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Procedia Engineering 8 (2011) 120–127

Engineering

Procedia

2nd International Science, Social-Science, Engineering and Energy Conference 2010: Engineering Science and Management

A Practical Method for Quickly PV Sizing

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Elsevier use only: Received 15 November 2010;revised 15 December 2010;accepted 20 December 2010

Abstract

Nowadays PV system is being worldwide installed. The potential of solar radiation in Thailand is recognized therefore the PV implementation in Thailand should be realized and supported for future renewable energy use. However, the PV sizing method is still complicated for developers and researchers. This paper will present a simple and practical method for PV sizing which takes very short time for zing PV system. The calculation in this paper will be both PV stand alone and PV hybrid system. The results will be simulated to improve that the method is right for the PV sizing.

***Keywords:** PV system; PV sizing; PV hybrid system*

1. Introduction

Photovoltaic system is realized as an energy source that transforms the solar radiation energy into electrical energy. The term photovoltaic is often abbreviated to PV. The radiation energy is transferred by means of the photo effect directly to the electrons in their PV crystals. To design the right and effective PV system is therefore depending on a great role of solar radiation[1]-[4]. The simple idea for sizing is the energy balance *(1)*.

$$Edemand \leq Esupply \quad (1)$$

In order to construct a reliable PV system an accurate planning is necessary. Therefore, a photovoltaic system should be sized according to following planning Fig. 1.

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1877–7058 © 2011 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2011.03.022

Presizing

One of the most parameters required for presizing PV systems is a value of annual global solar radiation. The annual global solar radiation at a site has to be quickly approximated at first for example in Thailand is about 5 $kWh/m^2/d$.

After the potential of solar energy was approximated, the next parameter is how much energy is required by consumers, it is necessary to know which consumers and how many of them would be included into the system. In case of village electrification it must be informed if there are schools, health stations, small enterprises or private households. For example, some of common household appliances and their approximate daily and annual energy consumption are listed in Table I.

It should be noted that air conditioners and some other electrical heating applications such as space and water heating should not be included into PV systems due to their relative high-energy consumption so that they are not economically supplied by PV electricity, but rather by thermal solar energy. In addition, the user should look for the most efficient appliances or should also consider all appliances if they are really necessary. As in Table I, it is necessary to find out the energy consumption in $kWh/m^2/d$ for properly size the PV system. However some of appliances can not be found in daily consumption, it is therefore approximately calculated in kWh/m^2/annual.

Due to the uncertainty of demand prediction and the assumed radiation, the energy supply should be basically higher than the energy demand. However, it could sometimes happen that the supply could not meet the demand and the system fails consequently. For this reason, *a quality factor (Q)* is commonly used to present how well the supply meets the demand.

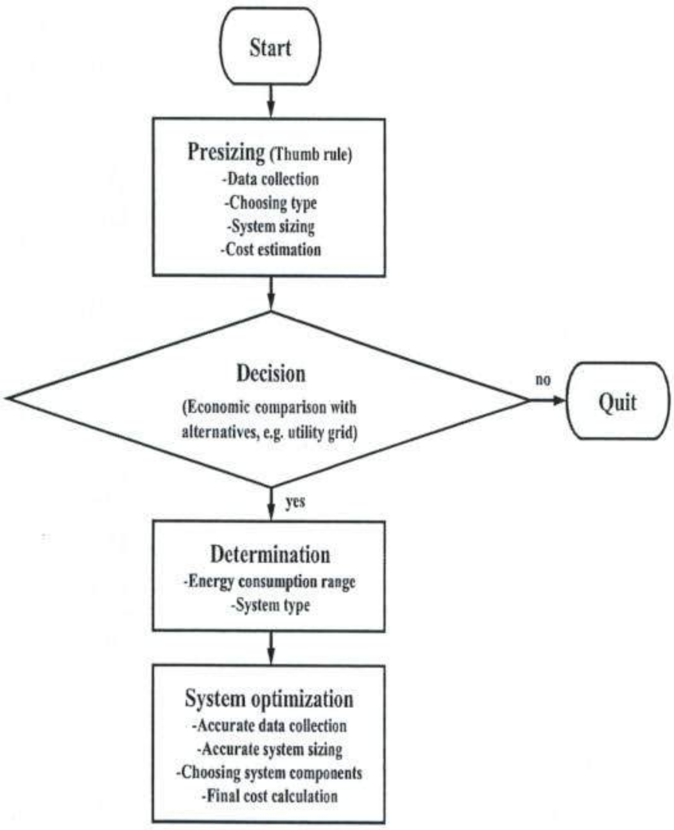


Fig. 1. Procedure for planning and sizing of PV systems

Table I: Energy consumption of household

Appliance	Power rating [W]	Daily consumption [kWh/d]	Annual consumption [kWh/a]
1 Incandescent bulb	60	0.25	90
1 Typical fluorescent lamp	40	0.15	60
1 Compact fluorescent lamp (CFL)	15	0.07	25
1 Fan	375	0.75	270
1 Radio	55	0.10	35
1 Television, colour 19″	80	0.14	50
1 Drill, 318″ variable	240	-	10
1 Blender/Mixer	350	0.07	25
1 Refrigerator (12cu. ft./340 litre)	330	2.75	1000
1 Vacuum cleaner	900	-	45
1 Iron	1000	-	50
1 Clothes washer	1150	-	120
1 Toaster	1200	0.12	45
1 Coffee maker	1200	0.30	110
1 Hair dryer	1500	0.33	120
1 Microwave oven	2100	0.35	130

Quality factor (Q)

The quality factor (Q) is defined as the quotient of the real electric output energy measured at the system output (E_{load}), which is the system load (E_{demand}) and the theoretical output energy (E_{th}), which is defined as the output energy from the same system under ideal conditions, which is the Standard Test Conditions (STC).

$$Q = \frac{E_{Load}}{E_{th}} \tag{2}$$

where Q = quality factor of the system, E_{load}=real electric output energy [kWh] and E_{th} = theoreticqal output energy of the system [kWh].

The quality factor can be determined over any given time period. In most cases, a time period of one year is chosen to presize PV systems. The theoretical output energy (Eth) is defined as the energy output, which is produced by a PV array with an area of Aarray, the global radiation Eglob incident on a horizontal surface and efficiency η determined under STC:

$$E_{th} = \eta \cdot E_{glob} \cdot A_{array} \tag{3}$$

where E_{th} = theoreticqal output energy of the system [kWh], η = efficiency of the PV array [decimal], E_{glob}=gobal radiation [kWh/m^2] and A_{array}=area of PV array [m^2].

It is often difficult to obtain values like the efficiencies from manufacturers. Besides, the area of the array is frequently unknown. However, the peak power measured under STC is normally given (STC: I_{STC} = 1000 W/m^2; T_{STC} = 25 °C, AM = 1.5).

$$P_{peak} = \eta \cdot I_{STC} \cdot A_{array} \tag{4}$$

where P_{peak} = peak power of the PV array [kWp], η = efficiency of the PV array [decimal], I_{STC}=gobal radiation under STC [1 kW/m^2] and A_{array}=area of PV array [m^2].

According to the equations (3) and (4) after substitution of η· Aarray:

$$E_{th} = P_{peak} \cdot \frac{E_{glob}}{I_{STC}} \tag{5}$$

According to the equations (2) and (5) the quality factor can be found out:

$$Q = \frac{E_{el}}{E_{glob} \cdot P_{peak}} \cdot I_{STC} \tag{6}$$

With the quality factor formula (6) and the empirical quality factors of existing systems it is practical to use this quality factor (Q) to presize the PV array.

Sizing of PV system

From the quality factor (Q) in *(6)* , the PV array can be sized accordingly:

$$P_{peak} = \frac{E_{Load}}{E_{glob}} \frac{I_{STC}}{Q} \tag{7}$$

where P_{peak}=peak power of under STC [kWp], E_{load}=real electric output energy [kWh/a], I_{STC} = solar radiation under STC [1 kW/m^2], E_{glob} = annual global solar radiation [kWh/m^2/a] and Q = quality factor of the system.

In the theory, supply and demand values are equivalent and the quality factor is therefore equal to one (Q = 1). A measured value of, for example, Q = 0.75 means that 75 % of the electric energy, which is converted from the incident solar energy, is used whereas 25 % of the electric energy is lost between the solar cell and the system output or it is not used.

The quality factor depends strongly on the system type. In case of grid-connected systems all produced energy could be used, so there will never be surplus energy. In a PV system it could however happen that the battery storage is full and then PV energy will be dissipated. For this reason, the quality factor relates to the system type. In order to make a decision reasonably on the system type the amount of energy consumption could be useful (Table II). The quality factors are then given in Table III.

Therefore, the PV array can be sized by using formula (7), the size of PV will be in Watt Peak (P_{peak}) after sizing PV array, the investment cost is also considered. The cost and economics result will not be described in this paper.

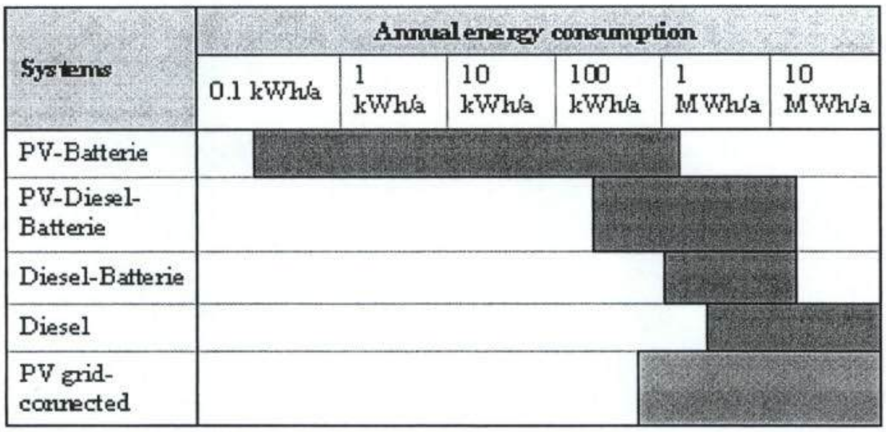


Table III: Quality factors of components and different PV systems [2]

Component/System	*Q*
PV module (Crystalline)	0.85…0.95
PV array	0.80…0.90
PV system (Grid-connected)	0.60…0.75
PV system (Stand-alone)	0.10…0.40
Hybrid system (PV/Diesel)	0.40…0.60

Battery sizing

For PV systems, the battery storage is commonly used for supplying energy during night for stand alone system therefore the battery capacity and investment costs should be also considered.

Due to the fact that the batteries are the second biggest part of the investment and operation costs in PV- and PV hybrid systems. However, experience has indicated that operation cost of the battery is sometimes higher than its investment cost.

The battery capacity depends on characteristics of radiation, load, and system reliability as well as intention of the user. From experience, the relation between storage capacity [kWh] and peak power [kWp] of the PV array is more or less 10:1. In case that the global radiation at the site is nearly constant throughout the year, this value will be lower than 10:1. When having a system where the power consumption is mainly during the night this must be corrected to the value higher (up to 20 % more) and vice versa when e.g. a wind generator or a diesel generator is integrated into the system (Fig. 2). The proposed formula for battery sizing is as formula (8).

$$C_B = 10 \cdot P_{peak} \tag{8}$$

Where C_B = battery capacity [kWh] and P_{peak} = peak power of the PV array [kWp].

From the formula *(8)* can be described as in Figure 2. The method requires only little information and provides a quick system design. However, there are some disadvantages because results are not optimized solutions due to only rough estimation and therefore contain high degree of uncertainty. There is also no consideration of different system variants (for example, adapting the size of the PV array to available values and compensating this decision through smaller or larger storage installations).

Anyway, when planning a PV system, consumer load is much more uncertain factor and experience has shown that the empirical method provides as good results as when the system is sized by simulation programs.

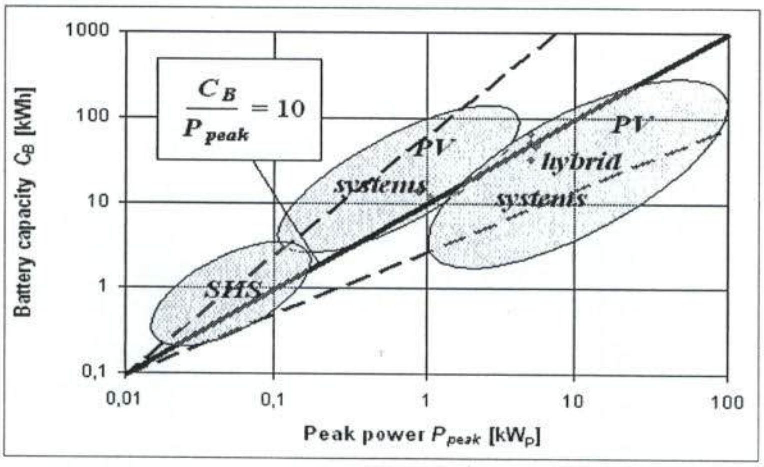


Fig. 2. Battery capacity and PV nominal power

2. Optimization and Simulation

After obtaining the size of PV from the formula process, it is recommended that the system should be optimized. There are many uncertainty factors for optimization. A factor should be considered firstly is load demand, what load profile is? How the peak load is? This information can be used for PV or battery optimization. Secondly, PV tilt angle should also be considered, the easy method is that the PV array should face to the sun the latitude and longitude have to be taken into account. However from experience, the tilt angle for 15 degree is good for self cleaning during rain.

The optimization process can be executed either by computer or by hand. The simulation program can approximately simulate the fact of the design system. There are nowadays many programs available. For this paper, to prove the sizing method, the software Homer is here used. The example load profile for the simulation is as Fig. 3

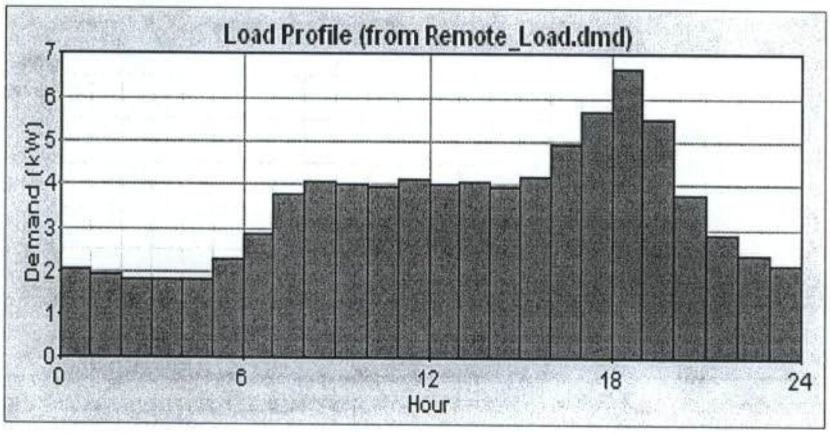


Fig. 3. Proposed example Load profile for sizing

The stand alone PV system is firstly implemented. The energy consumption for this load profile is 85 kWh/d. The solar radiation is selected from Thailand 5 kWh/m^2/d. Using the formula *(7)* with Q = 0.4, obtains as following:

$P_{peak} = (85\ kWh/d \times 1\ kW/m^2)/ (5\ kWh/m^2/d \times 0.4)$

$P_{peak} = 42.5\ kW_P$

$P_{Batt} = 10 \times 42.5\ kW$

$P_{Batt} = 425$ kW/h

Therefore from the calculation, the selected PV-battery system has the PV array of 42.5 kW_P and the Battery capacity is 425 kWh. The homer program is used to simulate and it can be set up the system as in Fig. 4. The simulation output is therefore shown in Fig. 5. The selected inverter is 43 kW. According to a limitation of the market for available Battery in the program, 423 kWh Battery capacity is selected.

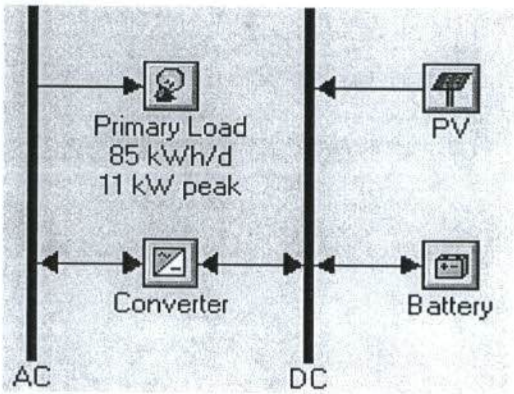


Fig. 4. System set up for simulation

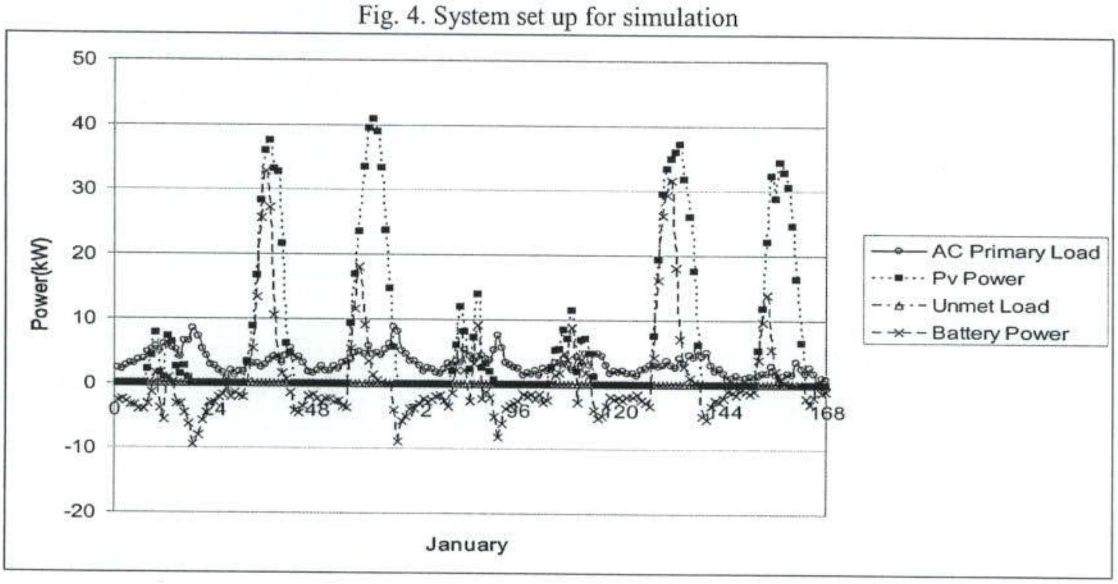


Fig. 5. Simulation result for PV stand alone system

The simulation result shows that the PV system can supply power to the load demand without any shortage or unmet load. The PV system cam cover the load even there are 2 continued low radiation days. This can prove that the formula is right for PV sizing. Moreover secondly a PV hybrid system is selected for this study using the same load profile as fig. 3. The generator is selected to supply the peak demand of 5 kW. The daily consumption is the same as 85 kWh/d and the Q = 0.6. The calculation is therefore:

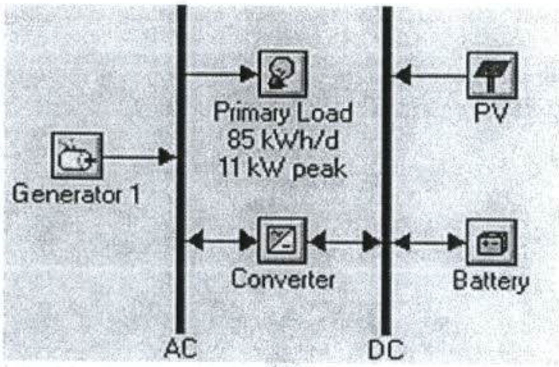
$P_{peak} = (85 \text{ kWh/d} \times 1 \text{ kW/m}^2)/(5 \text{ kWh/m}^2\text{/d} \times 0.6)$

$P_{peak} = 28.33$ kW_P

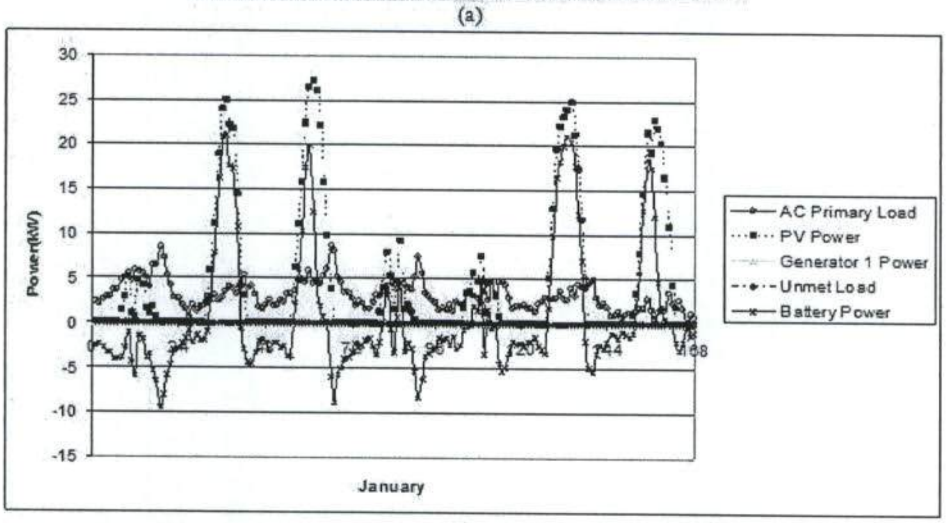
$P_{Batt} = 10 \times 28.33$ kW

$P_{Batt} = 283.3$ kW/h

The simulation diagram and result are as fig. 6. The result shows that the formula is effectively used for sizing PV hybrid system. The system can cover all demand, however the unmet load also occurs in the simulation but it is a small range and it can be optimized for the implementation such as increase capacity of PV, battery, or Generator.



(a)



(b)

Fig. 6. (a) System set up for Hybrid system and (b) Simulation result for Hybrid system.

3. Conclusion

The paper presents a short and quick method for sizing PV system both PV stand alone and PV hybrid system. The calculation and the simulation show that the formula is effectively right for quickly PV sizing. To be honor for a man who works hard, I would like to call this method as Schmid's formula.

References

[1] J. Schmid, Photovoltaic systems Technology, teaching script, IEE-RE, University of Kassel, Germany, 2002.
[2] Leadener, H.: Solare Stromversorgung: Grundlagen, Planung, Anwenddung; Freiburg: ökobuch Verlag, pp. 153-182,1996.
[3] Kaiser, R.: Sizing photovoltaic systems. In: Fraunhofer Institute for Solar Energy Systems: Course book for the seminar: Photovoltaic Systems; Freiburg, pp. 403-440,1995.
[4] METEONORM 4.0: Global Meteorological Database for Solar Energy and Applied Meteorology; Bern, Switzerland.