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RESEARCH ARTICLE

Analyzing Peak Clipping for Load Factor Improvement: Real Case Studies of a Solar Power Plant in a University Campus

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ABSTRACT

The increasing demand for sustainable energy solutions has sparked a growing interest in solar power plants (SPPs) as a viable option for reducing reliance on conventional energy sources. With the integration of SPP, the potential arises for a decrease in grid dependency during the day and improved stability in demand-side load profiles. To enhance the contribution of SPP toward sustainable energy solutions, it is crucial to explore effective load management strategies, including peak clipping. This paper investigates peak clipping as one of the demand-side management (DSM) techniques facilitated by SPP. The objective of this study is to provide comprehensive insights into the practical application of peak clipping techniques and their impact on improving the load factor (LF). To achieve this objective, the analysis in this study utilizes real data derived from an operational SPP located in the central campus of Manisa Celal Bayar University. To evaluate the impact of SPP on peak clipping and LF, a series of diverse case studies which encompass a range of campus scenarios are undertaken. The aim is to thoroughly analyze and understand how SPP systems affect peak clipping and LF under different circumstances. The analysis reveals significant improvements in LF resulting from the integration of the SPP, ranging from 1.04% to 10.62%. Results show that transition to online education and reduced campus population positively impacted LF during coronavirus disease 2019 compared to pre-pandemic times. These findings align with the dynamics of the campus lifestyle and underscore the favorable effects of these factors on LF.

Index Terms—Demand-side management, load factor improving, peak clipping, solar power plant, university campus

I. INTRODUCTION

A noticeable change in the climate and global warming are dragging societies into new practices and technologies. From the standpoint of power systems, the rapid growth in demand is accompanied by a parallel increase in the installed capacity of power generation. The trend toward renewable energy sources (RESs) instead of emission-emitting sources is one of these practices [1].

The concept of "prosumer" (*pro*ducer and con*sumer*) has emerged from small-scale renewable energy generation systems, as consumers are both in the position of supplying and consuming energy to the grid. These changes in the grid structure have further increased the interest in innovative applications called demand-side management (DSM) in power systems [2]. The DSM is defined by the Electric Power Research Institute as the planning, implementation, and monitoring of utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape, that is, time pattern and magnitude of a utility's load [3].

As technology improves, the transition from the traditional grid to the smart grid is also happening faster [4]. Depending on the increase in population and mass production demand in the industry, it may be necessary to run new electricity generation plants in order to meet consumer demand. However, supply–demand balance can also be achieved by performing DSM programs. Thanks to these programs, it is possible to reduce technical losses in the networks, regulate consumption at peak hours, and ensure energy efficiency. In this regard, the DSM for utilities can also be referred to as programs that ensure a balance between the consumers' demand and the generation capacity of the power system [5, 6].

Improving the load factor (LF) directly impacts the efficient utilization of energy resources, reduction of peak demand, and overall enhancement of system efficiency. This objective can be accomplished through the coordinated deployment of solar power plants (SPPs) and DSM techniques. Examining a concentrated analysis on peak clipping, within the specific context of their interplay with SPPs

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allows for the exploration of strategies to improve the LF and optimize energy consumption across various settings. By identifying and implementing effective peak clipping measures, energy-intensive facilities can better manage their energy demand, reduce peak demand, and enhance the sustainability of their operations.

When comparing the contributions of load shifting and peak clipping methods to overall energy production costs, it has been noted that the peak clipping method yields the highest benefit [7]. Conversely, in terms of the hourly electricity tariff, the load-shifting technique has been found to be more advantageous [8]. In [9], a novel methodology for load shifting in residential, commercial, and industrial settings was proposed. Additionally, [10] highlights that integrating Battery Energy Storage Systems (BESSs) with photovoltaic (PV) power increases the effectiveness of peak clipping. Furthermore, a grid condition monitoring and control algorithm was developed in [11] to manage peak loads and ensure a balanced supply–demand in a didactic smart grid system incorporating a scaled BESS. The algorithm implemented in the study enables the activation of the BESS connection to the grid based on multiple factors, including the system's peak load, the demand from the distribution system operator, and the prevailing energy unit price during peak demand periods. The investigation on how peak clipping can be effectively carried out using BESS, considering various consumption scenarios in residential areas, was conducted in [12]. In the study conducted in [13], a smart energy consumption management system is proposed to optimize energy consumption while minimizing consumer interaction. This system takes into account various factors such as consumers' preferences, grid stability, and implementation costs. The results show that the proposed approach leads to a significant reduction of 25.6% in electricity costs and a 45% decrease in the deviation of consumers' load profile. Furthermore, in [14], a comprehensive approach integrating energy management and energy trading strategies is proposed for minimizing the peak-to-average power ratio, peak load demand, and monthly energy expenditures in a distribution system that includes microgrids. The proposed strategies consider uncertainties such as the human interaction factor and consumer preferences. These findings highlight the effectiveness of the proposed approaches in enhancing energy efficiency and reducing operational costs within complex energy systems.

The renewable hybrid energy system including wind and solar energy in Dharan city was analyzed in terms of load shifting and peak clipping [15]. Peak clipping and load shifting techniques were applied by classifying the loads on the campus of Alagappa Chettiar State University of Engineering and Technology in India. As a result of the applied techniques, daily and monthly LF improvements were achieved, and its economic contribution was examined [16]. In the study at Motilal Nehru National Institute of Technology Allahabad University, a new algorithm was performed to shift the load profiles of the sections of the campus from peak hours to off-peak hours with the load-shifting technique [17]. In [18], a study was conducted to examine the effect of a grid-connected roof-type PV system on peak clipping that feeds the Andalas University Engineering Faculty in Indonesia and five separate buildings that are electrically connected to it.

Main Points

- The significance of effective load management strategies, particularly peak clipping, as a demand-side management (DSM) technique utilized by solar power plants (SPPs), is emphasized.
- Case studies are selected from real-life scenarios that occurred on the university campus to ensure the study's authenticity.
- The SPP's impact on load factor (LF) improvement is analyzed using real data from the SPP and energy consumption data on the university campus.
- Peak clipping performed by the SPP enhanced LF improvement by up to 10.62%.

The renewable hybrid energy system in Dharan city was analyzed with a focus on load shifting and peak clipping techniques [15]. Similarly, load shifting and peak clipping methods were applied to classify the loads on the campus of Alagappa Chettiar State University of Engineering and Technology in India [16]. At Motilal Nehru National Institute of Technology Allahabad University, a novel algorithm was developed to enable load shifting of specific sections within the campus from peak to off-peak hours [17]. Furthermore, in [18], an investigation was conducted to assess the impact of a grid-connected roof-type PV system on peak clipping. The PV system provided power to the Engineering Faculty of Andalas University in Indonesia, along with five separate buildings connected to it. The study aimed to evaluate the effectiveness of the PV system in reducing peak loads. These studies contribute to the understanding of load shifting and peak clipping techniques in different contexts, such as renewable energy systems, university campuses, and grid-connected PV installations. The findings shed light on the potential benefits of these techniques in improving LF and optimizing energy consumption.

In this paper, roof-type SPP of the Manisa Celal Bayar University (MCBU) Engineering Faculty with a capacity of 334.8 kWp data are collected, and demand data of the central campus of the MCBU are analyzed with different scenarios in terms of peak clipping and LF improvement. Through the investigation of these scenarios, our aim is to gain valuable insights into the operational efficiency of the SPP and optimizing LF within the campus environment. This paper offers three main contributions: (i) an analysis of the university campus, utilizing a comparison of real-generation and consumption data spanning a period of 3 years to assess the impact of peak clipping and LF improvement, (ii) an investigation into the consumption patterns of MCBU under various campus life scenarios, providing insights into the effects on energy usage, and (iii) the inclusion of real case studies, providing a practical and in-depth analysis of the subject matter. These contributions collectively enhance our understanding of the dynamics of energy consumption and highlight the significance of peak clipping and LF improvement strategies in optimizing energy management within the university campus.

The organization of the remaining part of the study is as follows: Section II provides the theoretical background of DSM. In Section III, the methodology for data acquisition is described. Section IV presents a detailed analysis of the collected data. The paper concludes

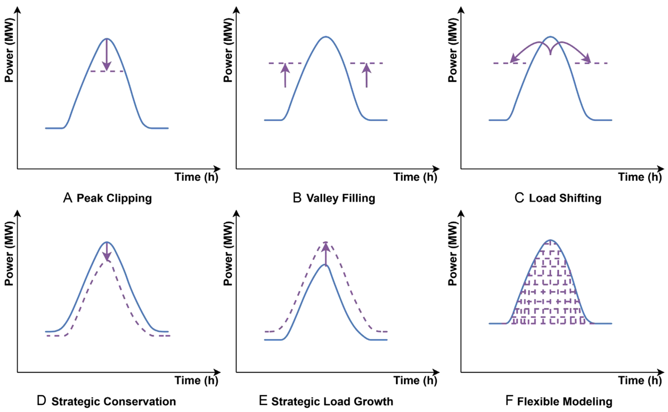

Fig. 1. DSM methods. DSM, demand-side management.

with Section V, which includes the concluding remarks, and Section VI outlines future research.

II. THEORETICAL BACKGROUND

The DSM has six different techniques including peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible modelling as illustrated in Fig. 1 [4]. Peak clipping is one of the DSM techniques that help to reduce demand load during peak hours. The objective of this technique is to improve the LF by reducing the peak load. It plays a key role in the energy unit cost per kWh. From the view of the system operator, energy is used more efficiently as the LF is close to 1. The LF is an expression of how much energy is used in a time period. The general expression of LF is given in (1-3).

$$LF\% = \frac{Average\,Load}{Maximum(Peak)Load} \times 100 \tag{1}$$

$$Daily\,LF\% = \frac{Energy\,consumed\,during\,24\text{hr}}{Maximum(peak)load \times 24\text{hr}} \times 100 \tag{2}$$

$$Annual\,LF\% = \frac{Total\,annual\,energy}{Maximum(peak)load \times 8760\text{hr}} \times 100 \tag{3}$$

The daily generation and consumption curves illustrate the variations in electricity demand and generation within an energy system on a minute or hourly basis throughout the day. The averages of time intervals (hourly) on different days are calculated using the following equations.

$$Avg_{geni,t} = \frac{1}{N} \times \sum_{k=1}^{N} P_{geni,k,t} \tag{4}$$

$$Avg_{loadi,t} = \frac{1}{N} \times \sum_{k=1}^{N} P_{loadi,k,t} \tag{5}$$

where

i = month, k = day, t = hour.

III. METHODOLOGY

The methodology employed in this study aims to investigate the impact of SPP systems on peak clipping and LF improvement. Peak clipping refers to the reduction or mitigation of high-demand periods in electricity consumption by utilizing additional sources such as RES and energy storage systems. By reducing peak demand on the load profile, the maximum and average power values are expected to meet, resulting in increased LF and more efficient resource utilization; thus, it contributes to reducing costs by preventing the installation of new generation plants. This section provides a comprehensive overview of the approach employed to examine and measure the impact of SPP systems on peak clipping and their overall contribution to improving LF through the process of data acquisition and analysis. This study incorporates data acquisition through the collection of power generation and consumption patterns using monitoring systems, which will be further discussed in the following section. The analysis, as detailed in Part IV, involves a comparison of these data, with a particular emphasis on campus-specific cases given in Fig. 2. Furthermore, the electrical infrastructure of the MCBU Campus will also be presented in the following section.

A. Case Study Area: Manisa Celal Bayar University Campus

The MCBU runs its educational activities on three campuses in the city center and 17 vocational school campuses in other districts. Currently, MCBU continues its educational and research activities with a total of 68 units, including 15 faculties, 2 colleges, 15 vocational schools, 3 institutes, 32 research centers, and 1 research and application hospital. The university has 1911 academicians, 2313 administrative staff, and 40 026 students [19]. This study considers MCBU Ilhan Varank Campus, located at 38.68° N latitude and 27.30° E longitude because the SPP is administered there and nearly 44% of the total student population attends classes on the campus. Fig. 3 depicts a general view of the campus. On the campus, a total

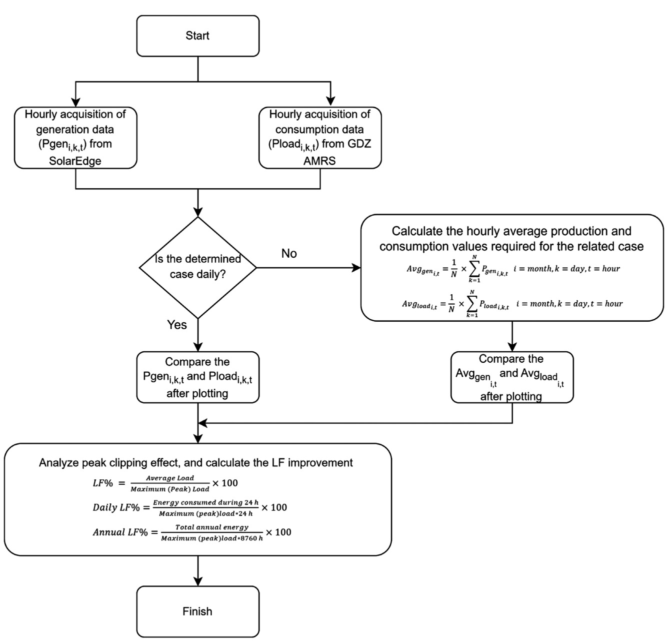

Fig. 2. Flowchart of the system.

Fig. 3. MCBU Ilhan Varank Campus. MCBU, Manisa Celal Bayar University.

of 14 different buildings are located. Hence, the power network of this campus consists of 14 distribution transformers and the SPP. Electrical energy is transmitted by using underground power lines at 33 kV and then reduced by a step-down transformer to 0.4 kV. The one-line diagram of the power system is given in Fig. 4. The power ratings of the transformers and the load feeder names are given in Table I. The total installed capacity is 11.59 MVA.

B. Solar Power Plant in the Campus

In order to provide some of the electrical energy consumption of the campus, a 334.8 kWp SPP was installed as a roof type, as shown in Fig. 5. The SPP consists of 11 inverters and 1240 PV panels. The power rating of each PV panel is 270 Wp. The power ratings of the inverters are 27.8 kW (10 units) and 10 kW (1 unit), respectively.

C. Data Collection and Energy Monitoring System

1) Consumption Data

GDZ Electricity Distribution Inc. is one of the distribution companies in Turkey. The company serves a total of 5.8 million people in the region. Approximately 40 000 energy meters, including high-consumption customer meters, are connected to the licensed and unlicensed distribution network through the companies' Automatic Meter Reading System (AMRS). Consumption and profile values of all energy meters within the distribution region are transferred to the system and read remotely. The considered data are obtained by using the AMRS system. The AMRS web monitoring panel is shown in Fig. 6.

2) The Solar Power Plant Data

The SPP generation data are obtained using the SolarEdge cloud-based monitoring system. The monitoring panel is shown in Fig. 7.

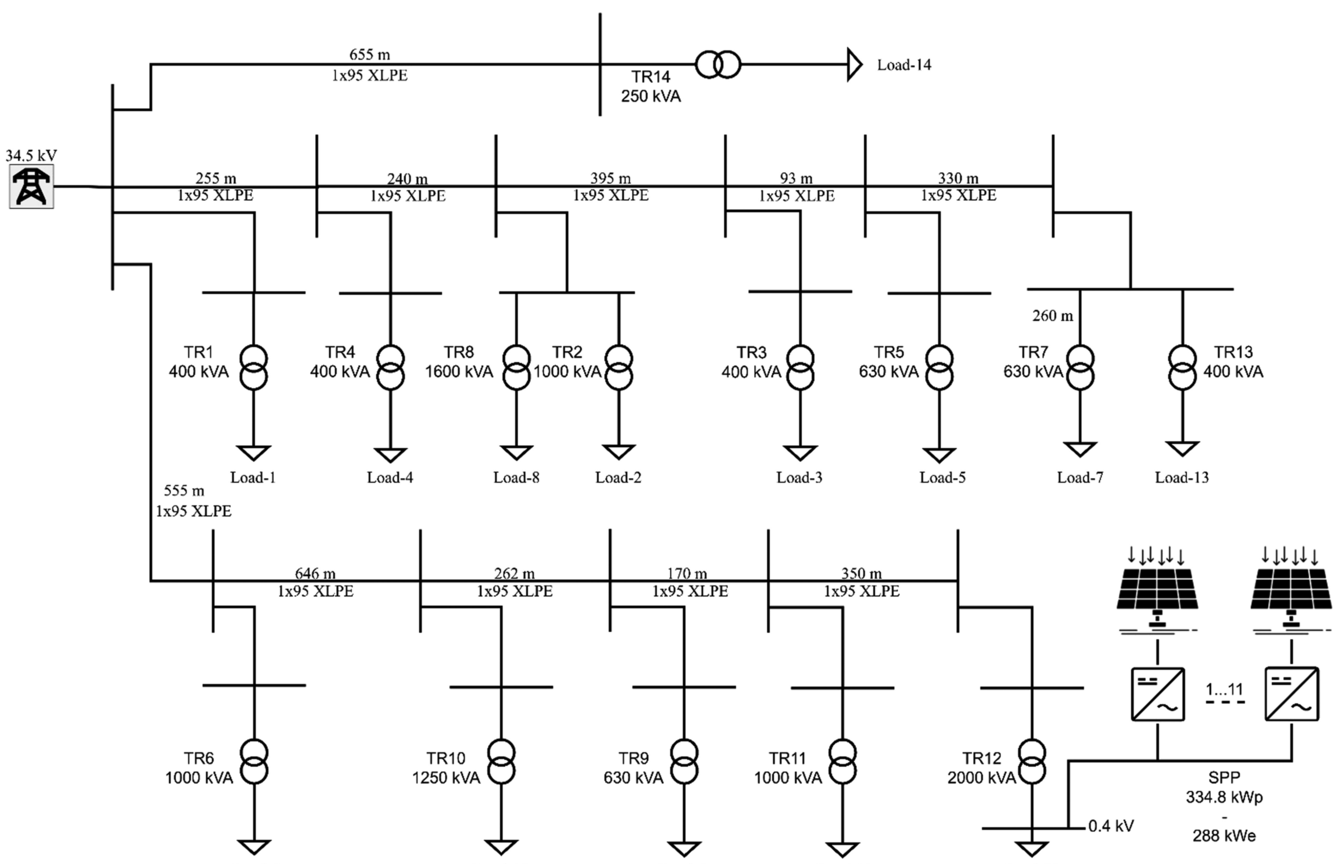

Fig. 4. One-line diagram of the power system for the MCBU Campus. MCBU, Manisa Celal Bayar University.

TABLE I.
THE POWER RATINGS OF THE TRANSFORMERS AND THE LOAD FEEDER NAMES

Transformer No	Apparent Power [kVA]	Load No	Load Feeder Name
TR1	400	1	Outdoor sport complex
TR2	1000	2	Dining hall
TR3	400	3	Faculty of Arts and Sciences
TR4	400	4	Faculty of Management
TR5	630	5	Auditorium
TR6	1000	6	Indoor sport complex
TR7	630	7	Research center
TR8	1600	8	Administrative building
TR9	630	9	Cafeteria
TR10	1250	10	Dormitory
TR11	1000	11	Faculty of Economics
TR12	2000	12*	Faculty of Engineering
TR13	400	13	Treatment plant
TR14	250	14	Institute of Science
Installed capacity	11590		

*Solar power plant is connected to load bus 12.

IV. ANALYSIS OF CASE STUDIES

The load profiles of the campus change periodically based on the activities such as examination days and holidays. The SPP generation and the total consumption of the campus data are obtained between June 2019 and January 2022 over the SolarEdge monitoring system and the AMRS portal, respectively. Considering load profiles, five different cases are defined to analyze the peak clipping effect of the SPP as follows. In this system, “the main bus load” data are measured by using a smart meter at the point of common coupling (PCC) which is shown in Fig. 3. Additionally, “the main bus load with SPP” data show the overall consumption of the campus, whereas “the main bus load without SPP” data indicate the amount of demand at PCC.

Fig. 5. The solar power plant on the engineering faculty of the MCBU Campus. MCBU, Manisa Celal Bayar University.

Case 1: Before and during the pandemic,
Case 2: Weekdays and weekends effect,
Case 3: Sunny and cloudy days effect,
Case 4: Holidays and learning periods, and
Case 5: Special activity periods.

In the first case, data from 2019 to 2020 are considered to assess the impact during the pandemic. In the second case, SPP generation and consumption data on the weekdays and weekends are evaluated separately during the summer and winter seasons. In the third case, the effects of sunny and cloudy days are studied. In the fourth case, the difference between power generation and consumption data is calculated as a monthly average considering holidays, face-to-face learning, and final examinations days. Finally, the load demand for graduation days is investigated. The cases and LF improvement details are given in Table II and III, respectively.

A. Case 1: The Pandemic Effect

In this case, the power generation and consumption data at the campus are investigated to observe the impact during coronavirus disease 2019 (COVID-19). To see the effect of the COVID-19 pandemic on the load demand change, the years 2019 and 2020 are considered. In 2019, data collection was launched in June.

Therefore, before the pandemic, only 7 months of data are available, and the total consumption in this time interval was 863.18 kWh, while it decreased to 589.86 kWh during the pandemic, as shown in Fig. 8. It can be observed that the average consumption decreased by 31.6% during the pandemic. The maximum demand was 1298.13 kW before the pandemic and 937.75 kW during the pandemic. The maximum generation from SPP was over 200 kW. The contribution of SPP to LF improvement during the pandemic period is approximately 2% more than before the pandemic. This is due to the decrease in consumption during the pandemic period because of online education.

B. Case 2: Weekdays and Weekend Effect

Due to the student activities, weekday and weekend load profiles are different. Hence, as shown in Table II, a specific week during the summer and winter was selected for the study. The analysis of the weekdays and weekends effects is depicted in Fig. 9. For the winter season, the average consumption was 998.039 kW on weekdays and 710 kW on weekends. Based on these values, there is a difference of 29% between weekdays and weekends. Also, the average generation of the SPP was 35 kW on weekdays and 33 kW on weekends in the selected period. The peak clipping effect of the SPP is not observed for the considered time interval because of the very low generation of energy.

However, in July, the average consumption during the weekdays was 968.62 kW, which is gradually lower than in the selected winter week. This is because the students are generally on holiday in July.

Fig. 6. Data collecting and monitoring system of the GDZ Electricity Distribution.

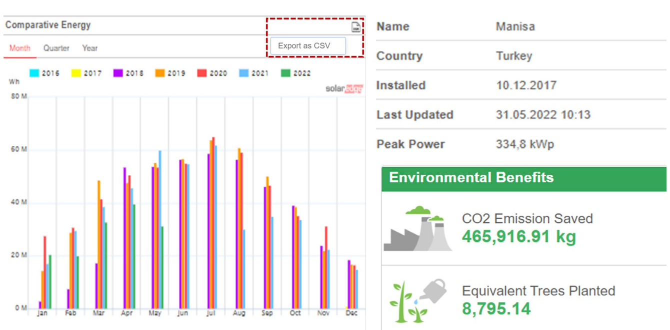

Fig. 7. View of the SPP data collecting and monitoring system. SPP, solar power plant.

The average consumption was 742.6 kW on the weekends. The rate of consumption decreased on the weekends by 23.3%. Hence, the LF improvement during the summer season weekends was 4.5% more than on weekdays.

C. Case 3: Sunny and Cloudy Days

In this case, the contribution of the SPP to the peak clipping effect and LF improvement is analyzed according to the power generation and consumption data on sunny and cloudy days. On a sunny day, the maximum power generated was 260.8 kW. The peak clipping effect of the system was also realized at 253 kW, as seen in Fig. 10. As expected, the SPP contributed more to the LF on a sunny day than on a cloudy day.

D. Case 4 Holidays and Education Periods

In order to examine the effect of the population on the power consumption on the campus, three different periods were determined: the holidays, learning, and final examination days. Since the holiday period covers the summer season, the PV system power generation was higher than in other periods. However, the total consumption during the final examinations is higher than during the holiday period due to the high population.

When evaluated in terms of peak clipping, the most noticeable clipping effect is seen during the holidays, and the lowest is during the final examinations. The contribution of the PV system to the improvement of LF during the holiday period and the learning period are 3.61% and 3.46%, respectively. In the final examination period, the LF improved by 1.66% due to the low production of the PV system and the higher consumption compared to other periods. In Fig. 11, the average hourly production-consumption profile for the three periods is given.

E. Case 5: Special Activities

For case 5, graduation week is compared with the previous week. As shown in Fig. 12, the maximum power of the SPP was nearly 200 kW at noon for the 2 weeks. The load demand changes between a normal routine week and a graduation week. While 683.6 kW was the average consumption and 812.34 kW maximum in the normal routine week, during graduation days, the average and maximum consumptions were 954.6 kW and 1399.5 kW, respectively. There was a 28% difference between the 2 weeks. It was also observed

TABLE II.
THE DETAILS OF THE CASES

Case No	Case Explanation	Time Interval: Years	Months	Weeks	Days	Period
1	Before pandemic	2019	Jun–Jul–Aug–Sep–Oct–Nov–Dec	All	All	Monthly
	During pandemic	2020				
2	Weekdays	2019	July	W27	All	Weekly
	Weekends	2019	December	W49		
3	Sunny day	2021	June	W25	21 Jun	Daily
	Cloudy day	2021	December	W50	19 Dec	
4	Holiday period	2021	Aug–Sep	W31-37	All	Monthly
	Learning period	2021	Oct–Nov–Dec	W38-52	all	
	Examination period	2022	January	W1-2	all	
5	Routine week	2021	July	W29	All	Weekly
	Special activities (graduation)	2021	July	W30	All	

that the LF improved by 10.30% during the routine week and 5.68% during the graduation week.

V. RESULTS AND DISCUSSION

In the first case, which specifically focuses on the years 2019 and 2020, our objective is to evaluate the impact of the COVID-19 pandemic on changes in load demand. These years are chosen as the reference period to gather data on generation and consumption patterns. Prior to the pandemic, the peak demand reached 1298.13 kW, whereas during the pandemic, it decreased to 937.75 kW. Conversely, the generation from the SPP remained relatively stable, with maximum values exceeding 200 kW in both periods, particularly in July. Based on these findings, it can be inferred that the SPP contributed to a LF improvement of approximately 2% higher during the pandemic period compared to the pre-pandemic period.

TABLE III.
LF IMPROVEMENT DETAILS FOR THE CASES

No	Case Explanation	Average Power [kW]			Peak Power [kW]			Load Factor [%]		
		With SPP	Without SPP	SPP	With SPP	Without SPP	SPP	With SPP	Without SPP	LF Improving
1	Before pandemic	863.18	804.59	58.59	1298.13	1265.25	249.12	66.49%	61.98%	4.51%
	During pandemic	589.96	531.27	58.68	937.75	700.23	250.244	62.92%	56.65%	6.25%
2	Weekday—summer	968.62	898.36	70.26	1537.13	1311.00	240.40	63.02%	58.44%	4.57%
	Weekend—summer	742.60	668.70	73.90	815.60	814.20	242.20	91.05%	81.98%	9.06%
3	Sunny day	602.60	514.39	88.20	830.30	598.90	260.80	72.57%	61.95%	10.62%
	Cloudy day	659.60	655.50	8.10	775.60	775.60	25.20	85.04%	84.51%	1.04%
4	Holiday period	859.18	819.15	40.03	1107.00	999.10	132.50	77.61%	73.99%	3.61%
	Education period	760.10	726.10	34.10	983.20	874.20	138.70	77.31%	73.85%	3.46%
	Exam period	820.00	800.10	19.10	1153.00	1132.10	87.70	71.12%	69.39%	1.66%
5	Routine week	683.60	599.90	83.70	812.34	775.50	263.20	84.15%	73.85%	10.30%
	Special activities (graduation)	954.60	875.10	79.60	1399.50	1178.50	252.60	68.21%	62.52%	5.68%

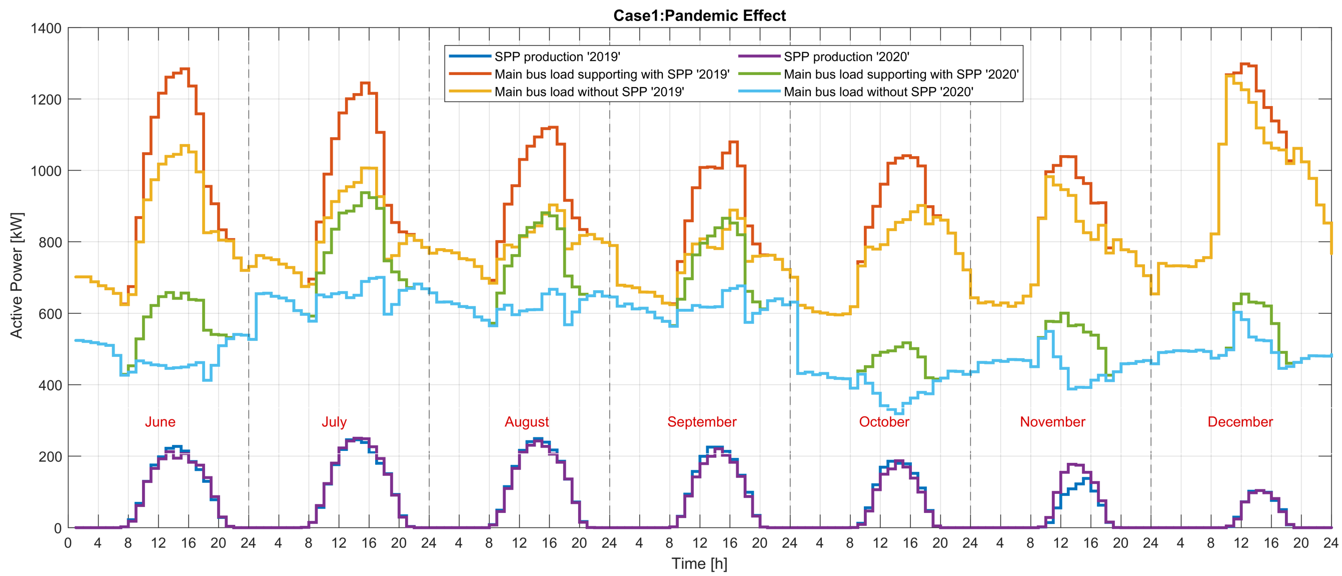

Fig. 8. Case 1: the pandemic effect.

Case 2 focuses on investigating the difference between weekday and weekend periods in terms of energy consumption. The analysis demonstrates significant variations in the overall campus consumption between weekdays and weekends, as illustrated in Fig. 9. Specifically, during both winter and summer seasons, the campus experiences higher consumption levels on weekdays compared to weekends. In the winter season, there is a notable 29% difference in consumption between weekdays and weekends. Conversely, during the summer season, when the selected period coincides with the closure of the academic year, the campus consumption values exhibit minimal deviation from those observed in the winter season. Furthermore, when comparing the generation and consumption values between weekdays and weekends and evaluating the SPP contribution to LF improvement, it becomes evident that LF improves by an additional 4.5% on weekends compared to weekdays. This disparity can be attributed to the differential change observed in consumption values compared to generation values.

In case 3, the analysis focuses on power generation and consumption data during sunny and cloudy days. On a sunny day, the SPP achieves a maximum power generation of 260.8 kW. As expected, the SPP exhibits a significant contribution to LF improvement on sunny days.

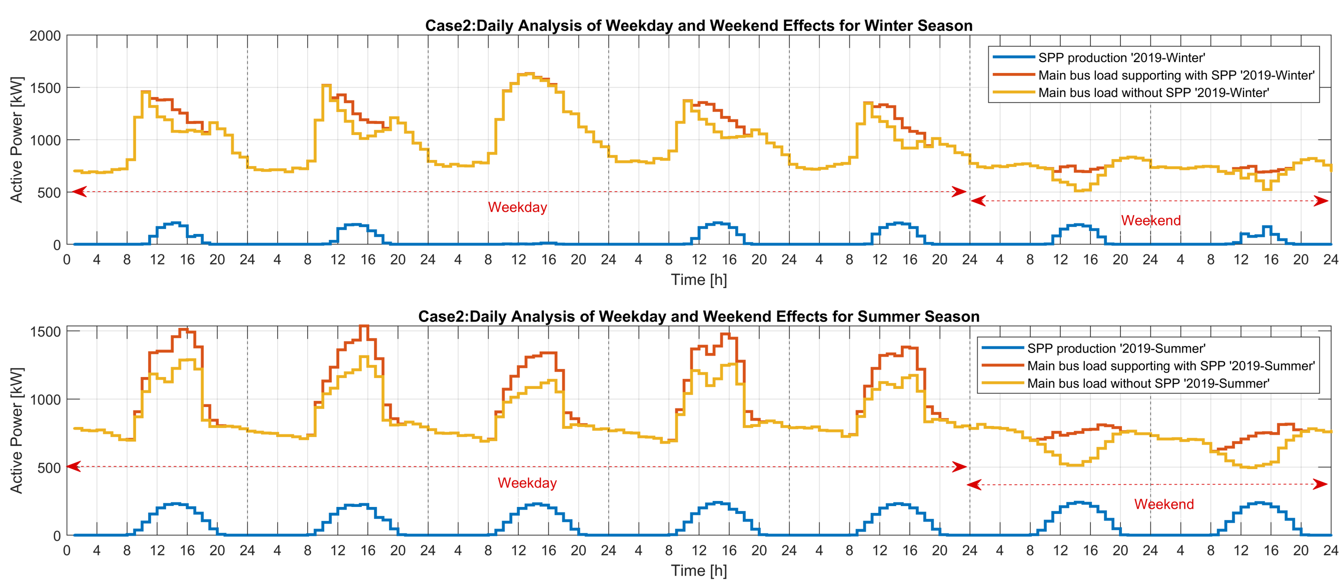

Fig. 9. Case 2: weekdays and weekend effect.

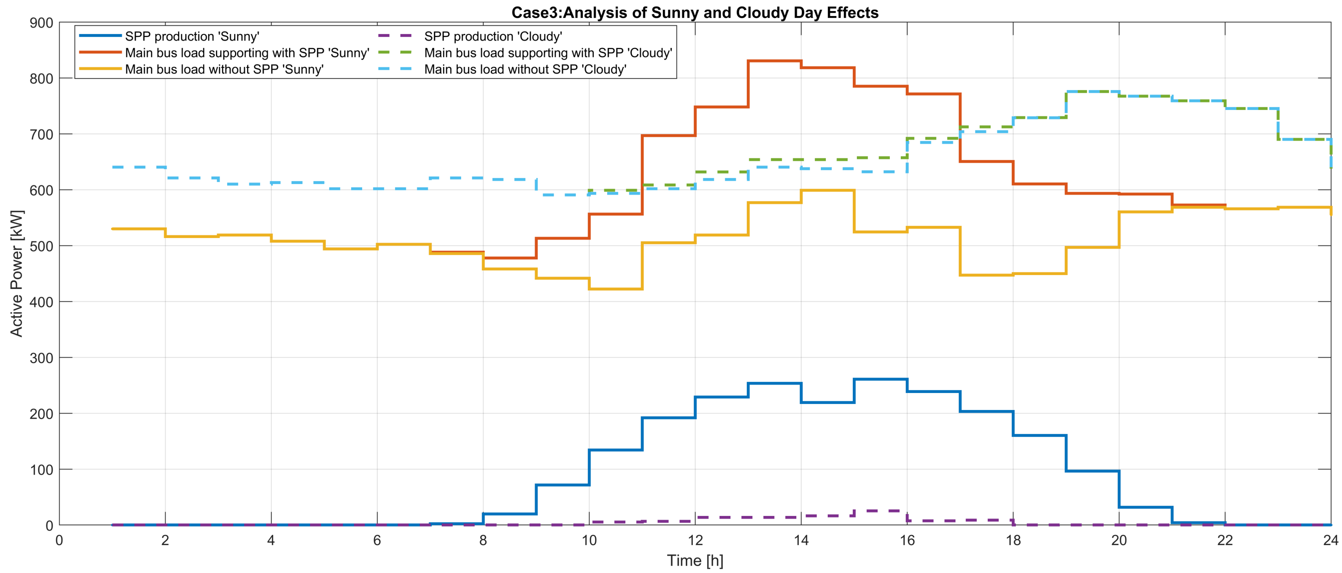

Fig. 10. Case 3: sunny and cloudy day effect.

In order to assess the influence of the population on power consumption on the campus, case 4 establishes three distinct periods for the fall semester: holidays, teaching period, and examination days. During the holiday period, which coincides with the summer season, the generation from the SPP is observed to be higher compared to the other periods. However, in terms of total consumption, the examination period surpasses the holiday period due to the higher population present on campus. When evaluating the peak clipping effect, it becomes evident that the most pronounced clipping effect occurs during the holidays, while the lowest effect is observed during the examination days. Moreover, the contribution of the SPP to LF improvement during the holiday period, teaching period, and examination period is determined as 3.61%, 3.46%, and 1.66%, respectively. The disparity in these percentages during the examination period compared to the other periods can be attributed to the lower generation from the SPP and higher campus consumption levels.

Case 5 focuses on comparing consumption patterns during graduation ceremony days and the teaching period days. During the routine week, the average and maximum consumptions are recorded as 683.6 kW and 812.34 kW, respectively. However, during the

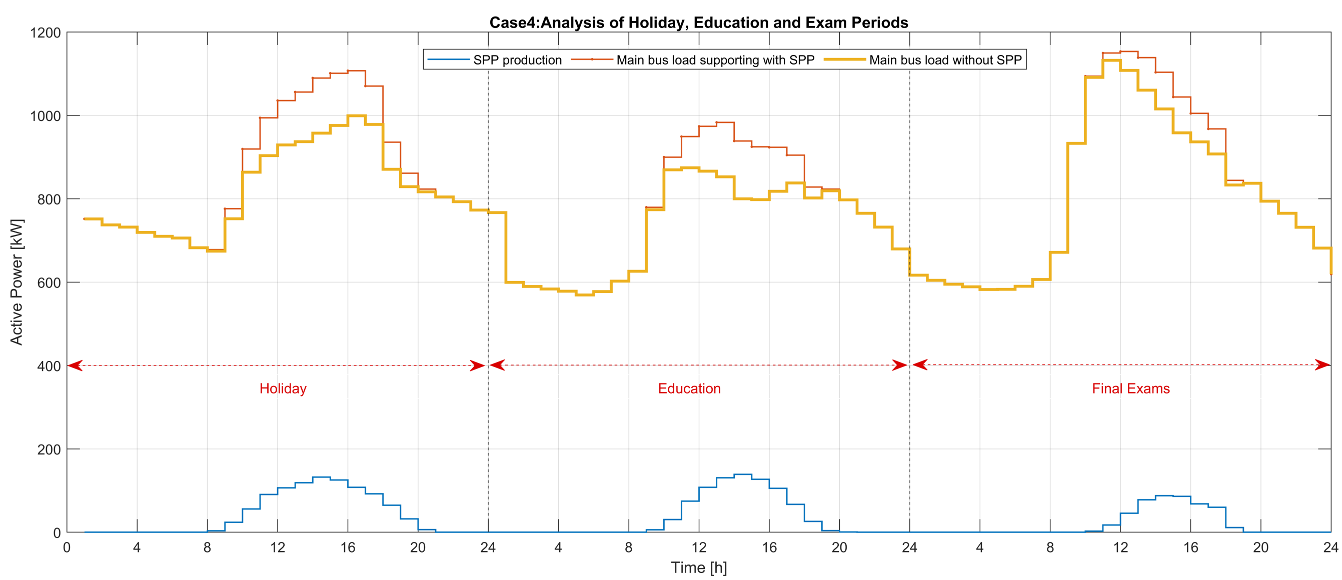

Fig. 11. Case 4: holiday, education, and examination days effect.

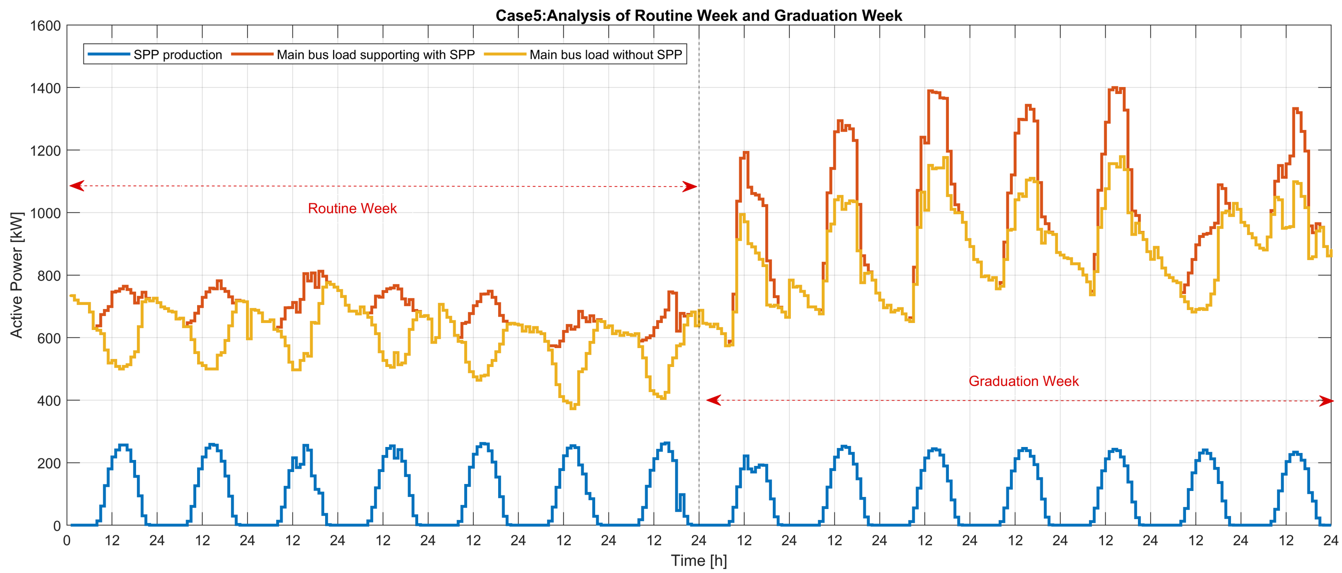

Fig. 12. Case 5: graduation week effect.

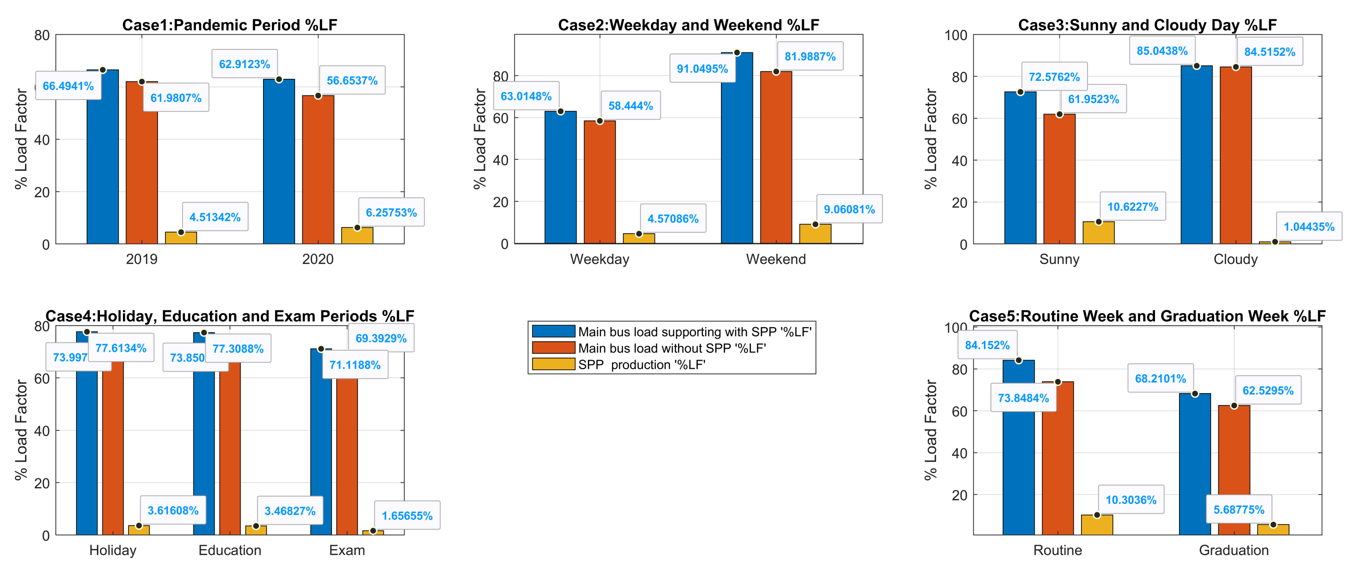

Fig. 13. LF improvement for all cases. LF, load factor.

graduation week, the consumption increased significantly, with an average of 954.6 kW and a maximum of 1399.5 kW. This divergence in consumption can be attributed to additional energy requirements during graduation ceremonies such as extra lighting and some entertainment activities. In Fig. 13, the improvement in LF for all cases is presented comparatively.

VI. CONCLUSION

This study examines the role of the SPPs in enhancing the LF through peak clipping, as well as their impact on the electricity consumption of the university campus. The study utilizes generation data obtained from the SPP and consumption data derived from the campus. The case studies are selected to align with different campus life scenarios, contributing to a comprehensive analysis. Five different cases are studied in this research: pre-pandemic and during the pandemic, weekdays and weekends, cloudy and sunny days, holiday and teaching periods, and special activities. Across all these cases, LF improvement is observed along with varying effects of peak clipping. The comprehensive analysis of the data obtained from these case studies provides valuable insights into the effectiveness of the SPP in optimizing energy utilization and improving the LF in the campus.

The analysis reveals a noteworthy improvement in the LF on sunny days, particularly in case 3, where there is a significant increase of 10.62%. This result emphasizes the positive impact of solar power generation on enhancing the LF of the system. Conversely, the lowest improvement in LF was observed on a cloudy day which is the same case, at 1.04%. Moreover, the study reveals a noticeable rise in campus consumption, particularly during the summer days when exams and teaching activities are underway. This observation can be attributed to the simultaneous operation of devices with high-rated power such as air conditioners and some laboratory equipment. Additionally, during COVID-19, it is also observed that consumption decreased compared to the pre-pandemic period due to online education and decreased on-campus activities.

One of the goals for future studies is to incorporate a simulation representing the presence of a BESS on campus and integrate the load shifting technique, another DSM technique, into the system. It will lead to a chance for analysis and comparison for a broader examination of the potential improvement in LF. Furthermore, increasing the SPPs contribution to campus consumption by expanding its installed power is considered another future study. Additionally, there is potential to increase the number of awareness-raising activities promoting the efficient use of energy, and the penetration of smart devices into the system can help reduce the peak load demand.

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