Design and Analytical Evaluation of a Centralized PV Power System for a Thai Village

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Abstract :

A sample village with 100 households in a rural area of Thailand is selected for design of a centralized PV power system with stand-alone type. This paper focuses on the design and analytical evaluation of PV system for a typically rural Thai villages based on climatic data at the design location, daily load demand, I-V characteristic of solar module and so on. Prediction of PV system performance using a computer programme, especially the best matching between the array size and storage battery capacity has been done. The daily electrical energy needs of a village can be broadly designed into four categories, namely (a) for each household, (b) for community centre, (c) for control and battery room and (d) for public used. A mini grid system within the village is designed for a case study that according to the farthest household from a control building. Conductor sizes, types of cable, grounding and lightning conductor have been calculated. Although this design does not minimise system cost mathematically, it gives a feasible design at the practical level on the basis of experiential knowledge.

Keywords : Stand-alone system-1, Analytical evaluation-2, Rural area-3.

1. Introduction

Rural electrification is one of the main application of photovoltaic (PV) systems. Stand alone PV generators are suitable to electrify isolated rural houses or small villages that are located far from the national utility grid. Since the grid system is more expensive for installation from utility grid to rural or remote areas, especially in developing countries. PV systems are already cost-effective for rural electrification of scattered houses and villages in sunny areas of the world. To increase the feasibility of a large scale application, there are some aspects that need improvement, some are technological but most are organizational social and institutional.

There are many rural villages in Thailand that are located without access to electric power. These villages are spread in rural areas through the country. Rural people have used kerosene lamps and candle for lighting applications and there are no facilities for community entertainment. Some areas the roads are in very poor condition, transportation of human being and material is a big problem. Hence, solar electric and photovoltaic power system are a valid alternative source of energy for use in these rural areas. However, PV systems have been widely used in typical remote villages in Thailand. Most systems are PV battery charging stations, followed by the telecommunication system [1].

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This paper will focus on the design and analytical evaluation of a centralized PV power system with stand-alone type for a rural Thai village based on climatic data at the design location. Analytical evaluation of a system has been done using a computer programme. Methodological process could be applied anywhere that similar climate, not just in Thailand.

2. Assessment of the daily load demand according to the electricity requirement in a rural Thai village

Table 1 Daily requirement of energy demand for each appliance in the village.

Appliances	Quantity	Appliance Power (w)	Expected Daily Used (h/d)
Radio	100	5	20
F.lamp 18 w.	100	18	8
LP gas lamp	8	125	6
F. lamp 36 w.	8	36	6
Water pumping	1	746	2
Television	1	100	6
Video recorder	1	30	6
Refrigerator	1	120	20
Electrical Requirement = 36.80 kWh/d			

First step of design will need daily load demand in each household. The design approach is the calculation of array sizing based on daily radiation data, line loss factor, system components' efficiency, performance rated output of solar modules and so on. However, the load profile of the village in each hour is one of the important data of the PV system. Four load profiles are selected for analysis in this paper, namely: (a) Night time load, e.g., indoor lighting, street lighting and a TV set. (b) Daytime load, e.g. water pumping. (c) Constant load demand, e.g. refrigeration. (d) Variable load demand, e.g. radio. The system designers should be given on the correct data concerning the load profile in village by Head Villager and/or the Committee of Village who are a responsible for making a decision to install the system. The selected distribution voltage is 120 Vdc for input voltage of battery bank because the generated power is supplied by a centralized PV array. If the system operates at a low voltage, the current passing through the cable will high, and the length of cable will long. The voltage drop in cable or power loss will higher for a low voltage system. It is important to state that in PV systems, minimization of energy losses is necessary. Large PV power plants are sometimes designed for a higher system voltage. Higher voltage allows thinner cable to be used for distribution. This reduced the cost of wiring, and are multiples of twelve, and are achieved by connecting group of modules or battery in series. The selected distribution voltage of AC load in a village is 220 Vac that is the conventional utility system voltage in Thailand. In addition, this voltage level can be used for grid connection (if any) from utility grid.

3. Sizing of PV system and storage battery capacity

The minimum array size depends on climatic data at design location, and depends also on the I-V characteristic of solar module. In addition, the design of array size must take into account various factors, such as total load demand in ampere-hours or kWh, battery efficiency, self discharge level of battery, regulator efficiency, inverter efficiency and line loss factor of system. By using data from weather stations in similar climate zone some estimate of the insolation can be made, which then needs to be modified through a "variability factor" to allow for the variation from year to year both in mean and worst case values. By taking a large variability factor 10 or 15%, it is reasonable to work with monthly insolation averages, as storage capacity will be high and so system performance is unlikely to be seriously effected by short term fluctuations. The minimum array size that can meet the load requirement can be written as

$$N_A = (N_S \times AH_{(load)} \times \varnothing)/(K \times VF \times A_M \times D_M) \quad (1)$$

$$K = \eta_B \times SD \times \eta_L \times \eta_R \times \eta_I \quad (2)$$

Where N_A is total number of modules that is connected in a PV array, N_S is number of modules in a series string. $AH_{(LOAD)}$ is total daily load in ampere-hours, $\varnothing$ is an insolation intensity for testing a module in kW/m^2. The following factors present in a decimal, namely VF is a variability factor specified, A_M is an output current at output voltage at $\varnothing$ in amperes. D_M is mean annual insolation in kWh/m^2.day^{-1}, η_B is a battery charging efficiency. SD is a battery self discharge level, η_L is a line loss factor, η_R is a regulator efficiency and η_I is an inverter efficiency.

$$N_S = (V_B + V_D + V_W)/V_{mp} \quad (3)$$

Where V_B is the nominal battery bus voltage, V_D is a forward voltage drop of blocking diode. V_W is the total wiring voltage drop between solar modules and battery and V_{mp} is the voltage at maximum power point and under operating cell temperature.

Due to the fact that the system is designed to be stand-alone type. Battery bank is a major part of a PV system. It stores any excess (above instanta neous demand) energy produced by the array during high solar radiation, and supplies the load during period of insufficient radiation or during the hours of darkness. The number of days that are provided for during low insolation in winter or rainy season is one of the factors for calculation of battery capacity. The strongest factor influencing the selection of battery capacity is the occurrence of periods of continuous low insolation. These are likely to arise in during the rainy season in Thailand. Choosing the available reserve days depends on solar radiation data, mean annual insolation and depends on the type of batteries including the maximum depth of discharge (DOD). To obtain the full life of a battery, the cycle depth should not exceed the depth recommended for that type of battery. Usually, the typical battery is used storage energy for PV power systems should not be discharged over 50 % DOD that is recommended. The required batteries capacity in ampere-hours can be found from the equation as follows [2]:

$$E_b = (xE_n + yE_d)/[\eta_L \times V_D \times (DOD/100)] \quad (4)$$

$$xE_n = x_1E_{(RADIO)} + x_2E_{(LIGHTING)} + x_3E_{(STREET\ LIGHTING)} + x_4E_{(TV)} + x_5E_{(VIDEO)} + x_6E_{(REFRIGERATOR)} + \ldots + x_nE_{(OTHER\ LOAD)}$$

$$yE_d = y_1E_{(RADIO)} + y_2E_{(REFRIGERATOR)} + y_3E_{(PUMPING)} + \ldots + y_nE_{(OTHER\ LOAD)}$$

Where E_b is the battery storage capacity that is expressed in ampere-hours, E_n is the total energy of load demand during night-time in watt-hours. E_d is the total energy of load demand during daytime in watt-hours, $x_1, x_2, \ldots, x_n$ are the periods for that storage are to be provided for different load during night time that is expressed in days. On the other hand, $y_1, y_2, \ldots, y_n$ are the periods for that storage are to be provided for different load during daytime that is expressed in days. V_D is the average voltage of discharge of the batteries in volts and DOD is the maximum permissible depth of discharge in percentage.

4. Typical example of a rural Thai village

A typical Thai village with approximately 100 households and isolated far from the utility grid is selected for a sample design at Udon Thani province of Thailand that is located on latitude 17^{o} 23 ′

N and longitude 102^{O} 48^{O} E. The monthly average global solar radiation is shown in Table 2.

The mean annual global solar radiation received at Udon Thani province is about 4.332 kWh/m^2.day^{-1} with minimum of 3.910 kWh/m^2-day^{-1} in August (Autumn) and maximum of 4.850 kWh/m^2-day^{-1} in April (Spring). From the table 1, daily load demand is 306.67 Ah at 120 Vdc, if the overall efficiency factor is 0.533 (η_B and η_R = 0.85, η_I = 0.80, η_L = 0.95 and SD = 0.97). Based on solar module type # BP 585 (at 1 kW/m^2, 47°C, I_L = 4.848 A, V_{mp} = 16.2 V), and also using the equation 1 through 4, PV array size and storage battery capacity can be concluded in Tables 3 and 4.

One of the main points for battery charging in a stand-alone PV system is the battery must be sufficiently charged to avoid problem associated with under charging battery. However, it depends on the electric power from PV array, variation of the solar sources and so on. In fact, the high reliability of a system will concern the best matching between the size of PV array and storage battery capacity rather than installation a very large battery capacity and PV array size. A C-programme has been developed to calculate daily state of charge (SOC) of batteries based on the climatic data at design location. The block diagram of simulation programme is shown in Figure 4. The input of the simulation programme includes PV array size, battery capacity, load profile, daytime and night time load, daily global solar radiation data [3] and the I-V characteristic of solar module. In addition, an average hour duration of sunshine and efficiency parameters are also concerned. Considering the data in Table 3, the number of modules in a series string and number of panels (rows) in parallel are 8 and 30 respectively. The simulation results of daily SOC of battery for a PV stand-alone system in a sample village is shown in Figure 3 (a through d). These figures show the relationship between PV array size and storage battery capacity in different conditions. In fact, Figure 3a shows their relationships for PV array size with 30 panels and a 3200 Ah batteries capacity. Figure 3b shows the same case but it is assumed that climatic data is reduced by 10% (variability factor is 0.90). In the same way, Figure 3c and Figure 3d show their relationships but the number of panels is reduced to become 29 panels. They have been found that the best relationship is Figure 3a with PV array size of 30 panels and 3200 Ah batteries capacity. Although in the figure 3c looks a good relationship, in the case of climatic data is reduced by 10%, the system will meet a failure in the next stage. Since the last day of the year (31^{st} December) the batteries cannot be fully charged and DOD reaches over 50% in August (worst month) that is a rainy season in Thailand. In this case, for a PV stand-alone type, the system will be designed by some loads should not be connected until the batteries are recharged up to 80% of maximum battery capacity, then these loads will be normally reconnected. The simulation results can provide a useful information for system designers to decide on a best system for installation.

5. An electrical power distribution system and lightning protection.

In the case of PV array is a centralized PV generator that is installed outdoors and which electric power is directly delivered from PV array via an electrical inverter to any load through an electrical power distribution system. Generally, single phase power is suitable for lighting and small load. The objective of this topic is to design a mini grid system that will be used within a village in rural area. The size of conductor of electrical power distribution system, type of conductor and grounding will be done. Furthermore, lighting protection system using a computer programme will also be done to protect PV array area. Based on previously designed, the location plan of an electrical power distribution system based on the radial system in the village and layouts of site for location of PV array area are shown in Figure 5 and Figure 6. The design is based on the maximum allowable voltage drop is 2% from 220 Vac, power factor is 0.85, the length of cable from control building to farthest household is 500 metres. Furthermore, thunderstorm days per year and mean lightning flashes per km^2 per year for Thailand are 80 and 4.7 respectively [4]. The results can be concluded as follows: (i) In the case of cable is directly installed in the ground from PV array to control building (30 metres). Cable type is NYY, MEA Type C, copper cable size is 50 mm^2, deep of installation is about 60 cm. (ii) The suitable cable size for installation of electrical power distribution system is 95 mm^2 (single phase system). (iii) For electrical equipment in building, the number of air terminators is 3 and number of down conductor is 2 and the size of copper conductor is 50 mm^2. (iv) Grounding system use 16 mm^2 (bare copper).

6. Conclusions

A centrally stand-alone PV system in a rural area of a sample village with 100 households is designed based on climatic data at Udon Thani province of Thailand and daily load demand. Analytical evaluation of the PV system performance throughout the year using a computer programme to find the best matching between solar array size and storage battery capacity has been done. Due to the fact that the meteorological data on the particular tilted surface at Udon Thani and other provinces are not available, it is necessary to use daily global solar radiation for simulation. That is slightly more accuracy than using daily global solar radiation. However, the results of simulation programme using global solar radiation for Thailand that is located at low latitude angle are quite enough accuracy to prediction of the system performance. Moreover, an electrical power distribution system and lightning protection system are designed, and direct strikes are rare and induced high voltage surges due to strikes nearby are more likely to damage wiring and system components. A good system grounded will reduced the damage due to surge. The use of varistor as surge arrester in components and appliance or across the AC and DC supply cables is recommend to provide the further protection. For a control building should be protected against direct strokes with complete lightning protection system. They are composed of air terminator, down conductor, system grounding and rod electrode with the best bonding to keep the minimum earth resistance and sides flashing to be avoid.

Table 2 Monthly global solar radiation at Udon Thani province of Thailand

Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
4.558	4.341	4.135	4.850	4.348	4.770	4.115	3.910	4.375	4.318	4.096	4.178
Mean annual global solar radiation = 4.332 kWh/m^2											

Table 3 Array size of a sample village

Nominal system voltage (Vdc)	Modules in a series string	No. of strings in parallel	Maximum current (I_{mp})	Maximum voltage (v_{mp})	Maximum power (kW_p)
120	8	30	141.6	144	20.4

Table 4 Storage battery parameters and sizing

$x_1, x_2, x_3, x_4, x_5, x_6$ (days)	y_1, y_2, y_3 (days)	V_D (Vdc)	DOD (%)	x E_n (kWh)	y E_d (kWh)	Capacity designed (Ah)	Battery rated each (Ah)@12V	Battery in a series string	No. of rows in parallel
5	5	120	50	135.14	43.46	3200	200	10	16

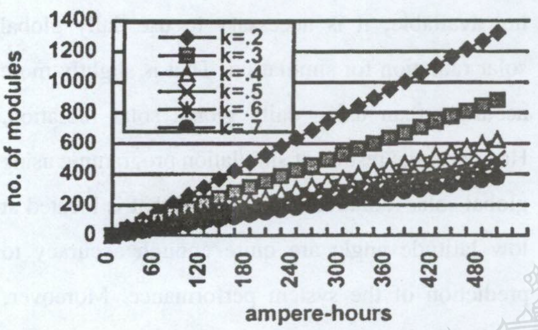

Figure 1 Influence of a constant K on the No. of modules.

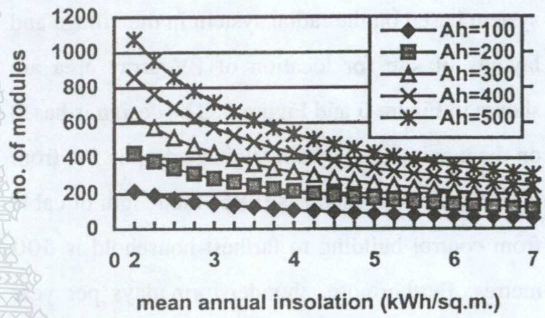

Figure 2 Influence of load demand (Ah) on the No. of modules.

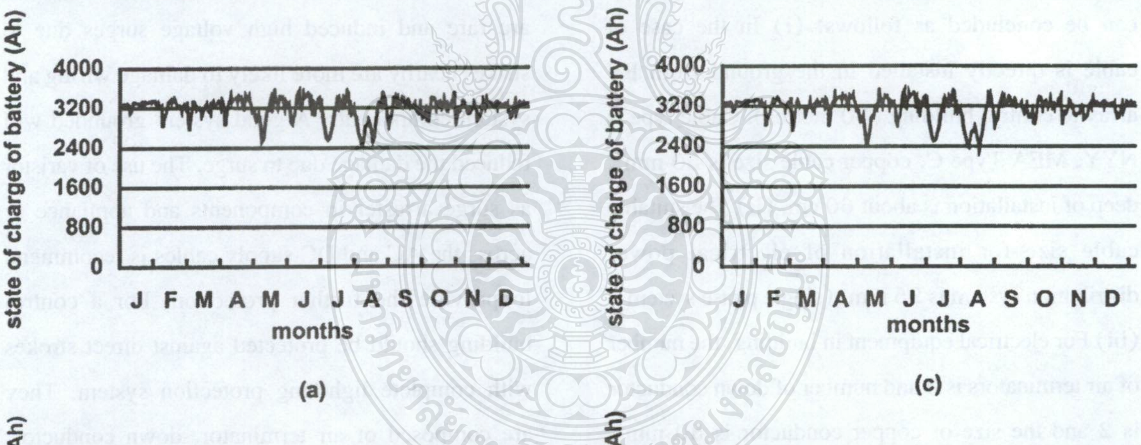

Figure 3 Daily SOC of battery based on climatic data

(a) for a 3200 Ah (30 panels)

(b) in the case of the climatic data is reduced by 10%

(c) for a 3200 Ah (29 panels)

(d) in the case of the climatic data is reduced by 10%

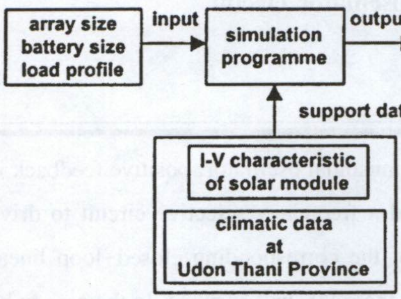

Figure 4 Input and output include support data base of a simulation programme.

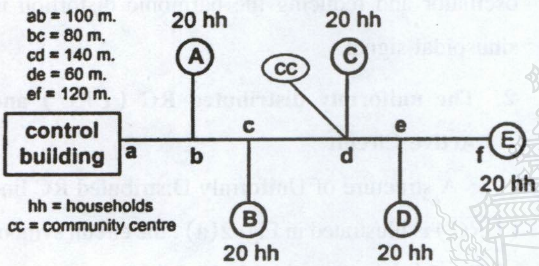

Figure 5 Layout of location of electrical distribution power system based on the radial system.

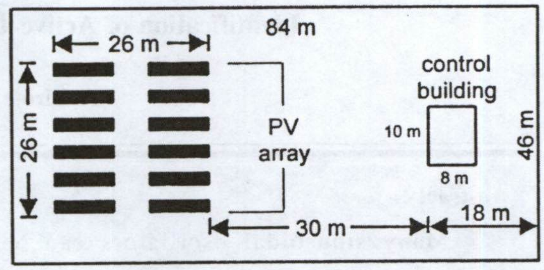

Figure 6 Layout of site and location of a PV array.

7. References

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