

The Potential of Using a Small PV Battery System to Overcome Electricity Supply Disruptions

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Abstract. *The potential of using small PV battery systems to satisfy electricity demand during disruptions in the electricity supply is investigated in this paper. The analysis was done for the year 2023 which is characterized with more disruptions caused by extreme weather in Croatia. The day-ahead scheduling is done according to the hourly forecast data considering planned and potential interruptions. Evaluation of day-ahead scheduling is done through simulation according to hourly actual data considering all interruptions. According to results, the PV battery system is capable to meet electricity demand during 85% of the time in the cable power grid and during 83% of the time in the overhead power grid when the main grid is not available due to grid interruptions.*

Keywords. Disruptions, PV battery system, day-ahead scheduling, electricity demand, reliability indices

1 Introduction

Modern society is highly dependent on electricity, and even short electricity supply disruptions cause discomfort. In the first place, it is thermal discomfort due to lack of heating or cooling (Hachem-Vermette and Yadav, 2023). In addition, people are unable to charge phones, watch movies, or prepare dinner, which is the main willingness to pay, as it is not possible to objectively assess financial loss in households during disruptions in electricity supply (Carlsson et al., 2021). Extreme weather conditions, such as thunderstorms or strong winds, are the main cause of unplanned interruptions (Alpay et al., 2020). However, grid interruptions can often be planned to ensure a safe environment for electricians during regular electrical network maintenance (Crognier et al., 2021). The reliability of the distribution system is evaluated with the following index values (Chitumodhu and Pilly, 2024):

- System Average Interruption Frequency (SAIFI)
- System Average Interruption Duration (SAIDI)
- Customer Average Interruption Duration (CAIDI)
- Energy Not Supplied (ENS)

Existing solutions for electricity supply during interruptions are Uninterrupted Power Supplies (UPS) and backup generators. The drawbacks of the mentioned systems are the potentially high running and maintenance costs. Furthermore, the use of backup generators powered by fossil fuels is inconsistent with the decarbonization of the energy sector.

Researchers are focused on the implementation of carbon-free technologies to ensure electricity supply during interruptions. The electric vehicle (EV) can meet electricity demand during interruptions while ensuring enough battery capacity for the next day (Zhang et al., 2023). Vehicle-to-home (V2H) technology is suitable for providing backup power for 12 hours in mild climate conditions, the resilience depends on the start time of interruption and daily EV requirements (Liu et al., 2025). The island operation of grid-tied photovoltaic (PV) systems is not allowed in EU countries (Miao, 2024). On the other hand, the island operation of hybrid PV battery storage (BS) microgrids during grid interruptions is possible (Grant and Clark, 2024). There are practical cases of hybrid microgrid applications in Spain and Portugal. To meet a regulatory framework, physical disconnection of the microgrid from the main grid is required (Giorgi, 2025). The main advantages of hybrid PV battery systems are modularity that provides a better match with electricity demand and lower investment and running costs than with a backup generator (Chatterji et al., 2021). The contribution of this paper is summarized as follows:

- Generation of random interruptions through 50 different cases in cable and overhead power grid
- Each case represents one year with random frequency, durations and start times of interruptions
- Consideration of planned interruptions and extreme weather forecast in day-ahead scheduling
- Evaluation of day-ahead scheduling through simulation with consideration of all grid interruptions

This paper is organized as follows. In Section 2, a summary of the power reliability indices is given, while in Section 3, methodology and input data are described. In Section 4, results are presented and discussed, while the last section is the conclusion of the paper.

2 A Summary of the Power Reliability Indices in Croatia

The decrease in the SAIFI and SAIDI value in Croatia is noticeable between 2011 and 2022 (HEP-ODS, 2024). In 2011 the SAIFI was 4.84 and in 2022 it was 2.46, as can be seen in Fig. 1. The SAIDI was reduced from 9.32 h in 2011 to 4.31 h in 2022 as shown in Fig. 2. The power reliability indices are improved due to significant investments in power infrastructure.

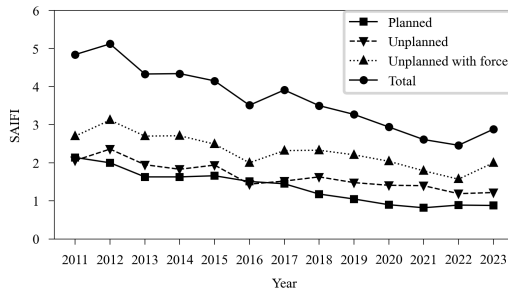


Figure 1. SAIFI in Croatia from 2011 to 2023

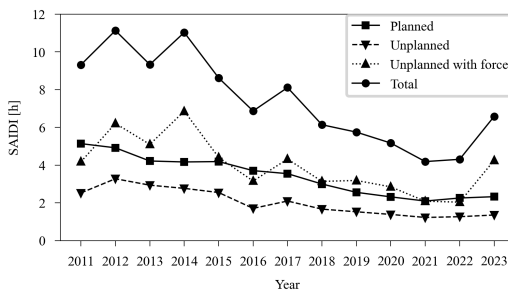


Figure 2. SAIDI in Croatia from 2011 to 2023

In 2023, the SAIFI value increased to 2.88, or 0.42 compared to the previous year. The SAIDI value is increased to 6.58 h in 2023 which is 2.27 h more than in 2022. The main reason for this increase was the strong storms during the summer of 2023. The damage to the infrastructure was significant and a long time was required to restore the power supply (HEP-ODS, 2024).

The general power reliability standard in Croatia (*Pravilnik o uvjetima kvalitete opskrbe električnom energijom*, 2022) defines 3 long interruptions per customer for the cable power grid and 6 long interruptions per customer for the overhead power grid. The duration of interruptions per customer is 400 minutes or 6.67 h during a year in the case of cable power grid and 700 minutes or 11.67 h during a year in the case of the overhead power grid.

The Croatian distribution system operator (HEP-ODS) is divided into 21 distribution areas. In 2023 the SAIFI standard for the cable power grid is not met in 2 while the SAIFI standard for the overhead power grid

is not met in 7 distribution areas according to Fig. 3. According to Fig. 4 in 2023 the SAIDI standard for the cable power grid is not met in 1 while the SAIDI standard for the overhead power grid is not met in 9 distribution areas (*Izveštaj o kvaliteti opskrbe za 2023. godinu*, 2024). It is expected as the cable power grid is protected from extreme weather conditions, unlike the overhead power grid.

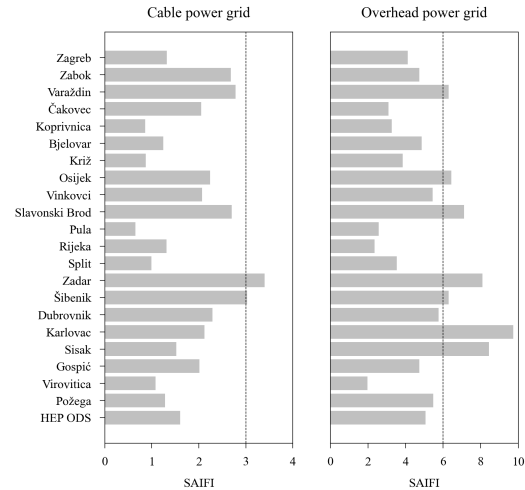


Figure 3. SAIFI for each distribution area in 2023

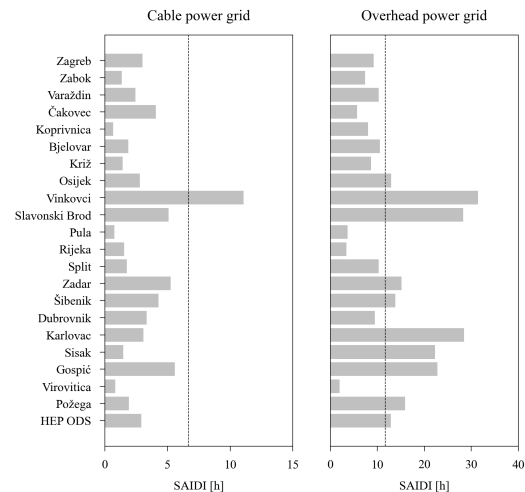


Figure 4. SAIDI for each distribution area in 2023

3 Methodology and Input Data

Although power reliability indices are improved over years, extreme weather conditions can lead to increase of power interruptions. PV battery systems can provide electricity supply even during grid interruptions, but day-ahead scheduling is required due to limited battery capacity. The flow chart of methodology applied in this work is presented in Fig. 5.

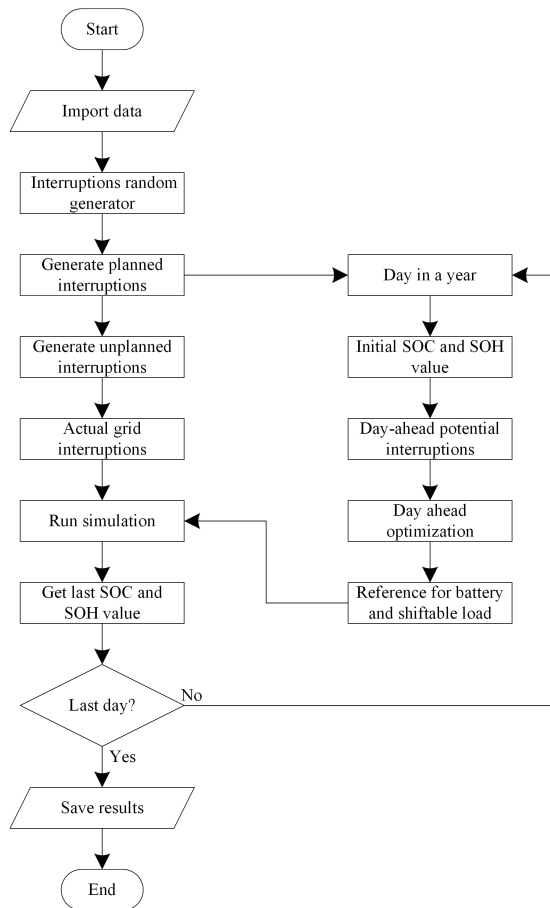


Figure 5. Flowchart of applied methodology

Input data required for simulation is weather and electricity consumption data while required input parameters are reliability indices for the subject distribution area and PV battery system parameters. First step is generation of random grid interruptions while satisfying average power reliability indices.

A day-ahead optimization is done with forecast weather and load hourly data with considered planned interruptions and possible interruptions due to extreme weather. Results of optimization are referent battery charging and discharging currents and start times of two time-shiftable appliances. Then simulation is done with actual weather and load hourly data with all interruptions considered. In normal operation battery is charging and discharging according to reference from day-ahead optimization. During grid interruption battery charging and discharging depends on the amount of electricity generation from PV system and power demand. Last battery state of charge (SoC) and battery state of health (SoH) values are initial SoC and SoH values for next day optimization. The algorithm is repeated for each day during a year and when last day is simulated, results for entire year are saved.

The methodology is applied to a household with a PV battery system located in continental part of Croatia in distribution area "Osijek".

3.1 Weather Data

The weather data is downloaded from Open-Meteo (Zippenfenig, 2023) open-source weather API for location Osijek with the coordinates 45.55°N, 18.69°E for year 2023. Two datasets are downloaded, the first is forecast weather data required for day-ahead planning and the second is actual weather data from satellite.

For the estimation of the electricity generation from the PV system solar irradiation and temperature data are required. Electricity consumption of air conditioning is estimated according to temperature data. Fig. 6 represents forecast and actual hourly solar irradiation data for one summer week while Fig. 7 represents forecast and actual hourly temperature data for the same summer week.

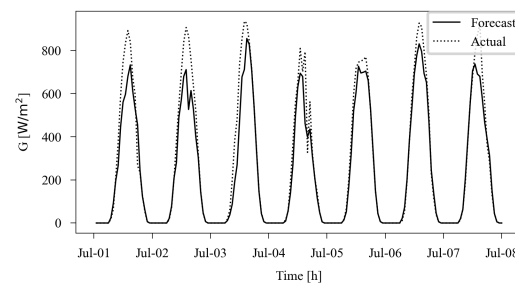


Figure 6. Forecast and actual hourly solar irradiation data from July 1 to July 7

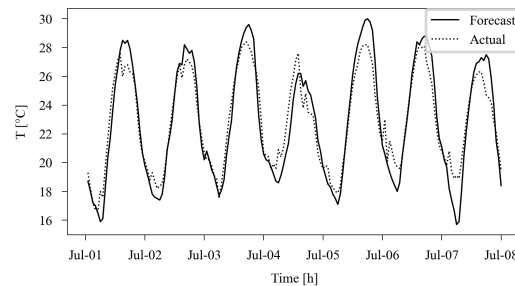


Figure 7. Forecast and actual hourly temperature data from July 1 to July 7

According to (Izveštaj o kvaliteti opskrbe za 2023. godinu, 2024) 39% of the unplanned interruptions in 2023 are associated with extreme weather conditions that can be predicted and included in day-ahead planning. Thunderstorms are predicted according to convective available potential energy (CAPE) day-ahead forecast while strong winds are predicted according to wind gusts day-ahead forecast. Fig. 8 represents day-ahead hourly forecast of CAPE and wind gusts during 2023. Hours with CAPE value above 1 kJ/kg and wind gusts above 40 km/h are considered as hours with potential grid interruptions in day-ahead planning.

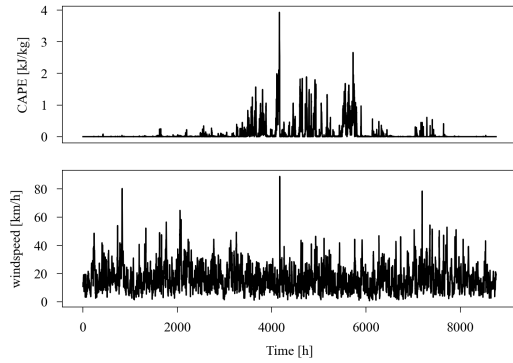


Figure 8. The forecast of CAPE and wind gusts for each hour during 2023

3.2 Electricity Consumption Data

Electricity consumption data is obtained from measured electricity consumption of separate appliances. Electricity consumption of different home appliances is measured with VOLTcraft SEM5000 energy meter with integrated data logger. In the continental part of Croatia, electricity is not dominant heating source for households and heating requirements are not included in estimation of electricity consumption. On the other hand, cooling requirements during summer are considered. Forecast and actual hourly electricity consumption during one summer week is presented in Fig. 9.

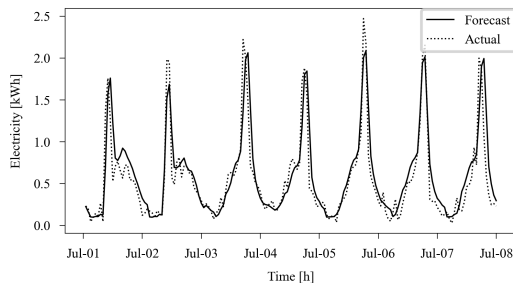


Figure 9. Forecast and actual hourly electricity consumption from July 1 to July 7

3.3 Distribution Area Reliability Indices

The total number of electricity customers at the end of 2022 in distribution area "Osijek" is 154 948. According to the type of grid interruption, SAIFI is 1.59 for planned and 2.69 for unplanned interruptions while SAIDI is 4.07 h for planned and 3.68 h for unplanned interruptions. CAIDI value is 2.56 h for planned and 1.37 h for unplanned interruptions. Reliability indices according to the type of power grid are presented in Table 1. Values for total interruptions for cable and overhead power grid are from (*Izveštaj o kvaliteti opskrbe za 2023. godinu*, 2024) and values according to grid and interruption type are estimated.

Table 1. Reliability indices according to grid type and interruption type in 2023

Type	SAIFI	SAIDI [h]	CAIDI [h]
Cable	2.24	2.8	1.25
Planned	0.83	1.47	1.97
Unplanned	1.41	1.33	0.94
Overhead	6.43	12.95	2.01
Planned	2.39	6.80	2.85
Unplanned	4.04	6.15	1.52

3.4 Small PV Battery System

A small PV battery system consists of 4 kW PV power plant and 5 kWh battery storage which are connected to electricity consumption and the main grid over the bidirectional power converter, as can be seen in the schematic diagram presented in Fig. 10. The main technical specifications of PV modules and battery, according to (Bluesun, 2025) and (Fuji, 2023), are presented in Table 2.

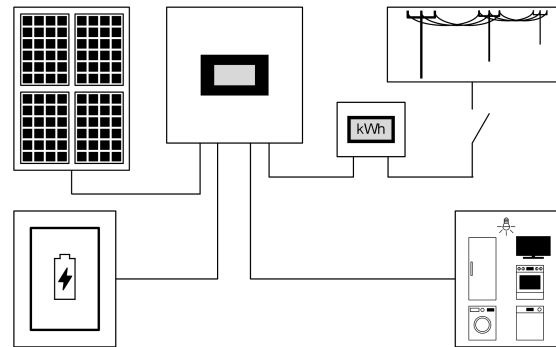


Figure 10. Schematic diagram of residential PV battery system

Table 2. Specifications of PV module and battery

PV module	
Technology	PERC
Rated power	500 W
Efficiency	0.213
Length	2.056 m
Width	1.140 m
NOCT	42.3 °C
Temp. coeff.	0.34 %/°C
Battery	
Technology	LiFePO ₄
Rated capacity	100 Ah
Rated voltage	51.2 V
Max. DoD	80%
Max. current	60 A
Cycle life (0.2C)	6000
Cycle efficiency	0.92

4 Results

In this section results are presented for cable and overhead power grid. The number of interruptions is conditioned with SAIFI values according to the grid and interruption type in Table 1. The average durations are conditioned with the CAIDI values in Table 1. The hours in which interruptions occur depend on the type of interruption. Planned interruptions are limited to workdays, without rain and strong winds, and to work time between 08:00 and 15:00. The start times of unplanned interruptions associated with extreme weather conditions are defined based on events with reported damage to the electrical network, while the start times of other unplanned interruptions are random.

4.1 Results for cable power grid

The grid interruptions for 50 cases are generated and presented in Fig. 11. The total duration of all grid interruptions is 132 h and divided by 50 gives 2.64 h per case. The duration of planned and unplanned interruptions is 66 h total or 1.32 h per case. These values are similar to the SAIDI values in Table 1.

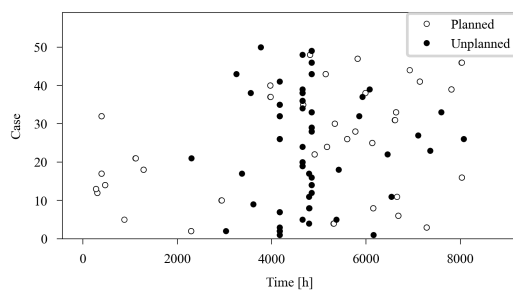


Figure 11. Occurrence of planned and unplanned interruptions in cable power grid

The capability of a PV battery to meet demand during interruptions is shown in Fig. 12. During planned interruptions, electricity demand is covered in all cases, which is expected as planned interruptions are considered in the day-ahead optimization.

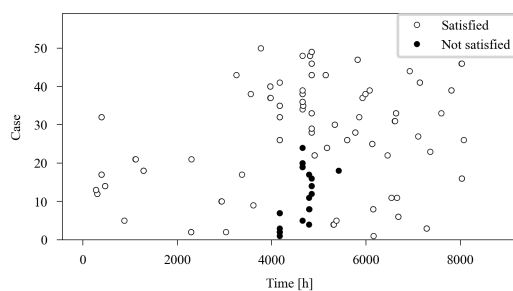


Figure 12. The capability of PV battery system to satisfy electricity demand during interruptions in cable power grid

However, during unplanned interruptions, the electrical supply from the PV battery is provided for 46 h or 70% of time when the main grid is not available due to unplanned interruptions. During all interruptions, the PV battery can meet the electricity demand for 112 h or 85% of the total time without the main grid. In a single case, the demand requirements are satisfied during 2.24 h from 2.64 h without the main grid.

4.2 Results for overhead power grid

The occurrence of planned and unplanned grid interruptions is shown in Fig. 13. The total duration of all interruptions is 640 h. When this total time is divided by 50, it is 12.8 h in a single case. The duration of planned interruptions is 335 h or 6.7 h in a single case, while the duration of unplanned interruptions is 305 h or 6.1 h in a single case. The values obtained are close to the SAIDI values in Table 1.

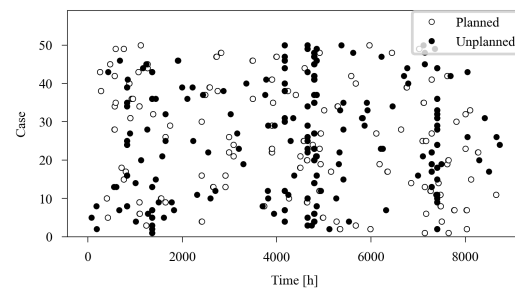


Figure 13. Occurrence of planned and unplanned interruptions in overhead power grid

The capability of a PV battery to provide electrical supply during grid interruptions is presented in Fig. 14. Demand requirements are met during all planned interruptions as expected. However, during unplanned interruptions, electricity demand is satisfied for 198 h or 65% of time without the main grid. During all interruptions, the demand requirements can be met for 533 h or 83% of time without the main grid. In a single case, the PV battery is capable of satisfying demand during 10.66 h from 12.8 h without the main grid.

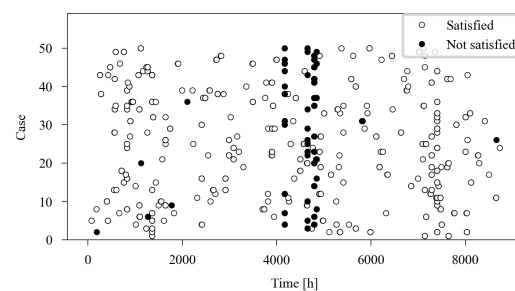


Figure 14. The capability of PV battery system to satisfy electricity demand during interruptions in overhead power grid

5 Conclusion

The PV battery has great potential to overcome electricity supply disruptions. The day-ahead planning is necessary to ensure electricity supply even when the main grid is not available during grid interruptions. Planned interruptions can be included in day-ahead planning, as well as potential disruptions associated with extreme weather conditions.

The results show that the PV battery is capable of satisfying the demand for electricity during all planned interruptions, while during unplanned interruptions, the demand for electricity is satisfied for 70% of the time in the cable power grid and 65% of the time in the overhead power grid. Most unplanned interruptions when demand is not satisfied occur in summer during thunderstorms. Although thunderstorms are considered in day-ahead planning, interruptions occur in the afternoon when the electricity demand in households usually increases and due to limited battery current and capacity, demand is not satisfied.

To ensure more electricity supply during interruptions, the increase of battery capacity and implementation of demand response should be considered in future work. There is also a potential for using EVs during grid interruptions through V2H concept due to the large available battery capacity in EVs.

Acknowledgments

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