AN EMPIRICAL APPROACH TO SAPV SIZING IN TROPICAL ISLANDS

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ABSTRACT

Many Stand- Alone Photo Voltaic (SAPV) situations require a battery storage due to need of stable current supply as well as to ensure no load shedding scenario. In matching a PV generator and a storage battery for a given load, it is important to optimize the capacities of the two to minimize the system cost. If a generic curve can be developed for a particular geographic region, where the annual incident solar radiation levels are known, a matching pair of PV generator and storage battery can be selected for any given load, based on the components cost, which can be used as a tool in designing SAPV systems. As the rainfall patterns and hence the cloudiness in the tropical islands are seasonal and predictable, system performance can be established using short term radiation data. In this research, the tropical island of Sri Lanka is taken as a case study and generic curves for SAPV sizing are developed for two main climatic regions of the country.

Key words: *Photo Voltaic, Storage battery, Rainfall, Tropical islands*

1. INTRODUCTION

As more attention is given to PV systems as energy converters in place of fossil fuel, the need to optimize such systems in terms of performance and cost arises. This is more so in case of stand-alone PV systems where optimum system reliability is required at the lowest cost due to higher percentage of cost is incurred on the PV modules. The accurate sizing is an essential step to achieve these aims since it will ensure that demand is met and costs to be cut, thereby lending greater credibility to the practical use of PV systems in the renewable energies market. This is more so, in situations where no grid power is available, and the performance of the load solely depending on the performance of the PV module and the associated storage battery capacity. Many SAPV situations require battery storage due to the need of stable supply of current, as well as to ensure a no load shedding scenario. Essentially, with any PV generator with a backup battery, the right sizing of the generator and storage capacities bear a greater impact on the system cost.

In the tropical islands, meteorological parameters such as total cloud cover play a significant role in determining the amount of incident solar radiation at any location and the land mass is broadly demarcated in to geographical regions based on annual rainfall figures. It is observed that due to well established seasonal rainfall patterns brought in by monsoons and convective clouds, the monthly average daily radiation values do not vary significantly within the said region. On the other hand, as the ambient temperatures remain stable with minimal fluctuations in the tropics, the effect of temperature variation on the performance of the battery is minimal. Hence, if a load independent graphical relationship can be developed between the capacities of the PV generator and the storage battery, for no load shedding scenarios, such can be used as a generic curve for a particular region defined by the rainfall pattern. Taking into account the percentage of power requirement out of the generated power output from the PV module for the load and the variations in incident solar irradiation levels over a period of time, the need of a storage battery is discussed.

Power output characteristics of a lead acid accumulator is non linear and varies with the load characteristics. Besides the battery life is determined by the load as well as the duty cycle and the system has to be properly designed so as to match the PV generator and the accumulator with the load. This will ensure a non load shedding scenario indicating reliability in operation. Hence a generalized sizing curve is developed and validated to facilitate the selection of a matching pair of generator and battery capacities for a non load shedding situation. Such a curve can be used as a useful design tool.

2. OBJECTIVE

To develop load independent iso-reliability curves for a given geographic location to select matching pairs of PV arrays and storage battery capacities to minimize system costs for non-load shedding scenario.

3. MATERIALS AND MATHODS

A Numerical-Analytical approach to SAPV sizing is used based on the concept in which supply reliability is defined in terms of the length of time that the system supplies load without interruptions (1). Considering the system load or demand to be constant in time, the study attempts to characterize the daily energy balances. When dimensionless variables are used to analyze these balances, more universal results are obtained (2).

Hence, the photovoltaic generator capacity, C_A, is defined as the ratio between the average daily energy consumed by the load. The accumulator capacity, C_S, is defined as the useful storage capacity of the accumulator, C_U, divided by the energy consumption of the load. Thus,

$$C_A = \frac{\eta_G A_G G_{m=\beta}}{L} \quad [1]$$

$$C_S = \frac{C_U}{L} \quad [2]$$

Where A_G and η_G are the area and conversion efficiency of the PV generator, $G_{m-\beta}$ is the monthly mean value of daily irradiation on the south facing generator surface at a tilt angle of β. L is the mean value of the daily energy consumption of the load and C_U is expressed as;

$$C_U = C_B . PD_{max} \quad [3]$$

Where C_B is the nominal capacity of the accumulator and PD_{max} is the maximum depth of discharge.

Considering the basic engineering design concept of

$$Q_t < C_t \quad \text{for any t,}$$

Where Q_t is the demand in time t, and C_t is the capacity in time t, for the functional reliability of the system.

Applying same for a SAPV battery charging system;

$Q_{max} < C_{min},$ for any given t, assuming that both the system capacity and the demand vary with time.

Using measured and synthetically generated radiation data at site, a sizing curve is derived using the dimensionless parameters C_A and C_S, calculated using daily energy balance. C_S is calculated as a function of the generator over the period of time and thus determining the maximum storage required for the system to operate without shedding load for the minimum generator size.

To collect data, prototype models are set-up in two locations in Colombo, in the wet climatic region of Sri Lanka and in Anuradhapura, in the dry climatic region of Sri Lanka respectively. The model consists of a 12V, $75W_p$ stand-alone PV module of exposure area of 0.25 m^2 (i.e. 0.5 mx0.5m) with manufacturer specified conversion efficiency (η) of 10% is connected to a 100Ah, 12V deep cycle lead-acid battery via a 10 Amp charge regulator. The battery is allowed to charge when solar radiation is available during the day and after allowing for a settling period of 1 hour for the battery to establish its chemical balance, a load of 115 Wh is connected to let the battery discharge.

Before the load is connected, the open circuit voltage (OCV) of the battery at "rest" is measured and recorded using a digital voltmeter and after the regulated discharge, OCV is measured and recorded again at "rest". The load is calculated to match the average annual generator capacity for the location (η*A*G_h) so that $C_A = \eta AG_h/L$ is approximately 1.00. G_h, the average daily global radiation values for one year are taken from the Department of Meteorology, Sri Lanka, whose weather stations are located in close proximity to the test sites. As such, those radiation values can be taken as that incident at site. In this case the load equivalent to 115 Wh is taken as 4 numbers 20 W CFL bulbs running for 1.3 hours. The PV module is placed horizontally to minimize the tilt effect hence to avoid monthly variations on incident global radiations.

The measurements were taken for one full year to encompass all seasonal variations. Using the recorded values of Open Circuit Voltage (OCV), the SOC% of the battery as a percentage is derived from the generalized curves (Perez) for deep cycle lead-acid batteries (3). The SOC% is taken to the nearest round figure from which the maximum battery usage, in days, is calculated ($C_S = C_U/L$). From all C_S values calculated for the year, the maximum value for a given C_A (in this case C_A = 1.00) is selected and plotted against C_A. The exercise is carried out simultaneously for C_A = 1.25, 1.5 and 2.00 with increased number of modules connected in series and the corresponding maximum C_S values are plotted against C_A values. For C_A = 2.00, 2 numbers of 75W_p modules are used with a combined exposure area (A) of 1.00 m^2 and for C_A = 1.25 and 1.5 the module surface is partially covered accordingly.

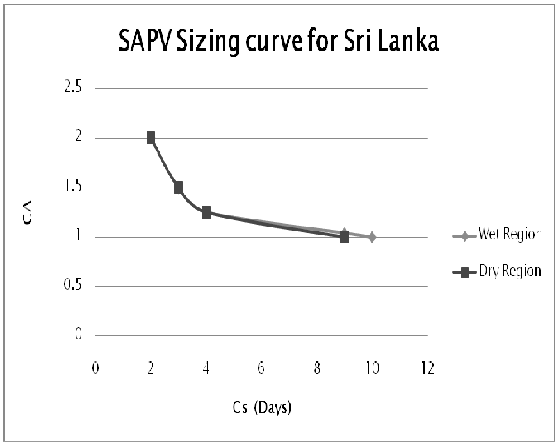

Chart 1.

4. RESULTS AND DISCUSSION

The load independent sizing curve derived from the models for battery assisted SAPV systems for the wet and dry climatic regions of Sri Lanka is shown in Chart 1. The resultant chart C_A versus C_S shows the minimum relationship required between the generator capacity and the battery capacity in order to maintain no load shedding and to ensure 100% system reliability. The chart is generalized to a particular geographical region and is independent of the load. Therefore, for any given load at a particular site, the generator capacity and size can be determined. Similarly, C_S multiplied by the load divided by the nominal battery voltage gives the battery capacity required in Ah. In the chart, C_S is selected to represent the deepest climatic cycle during the examined period thus giving a much reliable correlation between the parameters. This cycle is the effect of the daily correlation of the solar radiation, on the battery state of charge (SOC), for a system with a given generator and load. It is also noted that longer the radiation data time series, more the increase of prediction reliability. It is noted that when the coordinates corresponding to a particular period where the parameter C_S is high (corresponding to poor performance condition of the SAPV system) the sizing curve shifts upwards. This indicates that, though the presence of a 'bad' year has a pronounce effect on the shape of the curve, when a combination of small generator and large battery has been used, the effect is reduced for combinations of large generator and small battery. Therefore, it is shown how combinations of a large generator and a small battery seem to be more likely to withstand unpredicted events of low solar radiation sequence. Given the high sensitivity of the storage requirement on the length of the solar radiation data series used on system sizing, the above could be a practical way to deal with the unpredictability of solar radiation.

The chart provides the designer the option of choosing a desired combination of array size to battery storage capacity, which can be determined taking in to consideration the cost factors of individual components. However, when selecting the PV array and the battery size consideration should be given to match the charging and discharging currents as much as possible in order to prolong the battery life. Higher charging and discharging rates increases the internal resistance of the battery due to heavy electrolysis of chemicals shortening the battery life. It should be noted that the charts, battery voltage (in VDC) against SOC% are of different profiles for different types of batteries and the ones used in this research are the generalized form for deep cycle lead-acid batteries. Further, if non deep cycle batteries are used, the useful energy a battery can provide is restricted to its maximum Depth of Discharge (DOD), again depending on the battery type and make.

The lead-acid reaction is temperature sensitive. Cooling the cell changes its voltage against SOC% profile. As the lead-acid battery cools, its internal resistance increases. This means that voltage elevation under recharging is increased in cold cells. The same internal resistance increase produces increased voltage depression in cold cells when discharged. However, in tropical weather conditions, the effect of temperature on the chart profile is negligible though increased ambient temperature will shorten the cycle life of battery.

As Sri Lanka can be demarcated in to two distinct geographical regions based on the incident solar radiation levels (Chapter 4), another set of values for C_A versus C_S chart are obtained by taking measurements at Anuradhapura in the dry region. These two charts can be used widely for SAPV systems with battery storage designed for any load condition. It should be noted that for both data collecting set ups, C_A is taken as 1.04 instead of 1.00, i.e. for Colombo when the average generator size is 119 Wh/day, the load is taken as 115 Wh/day and for Anuradhapura in the dry region when the average generator capacity is 130 Wh/day, the load is taken as 125 Wh/day. This was to compensate for system losses as otherwise the load could be greater than the average generator capacity imposing a load shedding scenario at any given time.

Analyzing the two C_A versus C_S charts, for the wet and dry regions it is clear that at higher values for C_A the charts coinciding, demonstrating the existence of the two regions in a small geographical area receiving almost similar amounts of solar radiation throughout the year. The tropical climate of the country ensures an average of 4.5 KWh/day of global radiation levels for both regions with the radiation levels dropping to around 2-3 KWh/day in rainy or overcast days. However, at C_A = 1.00, the difference in the rainfall, hence the cloudiness experienced by the two regions is clearly visible with the dry region showing C_S value of 9 days as against 10 days for the wet region. Therefore, at C_A = 1.00 the systems in the dry region can adopt a slightly smaller battery for no load shedding situations. Hence for practical situations, the upper curve i.e. the curve for the wet region can be universally used in Sri Lanka for SAPV designing for any given load.

5. CONCLUSION

A set of load independent values can be obtained matching the capacities of PV generator and the corresponding battery storage for a given constant load in a specific geographical location where the incident solar irradiation is known. Graphically presented, such curves can be utilized by system designers as iso-reliability curves for SAPV systems indicating the optimum capacities of the PV generator and battery storage pair for system reliability.

6. REFERENCES

[1] Dennler, G., Bereznev, S., Fichou, D., Holl, K., Ilic, D., Koeppe, R., Krebs, M., Labouret, A.; Lungenschmied, C., Marchenko, A., Meissner, D., Mellikov, E., Meot, J., Meyer, A., (2007), "A self-rechargeable and flexible polymer solar battery," Solar Energy, Volume 81, Issue 8, Pages 947-957

[2] Klein S.A. (1994), "Calculation of monthly average insolation on tilted surfaces," Sol Energy, 43(3): 153-68.

[3] Perez, R., Seals, R.(1987), "A new simplified version of Perez diffuse irradiance model for tilted surface," Sol. Energy. 3: 221-231.