Sizing of a Standalone Solar Home System for Rural Electrification in Thar

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Abstract

The worth of autonomous solar home systems is associated with the precise sizing of system components. This paper presents a simplified intuitive method for sizing of solar home systems which assures the least possible cost at a preset power reliability to satisfy load. The system is sized by considering two most expensive components of solar home system, namely PV module and battery storage. A case study for sizing of solar home systems components was carried out for a load demand of 105Wh/day and 405Wh/day for rural electrification in Chachro, Thar. The system was sized to supply power for two autonomy days. The system slope was optimized for two different scenarios based on worst month and yearly average. The optimized angle was found to be 51° and 23.9° with the power output increase of 42.6% and 10.6% for first and second scenario, respectively. It was established that the systems could be successful in Thar if properly monitored and maintained on regular basis.

Keywords—Rural electrification, Sizing of solar components, Solar home system, Thar.

1 Introduction

Energy is a key to economic development and fundamental aspect to improve the quality of life [1]. Nearly 1.6 billion citizens are living without access to electricity worldwide [2]. It is the prime need to supply electricity at affordable prices to every individual. It is reported that approximately 70.4% of Pakistanis have grid connected electricity, 60% of that are living in countryside and 93.0% in urban areas. The government of Pakistan electrified 85,000 villages out of 125,000 un-electrified villages in 2005. The remaining 40,000 villages, consisting over three million families still use conventional sources to fulfill energy needs. The total number of villages in Sindh is 66,923 as per census of 1998 [3], and electrified only 21,799 numbers up to February 2008 [4]. The remaining un-electrified villages in Sindh are therefore 45,124. It is inferred from the reports that 67.4% villages are still devoid of the electricity. It is also reported by WAPDA that these un-electrified villages cannot be connected to the national grid in near future due to their remoteness from the national grid and other technical and economic problems [4].

Since every community deserves to have the basic facilities of life such as health, education and communications. The isolated villages should also be electrified with any means. However, it is quite difficult task to be solved easily except the installation of solar photovoltaic systems. These systems are practically viable in the places where the installation of transmission lines is expensive. Larger solar systems are costly due to addition and replacement of storage batteries at regular intervals. Thus, smaller systems are preferred due to their affordable prices and fewer maintenance requirements. A solar home system typically consists of a single solar photovoltaic panel or module, a charge controller, a battery for storage, and light electrical appliances as shown in Figure 1. The electrical load appliances may be small lighting appliances including energy savers, bulbs and/or LED lights, minor broadcasting devices, cell phone chargers, DVD players, television etc. All supporting components, which are not included in the major categories of solar home system, are named as balance of system components, which comprise of panel fixing poles, stands, tools, cables, switches, circuit breakers, fuses, measuring instruments etc [5].

Furthermore, the precise sizing of solar home system components is an important part of system design [6].

ISSN: 2523-0379 (Online), ISSN: 1605-8607 (Print)

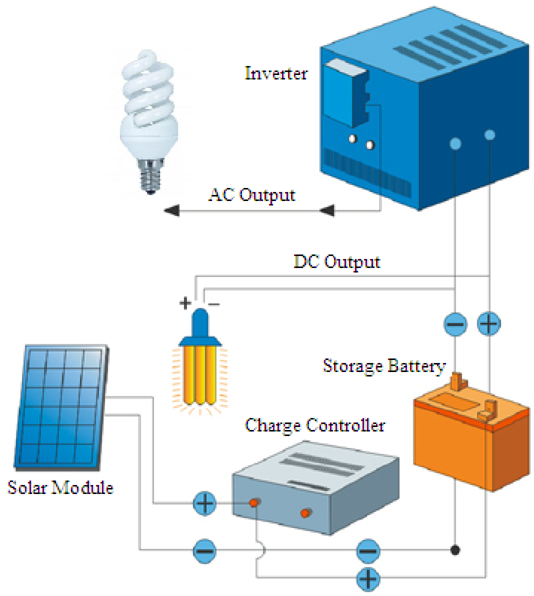

Fig. 1: Components of solar home System .

The development of these systems is associated with correct sizing of components, which in turn depends on the reliable data of the required variables and load profile [7]. The use of long term (more than 20 years) time series data with computer simulations is a best alternative for sizing of solar home systems. However, in many places such data is not available, and computer programs need skills, which is not an easy job [8] [9]. Due to the unavailability of required data, these systems became over-sized or under-sized. Over-sizing turns out to be a costly alternative, whereas the system breakdown happens due to under-sizing which makes the system less consistent. Therefore, proper sizing of solar home system needs careful consideration of two influential factors namely the system cost and power reliability for sustainable supply of energy to satisfy load demand [10].

1.1 Sizing Methods

Sizing methods can be categorized into three main groups namely intuitive, numerical and analytical [8] [9]. Intuitive methods are easy to implement and are proved suitable for obtaining the preliminary approximation of autonomous solar systems [11]. The required PV area is carefully chosen to assure the generation and supply of average energy demand of the designed period (most probably worst month). The projected power output of PV should be more than the energy demand by a safety margin. A similar procedure is required to be followed as that of PV area for the selection of the battery storage capacities. In contrary to the intuitive techniques, numerical methods are based on the simulations of the system behavior. Computer simulations are executed at hourly, daily or monthly intervals with long term (more than 20 years) time series data. Energy steadiness of the system and charging/discharging behavior of batteries are computed for each time interval by assuming constant efficiency of the PV module. Different empirical models could be found for evaluating the performance of standalone solar photovoltaic system components by these methods. However, numerical methods have two limitations, as these are time consuming and require long term solar radiation data. Since analytical methods use algebraic equations describing the sizing of standalone solar PV systems as a function of power reliability [12]. These methods provide practical link between the variables to the sizing problem in an analytic form. Besides the above three methods, a number of combined numerical and analytical techniques have also been studied by various researchers [13] [14]. It is revealed from literature review that the intuitive techniques are simpler among other methods and suitable for approximation of system sizing. Numerical methods are rather complex, need long-term solar radiation data and are also time consuming. Analytical methods provide acceptable results and give explicit relationship between the variables to the sizing problem by means of mathematical equations [14]. The motivation of the work presented in thsi paper is to size the solar home system for rural electrification in Thar. It presents a simplified intuitive method to determine the sizing of solar home system components in usable form [8] [9] [14].

1.2 Sizing of Solar Home System

Sizing of solar home systems is mainly governed by two factors, namely the load demand and the amount of solar resource available to power the system. These both factors determine the quantity and size of solar system components.

1.2.1 Load Demand

Loads are the appliances that take out power directly or indirectly from the system for a particular moment. The first step in the sizing procedure is to select the electrical appliances. Since solar modules generate DC power, whereas, electrical appliances are usually AC powered. Therefore, the function of power inverter is to adapt DC power to AC for utilization in solar home appliances. The inverter itself acts as a load due to conversion efficiency losses resulted from the parasitic power draw. However, in many applications, inverter is not chosen due to its price and convolution [15]. In such cases, DC electrical loads, such as compact fluorescent light and light emitting diodes, small radios, portable digital video disc players and DC powered televisions are linked directly into a 12 volt DC solar home system circuit. The next step is to determine the wattage of each selected item. Usually, the wattage of electrical devices is stamped or printed on a nameplate on the back of the item. If only amps are listed, they are multiplied by the nominal voltage of that item to find the wattage. If the consumption rate of appliance is known, then Eq. 6 can be used for the calculation of the energy consumption EL that any type of load consumes in day (Wh/d).

$$E_L(Wh/D) = \frac{n \times P_L \times H_d \times D_w}{7} \tag{1}$$

Where η denotes the number of that type of load, (PL) is the power consumption of load, Hd is the number of hours power is consumed in a day and D_w is the number of days the load is used throughout a week. The total load demand per day (Wh/d) of overall load is obtained by adding different load consumption.

$$D_L(Wh/D) = \sum_i E_{Li} \tag{2}$$

where the DL is the total load demand (Wh/d), which is the summation of the individual i load consumption in Wh/d. Similarly, the yearly load consumption is calculated as by multiplying days of year with total Wh/d. The total wattage installed or maximum power wattage PT is calculated by summing the PL of all individual i loads as,

$$P_T = \sum_i P_{Li} \tag{3}$$

1.2.2 Available Solar Resource

The amount of sun light obtainable to the solar module to produce electricity is termed as solar resource. Two terms are commonly used for availability of solar resource namely solar irradiance and solar insolation. Solar irradiance is the magnitude of solar intensity confronting a particular area, measured in watts per meter square (W/m^2). Above the earth's atmosphere the value of solar irradiance is almost constant with 1,367 W/m2. Its value is 1,000 W/m^2 on earth's surface at the equator in a clear sunny day around noon. Solar insolation is the quantity of solar energy reached to a particular area determined in kilowatt hours per meter square (kWh/m^2). Solar insolation of 1 kWh/m^2 is equal to one peak hour (peak sun hour). All solar PV modules are rated at standard condition of 1000 W/m^2 (one peak hour) at 25°C by the manufacturers. Therefore, for calculations, mostly peak sun hour is refereed. For example, a 100 Wp module will produce 100 Wp, if the solar irradiance striking on the module is 1000 W/m^2 with a module temperature of 25°C. Higher temperatures, hazy and cloudy conditions will lessen the power output of photovoltaic. If a location has a peak sun hour of 5, and if the standard rating of solar module is 100 Wp, then it will produce 100 W x 5 = 500 Wh of electricity per day, presuming that the temperature of the module is remain constant at 25°C.

1.2.3 Sizing of Solar Module

The electricity produced per day by a solar module or panel EP can be calculated as follows,

$$E_P = S_P \times P_r \tag{4}$$

where E_P is daily electricity output of a single solar module or panel (Wh), S_p is the number of peak sun hours (hours) per day and P_r is the rated power output of solar module or panel (W_p). Generally, at least 20 percent safety factor is added to the actual load demand, as the batteries and inverters consume or temperature affect a certain amount of the power generated by the solar modules or panels. The number of modules or panels N_p is thus calculated as follows:

$$N_P = D_L \times 1.2/E_P \tag{5}$$

1.2.4 Sizing of Storage Battery

It is necessary for the owner to decide the days of autonomy for the system to supply power during the periods of little or no sun, or without any electricity generated by the solar modules or panels. Batteries are commonly rated by taking discharging period of a fully charged battery to 10.5 Volts in twenty hours at 25°C, which is indicated as C/20. The discharge ratings of the ordinary batteries are taken as 100, 10 or 6 hours. Let's say, a 200 Amp-hr C/20 rated battery signifies that the battery can deliver 10 amps for 20 hours (C/20 = 200/20 = 10). Since, 200Ah battery has a dissimilar capacity rating at other discharging rates. The disparity in their capacity caused by discharge rate is termed as Peukert effect. The higher rate of battery discharge results the lower battery capacity as shown in Figure 2. The numbers mentioned on every line of graph indicates the Peukert number, which is specific to every type of battery. A 120Ah rated battery with Peukert number of 1.2 (indicated with red route), becomes a 60Ah battery at current extraction is 30 Amps. It is to be noted that the rated battery capacity is different from the operating battery capacity. The Peukert effect can play a major role when the ultimate load current exceeds the battery rated (C/20) discharge rate. In such cases, the designed storage capacity of the battery becomes smaller and smaller

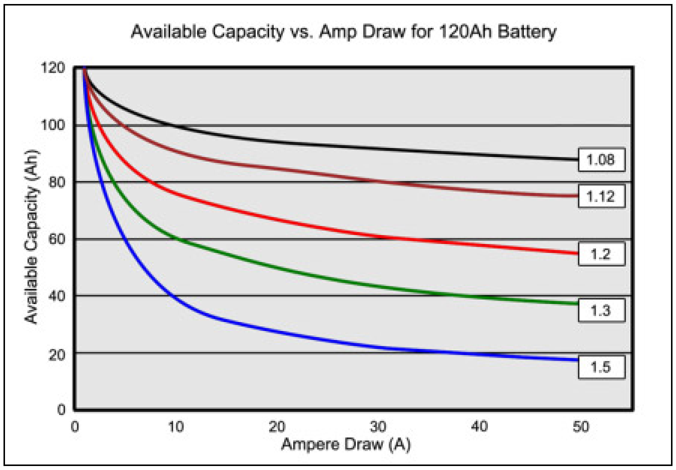

Fig. 2: Peukert effect on available capacity. Adapted from Battery University

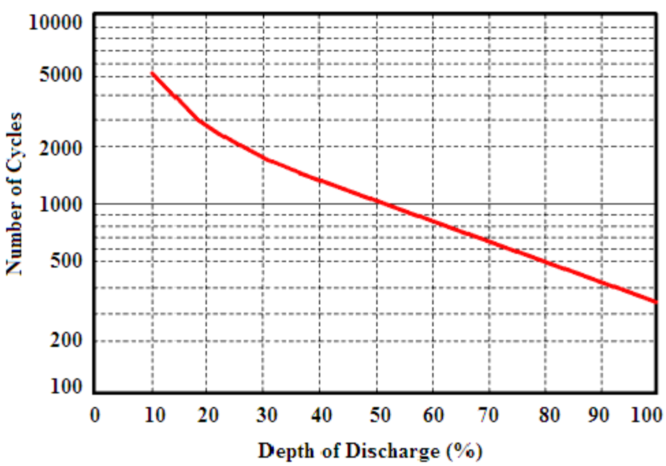

Fig. 3: Battery life cycle versus depth of discharge.

resulting in more discharge which further lowers the battery voltage, taking out the additional current. For example, if voltage declines, current will rise to retain the unchanged power level, because power = volt x amp. Consequently, it results in more shrinkage of the battery capacity [16].

There is another factor that makes battery sizing more problematic. The practical battery capacity is more decreased by life of battery versus depth of discharge as shown in Figure 3. Here, the y-axis is in logarithmic scale. Due to these effects, usually there is a conciliation among battery capacity, its life and replacement costs. The most common accepted trade-off for usable battery capacity is 50% depth of discharge [17]. Once the battery capacity is determined, the number of batteries required can be calculated as follows,

$$N_b = D_{L,b} \times D_A / (C_b \times DOD_{max}) \quad (6)$$

where N_b is the number of batteries required, DL.b is overall necessary battery capacity (Ah/d), DA is the number of autonomy days that battery will supply energy when there is no output from solar modules due to cloudy skies, Cb is the nominal capacity of a single battery (Ah) and DODmax is the maximum depth of discharge of the battery per day. Since, the voltage of batteries will be adjusted or maintained as per required system voltage.

2 Methodology

Sizing and installation of an autonomous solar home system was carried out for Chachro (25.12°N, 70.25°E), District Thar, Sindh. Monthly average daily solar radiation data of 24 years was used for this study, which was acquired from NASA [18]. The system sizing was carried out for a load demand of 105 Wh/d and 405 Wh/day with two autonomy days. It was presumed that the electrical demand is same during the whole day. The system slope was optimized for two scenarios namely worst month and yearly average methods. The three most important and sensitive parameters were considered for this study includes solar radiation, ambient temperature and system slope. The maximum battery depth of discharge DODmax was taken as 50%.

3 Case Study for Sizing of a Solar Home System

The case study performed for the sizing of a solar home system comprises the following steps.

3.1 Estimation of Solar Insolation

The estimation of solar insolation of the selected site was made using 24 years data acquired from NASA [18] as shown in Figure 4. It was found that there is a little variation in the amount of solar radiation between the summer and winter from 2 to 3 kWh/m2/d. The average amount of solar radiation in December is about 3.7 kWh/m2/d and January 4.1 kWh/m2/d. The highest radiation level is confronted in the months of May with 6.40 kWh/m2/d and June 6.36 kWh/m2/d. However, the average annual solar radiation is about 5.2 kWh/m2/d. In the worst months, i.e. in December and January, the average monthly solar insolation is around 3.9 kWh/m2/d. If the system is optimized based on worst month (December) then the radiation capturing could be enhanced from 3.75 kWh/m2/d to 5.35 kWh/m2/d with an increase of 42.6% for that particular month. When the system is optimized on yearly basis, then the system output could increase

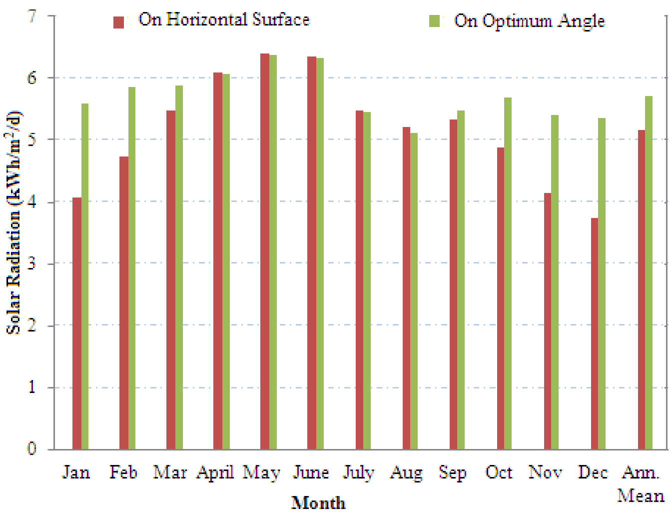

Fig. 4: Solar radiation intensity of different months at Chachro, Thar.

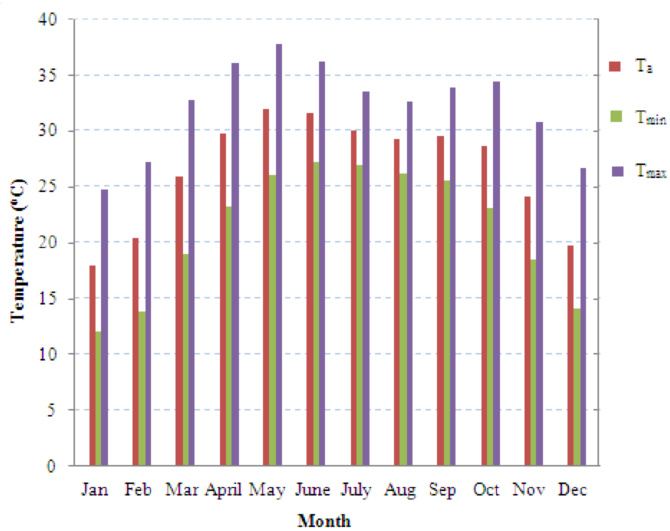

Fig. 5: Temperature profile during various months of year at Chachro, Thar.

from 5.16 kWh/m2/d to 5.71 kWh/m2/d with an increase of 10.6%.

Furthermore, the higher temperatures decrease the performance of solar photovoltaic panels. Therefore, the study of air temperature of the area was carried out for incorporation of system design process. Figure 5 characterize the monthly average ambient, minimum and maximum air temperature at Chachro, Thar. It was found that the average annual mean of ambient air temperature at the site was 26°C. The lowest average monthly minimum air temperature was recorded in the month of January with 12.1°C and the highest average 27.2°C in June. The highest average monthly maximum air temperature was recorded in the month

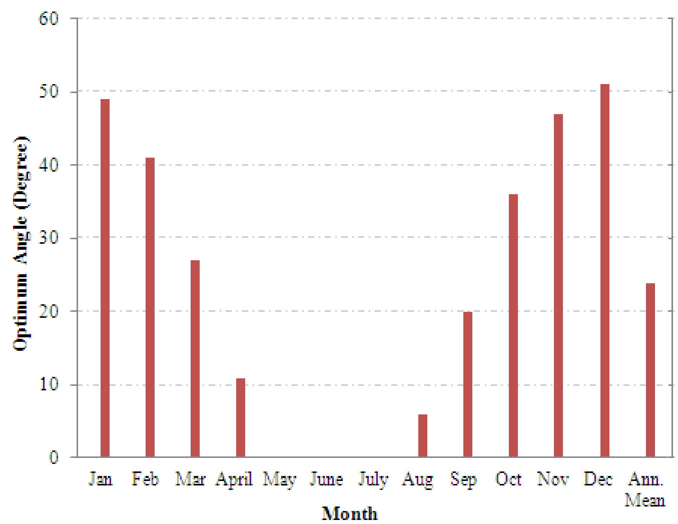

Fig. 6: Monthly average optimized angle for installation of PV panels at Chachro, Thar.

of May with 38.0°C and the lowest maximum average 24.7°C in January. It is revealed from the analysis that the air temperatures in the months of July and August were relatively low as compared to the months of May, June, September and October due to cloudy skies and monsoon season.

3.2 Orientation of Panels

In addition to the estimation of solar data and considering the influence of temperature, appropriate physical orientation of the panels is indispensable for trapping more solar radiation that striking the panel surface. In general, for a fixed mounted panel, the panel is tilted towards true south at the latitude of location. If the system is designed for winter, then the tilt angle is set with latitude +15° [19]. It is found that, on annual average basis, the optimized angle at Chachro was 23.9°as shown in Figure 6. The maximum optimum angle was found to be 51°in December and 49°in January. The less optimum angle was zero for three months from May to July. If a solar system has a steady load demand, then the designed month will be of less solar insolation month. However, a minimum of 15°tilt is preferred irrespective of the location latitude to facilitate the self-cleaning of panels during rains.

3.3 Proposed Applications of Solar Home Systems

The two different models are proposed for solar home system applications as described in Table 1 and 2. The first model is tabulated for a daily load demand of 105 Wh and the second one is for 405 Wh. The first model is chosen for lowest income people or small users, whereas, the second one is proposed for relatively larger communities and middle class people. The number and selection of system components are made after receiving the specifications from the suppliers. Since the cost of equipment is not provided by the suppliers, therefore, it is not included in this study.

It is established from the study that autonomous solar home systems are quite feasible for the supply of electricity to the rural communities of Thar region. However, the government or other agencies should monitor and maintain the systems in regular intervals of time. It is also recommended that the selected groups from the end-users must be trained in order to examine and uphold the solar home system components. Unprofessional home installations can create problems by installing the PV panels on the traditional thatch roofs. The roofs are made in the shape of cone in the Thar area which requires special installation method. If the PV panels do not face true south, the improperly trapped energy will result in a wastage. A careless installation of systems should be avoided that leads to an under-performing and short-lived system due to battery under charging.

4 Conclusion

It is difficult to supply electricity at affordable prices to the isolated communities settled in Thar where the extension of transmission lines from national grid is expensive and other resources are lacking. The installation of solar home systems is only practicable solution to this fundamental problem. However, the proper system design and maintenance is crucial to meet the demand under different environmental conditions and cost constraints. Therefore, a simplified intuitive method is used for sizing of solar home systems with a load demand of 105 Wh/d and 405 Wh/day for two autonomy days. The two key parameters were considered for the design of solar home systems, i.e. the solar resource and energy demand that will increase the lifespan of system components. The system slope was also optimized for two scenarios, namely worst month and yearly average methods. The optimized angle was found to be 51°and 23.9°, with the power output increase of 42.6% and 10.6% for first and second scenario respectively. It was established that the systems could be successful in Thar if properly monitored and maintained on regular intervals of time.

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TABLE 1: Proposed Model-1

Appliance	**Model Specification**	**Load Power (W)**	**Quantity**	**Work Hours Per Day**	**Total Wh/-day**	**Autonomy Days**
Light	PAE-7W-2U12VDC	7W	2	7.5	105	2

TABLE 2: Solar Home System Equipment (Proposed Model-1)

Description	**Model**	**Power**	**Quantity**	**Total Capacity**
Solar Module	THD25/12-AE4/9	25Wp	1	25Wp
Storage Battery	BT38-12	40Ah/12V	1	40Ah
Charge Controller	EPHC 5A/12/24V	5A/12V/24V	1	5A

TABLE 3: Proposed Model-2

Appliance	**Model Specification**	**Load Power (W)**	**Quantity**	**Work Hours Per Day**	**Total Wh/-day**	**Autonomy Days**
TV	PAE-11W-2U12VDC	11W	3	5h	165	2
Table Fan	PAE-12VCD 30W 14”	30W	1	8h	240	
Total					405	

TABLE 4: Solar Home System Equipment (Proposed Model-2)

Description	**Model**	**Power**	**Quantity**	**Total Capacity**
Solar Module	THD100/12-AE6/18	100 Wp	1	100Wp
Storage Battery	BT150-12	160Ah/12V	1	160Ah
Charge Controller	EPHC 10A/12/24V	10A/12V/24V	1	10A
Inverter	PI-3-12(230VAC)	300W	1	300W

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