Ramallo-González, A.P., Loonen, R. C. G. M. & Hensen, J. L. M., 2019. A new method to evaluate environmental conditions for appropriate sizing of PV-battery systems, in Proc. of the 16th International IBPSA Conference (Building Simulation 2019), Rome, 8p

A new method to evaluate environmental conditions for appropriate sizing of PV-battery systems

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Abstract

Several initiatives have started to move the building stock towards a more self-sustained and self-reliant one, with respect to energy use. In most countries, photovoltaic installations have great potential to make a dwelling energy-autonomous. To do so, the PV installation has to be coupled with a battery bank that will be capable of storage enough energy in the periods with large solar resource so they can be delivered to the periods with little or no resource. Several tools are available to investigate what capacity is needed in terms of storage to optimise the PV-batteries installation and minimise the time that the user may suffer a black-out without increasing the battery size and therefore its price. These tools are rather accurate, however, their use tends to be limited to technical professionals such as engineering firms or the academia. If the predictions are correct, dwellings that almost do not need the grid will appear at a fast rhythm what implies that PV-battery installations will have to be designed in large numbers. A tool that is simple enough to be used by a constructor and that is accurate enough to give similar answers to those obtained with complex dynamic simulators, would be of great value, and will promote the deployment of such solutions. This paper shows a methodology for the creation of dimensioning charts, that could be use with this purpose. The method has been tested in two locations and it seems to be robust despite the demand profiles; and also, it seems to give accurate answers for dimensioning battery systems.

Introduction

[Some help would be good here]

Methodology

This work aimed to develop a simple dimensioning chart that would allow practitioners to size the PV-batteries installation for any given dwelling. It was important to extract all the relevant parameters for any case, and to perform a synthesis exercise to ensure that the access parameters of the chart were available and valid for any case. For this, we took the same approach of creating dimensionless numbers. This is also used in Fluid Dynamics and other branches of physics. With this, we were able to create a normalisation method that would allow to use the sizing chart for any case.

Normalisation

The normalisation has to be such, that maintaining the real significance of the project, moved the figures to a normalised space that will extract all the relevant ratios and proportions.

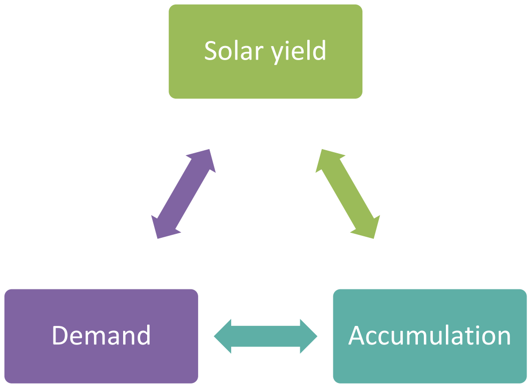

Figure 1. Triangle of interrelationships on a PV-batteries installation.

The production or yield provided by the PV panels will serve the demand, and any deficit or surplus will have to be directed from or to the accumulation (batteries). PV installations are sized using the so called watt-peak (Wp) which represents the yield of the plant under standard conditions of irradiance, which are fixed to 1000W/m2. This value of Wp can be considered as a good proxy of size of the installation. Also, the average power demand of the dwelling is a key parameter, and one can anticipate that the proportion between the two is an important figure. This ratio will provide an idea of the proportion between the energy that could be expected from the solar panels compared to the demand. This ratio is therefore fundamental for the understanding of the level of surplus that one may expect. It is for this reason that the first ratio we normalised was the average electric demand with the installed power of the PV installation and we called it the Power Generation Ratio.

$$PGR = P\ average\ demand\ /\ P\ PV\ watt\text{-}peak$$

(**Error! Bookmark not defined.**1)

This normalisation allowed us to use the same charts despite the size of the dwelling, its electrical requirements or the size or their PV installations. With this number we are taking only into account what is relevant for the problem at hand, which is the ration between what is produced and what is consumed. Also, we see that for each location this ration will have a turning point which is interesting for the sizing of the installations. If one imagines a PGR that is very small, then the PV installation will generate enough electricity for covering always the power demand, and no batteries will be needed. If on the contrary the PGR is very large, then one will see that even with batteries it will not be possible to cover the demand of the house, as there will be not enough energy in absolute values in the yield of the generators to cover demand.

There will be then a set of PGRs in which the batteries will be highly relevant and will bring the installation into optimal utilisation. This ratio will depend on the location at hand, and will go from the PGR that makes the annual yield equal to the annual demand (larger PGRs will have black outs despite of the battery size), and that we have called critical PGR (PGR_{crit}) to lower values of PGR.

After this normalisation, it was possible to carry on and to normalise also the capacity of the battery bank. The most common unit used for battery banks is the kilo watt hour [kWh]. It was rather straightforward to add the same normalisation to this unit, so we obtain a ratio with dimensions of time, what is highly relevant for the dimensioning of the system. Time is also the unit to measure potential black-outs. Because of this, we use the following normalisation for the capacity of the batteries:

Cnorm = *Battery capacity / P PV watt-peak*
(**Error! Bookmark not defined.**2)

With this two normalised values it was possible to start defining ways in which the sizing charts could be developed. The objective figure for the sizing was chosen to be days of black out.

Simulation

The idea of this work is to perform as much pre-processing as possible and as general as possible with the weather data, so the work that needs to be done at the practitioner's side is reduced to a minimum. For this, we took advantage of a series of parameters of PV installations that are seen to be normally within small ranges and use those for pre-processing the data. Our assumptions were that these ranges will not add much error to the dimensioning charts. The parameters are explained in the following.

One of these parameters was the performance of the batteries. Electric batteries have different technologies. However, due to their different characteristics (mainly volume and weight) some technologies are more popular than others for housing applications. Traditionally, and due to the un-importance of the weight, lead-acid batteries have been used in off-the-grid homes. New market developments have made available smaller size batteries based on Lithium-Ion technology which offers substantial benefits for the users.

In the past, Lead-acid batteries could have very different performances depending on the quality of the batteries acquired. However, with Lithium-Ion batteries, a standardisation of the performances has been seen. It appears that a charging and discharging efficiency of 90% is realistic for all the batteries that have appeared in the market with this technology.

The fact that a value of performance for charging and discharging is available and holds true for most devices allows to develop a simple simulation routine that would evaluate the suitability of different systems depending on the size of the accumulation and the ratio of yield/demand (Eq. 1). Although these two seem to be available, the third component of the system that has been shown in Figure 1, the actual demand, holds unknown, and it will be unrealistic to assume that there will only be one type of demand profile.

The demand will therefore be variable depending on the users. Nevertheless, the batteries will smooth by definition this demand, so there is room for investigation in this aspect. In this work we have considered 4 different profiles of electricity demand, to evaluate if it is really possible to use the average power demand as an entry for the sizing charts and still get good results, or there are better options.

Electricity profiles

Four different electricity profiles were used to evaluate how much the curves obtained would differ. With this, we were able to make a sensitivity analysis that would check the validity of the sizing charts at the same time that a confidence interval or estimation error is provided.

The first and simplest electricity profile was a constant demand with value the average of the power consumption of the dwelling. As mentioned before it should be considered that all these time series of power were normalised by the nominal power of the PV system and have units W/Wp.

The second profile is a standard load profiles taken from (Linssen et al. 2017).

The third profile was extracted from the VDI. Reference load profiles of single-family and multi-family houses for the use of CHP systems (VDI Guideline 4655). Düsseldorf: VDI Verein Deutscher Ingenieure e.V.; 2008.

The four profile was chosen from Pflugradt N. Load profile generator. Chemnitz: Technical University Chemnitz; 2014.

The four profiles are shown in Figure 2. The first profile in blue is rather smooth as it represents the profile that one may expect for a multifamily building. Profiles 2 and 3 in green and red respectably are sharper and show larger skewness of the profile towards the evening.

The profiles represent the power distribution for 24 hours, to convert this into year demands the profiles were concatenated 365 times. No seasonal variations of the data have been considered in this work. However, a detailed study about the effect of the seasonality of conditioning loads in poorly insulated buildings could be interested for further work.

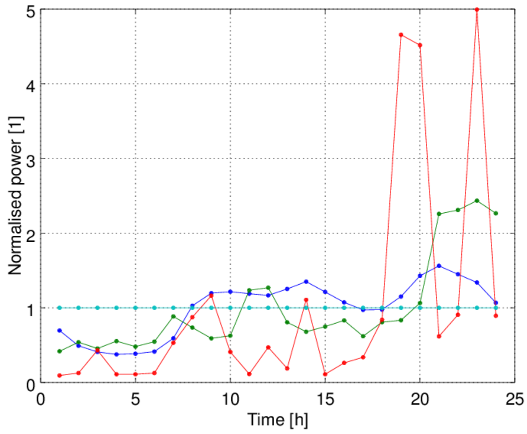

Figure 2. Daily profiles used in the simulations.

Weather data

There are several sources of weather information that contain solar irradiance. In our case, we have used energy plus weather files (.epw) obtained from enrgyplus.net. Two weather files were used as examples, the weather file from Beek, in The Nederland which is an IWEC file, and the weather file from Murcia which is a SWEC[1] file.

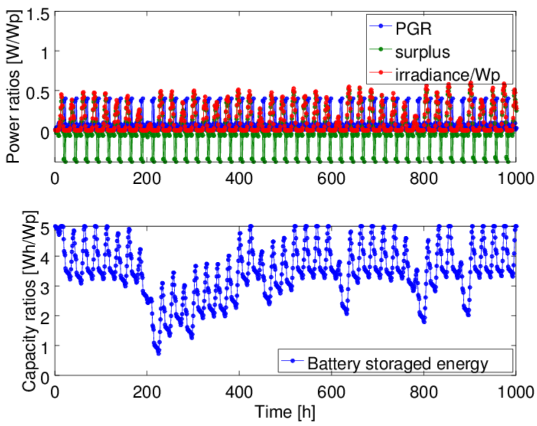

Figure 3. Example of simulation for Murcia with a PGR of 0.08W/Wp, a profile 3 and a storage of 5Wh/Wp during 1000 hours.

For the simulation, horizontal irradiance was used. With this we assume that the panels are located in a horizontal position. It is known that this is not the ideal orientation for a PV panel, and that the tilt will be a function of the latitude when one wants to optimise the yield. However, it should be remembered that the sizing charts are in all cases normalised by the watt-peak of the installation. A correction factor can be applied to take into account the different orientations and in that way make possible the use of the chart for any orientation.

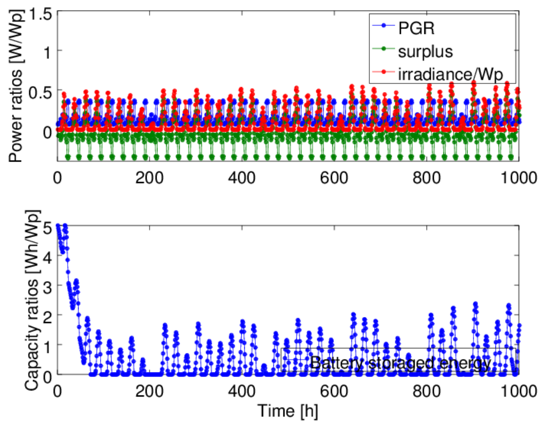

Figure 4. Example of simulation for Murcia with a PGR of 0.15W/Wp, a profile 2 and a storage of 5Wh/Wp during 1000 hours.

Results

Several results were obtained from the work here explained. Although the main aim was to develop a sizing tool that can be used with almost no-expertise and that can help to sizing PV-battery systems, substantial learnings have been obtained thanks to the evaluations performed.

The charts

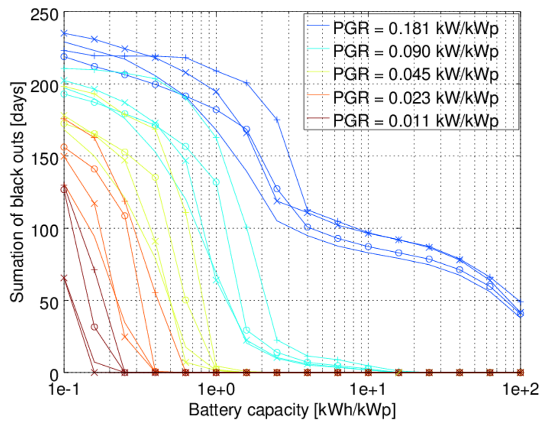

Figure 5. Different curves using different demand profiles. Diagram for Murcia.

The evaluation of the black-out times with different PGRs and different battery sizes has allowed to investigate the effect of different consumption profiles in the demand-accumulation balance.

Figure 5 shows this variability that one finds in the results when using the four different profiles (that has been marked respectively with '-' 'x' 'o' '+'). Although the number of profiles that were evaluated do not represent all options, due to their differences, they provide a good picture of the variability that one can find in real installations.

[1] The weather files were synthetically generated using Climed (Portuguese software developed by Ricardo Aguiar) from mean monthly data coming from the Spanish Meteorological National Institute by Prof Perez-Lombard.

The generation of this figure helped to understand how the profiles have significant influence in all cases, and only when one sizes the battery bank to ensure that no black outs will occur one can see that the curves from different profiles tend to converge.

After seeing this graphs, it was possible to see that the variability depending on the user profile could be an added value to the graph. This is because the new trend to install smart meters and other home automation devices that can optimise the load profiles may open a door to the user towards investing in home automation devices instead of purchasing a more expensive battery pack.

The variability between profiles was plotted as trans-lucid areas in the chart, each one corresponding to a given PGR.

In addition to that, the chart can be used not only for selecting the battery size, but also the PV installation size. By seeing at the charts, one can see the level of PGR that one may need, to make an installation self-sustained with batteries, or in case of going for a combined solution of PV and other on demand generation systems such as fuel generators, then one can see the optimal PGR considering the investment.

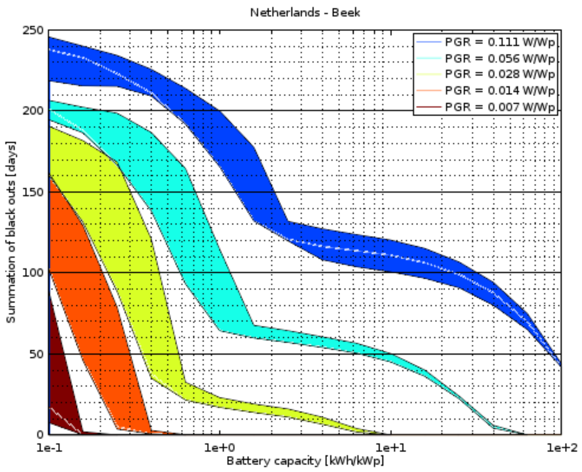

Figure 6. Sizing chart for Beek, Netherlands.

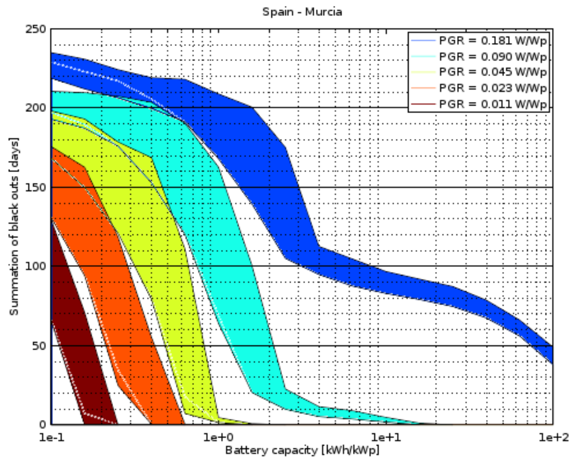

Figure 7. Sizing chart for Murcia, Spain.

For each one of the PGR bands we see two clear tendencies in the graphs. Taking for example the PGR = 0.056 W/Wp for Beek, one can see that the curve from 0.1kWh/kWp to 1.2kWh/kWp maintains a smooth curvature similar to that of an inverse square function. From 1.2kWh/kWp to 60kWh/kWp the curvature changes, and although the convexity is still the same, a small derivative is seen here as in 0.1kWh/kWp. This turning point occurs, because for this point, the batteries can cover the gaps produced by nights and sporadic dark days. As these represent the majority of the periods that need to be covered with the battery storage. This implies that after this threshold, the battery can cover that majority of gaps, and that for a further reduction of the blackout periods a substantial increase in the battery size has to be done.

In the same way, one can see how the profiles have smaller influence, this comes to no surprise, as if the battery is capable of covering the daily harmonics in demand, then the daily profiles will have little influence.

How to use the sizing chart

Examples

Conclusion

Acknowledgement

References