

Analysis of Grid Connected Hybrid Inverter powered by solar paver panels

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Abstract: Renewable energy has become the competitive solution for the depletion of conventional energy sources. However wind and solar energy are especially dependent on fluctuating weather and day-night cycles. To lessen these variabilities battery energy storage systems can provide a widespread solution. During the application of battery energy storage systems the main issue is to optimally determine the size of the battery for balancing between the energetic advantage and cost efficiency. This paper provides an overall view on measuring the efficiency and parameters of a hybrid system and calculating the necessary battery bank. This paper investigates the potential of using battery energy storage systems with PV system in low-voltage microgrid application.

Keywords: photovoltaic energy, renewable, energy storage systems, hybrid inverter

1. Introduction

There are different types of microgrid and island mode solution for renewable energy sources (RES):

- in some power systems electricity is generated by wind, solar energy, biomass, microhydro, etc [1], [2], [3] and [4];
- some power plants (PP) consist different types of energy storage, example: lithium-ion and lead-acid battery [5], [6], [7], [8] and [9].

In paper [8] a multiobjective optimization method is proposed to visualize the trade-offs between different objective functions.

Some paper proposed management of hybrid microgrid, the aim of management is to reduce multiple conversion, example in [5].

The goal of the study is to give a picture in detail on measuring the parameters and efficiency of one hybrid inverter.

2. Experimental

During the experiments the photovoltaic DC (Direct Current) voltage was provided by a power supply instead of PV (Photovoltaic) panels, because its adjustability made it easier to measure the parameters at different power points.

The investigated system has several operating states. On Figure 1 the conventional solar system can be seen.

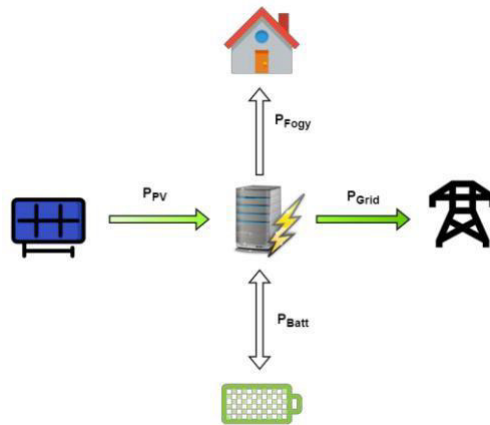


Figure 1
Energy flow during PV supply

In this case the inverter directly feeds the energy to the network. On Figure 2 the produced energy is stored locally, in this case the hybrid inverter charges the batteries with its built in unit. This solution prevents the necessity of expanding the existing electrical network.

Several studies highlighted that battery energy storage systems can make extra profit from buying energy off-peak rate and selling it at peak periods. Figure 3 shows this energy flow direction.

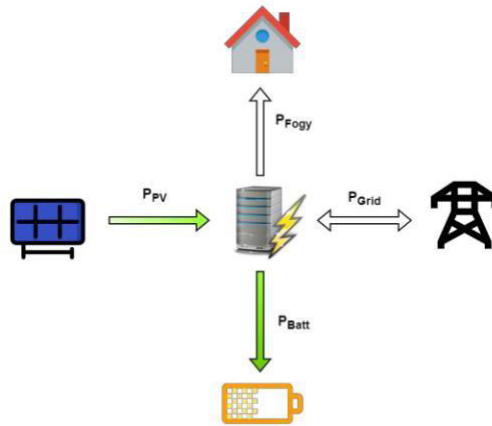


Figure 2
Energy flow during PV supply and charging battery

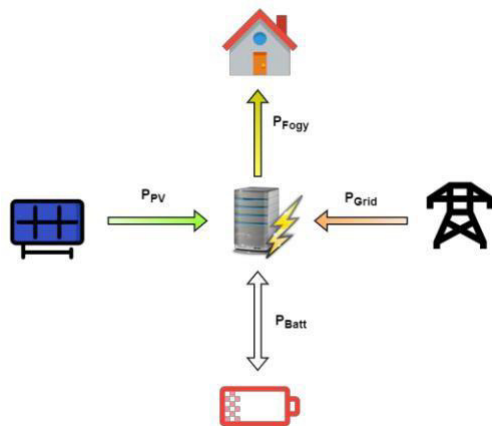


Figure 3
Energy flow during public load supply and charging battery

During the charging and main supply shown on Figure 1 - Figure 3, the values of the terminals of the hybrid inverter were measured with both AC (Alternating Current) and DC loads. These allow the system to be modelled more accurately.

3. Results and Analysis

The previously described model system was tested with 10 constant solar production values from 0 W to 225 W. Though the maximum DC input power of the hybrid inverter can be as high as 750 W, the goal of the investigation is to measure the efficiency at lower production caused by unfavorable weather conditions.

In the efficiency calculations the supplementation of solar production was provided by the public network, while the power absorbed was represented by the AC load. Due to its high state of charge, the 200 Ah battery bank also appeared as an energy supply during the operation of the system.

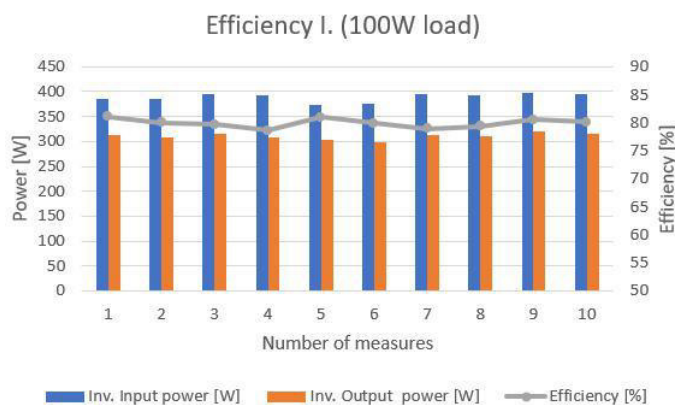


Figure 4

Efficiency at different production and constant 100 W load

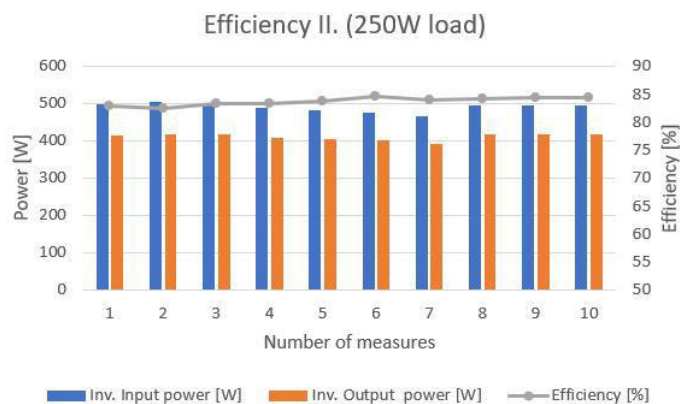


Figure 5

Efficiency at different production and constant 250 W load

The measurements were performed with both a 100 W (Figure 4) and a 250 W (Figure 5) load. According to the results, as the extent of load is increased, the efficiency of the inverter under test also increases. With 100 W load (20% of nominal AC load) the efficiency is in between 75 – 80%. When the load is increased to 250 W (50% of the nominal load), the efficiency of the inverter is constantly around 85%. Based on these measurements, it can be stated that the rate of the load has a greater impact on the inverter's efficiency than the proportion of power supplied to the system from photovoltaic production.

4. Discussion

The inverter system equipped with a power supply can only model the production of preset photovoltaic values. Although the real production is not constant, it varies in every moment depending on the current weather conditions and shading. For this reason the power supply was not appropriate to simulate these changes, so it was replaced by solar pavement panels. A total of 15 pieces Platío Solar 20 W solar pavers were connected into one string to provide photovoltaic power to the system.

The losses of the system under study are composed of several parts. There is a loss on the cables connecting the solar cells to each other and to the inverter. This form of dissipation can be reduced by increasing the cross section. In addition, the efficiency of the system is impaired by DC-DC and DC-AC conversion and loss of battery charge.

Based on the measurement of the system under real conditions, the average efficiency can be determined, which forms the basis for later calculations and modelling. To perform this, it is worth examining the energy conditions of the inverter over a longer period of time. Figure 6 illustrates the efficiency of the system averaged every 5 minutes from 7:15 AM to 4:10 PM. The daily average production is 68.7%.

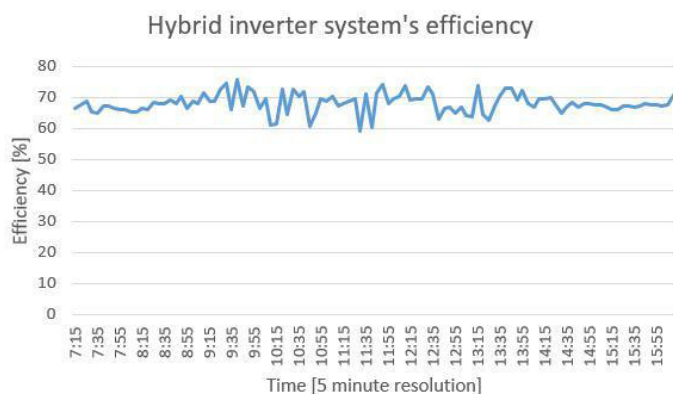


Figure 6
Daily efficiency averaged in 5 minutes

4.1 Pre-calculations for simulation

The purpose of this part of the article is to present a design algorithm for island mode systems that can be applied to any given consumer profile using the determined average system efficiency. During island operation, local energy demand is primarily supplied by the solar system, while the battery bank feeds back energy only in the event of a production deficit. Based on the specified consumer profile, the system calculates the number of panels to be installed and the battery capacity.

In the case of solar cells, the applicable type is scaled to pre-defined Platío Solar solar pavement. To determine the number of panels, an annual reference production of a 1 kW solar cell at an angle of 0° is required (P_a), which was calculated in the PVGIS (Photovoltaic Geographical Information System) system. By Knowing the daily consumption (E), the number of required solar cells (n_{panel}) can be calculated.

When sizing island-powered systems, it is recommended to take into account the number of cloudy reserve days (D), on which we assume near-zero solar production. During this period, the battery must provide power to the consumer. The most commonly used value of backup time in the literature is usually 2-3 days. The maximum discharge capacity (DoD, Depth of Discharge) as well as the daily energy consumption (E) also affect the sizing of the battery.

The calculated battery capacity (C) in this form is measured in Wh, so the system voltage should be selected based on this, as higher voltage batteries have a voltage level of 24 V or 48 V.

4.2 Simulation of operation in MATLAB

While the program is running, the calculations are performed for an entire day with a resolution of 5 minutes. Instantaneous solar production is calculated from 5-minute resolution weather data that can be read from an external file. In addition to the irradiation and temperature values, the consumer profile is also loaded, so the required battery capacity and the number of solar cells can be calculated.

The simulation consists of 188 steps as it calculates the output of the solar system, the state of charge of the battery, and the instantaneous excess or deficit of energy 12 times an hour for a day. If the battery charge drops below 20%, the system throws an error message, after which it is possible to reconfigure the initial parameters.

The program monitors the difference between the current production and consumption during the run, then charges or immerses the battery after a condition test, taking into account the previously average efficiency.

For the calculations, the system models the operation of a consumer that consumes 200 W during the day (6 AM–6 PM), while operating at night (6 PM–6 AM) in energy saving mode, in which case it consumes 100 W. In terms of the nature of the consumption profile, this corresponds to the consumption of a smart urban information board. The highest production values can be measured in summer, in which case the battery will have a higher state of charge after daytime charging and then after evening immersion than at the beginning of the day. Besides supplying the consumer, significant solar production is available, Figure 7. The state of charge (SoC) is the ratio of the available capacity and the maximum possible charge that can be stored. Fully charged battery's SoC is 1, while in fully discharged case it equals to 0.

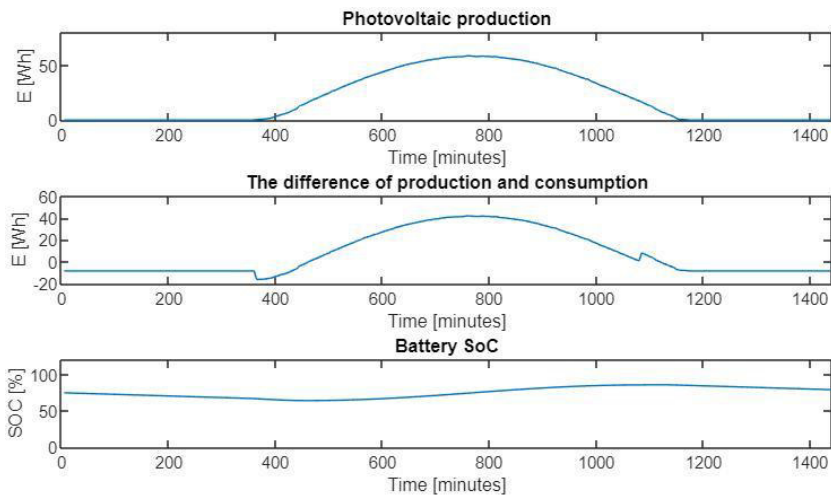


Figure 7

Summer production, initial SoC = 0.75

Figure 8 illustrates a slightly different operation. By the end of the day, the battery is in the discharge phase again, its charge status drops from the initial 100% to 70%.

Until the start of solar production, the consumer gets the energy from the battery, and then in the case of increasing production, the charging process starts, however, the difference between solar production and consumption is much smaller than in summer time in sunny weather. Although there was power supply to the system, the battery charge level was lower than at the beginning of the day. Therefore, it is necessary to use a constant number of spare days (D) as this prolongs the discharge process, thus giving the system time to charge the battery in case of favourable weather conditions.

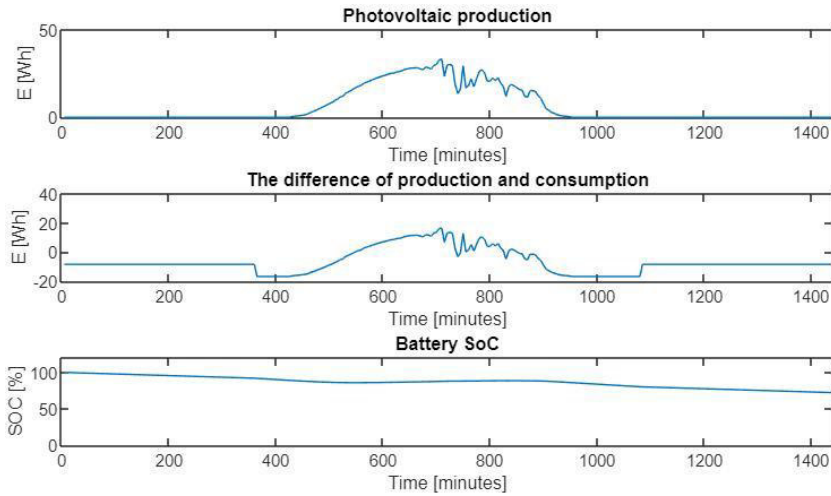


Figure 8

Fall production, initial SoC = 1.00

4.3 Partial shadow effect on production

By applying island-based systems using solar pavers, it is important to mention the role of the shading effect on production. If the amount of irradiation is uneven, it will affect the performance of the panel. In the case of panels connected in series, this phenomenon is weighted, the principle of the weakest link applies. The panel with the least radiation also degrades the performance of the other panels. If less current can pass through one panel, it will limit the current in the other panels too. This phenomenon leads to increase in the panel's temperature which results a deterioration in the efficiency of the panels when the string is asymmetrically shaded.

4.4 Increasing production efficiency

There are several ways to maximize the energy produced with island mode solar systems. The most cost-effective solution is to carefully inspect the installation site in advance. In such cases, periodic and permanent shadow factors must be taken into account, and the optimal solar cell allocation and stringing must be sought with these in mind. For inverters with multiple MPPTs (Max Power Point Tracking), multiple strings can be created without the need for additional equipment. This is useful because it reduces the chaining of panels to a string that are exposed to very different irradiances during production. Purchasing inverters with multiple MPPTs does not necessarily mean higher costs, as only multi-point inverters are available at higher power.

In the recent years, so-called microinverters, also known as power optimizers have become more and more common. Their use is justified in places where a partial shadow effect may occur on the solar string. The power optimizer is connected in parallel to one or a few solar panels, and then the resulting structures are connected in series. As a result, the partial shadow effect can be eliminated, and each optimizer can extract maximum power from the connected solar panel.

Conclusion

In the case of hybrid inverter and island systems, it is especially important to ensure efficient operation, which requires accurate sizing of the following factors:

- sizing the inverter,
- battery bank capacity,
- designing the panel layout by taking into account the possible shading factors.

The created designing calculator can be successfully applied at the designing of island mode systems. It can be further developed to be able to calculate the appropriate parameters based on the weather data of an entire year.

Acknowledgement

The research was supported by 2018-1.1.2-KFI-2018-00193 project “Innovation for energy and electrical industry at CoreCommSI Ltd and NRG Services Ltd (Greenverter)”.

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