Enhancing Self-Consumption for Building Integrated PV System Under Zero Export Constraints by Applying Proactive Load Management

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***Abstract*—Building integrated microgrids and building integrated photovoltaic systems (BIPV) are emerging as a promising avenue for seamlessly integrating small scale renewable energy sources (RES) into the grid. Challenges arise as new ideas are being explored and implemented in this area, and one of them is maximizing self-consumption and self-sufficiency, for any energy policy, but especially while adhering to zero energy export (ZEE) policy restrictions. As a solution to enhance the utilization of BIPV system this paper proposes a load management (LM) technique. By combining on-grid photovoltaic (PV) system with controllable loads, this paper demonstrates how proactive LM can increase self-consumption and self-sufficiency factors, as well as mitigate PV produced energy dumping due to ZEE restrictions. A case study in the wood sector's industrial building illustrates the efficiency of this approach, showcasing reduced reliance on grid power during sunny periods and increased self-sufficiency through strategic load scheduling. Real-world data analysis validates the effectiveness of LM in aligning PV generation with building energy demands, offering insights into its potential for broader adoption in the renewable energy sector.**

***Index Terms*—load management, photovoltaic system, self-consumption, self-sufficiency, zero energy export**

I. Introduction

In the last decades, there has been a growing interest in increasing production of energy from RES to achieve reduction of carbon footprint. Industry, buildings, transportation, and agriculture are major energy consumption sectors. Buildings and industry are the largest energy consumers, accounting almost equally for around 33% of total final energy consumption (TFEC). In 2020, the share of renewable energy in TFEC in the industry sector was 8.5%, while in the buildings sector was 9.8% [1]. A gradual increase in the share of renewable energy was recorded in both sectors during the last decade. For example, the use of renewable energy in buildings grew from 6% to 9.8% between 2010 and 2020 [1]. However, buildings and industry still contribute greatly to greenhouse gas emissions. Therefore, these two sectors are often considered to have the greatest potential for increasing the share of RES in TFEC.

Buildings can be prosumers in the energy market, i.e. they can play a double role: they can be energy consumers and, simultaneously, energy producers by hosting renewable energy facilities [2]. The use of renewable energy in buildings is provided mainly through the power distribution system, but a growing number of loads in buildings are powered using various on-site systems, including rooftop or facades solar PVs. These systems are known as BIPV. In our country, BIPV systems are usually installed on commercial, institutional, and industrial buildings of medium/small/micro-size enterprises, while to a lesser extent they are installed on residential and infrastructure buildings. BIPV systems can be stand-alone or connected to the local power distribution system (on-grid BIPV).

Today, most of BIPV systems are on-grid and they can export surplus energy to the power system. But if this intermittent PV energy is too large, power quality can be reduced or unacceptable. Therefore, power distribution system operator (DSO) can impose some restrictions on PV energy export or even ban it altogether [3], [4]. In the latter case, BIPV system should be actively monitored to prevent injection of energy

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into the power distribution system, thus ensuring ZEE policy [5]–[7]. Usually, ZEE policy applies to small PV systems. Regardless of whether on-grid BIPV system can export surplus energy to the grid, or it is prohibited, self-consumption of on-site PV energy production should be promoted. The BIPV self-consumption can be defined as the capacity of the producer to consume their own production across in-building appliances without reverse power flows or dumping [2], [8].

If the BIPV system can export surplus energy to the grid, recently net-billing or net-metering policy is usually implemented, while feed-in tariff mechanism is becoming outdated, or its tariff is continually declining in many countries worldwide [9]. When implementing net-billing policy, self-consumption is considered as primary solution that can help to comply with DSO's grid rules to avoid excess of intermittent PV energy overloading the grid and deteriorating power quality. Net-metering policy aimed at promoting self-consumption through so called grid parity - situation where an expected unit cost of BIPV generated electricity matches or is lower than the cost for energy imported from the grid. If DSO imposed ZEE policy, the increase of self-consumption means that there will be less PV energy that has to be dumped or the rated power of PV system can be increased.

Generally, the use of local energy from BIPV should be maximized to achieve various economic gains for the prosumer: lower electricity bills, the increase in electric energy price has a smaller impact, higher returns of investment from BIPV system, avoid charges related to utility peak usage or time of usage. Also, prosumers will have a higher level of security from grid outage with reliable back-up power. Traditionally, two main strategies for increasing self-consumption in BIPV can be recognized [2], [9], [10]: (1) demand side management (DSM); (2) installation of optimally sized stationary energy storage system (ESS) based on batteries. Although these strategies can be implemented separately, the simultaneous implementation of DSM and ESS, which is frequently researched as shown in [2], [9], [11]–[15], is the most efficient way to maximize BIPV self-consumption. Electric vehicles (EV), as a relatively new type of dynamic energy storage with grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operation, can also contribute to a further increase of self-consumption in BIPV when they are used in combination with ESS [11]. Both ESS and EV attract growing academic interest, but their prices, even though they are decreasing, are still very high and that makes them unattainable for many prosumers. This is particularly true in our country where ESS is installed in very few BIPV systems and EVs are hardly used at all.

Therefore, DSM approach seems to be more feasible approach to increase self-consumption in BIPV. DSM is the energy management technique that is used to modify the load pattern of the prosumer. This technique can be implemented through different sets of activities [16], [17]: (1) energy efficiency (EE); (2) demand response (DR); (3) load management (LM). EE is often considered as the activity aimed to replace inefficient older equipment with efficient equipment. DR is a tariff or program, implemented by utilities or DSO, that encourages energy consumers to change their normal consumption patterns in response to the external signals. DR is either price-based or incentive-based. Price-based mechanisms are established to encourage users to change their energy consumption in response to dynamic changes in energy prices over time. Incentive-based mechanisms are established to give incentive payments to the users to induce lower energy use at times of high wholesale market prices or when system reliability is at risk [18]. LM is a smaller-scale tactic that refers loosely to the adjustment of demand to match supply and can be understood as a user's solutions for responding to demand response programs [19]. LM includes various specific algorithms and techniques used by individual businesses or consumers to obtain different objectives.

BIPV system with LM is explored in this paper, under ZEE policy restrictions. The goal of LM is to increase the self-consumption of PV power, self-sufficiency of the installed PV modules, and lower the total cost for the customer. The literature to be explored for the option of ZEE policy is scarce, and for LM with ZEE even more. Several papers deal with sizing of renewable energy based systems under ZEE as in [7] for BIM. Also, comparison of net-metering and ZEE option in solar PV and ESS sizing is given in [20]. There is mention of ZEE in [21] where it is stated that the evolution of utility price plans typically starts with no financial reimbursement for renewable energy generation export, to net metering and feed-in-tariffs, to end with demand charges and zero export options. From this report one can conclude that exploring ZEE policy impacts needs to be considered, since it is suggested that it is the policy to be expected, if not for all the time then at least for some time periods during the day.

The paper is organized as follows. The proposed LM technique is presented in Section II. A case study of considered industrial building is described in detail in Section III. Conclusion with a short discussion of some issues for future work is given in Section IV.

II. Proposed Load Management Technique

LM is basically a user-side strategic approach for increasing efficiency in the supply-demand balance. It is utilized by active load control in the pursue of various objectives such as peak clipping, valley filling, load shifting, strategic conservation, and creating flexible load curve. This proactive strategy can reduce peak demand, increase renewable sources utilization, enhance grid stability and resilience, reduce system overall cost, prolong equipment lifespan, etc.

Usually, LM is focused on peak clipping and load shifting. Peak clipping, peak shaving or reduction of peak load is a mechanism of curtailing usage during peak hours by limiting the maximum power consumed. It can be achieved by using on-site PV systems, in order to supplement grid supply during peak times. Load shifting is a management technique of shifting the load from peak to off-peak periods using rescheduling of low priority loads.

Valley filling involves increasing the load during off peak hours in which the demand is under the consumer average,

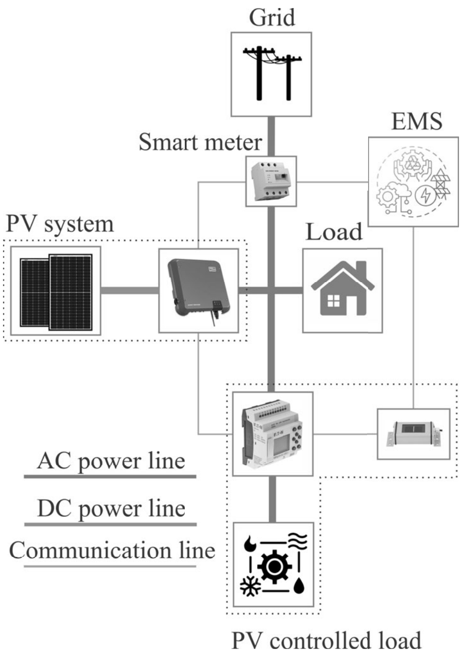


Fig. 1: Structure of a BIPV system with PV controlled load

which is often coincided with low price tariffs. Strategic conservation is a targeted measure in which the load is reduced in specific area in order to improve the system efficiency. Flexible load curve is a load profile that can be modified according to changing conditions, for example fluctuating energy prices.

The focus of this research will be on achieving objective of enhancing self-consumption for existing BIPV installation with a load control mechanism shown in Fig. 1. Shown BIPV system is consisted of a grid connected PV system with two types of loads: load driven by technological process and PV controlled load. A smart meter with closed-loop controller enables regulation of the power and performs energy management.

In practice, PV controlled loads are most often heating, ventilation and air-conditioning systems. Combining PV system with these loads offers the potential to improve energy efficiency, reduce operating costs, and increase sustainability in buildings and industrial facilities. However, it requires careful design, control strategies, and monitoring to ensure optimal performance and compatibility with the building's energy needs.

Two energy indicators, the self-consumption rate (SCR) and self-sufficiency rate (SSR) are usually used to quantify the exploitation of energy production at local level. SCR is a proportion of the energy generated by the PV system that is consumed on-site or within a specific location, rather than being exported to the power grid. In the considered case of ZEE, SCR is always 100% and therefore does not need to be evaluated. SSR is a measure of how much of the total energy demand or consumption is met by the PV system without relying on external sources.

The obvious way to increase the SSR is by increasing the amount of installed PV power. However, this may have limitations in the dimensions of the considered object, which is limiting the maximum amount of installed PV power. The other limitation is derived from the annual load profile of the building, since some countries limit the allowed PV installation size based on annual consumption.

In a power system with ZEE policy, an increase in installed PV power can lead to an increase in unutilized excess energy, and thus the profitability of the investment is decreasing. Therefore, financial aspects also need to be taken into account.

The amount of PV generated energy that needs to be dumped by the power converter can be significantly reduced by adding controllable loads. In this case self-consumption of PV energy is increased, leading to a better utilization of BIPV system. With this solution, it is always possible to install a storage system at a later time.

The outline of the proposed LM mechanism is given in Algorithm 1. The pseudo-code consists of two parts. The first part checks if the solar irradiation reaches the trigger point of $700W/m^2$. At this point the heaters are turned on resulting in increased load. In order to avoid unnecessary switching due to temporary clouding, a timer is used. Therefore, the heaters are turned off after the solar irradiation is below $700W/m^2$ for longer than 10 minutes. The second part is related to ZEE restriction, limiting the PV production in case of higher PV production than load consumption. In the opposite case, the remaining part of energy demand needs to be supplied from the network.

Algorithm 1 Pseudo-code of the load management mechanism

```
Get CurrentSolarIrradiation
Status = OFF
while True do
    if CurrentSolarIrradiation ≥ 700 then
        Turn ON heaters
        Status = ON
        Reset timer
    else if Status = ON and G < 700 then
        Begin timer
    else if Timer ≥ 600s and Status = ON then
        Turn OFF heaters
        Status = OFF
    end if
    if PVProduction ≥ Load then
        Limit PV production
    else
        Withdraw the lack of power from the grid
    end if
end while
```

III. Case Study and Discussion

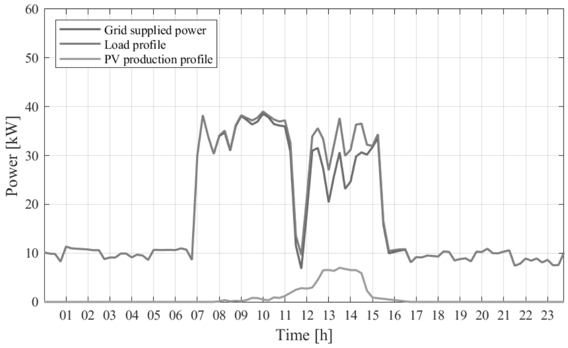
As a case study example we are considering a wood sector's industrial building, which can be classified as small-size enterprise. The working hours of the considered facility are from 7 a.m. to 4 p.m. Monday to Saturday, with a 30 minutes break at 11:30 a.m. The technological process includes three main working activities: wood cutting, wood processing, and wood drying. Wood cutting and wood processing are powered by electric energy from the local power distribution system, whereas the wood drying process relies on steam as its primary energy source. Steam is produced using a sawdust boiler.

In the wood drying process, the energy from the power distribution system is used to supply ventilators and pumps installed in steam-powered dryers. During the working day, energy is used to supply all electric machines, and electric power demand during working hours is between 30 and $50kW$. The power demand during non-working hours averages around $10kW$ and is utilized for the wood-drying process.

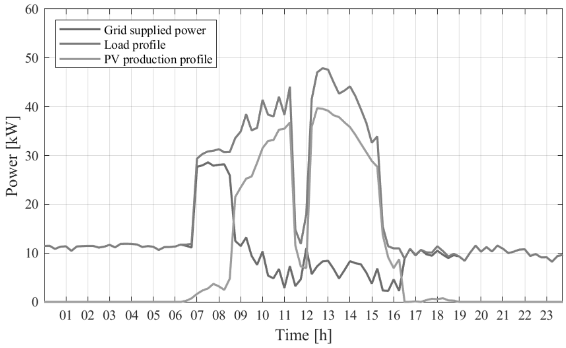
In order to reduce the need for sawdust, a PV controlled LM mechanism has been implemented. An integrated on-grid PV system with $64kWp$ installed power is built. The solar PV modules are positioned in an east-west orientation with an tilt angle of 15 degrees. Electric heaters were installed in the wood-drying chambers to be combined with sawdust boiler, with goal of reducing the total cost and enhnacing utilization of the produced PV power.

The controllable load consists of two electric heaters, each $24kW$ rated power, which are turned on depending on the PV production and wood drying process requirements. Heaters are turned on if the solar irradiation is greater than $700W/m^2$. After this condition is satisfied, turning the heater on/off is dictated by the technology of wood-drying process.

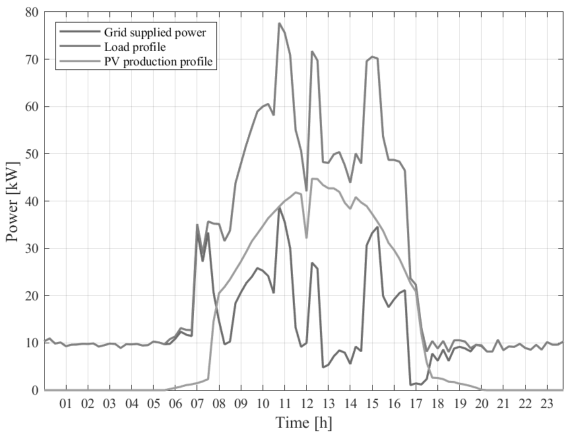
Real measurement data were used in this case study, with PV production, grid supplied power and load profile for working and non-working days are presented in Fig. 2 and Fig. 3, respectively.



(a) Cloudy working day

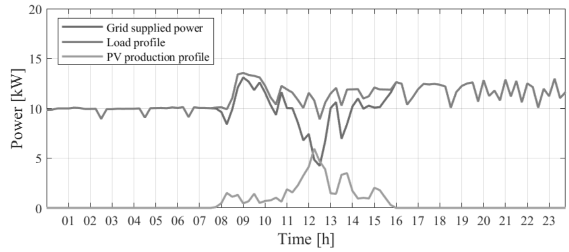


(b) Sunny working day without controlled load

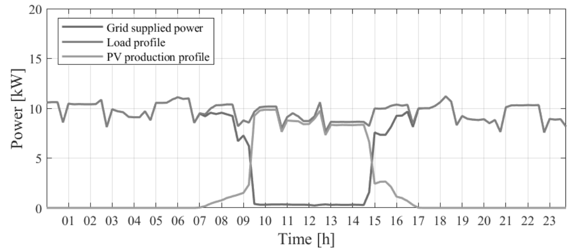


(c) Sunny working day with controlled load

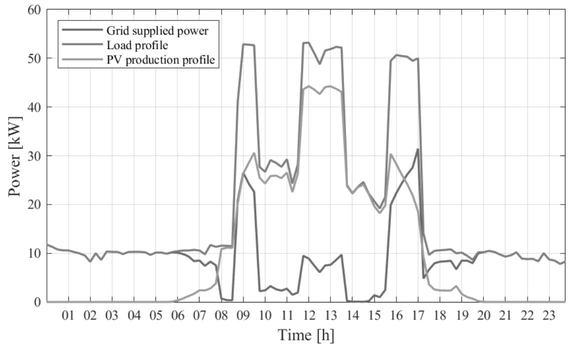
Fig. 2: Power diagram for working days



(a) Cloudy non-working day



(b) Sunny non-working day without controlled load



(c) Sunny non-working day with controlled load

Fig. 3: Power diagram for non-working days

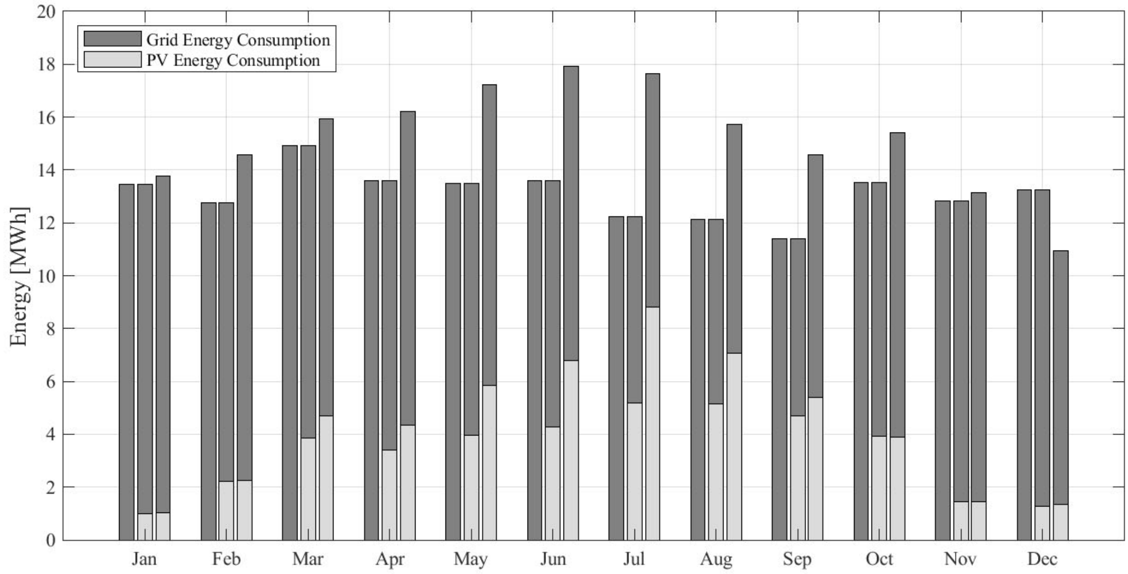


Fig. 4: Annual energy balance (1^{st} bars - the average monthly energy consumption for three years before installing PV system; 2^{nd} bars - the monthly energy consumption with PV system without controllable load; 3^{rd} bars - the monthly energy consumption with PV system and controllable loads)

During cloudy working or non-working days, as shown in Fig. 2a and Fig. 3a, the solar irradiation newer reaches the threshold limits, so the electric heaters are not turned on at any time. The relatively small PV generation was used to reduce the amount of grid supplied energy, thus reducing the electricity bill for the customer.

Otherwise, during sunny days, it is interesting to analyse the behaviour with and without the controllable load. The behavior of the load without the electric heaters is presented in Fig. 2b and Fig. 3b where the standard power demands related to the working process can be observed.

As shown in Fig. 2b, the PV production is used to significantly decrease the amount of grid supplied energy. Due to the fact that working process was stopped at lunch time, when the PV production is at maximum or near it, there is a significant amount of PV produced power remaining unutilized, and dumped due to ZEE policy restrictions. On the other hand, the consumption is fully covered by the PV production during non-working days between the hours 9:30 a.m. and 3 p.m., as shown on Fig. 3b. Since the PV production is considerably higher than the load demand, a significant amount of the PV generation is dumped, again in order to satisfy the ZEE policy restrictions. This case clearly presents a non-optimal use of the PV generation.

By adding the controllable load, the power profile shows increased consumption during PV production periods, as shown in Fig. 2c and Fig. 3c. The consumption of the electric heaters is fully covered by the PV production, resulting in no additional electricity costs, while reducing the amount of sawdust used in the process. Even during lunch time on working days there is very little PV produced power being dumped, as one can be observed from the shape of the green line in Fig. 3c. Furthermore, during non-working days, the PV production if fully utilized, and the amount of the PV generation remaining unutilized is much lower than in the case without the electric heaters. This results in an increased self-sufficiency ratio of the installed PV system, as well as increased self-consumption of the produced PV power and reduced amount of unutilized PV generated energy.

Finally, Fig. 4 shows the comparison between the annual grid supplied energy consumption (red color) and PV energy consumption (green color) of the industrial building. The first bars for each month are related to the monthly energy consumption before installing the PV system with controllable load. The second bars are the estimation of monthly energy consumption with PV system but without the controllable load, and the third bars in each month refer to the energy consumption with PV system and controllable load. Table I shows numerical values of annual energy balance for three considered scenarios, and SSR values before and after implementing the load management are computed and presented.

It is clearly shown that by installing the PV power plant the grid supplied energy (red) is significantly decreased, leading to savings in electricity bills. By adding the controllable load, the total consumed energy is increased compared to the situation before the upgrade, but comparing the green bars clearly shows that the self-consumption of the PV generated energy is increased thus lowering the amount of unutilized PV energy. From SSR values presented in Table I, it can be calculated that SSR has relative increase of about 12% when controllable

TABLE I: Annual energy balance

Parameter	Value
Average annual energy consumption without PV power plant and controllable load (MWh)	157.17
Annual grid energy consumption with PV power plant (MWh)	116.77
Annual grid energy consumption with PV power plant and controllable load (MWh)	130.07
Annual PV energy consumption without controllable load(MWh)	40.40
Annual PV energy consumption with controllable load (MWh)	52.95
SSR with PV power plant (%)	25.70
SSR with PV power plant and controllable load (%)	28.93

load is used. It is important to note that adding the controllable load also leads to the reduced use of other resources such as sawdust.

IV. Conclusion

This paper emphasizes the significance of LM techniques in unlocking the full potential of building integrated photovoltaic (BIPV) systems. This is particularly important in environments governed by ZEE policy, as a means of reducing the amount of unutilized PV generated power. By coordinating building energy consumption with PV generation, our proposed approach enhances self-consumption and self-sufficiency and also reduces dependency on the grid, thereby offering economic and environmental benefits to building owners. The case study presented highlights the advantages of proactive load control mechanisms, emphasizing the need for further research and implementation of such strategies in maximizing the efficiency and effectiveness of BIPV systems. As renewable energy continues to play a pivotal role in the transition towards a sustainable future, using innovative solutions like LM will be crucial in realizing its full potential across diverse applications and settings.

References

[1] N. M. Haegel and S. R. Kurtz, "Global progress toward renewable electricity: tracking the role of solar (version 3)," *IEEE Journal of Photovoltaics*, 2023.

[2] C. Fernández Bandera, G. Bastos Porsani, and M. Fernández-Vigil Iglesias, "A demand side management approach to increase self-consumption in buildings," in *Building Simulation*, vol. 16, pp. 317–335, Springer, 2023.

[3] M. Karimi, H. Mokhlis, K. Naidu, S. Uddin, and A. A. Bakar, "Photovoltaic penetration issues and impacts in distribution network–a review," *Renewable and Sustainable Energy Reviews*, vol. 53, pp. 594–605, 2016.

[4] M. M. Haque and P. Wolfs, "A review of high pv penetrations in lv distribution networks: Present status, impacts and mitigation measures," *Renewable and Sustainable Energy Reviews*, vol. 62, pp. 1195–1208, 2016.

[5] T. R. Ricciardi, K. Petrou, J. F. Franco, and L. F. Ochoa, "Defining customer export limits in pv-rich low voltage networks," *IEEE Transactions on Power Systems*, vol. 34, no. 1, pp. 87–97, 2018.

[6] Y. Wu, S. M. Aziz, and M. H. Haque, "Techno-economic modelling for energy cost optimisation of households with electric vehicles and renewable sources under export limits," *Renewable Energy*, vol. 198, pp. 1254–1266, 2022.

[7] L. Ahmethodžić, S. Huseinbegović, A. Smajkić, and S. Smaka, "Building-integrated microgrid with zero energy export-practical approach to sizing," in *2023 IEEE PES GTD International Conference and Exposition (GTD)*, pp. 345–349, IEEE, 2023.

[8] R. Luthander, J. Widén, D. Nilsson, and J. Palm, "Photovoltaic self-consumption in buildings: A review," *Applied energy*, vol. 142, pp. 80–94, 2015.

[9] U. Mulleriyawage, P. Wang, T. Rui, K. Zhang, C. Hu, and W. Shen, "Prosumer-centric demand side management for minimizing electricity bills in a dc residential pv-battery system: An australian household case study," *Renewable Energy*, vol. 205, pp. 800–812, 2023.

[10] J. Liu, X. Chen, H. Yang, and Y. Li, "Energy storage and management system design optimization for a photovoltaic integrated low-energy building," *Energy*, vol. 190, p. 116424, 2020.

[11] N. Das, A. Haque, H. Zaman, S. Morsalin, and S. Islam, "Domestic load management with coordinated photovoltaics, battery storage and electric vehicle operation," *IEEE Access*, vol. 11, pp. 12075–12087, 2023.

[12] H. Chen, S. Yang, J. Chen, X. Wang, Y. Li, Z. Wang, and H. Yu, "Low-carbon and economic optimal scheduling of multi-energy microgrid with integrated demand response considering waste heat utilization," *Journal of Cleaner Production*, p. 141415, 2024.

[13] Z. Klaić, K. Fekete, and D. Šljivac, "Demand side load management in the distribution system with photovoltaic generation," *Tehnički vjesnik*, vol. 22, no. 4, pp. 989–995, 2015.

[14] L. Barelli, G. Bidini, F. Bonucci, and A. Ottaviano, "Residential micro-grid load management through artificial neural networks," *Journal of Energy Storage*, vol. 17, pp. 287–298, 2018.

[15] S. Ali, I. Khan, S. Jan, and G. Hafeez, "An optimization based power usage scheduling strategy using photovoltaic-battery system for demand-side management in smart grid," *Energies*, vol. 14, no. 8, p. 2201, 2021.

[16] D. Kanakadhurga and N. Prabaharan, "Demand side management in microgrid: A critical review of key issues and recent trends," *Renewable and Sustainable Energy Reviews*, vol. 156, p. 111915, 2022.

[17] M. M. Iqbal, M. I. A. Sajjad, S. Amin, S. S. Haroon, R. Liaqat, M. F. N. Khan, M. Waseem, and M. A. Shah, "Optimal scheduling of residential home appliances by considering energy storage and stochastically modelled photovoltaics in a grid exchange environment using hybrid grey wolf genetic algorithm optimizer," *Applied Sciences*, vol. 9, no. 23, p. 5226, 2019.

[18] M. H. Albadi and E. F. El-Saadany, "Demand response in electricity markets: An overview," in *2007 IEEE power engineering society general meeting*, pp. 1–5, IEEE, 2007.

[19] Y. W. Law, T. Alpcan, V. C. Lee, A. Lo, S. Marusic, and M. Palaniswami, "Demand response architectures and load management algorithms for energy-efficient power grids: a survey," in *2012 seventh international conference on knowledge, information and creativity support systems*, pp. 134–141, IEEE, 2012.

[20] P. Kumar, N. Malik, and A. Garg, "Comparative analysis of solar - battery storage sizing in net metering and zero export systems," *Energy for Sustainable Development*, vol. 69, pp. 41–50, 2022.

[21] K. McKenna, K. Duwadi, S. Ghosh, A. Nagarajan, D. Palchak, A. Ranjan, A. Kumar, J. Bora, and K. Kaant Gupta, "Preparing distribution utilities for the future - unlocking demand-side management potential: A novel analytical framework," 2021.