# A Cost-Effective Fuzzy-based Demand-Response Energy Management for Batteries and Photovoltaics

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***Abstract*—Distributed energy sources play an essential role in microgrids to meet the load demand. To maintain power stability in a grid-connected microgrid, a fuzzy logic-based management system has been designed in this work for a photovoltaic (PV) and battery-based microgrid feeding power to the load in the MultiGood MicroGrid Lab in Politecnico di Milano. For this system, a design based on 34 rules has been implemented for effective power management considering the electricity tariff in Milan, Italy. The main goal of this design is to minimize the power bought from the main grid during peak hours throughout the day under high-load demand while maintaining a stable power supply to the load and keeping the batteries within safe limits. The controller rules and membership functions are optimized to meet the designed criteria of this system which has been implemented using the fuzzy logic toolbox in MATLAB (2020b) and tested through simulations in MATLAB/Simulink (2020b) environment. Lastly, a cost analysis of the power bought from the grid with the designed fuzzy-based EMS has been performed which shows minimum power intake from the main grid while maintaining the state of charge of BESS in safe limits.**

***Keywords*— Renewable energy generation, battery storage, fuzzy logic control, power sharing, microgrid, cost-effective power management.**

## I. INTRODUCTION

As the power demand increase with the advent of novel technologies and increasing population, a rapid acceleration in carbon dioxide emissions and greenhouse gases have raised the concern of environmental activists [1]. To cater for this, the economic and sustainable energy benefits associated with distributed renewable energy sources have proved to be a viable solution. Within the frame of this reference, microgrids formed with distributed energy sources and storage systems are considered to have a potential impact on the energy sector [2], [3]. The operation of microgrids in islanded as well as grid-connected modes has entirely transformed the power-sharing aspect between various energy units and loads irrespective of their location. Moreover, this type of power-sharing requires an effective power management approach to avoid transmission losses and minimize the microgrid operating costs [4].

Extensive research has been carried out in this field for over a decade to improve the performance of microgrids which is discussed in various presented approaches [5], [6]. Moreover, since the microgrids are based on distributed renewable energy sources, their stochastic power supply cannot be neglected which gives room to the integration of storage devices with these renewable energies [7]. Since the generated power and the load demand are uncontrollable, the system needs to have an additional source of power supply to fulfil the power criteria throughout the day [8]. In this context, energy storage systems, i.e. batteries, supercapacitors (SC), and superconducting magnetic storage systems (SMES) have gained tremendous attention due to their instant power-sharing characteristics during high-load demand [9]. This addition in the microgrids drives the system towards improved stability and better performance especially when the microgrid is operating in islanded mode or during a power failure [10].

With the integration of more elements in the microgrid, the increase in structural complexity leads to the adoption of an intelligent energy management system (EMS) responsible for the power management between the microgrid elements and the main grid [11], [12]. It is also in charge of controlling the power generation and storage between the units to achieve the objectives laid out with the system design such as maximizing the profits from the electricity market as well as minimizing the operating costs of microgrids and their units by limiting their operation within the safe limits during peak hours throughout the day [13], [14]. The next step which follows the design of the EMS objectives is the control method which needs to be adopted to implement the predefined EMS design [15].

In this context, numerous approaches have been applied and presented in the literature for microgrids handling different objectives in terms of control methodologies, cost function analysis and power-sharing [16]. The design of EMS presented in this work focuses on the compensation of power provided by the energy storage system operating in a grid-connected mode through a model predictive control [17]. Additionally, a system employing local predicting and forecasting approaches with dynamic programming for the control and improvement of the energy storage system's lifetime has also been presented [18]. Owing to its simplicity and rules formulated using human knowledge of the system and desired objectives, fuzzy-based EMS [19] are employed for the control of microgrids with the aim of prioritizing the supply of additional electricity from the renewable energy sources to the main grid especially during peak hours to increase the revenue [20]. For the system to work in the optimal situation with minimum electricity bought from the main grid, work has been done using fuzzy logic control considering the load demand and the energy on hand from renewable energy sources throughout the day to maintain an affordable microgrid operation [21].

Furthermore, fuzzy-based controllers having more degree of freedom are also employed to generate reference powers for the power sources integrated into the grid i.e. batteries, fuel cells and supercapacitors [22], [23]. These references are produced depending

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on the load demand (controllable or uncontrollable) and the safe operating limits of these elements. Fuzzy logic is popular in the design of demand-response strategies and demand-side management as the objectives of the work are well-defined and the goal is to optimize the power management between the renewable energy sources, storage devices and load [24]. In another approach, a fuzzy logic controller has been designed with 50 rules to improve the state of charge (SoC) of the battery in grid-connected mode with minimum grid power fluctuations having an additional grid power input to the fuzzy inference system (FIS) to generate a more accurate power profile [25]. A common disadvantage of these previous works is that they do not consider providing relevant inputs to the fuzzy logic controller on which the performance of the energy storage system depends i.e. SoC and the power production from renewable energy sources.

To overcome the drawbacks of the aforementioned works, a fuzzy logic-based EMS has been designed and presented in this paper for the demand-response energy management of a microgrid comprising PV and battery working in a grid-connected mode. The system is designed by providing four inputs to the fuzzy inference system (power demand, PV power generation, battery SoC, and the time of the day (hours) to know the peak hours). Three outputs are generated by this system (curtailed PV power, battery power, and the electricity bought from the main grid) according to the rule base designed for the cost-effective energy management of this microgrid. The EMS generates the output powers for a set of 24 hours of data used as the input obtained from the MultiGood MicroGridLab (MG$^2$Lab) facility in Politecnico di Milano, Italy [26]. The aim of this system is to fulfil the load demand while keeping the electricity bought from the grid at a minimum during peak tariff hours throughout the day. The highlights of this design have been presented as stated below:

- PV and battery are integrated into the microgrid operating in a grid-connected mode to fulfil the load demand (a water destination system).
- A fuzzy logic-based EMS has been designed to keep the operation of the battery within its safe limits to avoid overcharging and discharging.
- Electricity consumption bands have been provided as one of the inputs to the system to avoid power intake from the main grid during peak electricity tariff hours.
- The additional PV power is used to charge the battery in case of low power demand and low battery SoC. Conversely, it is curtailed to increase the efficiency and performance of PV arrays with time.

This paper has been organized in the following pattern: Section II describes the structure of the microgrid along with its elements, Section III deals with the EMS design and the formulation of the rules, Section IV illustrates the simulation results obtained from the designed EMS with real data and lastly, Section V concludes this paper with the system highlights and future work.

## II. DESCRIPTION OF MICROGRID

The microgrid under study is compromised of various types of power generation units, storage systems and loads. The elements of the microgrid under study are illustrated in fig. (1) in which the renewable energy generation source is the PV units along with electrochemical batteries working as the energy storage system. The aim of the designed system is to fulfil the load demand, which in this case is the provision of potable water to the residential areas as well as to meet their electricity demand.

With reference to fig. (1), it can be observed that the PV module is connected with a DC-DC boost converter to step up the output voltage. The PV panels operating in the MG$^2$Lab are connected with a solar inverter of 25kW to ensure the maximum power point tracking (MPPT) therefore, the PV power data provided as the input to the fuzzy inference system (FIS) is assumed to be operating at its MPPT. The second power source in this system is the battery energy storage system (BESS) which is connected to the bus through a DC-DC buck-boost converter whose operation depends on its charging/discharging operation. The output power from the BESS is governed by its SoC which is estimated through the battery management system. Firstly, the SoC is updated with the integration of current over time and to fix the drift appearing in the result obtained from the pure integration of current, look-up tables are employed for the voltage measurements. During this update, the BESS SoC is kept constant until it matches the actual value during charging/discharging. With reference to the loads connected with this microgrid, a desalination system operating on the principle of reverse osmosis is working for the production of freshwater which is stored in the water tank to increase the availability of potable water.

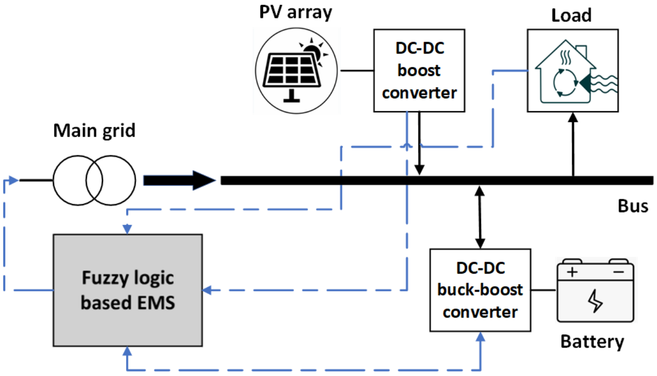
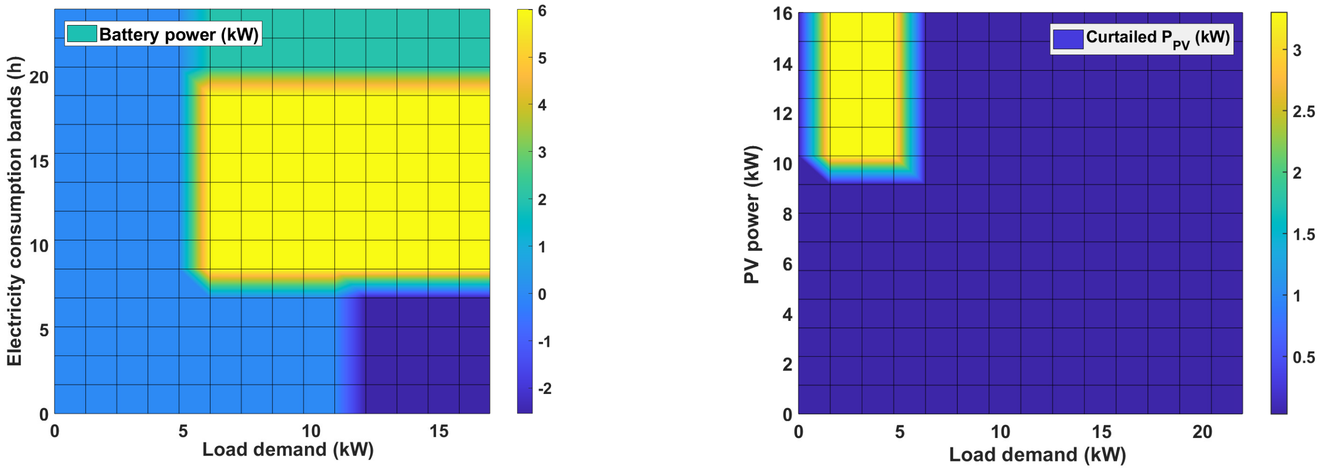


Figure 1: Structure of the grid-connected microgrid under study

## III. FUZZY LOGIC-BASED ENERGY MANAGEMENT DESIGN

The BESS plays a vital role in filling the gap between the generated power and the load demand that occurs due to the intermittency of the PV power source and the load variations. In this work, a fuzzy-based EMS is designed to distribute the power between PV, grid and load by generating respective power references from BESS. To reduce operational costs and design a cost-effective EMS, an electricity tariff is also considered as one of the inputs to the EMS to govern the battery and grid powers accordingly. The objective of this EMS is to maintain the system's stability throughout the day by coping with the load demand while keeping the electricity bought from the grid minimum, especially during peak hours of electricity tariff. Fig. (3) illustrates the working of the designed EMS with three inputs (power demand, PV power and electricity consumption bands) and two outputs (battery power and curtailed PV power). Mamdani FIS has been employed to generate the output in the form of fuzzy sets working on the principle of IF-THEN linguistic control rules [27]. The input to the EMS is a crisp value which after fuzzification becomes a fuzzy set given to the Mamdani FIS. The inference system is considered to be the engine of the system since it takes the fuzzified set as input, decides the output according to the membership functions and set of rules, and generates an output fuzzy set. In this work, a centroid method governs the defuzzification process to transform the output fuzzy set into a crisp output. The designed EMS should meet the following requirements:

- Charge the BESS during the off-peak hours of the day to keep the battery SoC at safe limits without compromising the performance of the system.
- Discharge the BESS during peak hours of the day to fulfil the load demand when the PV power is low.
- Maintain the SoC of the battery within 30% to 80% as this avoids the energy storage device from getting overcharged and under-discharged.
- Coordinate between the power sources (PV and BESS) and the power demand to buy minimum power from the grid throughout the day.



(a) (b)

Figure 2: Pseudo-color map of fuzzy logic responses. (a) Output 1: Designed battery power reference throughout the day under varying load demand, (b) Output 2: Designed PV power curtailment under varying load demand.

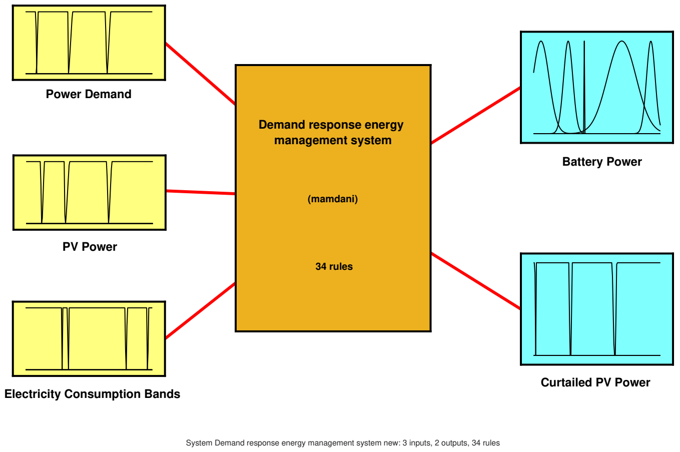


Figure 3: FIS for the designed strategy

Table I: Electricity tariff based on its consumption bands

| **Zones** | **Hours range** | **Tariff/kWh** |
|---|---|---|
| F3 | From 00 to 7 and 23 to 24 – “Off-peak” | 0.354€ |
| F2 | From 7 to 8 and 19 to 23 – “Mid-peak” | 0.361€ |
| F1 | From 8 to 19 – “Peak” | 0.373€ |

### *III-A EMS Inputs and Output Membership Functions*

To generate the output reference provided by the battery and the curtailed PV power, the fuzzy subset for the power demand has been divided into four membership functions which represent different power levels: D0 (Level 0: Very low demand), D1 (Level 1: Low demand), D2 (Level 2: Medium demand) and D3 (Level 3: High demand). The PV power (PPV) is divided into four membership functions: P0 (Level 0: Very low power generation), P1 (Level 1: Low power generation), P2 (Level 2: Medium power generation) and P3 (Level 3: High power generation). The third input based on the electricity consumption bands (ECB) of the day is divided into three membership functions representing the three different electricity tariff zones in a day: F1 (Zone 1: Peak hours) during which the electricity tariff is highest, F2 (Zone 2: Mid-peak hours) and F3 (Zone 3: Off-peak hours) during which the electricity tariff is the lowest. The electricity tariff for different zones throughout the day in Milan has been given in Table. I. The output battery power is divided into five membership functions to replicate the different power levels: B0 (Level 0: High power charging), B1 (Level 1: Low power charging), B2 (Level 2: Staying idle), B3 (Level 3: Low power discharging) and B4 (Level 4: High power discharging). The fuzzy subset of curtailed PV power is divided into three membership functions: C0 (Level 0: Low curtailment), C1 (Level 1: Medium curtailment) and C2 (Level 2: High curtailment). For this system, a set of 34 rules have been designed given in Table. II.

A graphical representation of the rules for a set of two inputs and respective outputs has been given in fig. (2) in the form of pseudo-colour maps in which the colour bar is used to indicate the power levels. Fig. (2a) shows the designed battery response under varying load demand with respect to the electricity slots throughout the day. The power levels (B0-B4) are represented by a gradient of colours varying from dark blue (Level B0) to yellow (Level B4) indicating the charging and discharging states of BESS. For instance, when the load demand is very high (level **D3**) during peak hours of the day when the specific time lies in the **F1** zone of the ECB, the battery delivers full power (level **B4**) to reduce the intake grid power. The colour bar in fig. (2b) shows the levels of curtailed PV power ranging from dark blue (Level C0) to yellow (Level C2). For example, when the load demand is very low (level **D0**) and PV power is high (level **P3**), high PV power is curtailed (level **C2**) to reduce the stress on the solar panels. Other similar conditions depending on the respective fuzzy subsets of inputs and outputs of the EMS can be verified through the set of rules laid down in Table. II.

## IV. RESULTS AND DISCUSSION

The performance of the system designed in the fuzzy logic toolbox has been observed in MATLAB/Simulink environment under varying power generation from the PV system and power demand on August 17, 2021, in Milan, Italy. A profile illustrating the varying load demand throughout the day has been given in fig. (4) in which it can be observed that the load demand starts to increase in the morning and remains high till the afternoon around t = 17h after which it starts to decrease till the end of the day. The corresponding input power from the PV modules obtained for one day under varying solar irradiance and temperature has been

Table II: Sample Fuzzy-based EMS rules

| **Demand** | | **Battery Power** | | | | **Curtailed PV Power** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **D0** | **D1** | **D2** | **D3** | **D0** | **D1** | **D2** | **D3** |
| **PPV** | **ECB** | | | | | | | | |
| **P0** | **F1** | B2 | B3 | B3 | B4 | C0 | C0 | C0 | C0 |
| | **F2** | B2 | B2 | B3 | B2 | C0 | C0 | C0 | C0 |
| | **F3** | B2 | B1 | B0 | B1 | C0 | C0 | C0 | C0 |
| **P1** | **F1** | B2 | B2 | B3 | B3 | C0 | C0 | C0 | C0 |
| | **F2** | B1 | B2 | B3 | B3 | C0 | C0 | C0 | C0 |
| | **F3** | B1 | B1 | B2 | B3 | C1 | C0 | C0 | C0 |
| **P2** | **F1** | B2 | B2 | B2 | B3 | C0 | C0 | C0 | C0 |
| | **F2** | B2 | B2 | B1 | B2 | C1 | C0 | C0 | C0 |
| | **F3** | B0 | B1 | B1 | B2 | C1 | C1 | C0 | C0 |
| **P3** | **F1** | B2 | B2 | B2 | B3 | C0 | C0 | C0 | C0 |
| | **F2** | B2 | B2 | B3 | B3 | C1 | C0 | C0 | C0 |
| | **F3** | B0 | B0 | B1 | B1 | C2 | C1 | C0 | C0 |

illustrated in fig. (5). In the afternoon, it can be seen that in the morning and night for low values of irradiance and temperature, the power produced by the PV system is low and gradually approaches zero. In the afternoon, the increasing PV current due to the change in the irradiance and temperature gradually increases the output PV power signifying the highest efficiency of PV system at noon. Power required from the grid depends on an additional factor which is the time (hour) of electricity consumption represented using fig. (6) and the respective hours can be cross-checked through Table I.

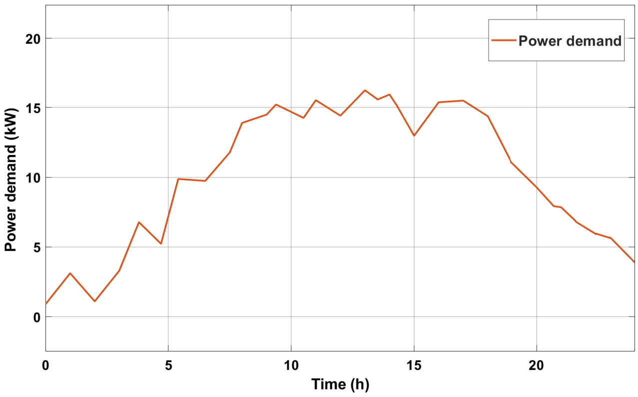


Figure 4: Power demand

Of all the acquired data from the inputs of this fuzzy-based EMS, the corresponding outputs have been investigated through the results given in figs. (7), (8) and (9). To maintain the SoC of BESS within safe limits as defined in the objectives ($30\% \leq SoC \leq 80\%$), the designed EMS charges the BESS during off-peak hours when the load demand is low and discharges during mid-peak and peak hours in conjunction with the load demand. During t = 0h to t = 5h, BESS is getting charged represented in fig. (7) with negative power and a gradually increasing SoC as can be observed in fig. (8) and the load demand is entirely fulfilled by taking power from the grid during off-peak hours. During peak hours from t = 8h to t = 19h, the BESS discharges and remains idle according to the load demand and the corresponding power provided by the PV modules. In this case, the power provided by the PV modules is always consumed to meet the load demand therefore, negligible PV power has been curtailed. Again, at night when the load demand decreases and the power produced by the PV also decreases, the BESS charges and discharges to maintain the power balance by taking power from the grid.

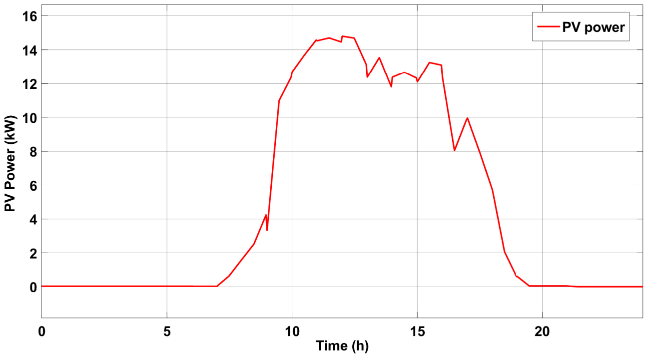


Figure 5: PV power generated on August 17, 2021 in Milan

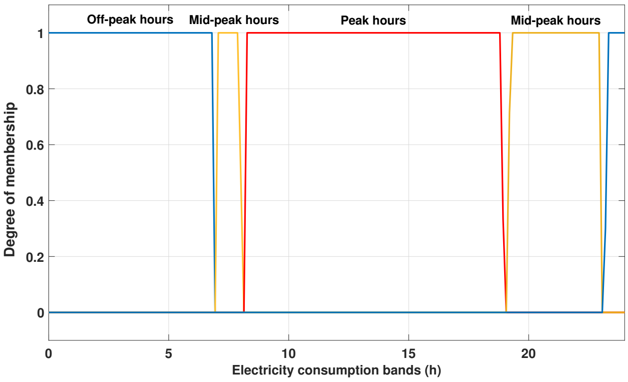


Figure 6: Electricity consumption zones in Milan

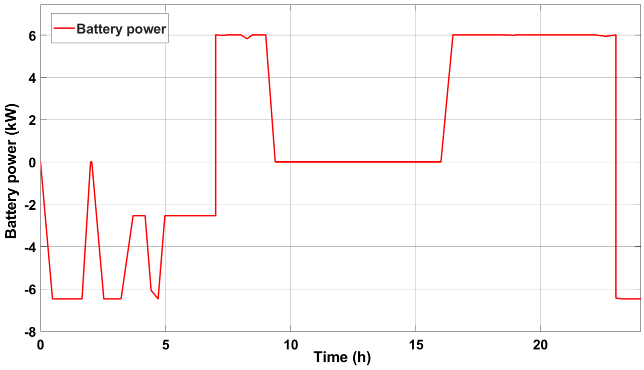


Figure 7: Simulation result of produced battery power

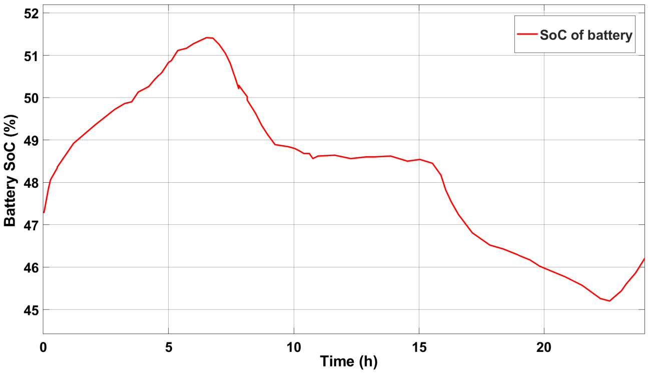


Figure 8: Varying battery SoC

The difference between the load demand $P_{Load}$ and the powers produced by the battery $P_{Bat}$ and PV $P_{PV}$ has been fulfilled by the grid which is calculated using the following equation:

$$P_{Grid} = P_{Load} \pm P_{Bat} - P_{PV} \tag{1}$$

Eq. (1) shows that the BESS acts as a power supply as well as a load depending on the load demand and electricity tariff. The resultant power bought from the grid has been illustrated in fig. (9) which provides three scenarios depending on the zones throughout the day. A comparison of the input and output powers of the system at any time interval between t = 0h to t = 24h verifies the power balance. In fig. (9a), it can be observed during the off-peak hours from t = 0h to t = 7h, the battery is charged with the additional power bought from the grid to fulfil the low load demand while the PV modules produce a negligible power. From t = 7h to t = 8h when the electricity tariff is according to the mid-peak hours, the battery discharges to reduce the input power from the grid and to meet the load demand. Fig. (9b) provides the responses of all the sources to meet the load under peak hours from t = 8h to t = 19h, PV produces maximum power in the early hours during which minimum power is bought from the grid to fulfil the load demand while the battery discharges or remains idle during this time zone to maintain the SoC. During this time when solar power starts to decrease and the electricity tariff is lesser than the peak tariff, battery discharges along with the grid power to meet the load demand. Again, during the mid-peak hours from t = 19h to t = 23h when PV is generating no power, the battery discharges to meet the load demand and during off-peak hours from t = 23h to 24h, the battery charges using the additional power from the grid to exhibit a satisfactory performance the next day as well. The power bought from the grid throughout the day from t = 0h to t = 24h varying with respect to the electricity consumption bands is shown in fig. (10). The shaded area in the graph represents the cost of the bought grid power associated with each time interval given in €/kWh. It can be observed that during peak and mid-peak hours, minimum electricity is bought from the grid depicted in the graph with red and brown curves respectively while most of the load demand is fulfilled with grid power during off-peak hours presented in the graph with the brown curve. The total cost of power bought from the grid has been calculated as given:

$$C_{Total} = \int_{t=0}^{t=24} P_i(t) * C_i \, dt \tag{2}$$

In eq. (2), $P_i(t)$ denotes the power bought in specific electricity consumption slots and $C_i$ is the corresponding electricity tariff provided by Table. (I). The variable $i$ shows the number of electricity consumption bands which is five as illustrated by fig. (6). Finally, the total cost obtained from this fuzzy-based EMS can be calculated by multiplying the respective grid power and electricity tariff in each zone shown in fig. (10) as follows:

$$\begin{aligned} C_{Total} = \int_{t=0}^{t=7} P_1(t) * 0.354 \, dt + \int_{t=7}^{t=8} P_2(t) * 0.361 \, dt \\ + \int_{t=8}^{t=19} P_3(t) * 0.373 \, dt + \int_{t=19}^{t=23} P_4(t) * 0.361 \, dt \\ + \int_{t=23}^{t=24} P_5(t) * 0.354 \, dt \end{aligned} \tag{3}$$

$$C_{Total} = 41.22€$$

Eq. (3) calculates the power bought from the grid and provides an estimate of the minimum power required from the main grid to meet the load demand while keeping the cost minimum under varying solar power as well as maintaining the battery SoC in safe limits.

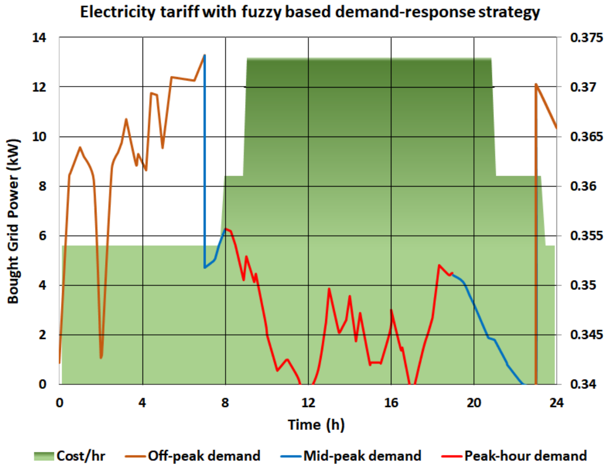


Figure 10: Power bought from the main grid

## V. CONCLUSION

In conclusion, a fuzzy logic-based EMS is designed and implemented in MATLAB and Simulink which improves upon the state of the art by minimizing the retail energy cost to a battery and solar PV microgrid while maintaining the battery state of charge in a healthy range. The fuzzy controller is designed in MATLAB using 34 rules belonging to three or four membership functions among five fuzzy subsets: power demand, PV power, electricity consumption bands, battery power, and curtailed PV power. The case study simulation is performed in Simulink, replicating the topology of the grid-connected Multigood MicrogridLab of Politecnico di Milano and a Milan rate tariff consisting of peak, mid-peak, and off-peak prices and hours. The input simulation time series data is 1-second-interval load demand and solar PV production. The fuzzy logic algorithm charges the battery early in the morning before the retail energy prices increase, and then selectively discharges the battery during peak hours to reduce the energy bought from the grid. Late in the day, the fuzzy logic controller recharges the battery to arrive at the same state of charge as the first timestep. The energy cost is effectively minimized to 41.22€ and the battery SoC is maintained between 45 to 51%. Furthermore, PV power is only curtailed when absolutely necessary, and when load demand is low, below 6kW.

## REFERENCES

[1] G. P. Peters, R. M. Andrew, J. G. Canadell, P. Friedlingstein, R. B. Jackson, J. I. Korsbakken, C. Le Quéré, and A. Peregon, "Carbon dioxide emissions continue to grow amidst slowly emerging climate policies," *Nature Climate Change*, vol. 10, no. 1, pp. 3–6, 2020.

[2] M. Karmellos and G. Mavrotas, "Multi-objective optimization and comparison framework for the design of distributed energy systems," *Energy Conversion and Management*, vol. 180, pp. 473–495, 2019.

[3] J. D. Fonseca, M. Camargo, J.-M. Commenge, L. Falk, and I. D. Gil, "Trends in design of distributed energy systems using hydrogen as energy vector: A systematic literature review," *International journal of hydrogen energy*, vol. 44, no. 19, pp. 9486–9504, 2019.

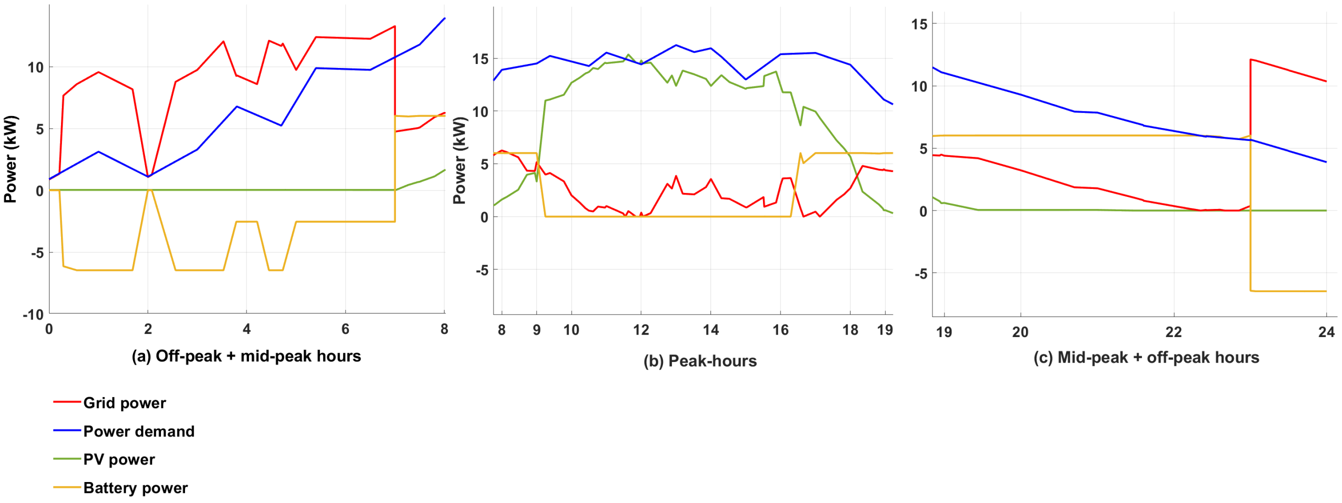


Figure 9: Comparison of input and output powers under varying load demand and electricity tariff for 24 hours.

[4] O. Krishan and S. Suhag, "An updated review of energy storage systems: Classification and applications in distributed generation power systems incorporating renewable energy resources," *International Journal of Energy Research*, vol. 43, no. 12, pp. 6171–6210, 2019.

[5] S. Sahoo, S. Mishra, S. M. Fazeli, F. Li, and T. Dragičević, "A distributed fixed-time secondary controller for dc microgrid clusters," *IEEE Transactions on Energy Conversion*, vol. 34, no. 4, pp. 1997–2007, 2019.

[6] A. Nespoli, S. Leva, M. Mussetta, and E. G. C. Ogliari, "A selective ensemble approach for accuracy improvement and computational load reduction in ann-based pv power forecasting," *IEEE Access*, vol. 10, pp. 32 900–32 911, 2022.

[7] M. Moncecchi, C. Brivio, S. Mandelli, and M. Merlo, "Battery energy storage systems in microgrids: Modeling and design criteria," *Energies*, vol. 13, no. 8, p. 2006, 2020.

[8] N. Stevanato, F. Lombardi, G. Guidicini, L. Rinaldi, S. L. Balderrama, M. Pavičević, S. Quoilin, and E. Colombo, "Long-term sizing of rural microgrids: Accounting for load evolution through multi-step investment plan and stochastic optimization," *Energy for Sustainable Development*, vol. 58, pp. 16–29, 2020.

[9] H. Hajebrahimi, S. M. Kaviri, S. Eren, and A. Bakhshai, "A new energy management control method for energy storage systems in microgrids," *IEEE Transactions on Power Electronics*, vol. 35, no. 11, pp. 11 612–11 624, 2020.

[10] V. S. UNDRE, "Highly renewable energy integrated grid analysis and islanded microgrid balancing by battery energy storage system," 2019.

[11] S. S. Zehra, A. U. Rahman, F. Grimaccia, A. Niccolai, and M. Mussetta, "Neuro-fuzzy based energy management of pv-fc based grid-connected microgrid for e-mobility," in *2022 IEEE International Conference on Environment and Electrical Engineering and 2022 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)*. IEEE, 2022, pp. 1–6.

[12] F. B. Armani, F. Grimaccia, S. Leva, and M. Mussetta, "Seamless grid: An off-chain model proposal for scalable p2p electricity markets and grids management," in *2019 IEEE Milan PowerTech*. IEEE, 2019, pp. 1–6.

[13] S. A. Mansouri, E. Nematbakhsh, A. Ahmarinejad, A. R. Jordehi, M. S. Javadi, and M. Marzband, "A hierarchical scheduling framework for resilience enhancement of decentralized renewable-based microgrids considering proactive actions and mobile units," *Renewable and Sustainable Energy Reviews*, vol. 168, p. 112854, 2022.

[14] A. Abbasi, K. Sultan, M. A. Aziz, A. U. Khan, H. A. Khalid, J. M. Guerrero, and B. A. Zafar, "A novel dynamic appliance clustering scheme in a community home energy management system for improved stability and resiliency of microgrids," *IEEE Access*, vol. 9, pp. 142 276–142 288, 2021.

[15] S. Leonori, A. Martino, F. M. F. Mascioli, and A. Rizzi, "Microgrid energy management systems design by computational intelligence techniques," *Applied Energy*, vol. 277, p. 115524, 2020.

[16] Y. Han, X. Ning, P. Yang, and L. Xu, "Review of power sharing, voltage restoration and stabilization techniques in hierarchical controlled dc microgrids," *IEEE Access*, vol. 7, pp. 149 202–149 223, 2019.

[17] S. A. G. K. Abadi, S. I. Habibi, T. Khalili, and A. Bidram, "A model predictive control strategy for performance improvement of hybrid energy storage systems in dc microgrids," *IEEE Access*, vol. 10, pp. 25 400–25 421, 2022.

[18] P. Aaslid, M. M. Belsnes, and O. B. Fosso, "Optimal microgrid operation considering battery degradation using stochastic dual dynamic programming," in *2019 International Conference on Smart Energy Systems and Technologies (SEST)*. IEEE, 2019, pp. 1–6.

[19] D. Arcos-Aviles, J. Pascual, F. Guinjoan, L. Marroyo, G. Garcia-Gutierrez, R. Gordillo-Orquera, J. Llanos-Proaño, P. Sanchis, and T. E. Motoasca, "An energy management system design using fuzzy logic control: Smoothing the grid power profile of a residential electro-thermal microgrid," *IEEE access*, vol. 9, pp. 25 172–25 188, 2021.

[20] M. Rodriguez, D. Arcos-Aviles, J. Llanos, A. Salazar, F. Guinjoan, E. Motoasca, and W. Martinez, "Fuzzy-based energy management system for isolated microgrids using generation and demand forecast," in *2021 23rd European Conference on Power Electronics and Applications (EPE'21 ECCE Europe)*. IEEE, 2021, pp. 1–10.

[21] F. J. Vivas, F. Segura, J. M. Andújar, A. Palacio, J. L. Saenz, F. Isorna, and E. López, "Multi-objective fuzzy logic-based energy management system for microgrids with battery and hydrogen energy storage system," *Electronics*, vol. 9, no. 7, p. 1074, 2020.

[22] A. Fathy, S. Ferahtia, H. Rezk, D. Yousri, M. A. Abdelkareem, and A. Olabi, "Optimal adaptive fuzzy management strategy for fuel cell-based dc microgrid," *Energy*, vol. 247, p. 123447, 2022.

[23] F. Vivas, F. Segura, and J. Andújar, "Fuzzy logic-based energy management system for grid-connected residential dc microgrids with multi-stack fuel cell systems: A multi-objective approach," *Sustainable Energy, Grids and Networks*, vol. 32, p. 100909, 2022.

[24] R. Khezri, A. Mahmoudi, and M. H. Haque, "A demand side management approach for optimal sizing of standalone renewable-battery systems," *IEEE Transactions on Sustainable Energy*, vol. 12, no. 4, pp. 2184–2194, 2021.

[25] D. Arcos-Aviles, C. Vega, F. Guinjoan, L. Marroyo, and P. Sanchis, "Fuzzy logic controller design for battery energy management in a grid connected electro-thermal microgrid," in *2014 IEEE 23rd international symposium on industrial electronics (ISIE)*. IEEE, 2014.

[26] "Multigood microgrid lab, politecnico di milano," accessed on February 21st, 2023. [Online]. Available: https://www.mg2lab.polimi.it/

[27] E. Pourjavad and A. Shahin, "The application of mamdani fuzzy inference system in evaluating green supply chain management performance," *International Journal of Fuzzy Systems*, vol. 20, pp. 901–912, 2018.