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Analysis of long term energy storage performance supporting a PV system and residential load

***Abstract**. Many elements make up the optimal management of microgrid operation. Beginning with the proper selection of components, by determining the technical and economic goals, and ending with the proper scheduling of individual devices. A key element in effective controlling the operation of the entire microgrid is the energy storage. The operation of the storage is related to its maximum capacity, border discharge limit, maximum charging and discharging power and the real device characteristics. Most energy storage control algorithms focus on one-day plans, resulting from the period for which forecasts are made. Such a solution, however, carries the problem of controlling the state of charge of the storage system at the beginning and end of the control period. In the presented paper, the authors analyze the operation of the microgrid for intervals of a day and a month. The analysis is made for reducing the power exchanged with the distribution system to zero for different values of the rated capacity of energy storage.*

***Streszczenie.** Wiele elementów składa się na optymalne zarządzanie pracą mikrosieci. Zaczynając od właściwego doboru komponentów, przez określenie celów technicznych i ekonomicznych, na odpowiednim planowaniu pracy poszczególnych urządzeń kończąc. Kluczowym elementem, zapewniającym efektywne sterowanie pracą mikrosieci, jest magazyn energii. Z funkcjonowaniem magazynu wiąże się jego maksymalna pojemność, dopuszczalna granica rozładowania, maksymalna moc ładowania i rozładowania oraz rzeczywista charakterystyka urządzenia Większość algorytmów sterowania magazynami energii skupia się na planach dobowych wynikających z prognoz krótkoterminowych generacji i obciążenia. Takie rozwiązanie niesie za sobą problem związany z kontrolą stopnia naładowania zasobnika SOC na początku okresu sterowania. W przedstawionej pracy autorzy analizują pracę mikrosieci dla dnia i miesiąca. Analiza wykonana jest dla ograniczenia energii wymienianej z systemem dystrybucyjnym do zera dla różnych wartości pojemności znamionowej magazynu energii. (**Analiza długoterminowej wydajności magazynowania energii wspierającej system PV i obciążenie mieszkalne**)*

Keywords: microgrid control; energy storage system; long-term analysis.
Słowa kluczowe: sterowanie mikrosiecią; system magazynowania energii; analizy długoterminowe.

Introduction

There proliferation of photovoltaic systems into the distribution grids is gaining momentum in recent years [1]. There are various complementary reasons for this development: climate change, reduction of greenhouse gasses emissions, growing prices of fossil fuel based electricity, etc. PV systems are technologically mature, guarantee long term trouble free operation and require little maintenance [2]. The prices of PV panels and small inverters were consequently falling in the last few years [3].

Along technological maturity and established standardization electricity market regulations and incentives make PV systems attractive for prosumers, i.e. small producers and consumers of electricity. The growth of prosumers installations in Poland in the last years is exceeding 100% on the year to year basis. Currently, there are more than 1 million installations connected to the distribution grid with the total installed power exceeding 8 GWp [4]. Wp (Watt peak) refers to standard test conditions for PV, usually better than operational conditions.

However, PV systems are intermittent in nature, with a generation characteristic hardly meeting the demand curve [5]. The distribution grid can no longer be regarded as a virtual storage managing the discrepancy between local production and consumption of electricity. Transporting bulk energy quantities causes severe voltage variations in the grid. In most acute cases the overvoltage protection is tripping the PV installation and reducing the generation to zero, despite favourable irradiance conditions.

The combination of PV installation with a local energy storage system is an established method for the handling of surplus energy and the reduction of energy exchange between the PV system and the grid [6]. It also supports the local voltage conditions and reduces the demand of fossil fuel based electricity.

There are several different technologies suitable for the combination with PV systems [5]. However, high cost of energy storage systems is still seen a significant drawback. There are numerous works related to the problem of optimal sizing of energy storage and the related control algorithm [7]. Usually, there is interest in long term efficiency assessment, but not explicitly long term storage [10].

System with a short time horizon, e.g. one day, can be divided into deterministic and forecast based systems. The use of generation prediction helps to manage the storage more efficiently [8].

Long term storage systems are an emerging and challenging field of research, as energy generation fluctuations are not restricted to 24 hours. Long term storage is needed to control the power flow from increasing number of renewable intermittent sources in the gird. Different sizing and control approaches are needed.

This paper presents an assessment of energy storage performance with regard to a day and a month. In case of a day storage the influence of initial SOC (State of Charge) is shown. The case study based on real measured data and four operational cases is presented.

Firstly, the algorithm for the control of energy storage is introduced. Then, consequently, the results of a month long operation are discussed and summarized.

Algorithm for energy storage control

The algorithm used is designed to optimally manage the power generated by the photovoltaic system, by controlling the energy storage. Power exchange with the power system will be carried out only when necessary to ensure the balance of power in the microgrid. In the case of excess generation, charging of the storage is preferred, and in the case of an energy deficit, discharging of the energy storage is preferred. The presented control algorithm in its basic version does not require generation and load forecasting, as it responds to current power values. However, for cases of complex technical and economic optimization, it can use forecasts to construct the power curve of energy exchange between the microgrid and the distribution system. A distinguishing feature of the algorithm is that it only controls the excess of locally generated energy or its deficit, preventing cases of hazard discharging with energy given off outside the microgrid.

Fig. 1 shows the block diagram of the algorithm.

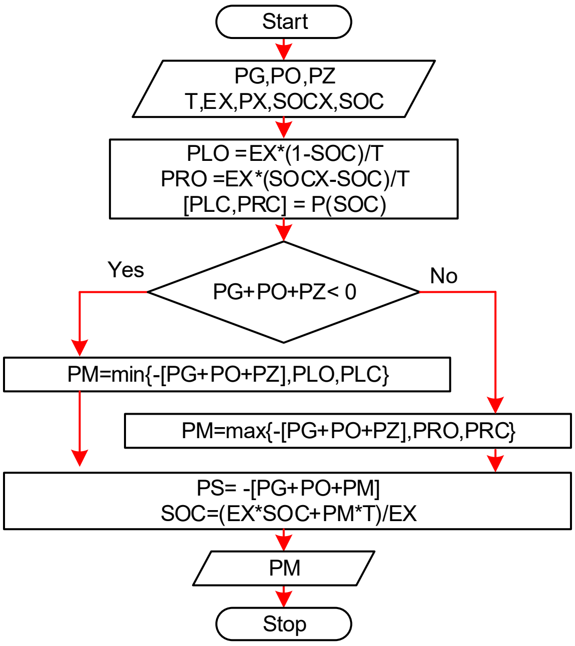

Fig. 1. Block diagram of the energy storage control algorithm.

The detailed description below and acronym explanation refers to Fig. 1.

1. <u>input data loading:</u>
- analysis step T
- maximum capacity of the energy storage EX
- maximum power of the energy storage PX
- the minimum level of discharge of the energy storage SOCX
- energy storage power PM
- generated power PG
- demand power PO
- preset level of power exchange with the system PZ
- state of charge of the energy storage SOC

2. <u>checking the permissible charging and discharging powers according to the set characteristics</u>
3. <u>calculation of the difference between the generated power and the demand power</u>
4. <u>decision to charge or discharge the energy store</u>
- if the decision to charge, choosing the smallest value among:
  - *the difference between the generated power, the demand power and the preset exchange power with the grid*
  - *the power resulting from the characteristics PLC*
  - *the power resulting from the available storage capacity PLO*
- if the decision to discharge, choosing the largest value from among:
  - *the difference between generation power, demand power and preset exchange power with the grid*
  - *power resulting from the characteristics PRC*
  - *power resulting from the state of charge of the storage PRO*

5. <u>calculating from the balance, exchange power with the power system PS, calculating the new state of charge of storage</u>
6. <u>execution the algorithm for current values PO, PG, PZ and SOC</u>

One-day horizon for planning and operation

An important element in the planning and subsequent analysis of microgrid energy storage performance is time. Most of the analyses we can find in the literature are one-day analyses. Despite the undoubted advantage of the accuracy of predictions of generated and consumed power, there is a problem related to the state of charge of the energy storage. Inaccurate determination of the initial SOC can have a significant impact on the accuracy of the control scenario. In order to analyze this issue in more depth, an analysis of power distributions was performed for different initial degrees of charge of the energy storage SOC.

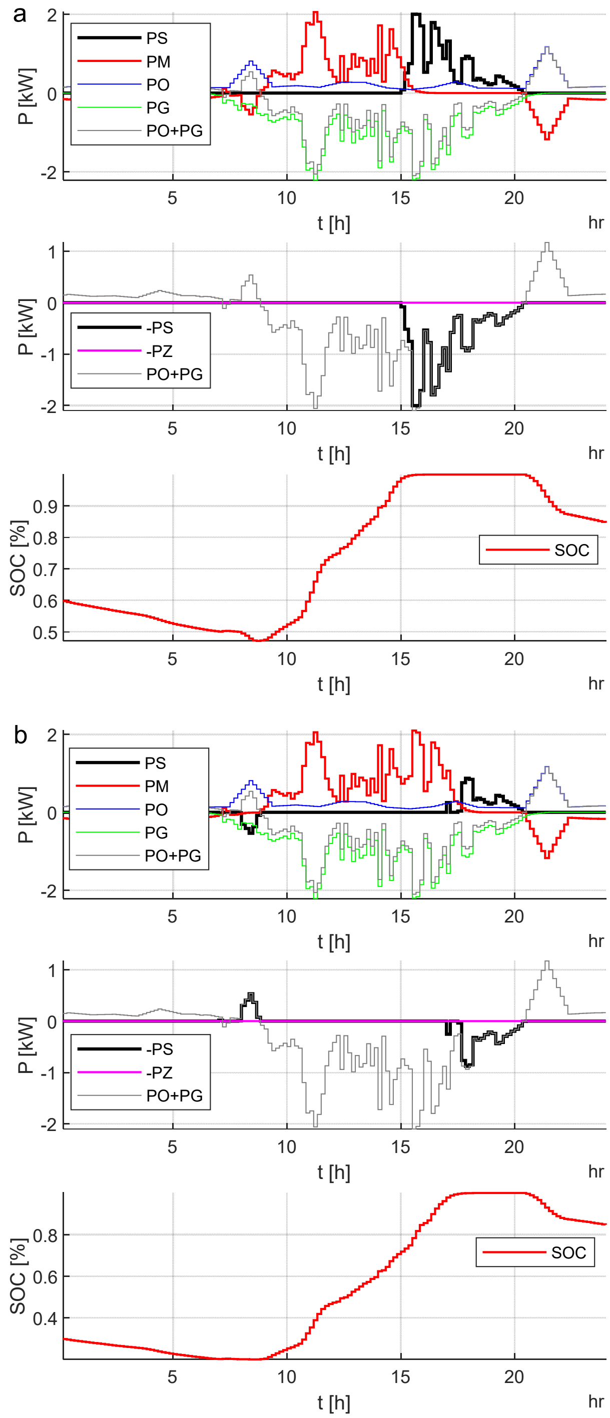

Fig. 2. One-day analysis of microgrid power distributions for two initial SOCs: a) 0.6 SOC; b) 0.4 SOC, where: P – power, t – time, PS - power exchanged with the power system; PM - power of energy storage; PO - demand power; PG - generated power; PO+PG - difference between demand power and generated power; SOC - state of charge of storage.

In Fig. 2 we can observe the power distribution in the entire microgrid, the power distribution considering only the power exchanged with the power system PS, the set power PZ, and the balance of the generated power and demand power PO+PG, as well as the change in the degree of storage charge. The analysis was performed for the day of July 8, 2021. The maximum charge level of the storage EX is 10 kWh. The maximum charging and discharging power of the storage PX is 3 kW. The object is a single-family house with a 3 kW photovoltaic power plant PG installed on the roof. The goal of the control algorithm is to minimize the power transferred to and consumed from the distribution system by forcing exchange power PZ to zero.

The difference in the performance of the energy storage is most easily observed in the middle and last graphs. Both one and the other storage discharges during the first hours. The difference occurs around 10 a.m., the storage that started with a smaller initial SOC can no longer give up more energy. The result is that in the second case the algorithm's goal for about 2 hours is not achieved. After 1 p.m., both storages, taking advantage of the fact that the generated power is higher than the consumed power, recharge. Then, when the sign of the difference between generated and consumed power changes, one and the other storage begins to give up energy. In addition, the storage that starts with a lower initial SOC is able to balance the generated power for longer, which can be seen from 1 p.m. to 6 p.m.

One-day analyses show only a small portion of the microgrid's operation. In addition, long-term analyses are particularly important in the economic context. The new way of billing prosumers, so-called net-billing, which will be in force in Poland from 2024, introduces the need for long-term studies that take into account dynamic changes in market prices. The billing system based on hourly billing of the cost of energy sold according to prices on the wholesale market is assumed to lead to balancing the various elements of the microgrid. Hence the rest of the article presents a study case, which consists of monthly analyses. Long-term analysis is also important for technical reasons. It makes it possible to analyze individual features of the entire system. Thus, the technical and IT design responsible for the control of power flow can be subjected to correction and modification aiming at a resilient and stable microgrid system under changing operating conditions. This is particularly important when using random generation, i.e. photovoltaic and wind.

Case Study

The presented study case consists of two cases: an energy storage with a capacity of 25 kWh and a power of 6 kW and an energy storage with a capacity of 10 kWh and a power of 3 kW. The goal of the control is to balance the power exchanged with the power system to zero. The analysis presented was performed for year-round data, and the article shows selected waveforms that best reflect the operation of the microgrid.

The first case analyzed is an energy storage with a capacity of 25 kWh and a power of 6 kW for the control objective: limiting the power exchanged with the power system to zero (island operation). The analysis began by examining the power distributions in the microgrid for an entire month. An interesting case, reflecting well the control problems of energy storage, are the distributions for July (Fig. 3) and October (Fig. 4).

In July, despite very good weather and a large energy storage capacity, the target is not met for most of the month because there is not enough available capacity in the storage system. The failure is due to the high value of generated power. Thus, it manages to fully cover the demand power, while a great deal of energy is given back to the grid. From the point of view of meeting the target, October turns out to be a better month. Despite a few days when it became necessary to take the missing power from the grid, it was possible to significantly reduce the transfer of power towards the power system.

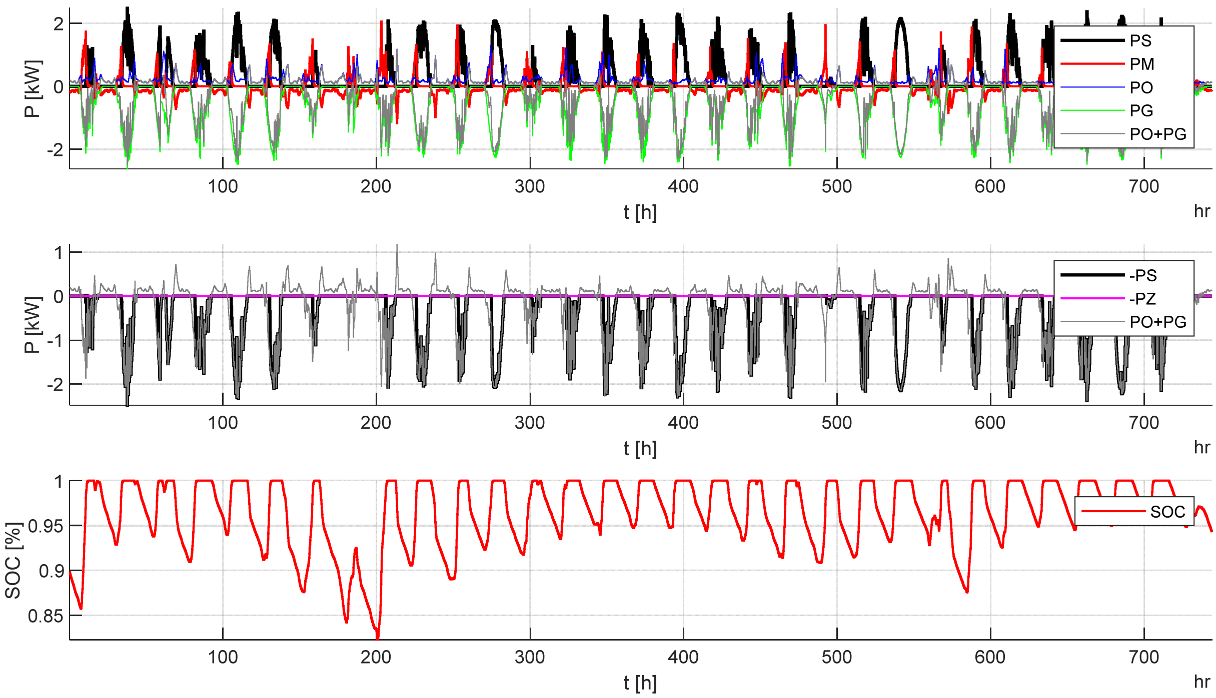

Fig. 3. Monthly power distribution analysis for July, where: P – power, t – time, PS - power exchanged with the power system; PM - power of energy storage; PO - demand power; PG - generated power; PO+PG - difference between demand power and generated power; SOC - state of charge of storage.

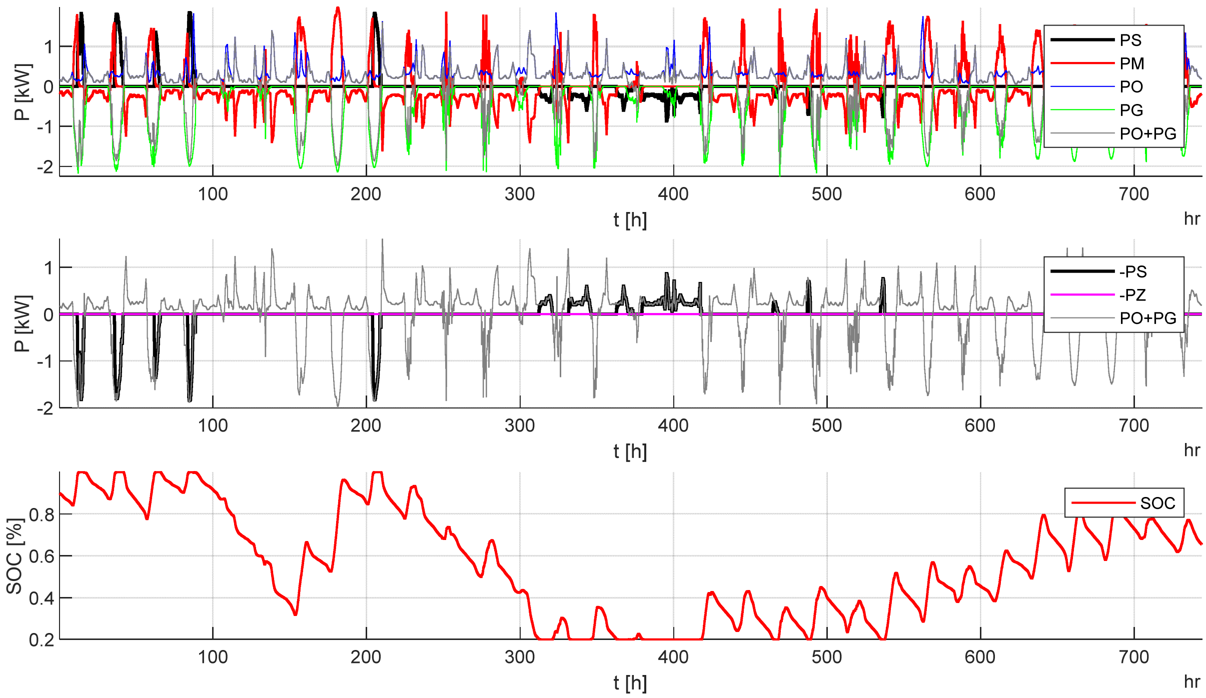

Fig. 4. Monthly power distribution analysis for October, where: P – power, t – time, PS - power exchanged with the power system; PM - power of energy storage; PO - demand power; PG - generated power; PO+PG - difference between demand power and generated power; SOC - state of charge of storage.

The next case analyzed was an energy storage with a smaller capacity, as 10 kWh and a power of 3 kW. Other parameters of the microgrid unchanged. The control objective was to equalize the power exchanged with the power system to zero. Fig. 5 shows power distributions for July, while Fig. 6 shows power distributions for October.

Observing the July waveforms (Fig. 5), we can see that, as for the larger capacity storage (Fig. 3), the control objective will not be met most of the time, which is due to the lack of available capacity for charging. On the other hand, the main difference we can see for the larger-capacity storage and the smaller-capacity storage is the depth of discharge. For the case study storage, the smaller one, the depth of discharge is much greater, as it reaches 0.6 full SOC. For the storage unit analyzed at the beginning, the depth was 0.85 SOC.

Turning to the power distributions for October (Fig. 6), we can see that the storage has a problem meeting the control objective. At high levels of generation, there is not enough available capacity to recharge, and at low levels of generation, there is not enough stored energy to cover demand power.

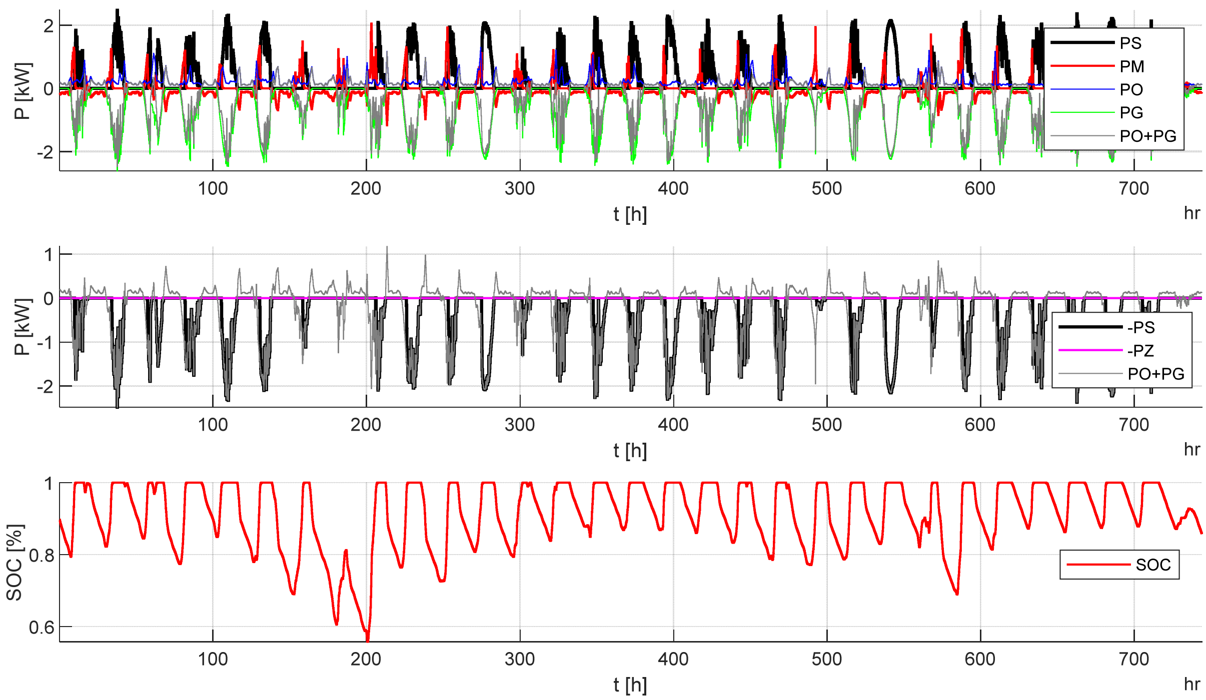

Fig. 5. Monthly power distribution analysis for July, where: P – power, t – time, PS - power exchanged with the power system; PM - power of energy storage; PO - demand power; PG - generated power; PO+PG - difference between demand power and generated power; SOC - state of charge of storage.

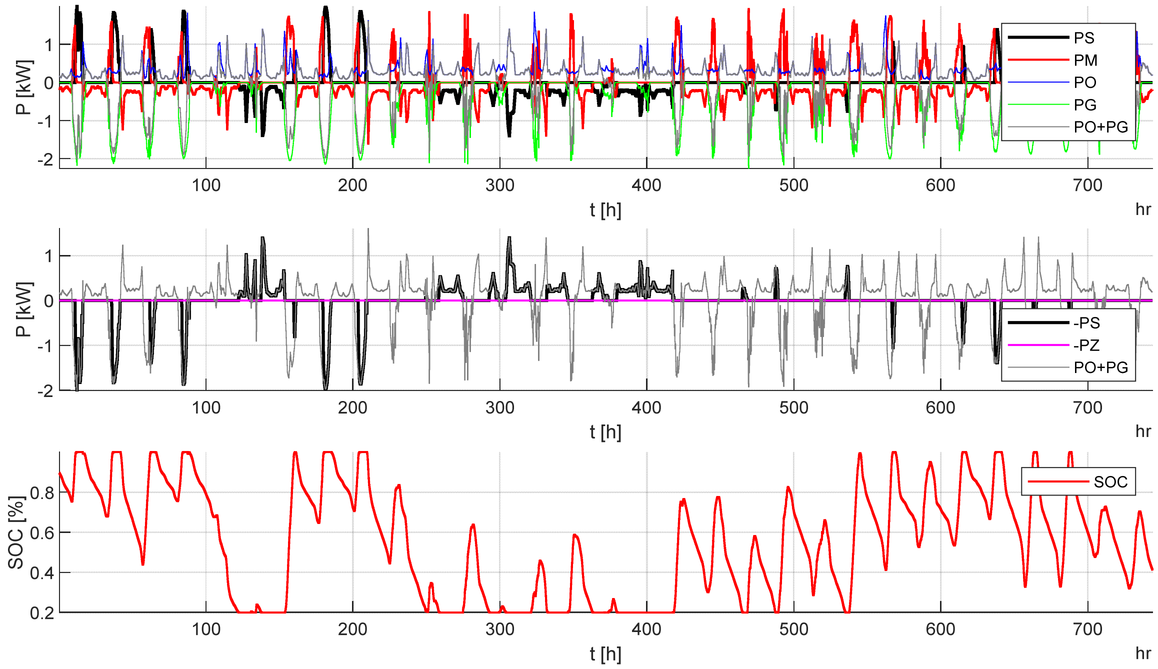

Fig. 6. Monthly power distribution analysis for October, where: P – power, t – time, PS - power exchanged with the power system; PM - power of energy storage; PO - demand power; PG - generated power; PO+PG - difference between demand power and generated power; SOC - state of charge of storage.

Conclusions

The article shows that the initial charge level of an energy storage SOC affects its operation. There are different ways to deal with the initial and final levels in the algorithms that control the operation of the storage. The most popular way involves keeping the initial and final SOCs at a constant level. However, this reduces the ability to control the storage system.

One-day analyses show only a small part of the microgrid's operation; therefore, the authors presented analyses for a month interval. Such analyses make it possible to observe the behavior of battery storage over a longer period.

Analyzing the obtained waveforms, it is possible to see how changing the size of the energy storage capacity affects its operation. However, exact values are strongly case specific.

When trying to limit the power exchanged with the power system to zero, for months when the level of generated power is high (such as July) regardless of the storage capacity, there is a problem with limiting the power fed to the grid. For different rated storage capacities, the depth of discharge differs, for a storage unit with a smaller capacity, the depth of discharge is greater. In months with lower levels of generated power, meeting the control objective depends on the storage capacity. Storage with a larger rated capacity copes well with the imposed constraints and the target is often met. In contrast, in the case of low-capacity storage, the control objective is virtually never met. This relationship stresses that storage with a larger capacity can obviously store more energy when there is an excess of production and then give back more energy when there is an undersupply.

The analysis carried out in the article is interesting not only because of the long-term, but also because of the control objectives. Although, it is a popular idea to allow island operation of microgrids, the article shows well how the size of the rated storage capacity, affects the operation of such a system.

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