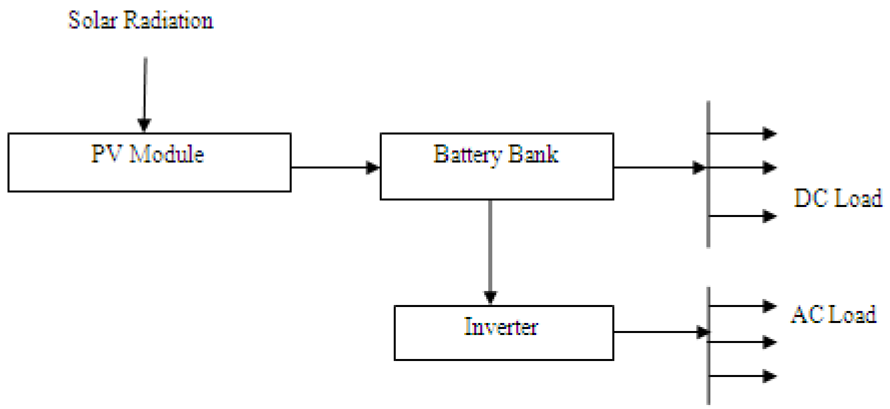

Fig. 1. The schematic of a photovoltaic system components

The total battery requirement for the system is a function of the daily ampere hour demand of the load, number of days of autonomy, system voltage and the constant K_2.

$$N_b = f\ (I_{hd}, n , V_{dc}, K_2) \tag{2}$$

The constants K_1 and K_2 are, respectively, the dependent factors which influences the performances of PV module and the battery . The K_1 compensate for the effect of module mismatching and dust de-rating in the modules. The K_2 represents the effects of battery performance to temperature, the depth of battery discharge and the rate factor. The battery delivers a better performance at higher temperatures and responds negatively to the freezing temperatures. Usually the value of the temperature derate factor ranges between 0.97 – 1. The depth of discharge is the maximum state of charge, in percentage, drained from the battery during a cycle. The K_2 is further expressed as ,

$$K_2 = K_2' \, x \, R \tag{3}$$

The rate factor is the ratio of the total ampere hour discharged during an instant to the total ampere hour it will discharge at standard discharge rate. Practically the discharge rates of solar field batteries are very slow, and hence it claims for a higher rate factor. Here K_2' is the product of depth of discharge and temperature derate factor.

3. Data Source and Methodology

The data input is very critical in regard to the sizing of PV systems. Mostly, sizing is an approximated approach that, is strongly site dependent. The algorithm input data is very critical as most of the decisions depends on the input. The following are the input and output data to the algorithms:

3.1 Input Data:

- Efficiency of the Inverter.
- System voltage or inverter input voltage.
- Number of days of battery storage required.
- Depth of discharge of battery.
- Rated ampere hour of the battery.
- Battery voltage.
- Temperature derate factor for battery.
- Charging and discharging rates from battery specification.
- PV module short circuit current.
- PV module current at maximum power.
- Load data: Load data should include the number of instruments, rated watt of the instruments, hours of operation, rated voltage of the instrument for DC loads.
- Current rating of current controllers.

3.2 Output Data :

- Number of modules (series and parallel).
- Number of batteries (series and parallel).
- Total Area required.
- Inverter specification.
- Number of current controllers.

A statistical fit is employed to determine the rate factor of the battery employed. The model developed is as in the form given in Eq. (4). The value of p and q is dynamic with respect to battery manufacturers. This can be derived from the battery manufacture data sheet.

$$A_{hy} = (p \times y + q) \quad (4)$$

3.3 Methodology

The data collection for the input to the algorithm is explained in this section. Two PV power plants in the district of Kerala is randomly selected for validating the algorithm. The details of the location and the power plant data is obtained from the ANERT (Agency for Non-conventional Energy and Rural Technology, Government of India), who installed these power plants. The site specific weather data is collected from Ministry of New and Renewable Energy, India. The specific data sheet of the PV module and battery is obtained from the manufactures websites. The details of the input data along with the PV module and battery specification is presented in Table1.

4. Proposed algorithm

The following are the steps of the algorithm in sequential order :

4.1. Calculation of daily load demand

The total daily load is calculated in ampere hours using the following equation. The summation of AC and DC load is performed.

$$\text{Daily load demand (Ah)} = I_{hdc} + \frac{Wh_{ac}}{E_i \times V_{dc}} \quad (5)$$

4.2. Sizing of inverter

The inverter is designed to meet unreasonable high surge demands caused by inductive loads. Hence, an inverter with high input voltage reduces the size of the other components like wires. The total inverter watt is fixed to a maximum value of,

$$P_{inv} = 1.1 \times W_{ac} \quad (6)$$

4.3. Sizing of battery

The battery sizing, as depicted in Eq.(2) is a function of the daily ampere hour demand of the load, number of days of autonomy, system voltage and the constant K_2. While calculating the number of batteries the effect of rate factor is included. It is given by,

$$\text{Number of batteries in parallel} = \frac{n \times I_{hd}}{K_2' \times R \times A_h} \quad (7)$$

$$\text{Number of batteries in series} = \frac{V_{dc}}{V_b} \quad (8)$$

4.4. Sizing of PV module

The module is fixed to meet daily ampere hour of the load. The number of modules thus required will be,

$$\text{Number of modules in parallel} = \frac{I_{hd}}{K_1 \times h} \quad (9)$$

$$\text{Number of modules in series} = \frac{V_{dc}}{V_b} \quad (10)$$

4.5. Battery Sizing recheck

The battery charging and discharging cycle need to be verified before concluding the final sizing requirements. The battery should not discharge fully in one day, since it is designed for a complete autonomy. The fast charging and discharging of the battery is undesired for a battery in solar applications. So, the charging and discharging rates of the battery is decided and checked for two constraints as in Eq.(11) and Eq.(12).,

$$\text{Rate of depth of discharge}, \quad DOD_r \leq 0.8 \quad (11)$$

$$e^X > C_{r,y} \quad (12)$$

where,

$$DOD_r = \frac{I_{hd}}{N_{bp} \times A_h}, \quad X = e^{\frac{K_{2'}}{(N_{bp}-0.1)\times p} - \frac{q}{p}}, \quad Cr,y = \frac{N_{bp} \times I_{hd}}{N_{mp} \times I_m}$$

Table 1. Details of the PV power plant

DETAILS	LOCATION I	LOCATION II
Place	Thrissur District, Kerala, India	Pathanamthitta District, Kerala, India
Lattitude and Longitude	10° 18' N , 76° 21' E	9° 16' N , 76° 47' E
Installed Capacity	4.76 kW	2.8kW
Sunshine hours(minimum)	4	4
Inverter parameters:		
Efficiency	0.9	0.9
Volt Ampere	2500	1200
System voltage	48V	48V
Module parameters :		
Model Number	L1270 (BHEL Make)	L1270 (BHEL Make)
Maximum Power	70 W	70 W
Short circuit current	4.7A	4.7A
Open circuit voltage	16.4V	16.4V
Current at maximum power	4.3A	4.3A
Number of parallel modules	17	10
Number of series module	4	4
Battery parameters :		
Model number	Exide LMS 1300	Exide LMS 500
Rated ampere hour	1300AH	500AH
Number of parallel batteries	3	2
Number of series batteries	24	24
Load Details :		
Total Load	9836 Wh	5970 Wh
Rating of current controller	10A	10A

The constraints in Eqs. (11) and (12) influence the number of battery requirements. If any one of the above limits are not satisfied , the sizing procedure is repeated , after increasing the number of batteries, till the conditions are satisfied. The model in the Eq.(12) defines the minimum value of charging hours for battery. For lesser value of the charging hours, the rate factor of battery reduces which demands for higher battery capacity. The detail algorithm is given in the Fig. 2.

5. Results and discussion

5.1. Simulation results

The complete sizing algorithm is developed using the MATLAB software (Version: R2010a). The data collected for the location I and location II are tabulated in Table 1.The simulation is performed for the data obtained for the specific locations I and II. The output of the simulation is compared to the existing site data as presented in Fig. 3(a) and Fig. 3(b). The bar graph depicts the number of battery ampere hour requirements and module requirements for two different locations. The simulated results are found to be matching with the field data, except for battery requirements of location I. A higher value of the rate factor, physically, signifies the ability of the battery to deliver higher ampere hours than rated. This reduces the total battery requirements in a PV system. The additional ampere hour conserved due to rate factor for each battery unit can satisfy the extra battery demand projected in field data. Higher the total ampere hour capacity of battery greater the ampere hour conserved due to rate factor. And for location II the ampere hour requirement is comparatively greater than location I. This could be the reason for simulation data to project lesser number of battery requirements. This algorithm thus introduces the effect of rate factor for fixing the number of batteries. This helps eliminating the extra battery demands, hence the cost. The bar graph proves the validation of the proposed algorithm to the existing field data. The number of modules and battery requirement for simulated and field data is tabulated in Table 2.

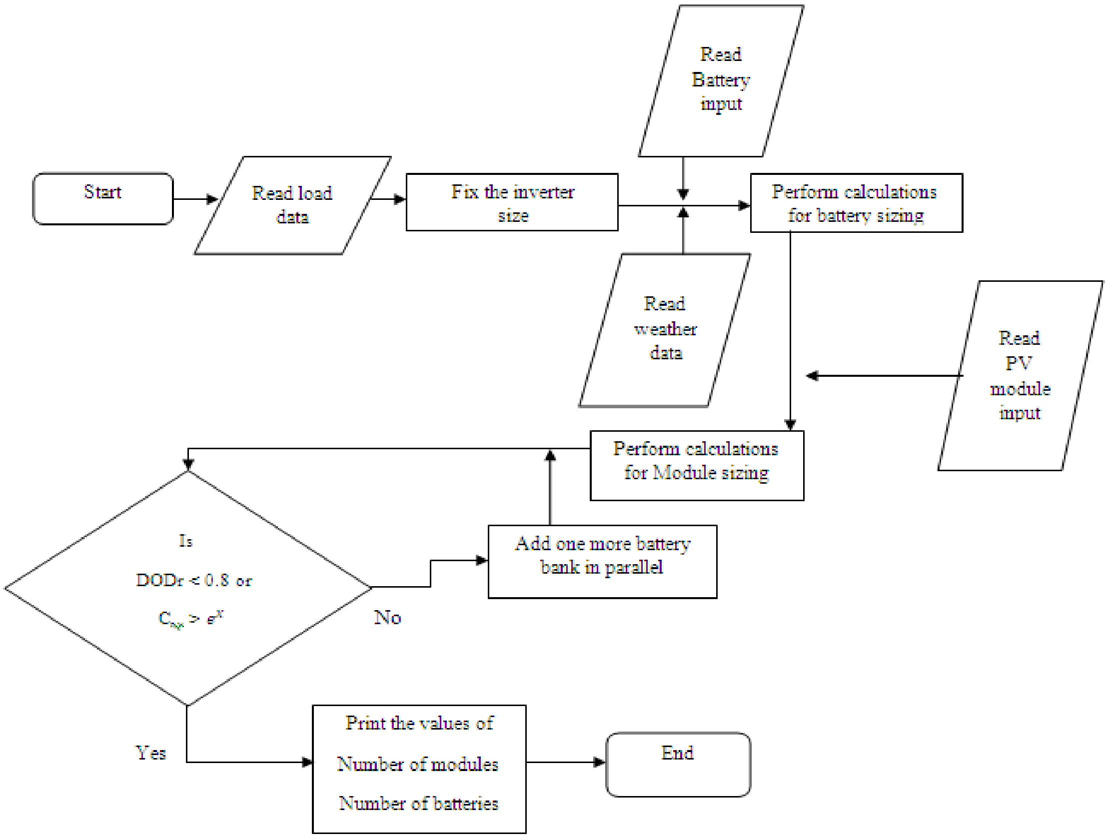

Fig. 2. Proposed algorithm for PV system sizing

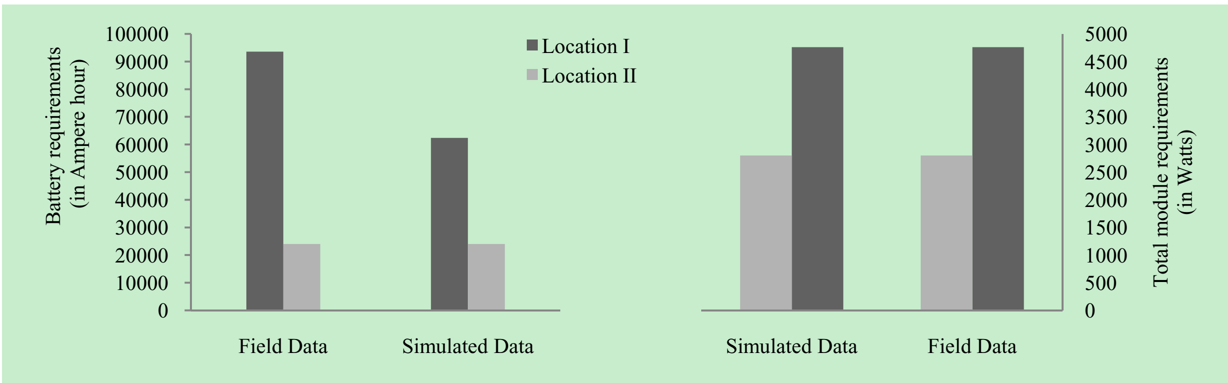

Fig. 3 Comparison of field and simulated data for two locations (a) Battery requirements (b) Module requirements

5.2. Charging rate cut-off

The values of p and q for the battery are determined from the graph in the Fig. 4(a) which is a statistical variable. The algorithm is further simulated to determine the effect of rate factor on the number of batteries using Eq. (7). The Fig. 4(b) shows the plot between the number of parallel batteries and rate factor. This curve is used to derive a model to fix the minimum charging rate to the battery. The model is given as in Eq. (12). The effect of other parameters, in the model, is not considered since it is a constant value for specific data input. The required number of batteries increases with decreasing rate factor, as shown in Fig. 4(b). This is due to the fact that the delivery capacity of a battery increases with the increasing charge rates. For higher charge rates, the current delivered is lesser and thus reduces the higher rating current controller.

Table 2. Algorithm output for two different locations, simulated and field data

Output data	Location I		Location II	
	Simulated data	Field data	Simulated Data	Field data
Number of batteries	48	72	48	48
Number of modules	68	68	40	40
Inverter specification(VA)	1800	2500	1150	1200

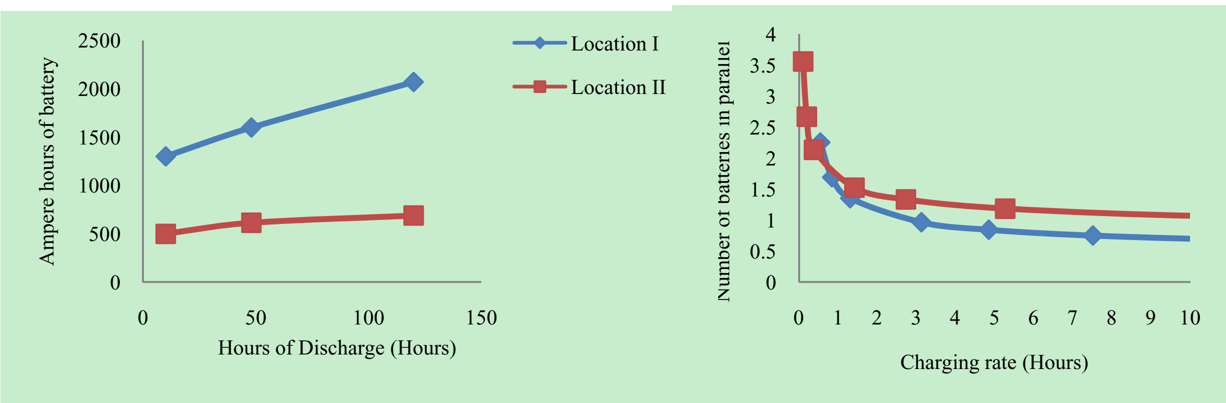

Fig. 4 (a) Variation of battery ampere hour with battery discharge hours
(b) Variation of number of parallel batteries with charging rate

The batteries in parallel need to be incremented in steps, of one, when the charging rate reaches the cut off charging rate value. The cut off charging rate value , in hours, for location I are 2.74 and 0.64 and that for and location II are 15.07 and 0.47. For charging below this limit the battery size should be incremented to meet the required load demand. However to avoid the other battery performance factors such as gassing, the charging rate is fixed little more higher value. But from the sizing aspect the charging rate can be extended up to the defined limit.

6. Conclusion

An algorithm for deriving the sizing requirements of a PV power plant is developed incorporating the effect of battery rate factor. The simulation results are compared to the field data for validation. The simulation results project that, when the rate factor is considered, the system can even work when battery size is reduced to 62400AH from 93600 AH for the specific case of PV power plant discussed. This helps to reduce the cost of the system. Further, a limit for the minimum charging rate is defined for given system specifications. This information will help any designer to fix the charge controller at the battery charging terminal.

Acknowledgements

The author thank the Department of Science and Technology, Government of India for the financial support during the period of this work.

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