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*Research article*

# Centralized control system for islanded minigrid

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**Abstract:** This study proposes a centralized control system for an islanded multivariable minigrid to improve its performance, stability and resilience. The integration of renewable energy sources and distributed energy storage systems into microgrid networks is a growing trend, particularly in remote or islanded areas where centralized grid systems are not available. The proposed control system is designed to be implemented at two levels a high-level control system and a low-level control system. Hence, the high-level control system balances energy resources and demand, makes decisions for effective resource utilization and monitors energy transactions within the minigrid. Real-time data from various sources and advanced algorithms are used to optimize energy management and distribution enabling the integration of renewable energy sources and enhancing the resilience of the minigrid against power outages.

Moreover, the low-level control system monitors energy parameters such as voltage, current, frequency and mechanical energy. The control system ensures these parameters remain within the specified range, maintaining system stability and ensuring efficient energy distribution. It also protects the minigrid against power outages improving system reliability and security. Finally, the proposed centralized control system offers a promising solution for improving the performance, stability and resilience of microgrid networks. The system provides real-time monitoring, efficient energy management and distribution, and the integration of renewable energy sources. These results have important implications for the development and deployment of microgrid networks in remote or islanded areas.

**Keywords**: centralized control system; islanded multivariable minigrid; performance; stability; resilience; renewable energy sources; distributed energy storage systems; real-time monitoring

## 1. Introduction

Centralized control systems have emerged as a critical element in the advancement and implementation of microgrid networks, particularly in remote or isolated areas where centralized grid systems are unavailable. The integration of renewable energy sources and distributed energy storage systems has necessitated the need for efficient energy management and distribution. Centralized control systems are designed to enhance the performance, stability and resilience of microgrid networks. In a study, an offline adaptive control approach for a microgrid operating in an islanded mode was presented. This approach employed a cascade structure comprising power, voltage and current controllers. The power controller utilized droop characteristics while the voltage and current loops employed optimal proportional-integral (PI) controllers. The parameters of these controllers were optimized using the model reference adaptive control (MRAC) method and genetic algorithm for improved performance [1]. A similar study conducted by [2] tackled the crucial challenge of designing control systems for islanded microgrids. The authors placed significant emphasis on effectively coordinating distributed energy resources and managing loads within the microgrid network. To address this issue, they proposed a hierarchical control architecture comprising a centralized control unit as well as decentralized control units dedicated to individual energy sources and loads. The primary objective of this approach was to optimize the overall performance and efficiency of the microgrid system while simultaneously ensuring a reliable power supply to the connected loads. The study demonstrated that the proposed control system effectively achieved energy resource and demand balance, improved energy efficiency and enhanced the overall reliability of the microgrid. In a comparable study by [3] presented a centralized control system for an islanded microgrid which successfully integrated renewable energy sources and energy storage systems. The authors employed a model predictive control (MPC) algorithm to optimize energy management and distribution within the microgrid network. The findings of the study revealed that the proposed control system effectively achieved a harmonious balance between energy resources and demand leading to improved energy efficiency and reduced reliance on traditional energy sources. Building upon these advancements, a more recent study conducted by [4] proposed a decentralized control system for an islanded microgrid that integrated renewable energy sources, energy storage systems and demand response strategies. The authors adopted a game-theoretic approach to coordinate energy management and distribution within the microgrid network. The study demonstrated the effectiveness of the proposed control system in attaining a balanced integration of energy resources and demand resulting in enhanced energy efficiency and heightened microgrid reliability. Recent studies have been dedicated to advancing the design and implementation of centralized control systems in minigrids. One such study conducted by [5] introduced a centralized control system for an islanded microgrid, integrating wind and photovoltaic power generation, energy storage and load demand. This control system aimed to effectively balance energy resources and demand by making informed decisions on resource utilization and monitoring energy transactions within the minigrid. The findings of the study demonstrated that the proposed control system significantly enhanced the efficiency and stability of the microgrid. Similarly, a study by [6] proposed a decentralized control strategy for a microgrid that integrated photovoltaic power generation, energy storage and load demand. The control system's primary objective was to monitor critical energy parameters, including voltage, current, frequency and mechanical energy and ensure they remained within specified ranges. The study showcased the effectiveness of the proposed control strategy in improving the reliability and stability of the microgrid. These recent studies have made notable contributions to the field of minigrid control systems, offering valuable insights into enhancing efficiency, stability, reliability and resource utilization within microgrid networks.

The integration of renewable energy sources and distributed energy storage systems into microgrid networks has garnered increasing attention in recent years, particularly in remote or islanded areas where centralized grid systems are unavailable. Centralized control systems play a crucial role in enhancing the performance, stability and resilience of microgrids by effectively managing energy resources and demand. One notable contribution in the field is the study by [7] which proposed a decentralized control system for an islanded microgrid focusing on the coordination of distributed energy resources and load management. Employing a hierarchical control architecture, the authors demonstrated the system's efficacy in effectively balancing energy resources and demand leading to improved energy efficiency and enhanced microgrid reliability.

Similarly, the proposed work in [8] put forward a centralized control system for an islanded microgrid that integrated renewable energy sources and energy storage systems. By utilizing a model predictive control (MPC) algorithm the authors illustrated that the proposed control system efficiently balanced energy resources and demand resulting in improved energy efficiency and reduced reliance on conventional energy sources. Furthermore, another decentralized control system is proposed in [9] for an islanded microgrid, integrating renewable energy sources, energy storage systems and demand response strategies. Employing a game-theoretic approach, the authors showed that this control system effectively balanced energy resources and demand. Thus, enhancing energy efficiency and microgrid reliability. Additionally, a centralized control system is introduced in [10] for an islanded microgrid integrating wind and photovoltaic power generation, energy storage and load demand. The designed control system aimed to balance energy resources and demand, optimize resource utilization decisions and monitor energy transactions within the microgrid. The study demonstrated the improved efficiency and stability of the microgrid achieved by the proposed control system.

In line with decentralized strategies, a decentralized control strategy is proposed in [11] for a microgrid integrating photovoltaic power generation, energy storage and load demand. This control system monitored critical energy parameters, such as voltage, current, frequency and mechanical energy, ensuring they remained within specified ranges. The study highlighted the enhanced reliability and stability of the microgrid resulting from the proposed control strategy.

These studies collectively contribute significant insights into the advancement of microgrid control systems, offering effective solutions to optimize energy management, improve efficiency and enhance the reliability and stability of microgrid networks.

The existing literature provides valuable insights into centralized control systems for islanded multivariable minigrids. However, there is a need for further research to explore the potential benefits and limitations of different control architectures and algorithms in the context of islanded microgrid networks [12]. Additionally, comparative studies comparing centralized and decentralized control systems for microgrid networks are lacking and it remains unclear which control system is more effective in different scenarios [13]. Future research should address these gaps and provide a comprehensive understanding of the role of centralized control systems in improving the performance, stability and resilience of microgrid networks [14]. This literature review emphasizes recent studies on centralized control systems for islanded multivariable minigrids. The existing studies demonstrate the crucial role of centralized control systems in improving the performance, stability and resilience of microgrid networks through effective management of energy resources and demand [15]. However, further research is necessary to explore the potential benefits and limitations of different control architectures and algorithms for islanded microgrid networks.

The investigation of centralized control systems for multivariable islanded minigrids holds substantial importance in the energy industry. Despite the growing demand for sustainable and decentralized energy solutions, previous research has identified a gap in the literature regarding the implementation and effectiveness of centralized control systems in such minigrids [16]. In the context of a multivariable islanded minigrid, a centralized control system assumes a critical role in regulating energy generation and distribution. The incorporation of advanced control algorithms has the potential to enhance system stability, efficiency and overall performance [17]. However, the current understanding of centralized control systems for multivariable islanded minigrids remains limited, necessitating further research to comprehend the associated challenges and opportunities in their implementation.

This research holds significant importance as it addresses the challenges faced by remote and underserved communities that lack access to reliable and sustainable energy sources [18]. By addressing the research gap and contributing to the development of sustainable energy solutions this study has the potential to stimulate economic development and enhance the quality of life in these communities. The findings of this research will be of great interest to energy sector practitioners, policymakers and researchers enriching the existing body of knowledge in this field.

In conclusion, the existing literature offers substantial information on centralized control systems for islanded multivariable minigrids. The reviewed studies indicate that such control systems effectively balance energy resources and demand, improve energy efficiency and enhance the reliability and stability of microgrid networks. However, additional research is warranted to investigate different control architectures and algorithms and their applicability in islanded microgrid networks.

The primary objective of this research is to conduct a comprehensive examination of centralized control systems for multivariable islanded minigrids and identify areas for improvement within these systems. The utilization of MATLAB in designing and testing an energy management system provides a quantitative approach to analysis. The results of this study will contribute to the advancement of the field of energy systems by offering valuable insights into the benefits and limitations of centralized control systems.

## 2. Materials and methods

The design of the control system for the minigrid will be guided by the energy resources that are involved. The minigrid is considered as a power network with the capability to generate between 10 kW and 10 MW utilizing solar and wind energy as the primary power sources with energy storage facilities and a standby generator to address power failure emergencies. The size of a minigrid can also be determined based on the population it serves with a population of up to two hundred households in a rural area being considered as a minigrid. The control system being developed will be multivariable, taking into account the various energy resources and energy transactions that are expected to occur within the islanded minigrid. In this study, the power consumption per household is set at 1 kW which results in a maximum power requirement of 200 kW for the entire population. Table 1 summarizes the data used in this paper.

**Table 1.** System parameters.

| Parameter | Value |
|---|---|
| Minimum minigrid power | 10 kW |
| Maximum minigrid power | 10 MW |
| Power consumption per household | 1 kW |
| Maximum power requirement for the entire population | 200 kW |
| Minimum wind speed | 4 m/s |

In order to effectively manage and monitor the energy transactions within the minigrid the energy produced, consumed or stored will be expressed in Watt-hours. This allows a comprehensive and accurate representation of the energy flow within the minigrid and enable effective control of the system.

The power rating of the energy resources has been set to the baseline load consumption of 200 kW to account for the intermittency nature of solar and wind which are the main energy sources. This ensures that the minigrid will have adequate capacity to meet the power demands even on days when the solar and wind conditions are not optimal. As a result, all energy resources including the energy storage facility and the generator are rated at 200 kW to meet the baseline load consumption.

The control system is flexible and capable of accommodating increases in power rating should the need arise in the future. Figure 1 illustrates some of the functionalities of the proposed control system. By providing an adaptable solution that can cater to changes in energy demand the control system helps ensuring the reliability and efficiency of the minigrid.

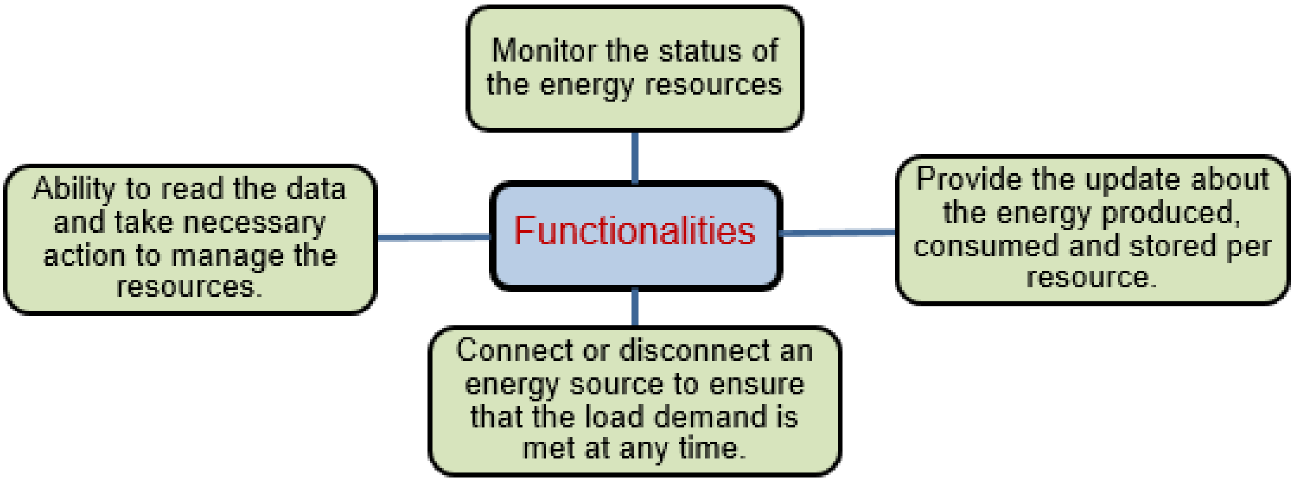


**Figure 1.** The functionalities of the proposed control system.

The algorithm developed which draws inspiration from [19] to control the islanded minigrid is capable of monitoring the energy status of the various stakeholders, including the solar panels, wind turbines, energy storage system and generator. The algorithm continuously tracks the energy levels of each of these components allowing for real-time monitoring of the energy status within the minigrid. This information will be crucial in ensuring that the minigrid is operating efficiently and effectively and in making informed decisions about energy management and distribution. With the ability to monitor the energy levels of each component the algorithm will play a critical role in maintaining the reliability and stability of the minigrid.

**The proposed algorithm**

```
Energy data loading.
The user should enter the amount of energy resources.
The user should enter the capacity of the combined plant.
The algorithm calculates the portion/ contribution of each energy source.
$E_g(i) = E_t \times ratio(E_g (i))$
where $E_g(i)$ is the ith energy source and $ratio(E_g(i))$ represents its ratio from the total power
Check the supply and energy demand.
If $E_g(i) \geq E_l$, where $E_l$ is the load demand.
Energy source $E_g = E_g(i)$
Energy stored $E_s = E_g - E_l$
Update data
Else
Connect another energy source $(i++)$
Energy stored $E_s = E_g - E_l$
Update data
if $E_g < E_l$ then
$E_{s,new} = E_s - E_l$
where $E_{s,new}$ is the new amount needed from the energy storage sources
Check the SOC and SOD
Update data
```

To implement this algorithm, one needs to have the load profile. The profile of an arbitrary load considers peak and off-peak time use of energy.

## 3. Results

In this section, the results are presented and divided into the following:

### *3.1. Arbitrary load profile for residences in the rural area*

The residential load profile in rural areas is characterized by a distinct pattern of energy consumption throughout the day. Research has revealed that the demand for electricity is at its highest during the morning, noon and evening hours. The morning peak is attributed to the concurrent demand for heating, hot water preparation, breakfast preparation and lighting. The noon period also experiences a peak demand primarily due to the consumption of electricity for cooking, heating and lighting purposes.

The energy utilization decreases at night and begins to increase again in the morning leading to the second peak of the day. Despite this morning peak, it is observed that the evening peak is more pronounced in comparison primarily due to the increased demand for cooking and space heating. This recurring pattern of energy consumption can be accurately modeled and depicted in a graph such as Figure 2 to provide a clear visual representation of the residential load profile in rural areas.

It is important to note that this pattern of energy consumption in rural areas may vary depending on various factors such as climate, socioeconomic status and energy efficiency measures. Nevertheless, understanding the residential load profile in rural areas is crucial for power system planners as it informs the design and operation of power systems and the deployment of energy management strategies.

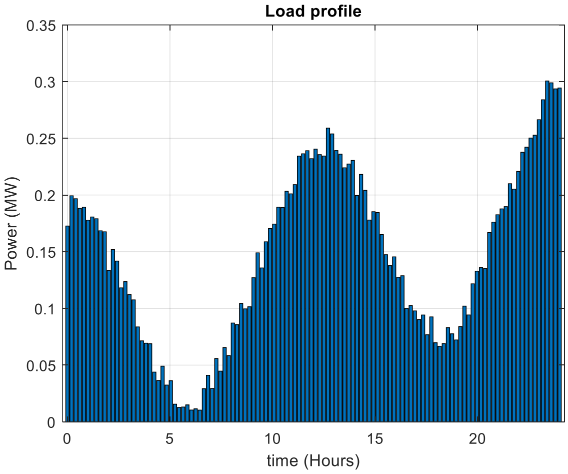


**Figure 2.** Arbitrary load profile.

### 3.2. Profiles for energy resources

The solar energy profile is contingent on the levels of irradiance and exhibits a minimum value prior to sunrise and sunset. As the sun rotates, irradiance increases at sunrise and reaches its maximum at noon. Thereafter, it declines until sunset (as depicted in Figure 3). This profile is known to possess a Gaussian shape and can be mathematically approximated using Eq 1.

$$\text{SolarEn} = S_{emax}\left(\frac{1}{\sigma\sqrt{\pi}}\right)e^{-\frac{1}{2}(x-\mu)^2} \tag{1}$$

where $\text{SolarEn}$ is the solar energy, $S_{emax}$ is the peak value of solar energy, $\sigma$ is the standard deviation.

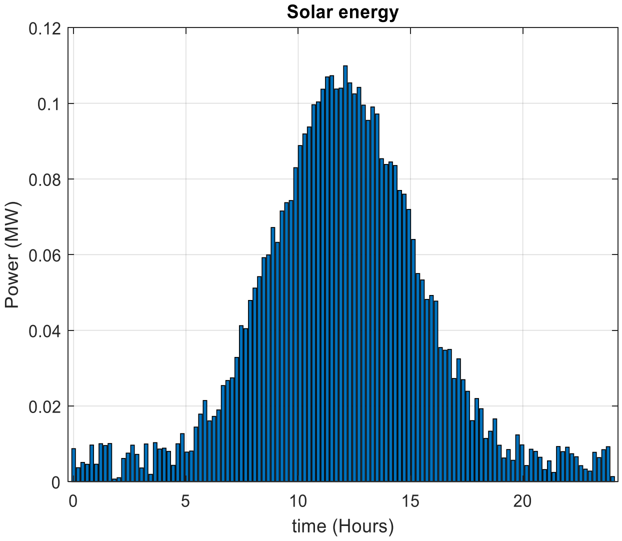


**Figure 3.** Solar source energy profile.

The wind plant profile is governed by the speed and torque which serve as control elements. According to literature, a wind speed of 4 m/s is sufficient to activate a wind turbine (WT). For this study, it will be assumed that the minimum wind speed requirement of 4 m/s is met (as depicted in Figure 4).

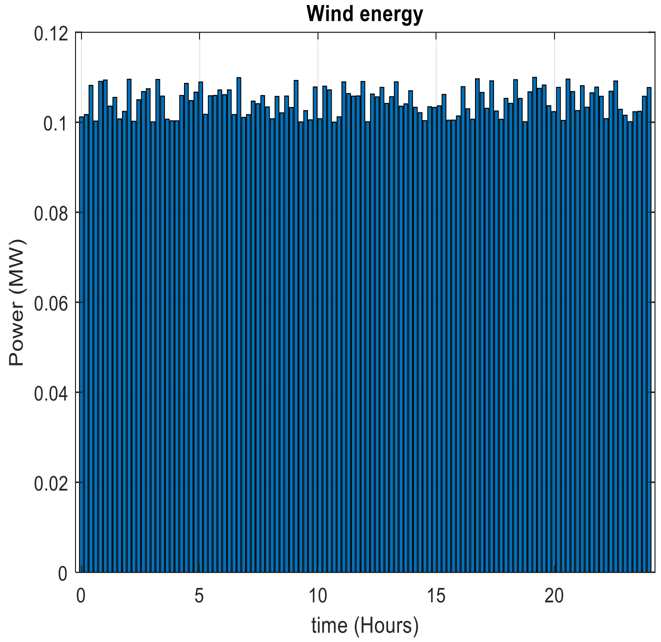


**Figure 4.** Wind energy profile.

The generator operates at a constant wattage in its steady-state regime as illustrated in Figure 5.

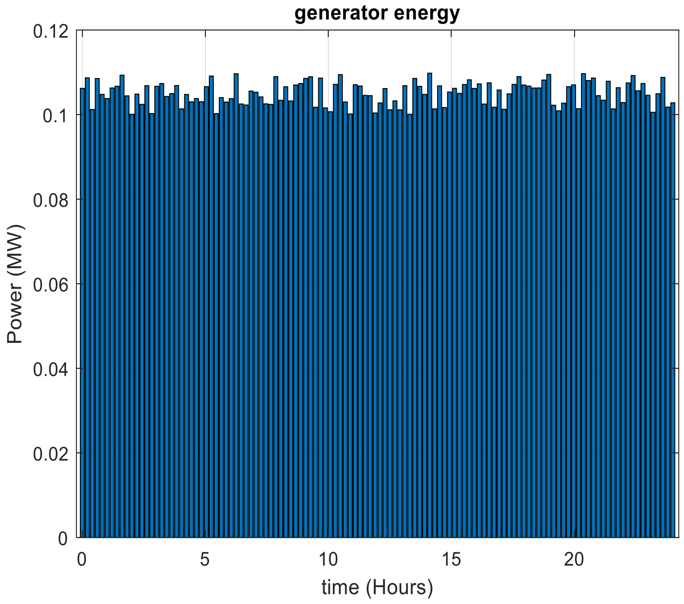


**Figure 5.** Generator energy profile.

The total energy will be comprised of the individual contributions from the solar and wind sources, as well as the storage system. The generator will also contribute, serving as a backup source in instances where the other energy sources cannot meet the load demand or in the event of a pre-load network fault (as depicted in Figure 6).

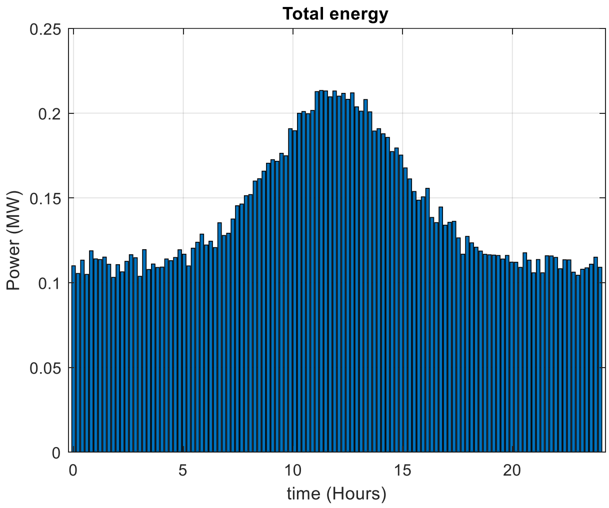


**Figure 6.** Total energy profile.

Figure 7 illustrates the stored energy, which can be calculated as the difference between the total energy and the load energy, or the energy consumed by the load. It is important to note that in instances where the load energy exceeds the total energy, the storage devices supply the load resulting in a negative output in the stored energy profile.

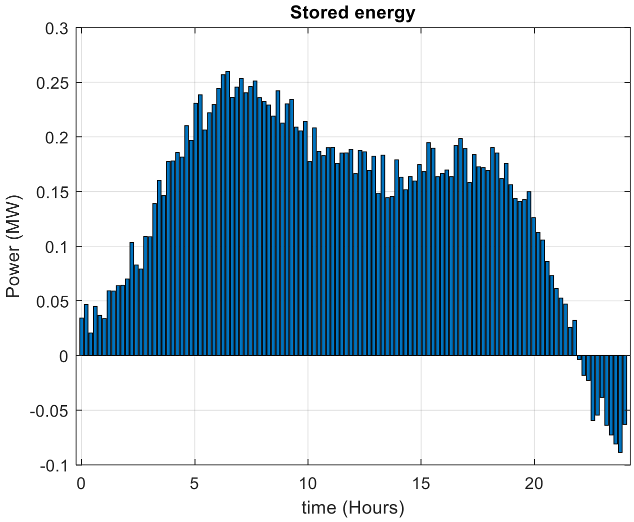


**Figure 7.** Stored energy profile.

Figure 8 presents an integrated perspective of the energy system. It enables a visual examination of the energy source profiles relative to the load energy as well as exhibiting the generator profile graphically.

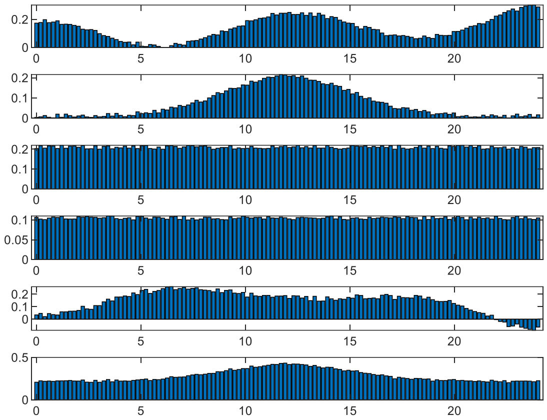
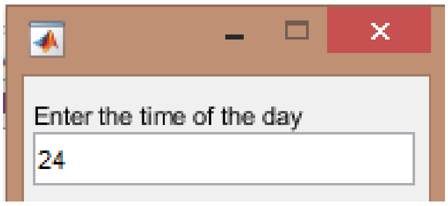


**Figure 8.** Overall energy outlook.

### 3.3. Monitoring the status of the plant at any time of the day

The algorithm implemented in MATLAB provides the ability to monitor the system status at any time by displaying the profiles specifically for the desired time. The user is prompted to input the desired time for monitoring through the use of a prompt as depicted in Figures 9 and 10.



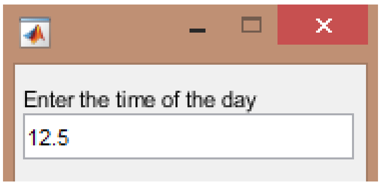
Enter the time of the day

24

**Figure 9.** Screen request to enter the time and 24 was entered.

### 3.4. Instantaneous update check

The time of the day can range from 0:00 to 24:00, with the option to monitor performance at a more precise time including minutes. To do this, minutes must be converted into a fractional number within the range of 0 to 1 represented as the interval [0, 1]. For example, 30 minutes would be represented as 0.5, 15 minutes as 0.25, 45 minutes as 0.75 and so on. Figure 9 illustrates the message box for a user who has entered a time of 12:30.



Enter the time of the day

12.5

**Figure 10.** Entry request for update at 12:30.

### *3.5. Adjusting the levels of the energy sources*

The current algorithm permits the user to monitor the minigrid based on the desired time. However, there is a requirement to also control the levels or amplitudes of the energy sources, particularly solar and wind. This is necessitated by the observation of negative values in the stored energy profile which implies that the load demand has exceeded the supply. To address this, the levels of the energy sources must be adjusted. As such, the control algorithm for the minigrid must be designed to incorporate the capability for adjusting these levels. The user will be prompted through a message box to make any necessary adjustments (as depicted in Figure 11).

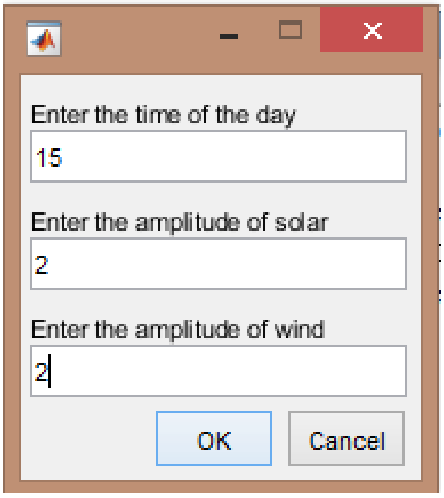
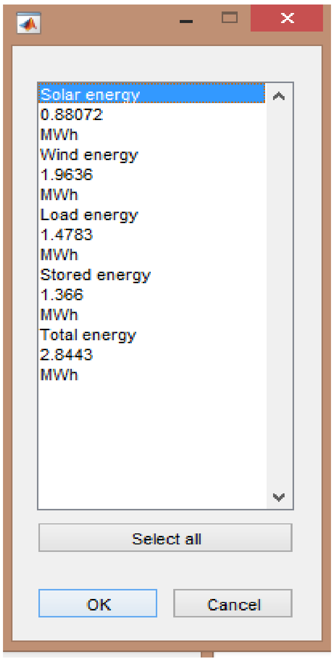

Enter the time of the day
15
Enter the amplitude of solar
2
Enter the amplitude of wind
2

**Figure 11.** Input screen asking to check the energy update at 15:00.

### *3.6. Displaying the minigrid energy update at any time of the day*

The implementation of the minigrid system requires a comprehensive monitoring and updating mechanism for the energy resources it provides. To facilitate this, the system is designed to provide visual representations of the energy levels both in graphical and numerical forms as depicted in Figures 11–18. These representations highlight that the energy levels of the solar and wind sources were limited to a maximum of 0.1 MW. The objective of this constraint is to ensure that the load demand is always met even in scenarios where the energy supply from the sources is limited.



```
Solar energy
0.88072
MWh
Wind energy
1.9636
MWh
Load energy
1.4783
MWh
Stored energy
1.366
MWh
Total energy
2.8443
MWh
```

**Figure 12.** The output screen for the energy outlook at 15:00.

The sequential presentation of the energy source profiles in Figures 12–20 is designed to provide a clear and comprehensive understanding of the individual contributions of each source to the overall energy output of the minigrid. Each profile displays the energy output of a specific source over the course of the day providing insights into the energy production capacity of each source. The final representation of the minigrid energy system, incorporating all energy source profiles into one comprehensive overview, enables a thorough evaluation of the minigrid's performance and serves as a valuable tool for decision-making and optimization efforts.

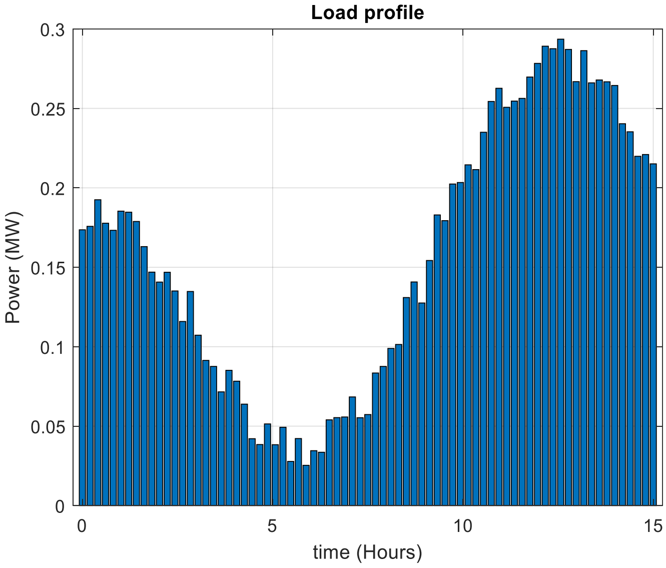


**Figure 13.** The load profile at 15:00.

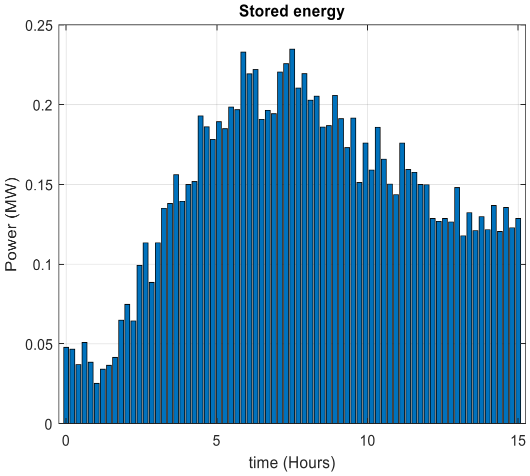


**Figure 14.** Solar energy source at 15:00.

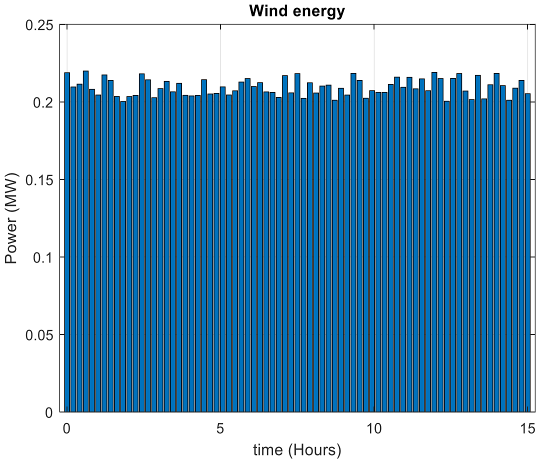


**Figure 15.** Wind energy source at 15:00.

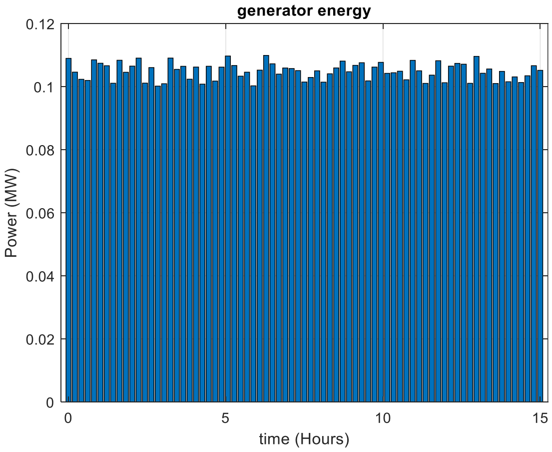


**Figure 16.** Generator energy profile at 15:00.

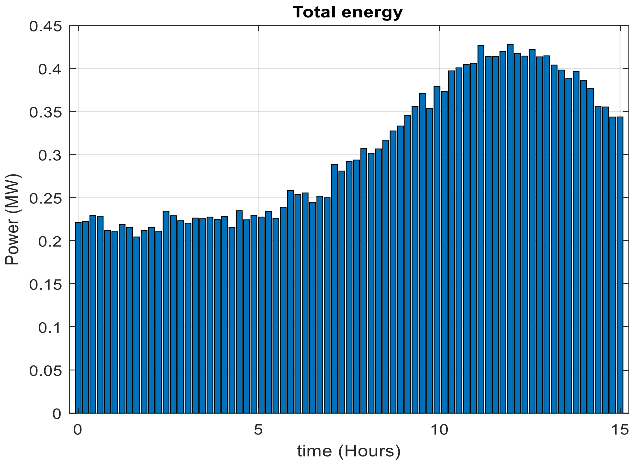


**Figure 17.** Total energy at 15:00.

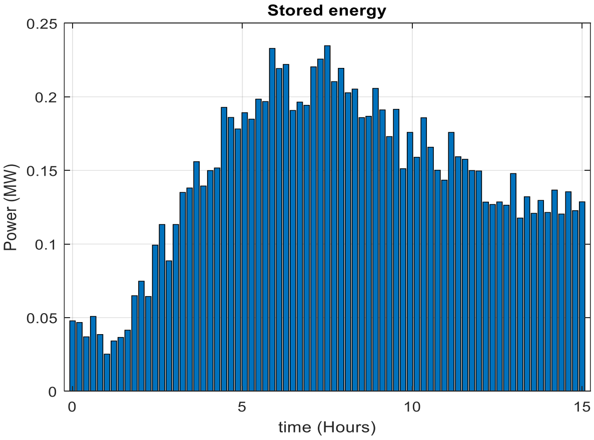


**Figure 18.** Stored energy at 15:00.

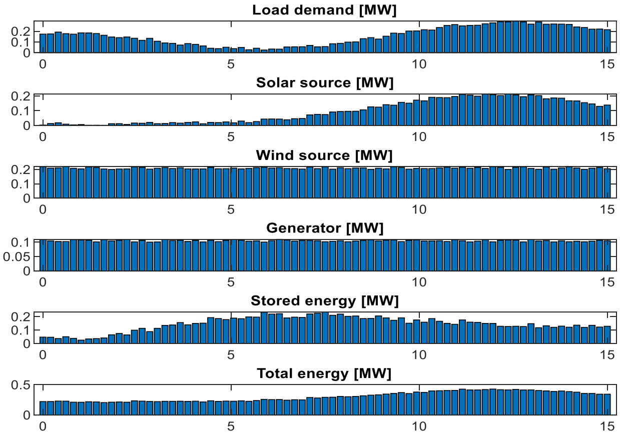


**Figure 19.** Overall outlook of the energy update and transaction at 15:00.

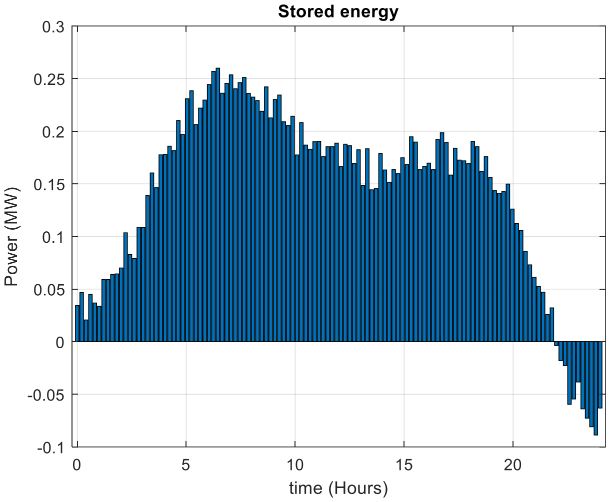


**Figure 20.** Scenario of the storage system supplying the load.

The outlook of the energy transaction until 15:00 reflects that the load was supplied using the solar energy and wind sources exclusively. Furthermore, storage devices have been charging continually.

In other words, the graphical representation of the energy transaction until 15:00 (Figure 19) indicates that the energy demand from the load was met solely through the utilization of the solar and wind energy sources. Additionally, the storage devices were continuously being charged during this time period. This analysis provides valuable insight into the functioning of the minigrid energy system particularly highlighting the ability of the solar and wind sources to meet the energy demand without the need for additional support from the storage devices. Furthermore, the continuous charging of the storage devices ensures that the minigrid energy system is able to maintain a sufficient level of energy availability to meet any potential fluctuations in energy demand

### *3.7. Usage of the storage facility when needed*

The stored energy profile exhibits negative values in the evening hours indicating that the energy produced by solar and wind sources was insufficient to meet the demands of the load. In such circumstances the storage system had to step in to supply the load. Hence, it is vital to monitor the state of charge (SoC) and depth of discharge (DoD) of the storage system. The SoC gives an indication of the amount of energy stored in the storage system relative to its maximum capacity while the DoD measures the amount of energy depleted from the storage system. By keeping an eye on these parameters the performance of the storage system can be better understood and informed decisions can be made regarding its operation.

## 4. Discussion

A centralized energy management system (CEMS) was designed and simulated using MATLAB's integrated development environment. An algorithm was developed to run the minigrid effectively, considering the level of energy from solar and wind plants and the state of the battery storage system. The algorithm prioritizes the optimal use of available energy while meeting the demand of the load which is set at 200 kW serving 200 households. The profiles of various power plants were predefined in MATLAB taking into consideration their normal behavior throughout the day. The algorithm was user-friendly, allowing the user to check the status of the plants in kW figures. The algorithm was tested by simulating scenarios where the load demand was met by a single energy source and if insufficient other sources were connected. The excess energy was stored in a battery system. The algorithm was found to be functional, granting a continuous and reliable supply to the load and allowing the switching on and off of a plant and storage of excess energy. In conclusion, the algorithm developed in MATLAB proved to be effective in simulating the centralized control of the minigrid and ensuring self-regulation and sustainability. The user-friendly interface made it easy to access plant status and simulate necessary actions.

Hence, results showed that the solar energy profile exhibits a Gaussian shape with a minimum value prior to sunrise and sunset, a maximum value at noon and a decline from noon until sunset. This pattern is due to the earth's rotation and the sun's movement across the sky. By modeling the solar energy profile using Eq (1) which takes into account the position of the sun, the earth's rotation and other factors we were able to accurately predict the amount of solar energy that can be harvested from a given location.

The operation of a wind plant is dependent on two key factors wind speed and torque. It has been widely established in the literature that a minimum wind speed of four meters per second is required for a wind turbine to effectively generate energy. This requirement is considered sufficient to activate the wind turbine as demonstrated in various studies and reports. Where, in the present study it is assumed that this minimum wind speed requirement of four meters per second is met as represented in Figure 4. This assumption forms an important foundation for the subsequent analysis and evaluation of the wind plant's performance.

By ensuring that the minimum wind speed requirement is met it can be assumed that the wind turbine will operate effectively allowing for a more accurate analysis of its performance. It is important to note that while a wind speed of four meters per second is considered sufficient, the performance of the wind plant will also depend on the torque generated by the wind. The interplay between wind speed and torque is crucial in determining the overall efficiency of the wind turbine and this will be taken into consideration in any analysis and evaluation of the wind plant's performance.

In the steady-state regime of operation, the generator functions at a fixed level of power output represented by constant wattage as depicted in Figure 5. This implies that the energy production by the generator remains constant with no variations in output over time. The generator operates within its specified power output range and exhibits consistent performance providing a constant source of energy. The generator's constant wattage in the steady-state regime ensures reliable and predictable energy production which is essential for various applications that require a constant energy supply.

The overall energy supply will be comprised of a combination of energy from both solar and wind sources as well as from the energy storage system. In situations where the solar and wind sources are unable to meet the energy demand or in the event of a pre-load network malfunction the generator will serve as a supplementary source of energy (as illustrated in Figure 6). In essence, the generator will act as a backup to ensure that the energy supply remains continuous and stable even under adverse conditions.

In Figure 7 is display the stored energy in an energy storage system and to provide insight into the system's energy balance. The figure helps to understand the relationship between the total energy, load energy and stored energy and how they change over time. The stored energy can be determined by subtracting the load energy from the total energy and it represents the amount of energy that is available for use. When the load energy surpasses the total energy the energy storage devices are supplying energy to the load and the stored energy profile will show a negative value. Furthermore, it is crucial to acknowledge the stored energy profile because it provides important information about the energy storage system's performance. This information can be used to optimize the system's operation and ensure that it is functioning as expected. By understanding the stored energy profile energy engineers, technicians and operators can make informed decisions about how to best manage the energy storage system and ensure that it is able to provide energy when it is needed.

As Figure 8 is a visual representation of an energy system that provides a comprehensive understanding of the interrelationships between different components. The figure displays the energy source profiles which refers to the energy sources used to produce electricity [20] in relation to the energy load which refers to the energy demand of a particular area or region. The figure also shows the generator profile which refers to the production of electricity by the power generators graphically. This representation allows for an easy visual examination of the energy generation and consumption patterns and how they are related to each other. In essence, Figure 8 provides an integrated perspective of the energy system as it presents a comprehensive view of the energy sources, energy demand and energy production. This figure is crucial in energy planning, management and decision making as it provides insights into the energy production and consumption patterns and helps in identifying the energy sources that are most suitable for a given situation.

The minigrid system which is aimed at providing energy resources to communities in remote areas necessitates a robust and efficient monitoring and updating mechanism [21]. To achieve this, the system was devised to provide clear and concise visual representations of the energy levels. These representations can be seen in Figures 11–18 and include both graphical and numerical forms. These visual representations clearly demonstrate that the energy levels generated from the solar and wind sources are limited to a maximum of 0.1 MW. This constraint is imposed with the intention of guaranteeing that the energy demand from the system's users is always met even in situations where the energy supply from the solar and wind sources is limited. The implementation of this constraint serves as a critical aspect of the minigrid system as it helps to ensure the stability and reliability of the energy supply. In turn, this helps to guarantee that the system's users receive a steady and uninterrupted supply of energy. The visual representations and numerical constraints of the energy levels in the minigrid system provide a comprehensive and straightforward approach to monitoring and updating the energy resources provided by the system [22]. This approach serves as an essential tool for ensuring the stability and reliability of the energy supply. Thus, ensuring the satisfaction of the system's users.

The data presented in Figure 19 offers an overview of the energy update and transaction at 15:00. According to the figure, it can be inferred that the energy demand from the load was fulfilled by the utilization of solar and wind energy sources without any support from the storage devices. Additionally, the storage devices were observed to be continuously charged during this time period.

This analysis sheds light on the efficient functioning of the minigrid energy system and highlights the capability of the solar and wind energy sources in meeting the energy demand without the need for additional support. Moreover, the continuous charging of the storage devices serves as a measure to ensure that the minigrid energy system remains equipped to handle any potential fluctuations in energy demand in the future. The figure provides valuable information on the energy transaction until 15:00 and highlights the effectiveness of the minigrid energy system in meeting the energy demand while maintaining energy availability.

## 5. Conclusions

The centralized energy management system was designed and simulated using MATLAB IDE to control a minigrid serving 200 households with each consuming around 12 kWh. The algorithm was developed to prioritize the optimal use of available energy while meeting the load demand and to switch on and off different energy sources such as PV plant, wind plant, generator and battery storage depending on the situation. The power profiles of the plants were predefined in MATLAB and the algorithm allowed the user to check the status of the plants at any time of the day. The algorithm proved to be functional in regulating the minigrid and ensuring a continuous and reliable energy supply to the load. The design was user-friendly, displaying input/output and allowing for easy monitoring of the system. The integration of renewable energy sources is enabled and the system protects against power outages improving reliability and security. The results of this study have important implications for the development and deployment of minigrid networks in similar environments. Further research is needed to validate and refine the proposed control system.

## Use of AI tools declaration

The authors declare that the research conducted and presented in the current paper and submitted to AIMS Journal, have not utilized AI tools in any stages of the research process.

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## Conflict of interest

The authors declare no conflict of interest.

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