

Energy Supply and Scheduling for a DC Microgrid-Integrated Electric Vehicle Charging Station

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Abstract- The recent surge in electric vehicle (EV) adoption is driven by increasing fossil fuel costs and CO₂ emissions. However, the proliferation of EV-charging stations has stressed utility grids, prompting a need for more efficient solutions. Charging on DC grids is more efficient than AC due to reliability, higher conversion efficiency, and integration with renewable energy sources (RESs) and energy storage units (ESUs). Storing RES-generated power locally in ESUs is a viable solution. Effective management strategies are crucial, especially for EV charging in microgrids. This paper introduces a real-time energy management framework for EV charging in a DC microgrid, incorporating wind and photovoltaic systems, ESUs, AC load, and EV chargers. The objective is to ensure voltage and frequency stability. Fuzzy intelligent control of ESUs optimizes energy flow, accommodating diverse energy flow modes. The contribution of the proposed energy management system materializes in the regulation of the DC bus voltage and frequency, effectively managing variations in power generation from renewable sources and load demand while addressing different scenarios of requested loads and various statuses of electric vehicle charging stations. The interpretation of these findings emphasizes the sufficiency and reliability of the EMS design, utilizing data from Addis Ababa Microgrids.

Keywords DC microgrid, Fuzzy logic controller, Electric Vehicle (EV), EV charging, Energy management system, Renewable energy systems (RESs), Energy storage unit (ESU)

1. Introduction

The growing popularity of electric vehicles can be attributed largely to their reduced emissions and decreased reliance on fossil fuels [1]. Utilizing renewable energy sources in distribution networks, especially in the context of electrifying charging stations within smart grids, offers the opportunity to achieve high power conversion efficiency and mitigate emissions[2]. The microgrid comprises various dispersed energy sources and energy storage devices utilized locally by different types of loads, operating in two modes: grid-connected and islanding. A typical electric vehicle charging station is often integrated into the microgrid infrastructure. However, a significant increase in high-capacity EV charging stations intensifies the demand for charging infrastructure, placing strain on the power grid [3]. The rapid evolution of electric vehicles (EVs) has sparked a

noticeable increase in the demand for electricity associated with these vehicles. This has led to the exploration of a variety of solutions to address the growing energy demand. Various research directions are being pursued in response to this challenge, with a specific emphasis on integrating EVs into microgrids[4]. As the demand for energy continues to rise, it becomes essential to incorporate electric vehicles (EVs) into microgrid systems. Energy storage systems (ESS) and renewable energy systems (RES) are incorporated to maximize this integration. The convergence of these technologies is crucial in addressing the increasing energy demands while promoting sustainability and grid resilience. Such synergy allows for the maximization of renewable energy sources' potential and harnesses EVs as temporary storage units within homes, serving as both energy storage and production sources. This dual function aims to reduce the operational costs of EVs and home consumption while

alleviating stress on the public electricity grid. Charging stations powered by renewable energy sources, such as wind and solar, contribute to environmentally friendly EV charging practices. This approach not only diminishes fossil fuel depletion but also optimizes investment costs and accommodates fluctuations in power generation from renewable sources. The evaluation standards for charging stations include grid impacts, price schemes to encourage off-peak charging, consumer approval of the device, and operational performance [10]. Integrating renewable energies alongside an energy storage system within a standalone microgrid represents a growing area of research. Typically, combining various renewable energy sources such as tidal, wind, and photovoltaic (PV) is favored to enhance the maximum capacity of the energy storage system. Typically, the energy storage system (ESS) comprises a blend of batteries and supercapacitors, which not only prolongs battery lifespan but also provides rapid system response to mitigate transient fluctuations [5]. Incorporating electric vehicles (EVs) into the current public grid stands as a crucial step in tackling the challenge of high energy demand. By effectively integrating renewable energy systems (RES) and energy storage systems (ESS), this integration enables maximizing the utilization of renewable energy sources. Moreover, it allows for leveraging EVs as temporary storage units within hybrid microgrids and as additional sources of energy generation. This dual functionality aims to reduce the operational costs of EVs and home energy consumption while alleviating strain on the public electricity grid [6]. In [7], the authors present an energy management system (EMS) for microgrids (MGs) based on computational intelligence. They utilize a multiagent system to decrease energy consumption costs within an intelligent building. This system integrates various energy-saving techniques along with two incentive and instructional strategies for energy conservation. Additionally, it incorporates multiple student engagement behaviors. These methods are based on a graphic novel tool designed to study MG energy flows either in real-time or across the entirety of the dataset analyzed in [8]. In order to improve the microgrid's resilience and streamline its operation while integrating dispersed generation, the use of a DC microgrid is suggested [9]. A fuzzy logic controller serves as a helpful tool for monitoring the power converter at the charging station [10]. In this study, the fuzzy logic controller (FLC) plays a crucial role in facilitating the harmonious operation of the energy storage unit (ESU), state of charge (SOC), and DC bus voltage. Microgrids (MGs) rely on Energy Storage Systems (ESSs) to regulate fluctuations in voltage and frequency and maintain system stability. When operating in grid-connected mode, Microgrids (MGs) use Energy Storage Systems (ESSs) to store backup production, manage peak demand during extended grid outages, and maintain system stability by keeping frequency and voltage within acceptable ranges. The central theme of this research revolves around optimizing energy flows within a DC microgrid while ensuring stability in both DC and AC voltages. The complexity arises from diverse scenarios involving the presence of Electric Vehicles (EVs), illustrated through various modes adopted in the DC microgrid, however in

some similar studies they considered the recharging of vehicles as being a fixed problem as the study of the reference [11], where we begin a comparison in the discussion part. To address these challenges, an algorithm is developed to comprehensively cover all scenarios, ensuring robust energy management within the microgrid. The application of this algorithm extends to a geographic area encompassing meteorological data, storage system information, converters, and DC bus parameters, providing a robust testing ground for control strategies and management systems. The specific microgrid installation in Ethiopia – Addis Ababa serves as a practical case study. The key contributions and structure of this paper are outlined as follows: Section 1 provides an overview of the integration of EVs in microgrids, emphasizing the role of a charging scenario management system and the impact of storage system control on system stability, particularly through the use of fuzzy intelligent control. It also details the microgrid configuration for the EV charging station. Section 2 delves into the Real-time Energy Management Scheme, exploring potential energy modes related to the charging station and scenarios to seamlessly converge these modes for continuous energy supply to the microgrid's various components. The third section focuses on the control systems associated with each microgrid component. Section 4 discusses the use case in the city of Addis Ababa by carrying out a comparison of method and data in the study noted in the reference [11], simulation tools employed and presents the results. The paper concludes in Section 5.

2. System description

The exploration of combining renewable energies with an energy storage system in an independent microgrid represents a growing field of research. Typically, the incorporation of various renewable sources like wind and photovoltaic (PV) is favored to enhance the overall capacity of the energy storage system and meet the demands of electric vehicle (EV) charging loads. Furthermore, there is the option to adjust the configuration of the storage systems, as discussed in reference [12]. In this reference, there is a description of an architecture for a Renewable Microgrid with Hydrogen for Residential Use, which bears a resemblance to our architecture, centered on a storage system primarily consisting of a li-ion battery.

The energy storage system commonly comprises both batteries and supercapacitors, working together to prolong battery lifespan and provide a rapid system response for addressing transient events [13]. The analyzed system is formulated on the foundation of a DC hybrid microgrid. Illustrated in Figure 1, it consists of PV sources, a wind source, a storage system, a connection to the public grid, AC loads, and an EV charging station equipped with five EV chargers. A DC microgrid is a low-voltage network made up of distributed energy resources and controllable loads, among other energy components. This self-sufficient system has the capacity to reduce and minimize carbon footprint and transmission losses in electrical power [14]. In Figure 1, a standalone DC microgrid is depicted, providing power to an

electric vehicle (EV) charging station. The examined system comprises a wind system, photovoltaic (PV) sources, energy storage systems (ESS), electric vehicles (EVs), and AC loads. The EVs are charged from the DC microgrid utilizing a circuit breaker, a choice made to ensure the stability of the DC voltage at 400 V. Throughout the entire system, the storage system for batteries has a parallel power flow that, depending on the state of the wind turbine and PV panel production, functions as both an energy producer and a consumer. Figure 1 depicts the standalone charging station's implementation. The PV and wind systems are linked to the DC microgrid via a DC-DC converter, which is regulated by the maximum power point tracker (MPPT) scheme. Simultaneously, the battery bank undergoes charging and discharging within the DC microgrid, facilitated by a bidirectional DC-DC converter and fuzzy logic controller. The primary objective is to ensure uninterrupted charging of electric vehicles (EVs) during daytime, without affecting AC load demand. The rule-based approach involves examining various operating modes essential for addressing potential scenarios within the microgrid. The Energy Management System (EMS) decides the operational mode by considering the State of Charge (SOC) of the three Battery Electric Vehicles (BEVs). Conversely, the selection of operating modes relies on the reference DC power generated by PV and the current of the distribution transformer.

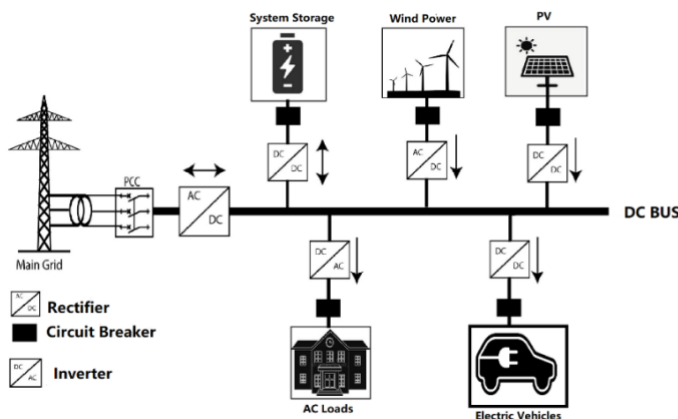


Fig. 1. Microgrid structure

The objective of the system is to ensure continuity of energy supply. The power balance mathematical model is formulated as noted in references [15] [16] :

$$P_{PV} + P_{wind} + P_{batt} = P_{AC} + P_{DC} + P_{EV} \quad (1)$$

3. Energy Management of Proposed EVs Charging Model

3.1 Operating Modes of Charging Station

The Energy Management System (EMS) for the charging station was meticulously crafted, taking into account a multitude of parameters unique to the station's operations. Its principal objective is to guarantee an

uninterrupted and dependable power provision to the charging points.

➤ Mode 1: ESU to Loads

- Description: The Energy Storage Unit (ESU) directly supplies power to the loads in the DC microgrid, meeting the electricity demand of connected loads.
- Applicable when: EVs do not exist, and Renewable Energy Sources (RES) are zero.

➤ Mode 2: RES to ESU

- Description: Renewable Energy Sources (RES) supply power to charge or replenish the Energy Storage Unit. Energy generated from sources like solar or wind is used to store energy.
- Applicable when: EVs do not exist, RES is not zero, and ESU is less than 80%.

➤ Mode 3: RES to Loads

- Description: Renewable energy sources directly supply power to loads within the microgrid without involving the energy storage unit. Utilizes renewable energy in real-time to meet the demand of connected loads.
- Applicable when: EVs do not exist, RES is not zero, and ESU is greater than or equal to 80%.

➤ Mode 4: ESU to EV

- Description: The Energy Storage Unit provides power to Electric Vehicles (EVs), using stored energy to charge and support the EVs connected to the microgrid.
- Applicable when: EVs exist, RES is zero, and State of Charge (SOC) is less than 80%.

➤ Mode 5: RES to EV

- Description: Renewable Energy Sources directly supply power to Electric Vehicles within the microgrid without involving the energy storage unit. Uses renewable energy to charge and power EVs.
- Applicable when: EVs exist, SOC is less than 80%, and RES is not zero.

➤ Mode 6: EV to ESU

- Description: Electric Vehicles (EVs) supply power to the Energy Storage Unit. Energy stored in EVs is transferred back to the energy storage system.
- Applicable when: EVs exist, SOC is greater than or equal to 80%, and RES is not zero.

The diverse modes outlined here showcase the flexibility and adaptability of microgrid systems in managing various sources and loads, effectively addressing different energy generation, storage, and distribution scenarios. To bridge these modes and fulfill the demands of Electric Vehicles (EVs), three specific scenarios are considered based on the energy availability within the microgrid. These scenarios will be elaborated on in the following chapter, providing a comprehensive understanding of how the microgrid

dynamically responds to varying energy conditions to meet the specific requirements of EVs.

3.2 Charging System Operating Scenarios

Certainly, the proposed charging system operations are categorized into three fundamental scenarios. These classifications are based on Electric Vehicles (EVs) demand and Renewable Energy Systems (RES) power :

- Scenario 1 : AP higher than EVs demand (Over-load).
- Scenario 2 : AP Less or equal EVs demand (Under-load)
- Scenario 3 : AP can cover a part of EVs (pseudo-over load)

The Energy Management System (EMS) plays a crucial role in determining which operational scenarios are adopted within the microgrid. This decision relies on assessing the remaining energy in the microgrid after considering the power consumed by both DC charging and AC loads. The power that remains post these consumptions is then compared to a predetermined threshold of 50 kW, serving as a benchmark to evaluate if the available energy is sufficient for the station's needs. Equipped with 5 chargers for electric vehicles and assuming an average charging power of 10 kW per vehicle, this threshold comparison assesses whether the microgrid can adequately support the simultaneous charging demands of multiple electric vehicles. This systematic approach ensures that the Energy Management System makes informed decisions based on the real-time energy dynamics of the microgrid and the specific power requirements of the station's charging infrastructure. The following equation expresses the available energy:

$$[AP] = P_{PV} + P_{wind} - P_{AC} - P_{DC} \quad (1)$$

$$P_{RES} = P_{PV} + P_{wind} \quad (2)$$

- Scenario 1 : AP higher than EVs demand (Over-load).

The remaining power, obtained by subtracting both AC and DC power, plays a critical role in formulating charging strategies within the Energy Management System (EMS) of the microgrid. The initial circumstance arises when the available power surpasses the demand from the five electric vehicles, indicating a value greater than 50 kW. In such instances, two distinct scenarios are considered. If electric vehicles are present at the station, an evaluation of their state of charge is imperative. Should it exceed 80%, these vehicles contribute power to the storage unit. Conversely, if the state of charge falls below 80%, a comprehensive examination of the Renewable Energy Sources (RES) situation is required to determine the optimal course of action. Even in situations where electric vehicles are not present at the station, negotiations with RES are initiated to ascertain suitable operational modes. The ensuing diagram provides a concise summary of the modes recommended for adoption in this initial scenario. the Figure 2 show the required diagram.

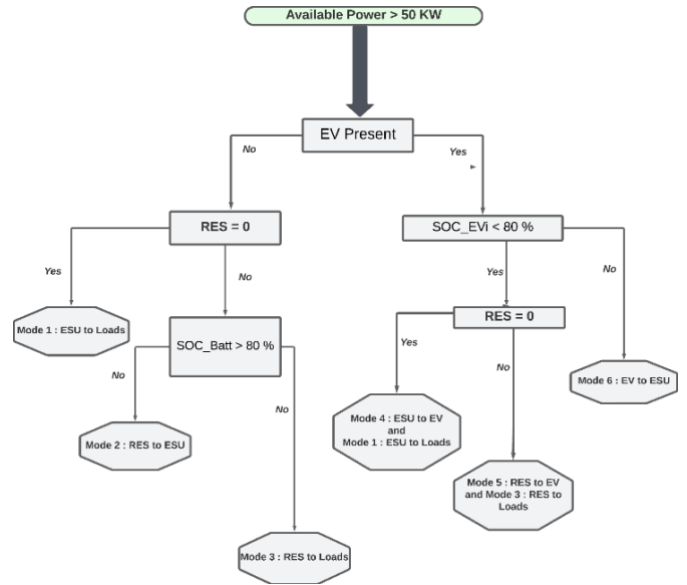


Fig. 2. Scenario 1 Flowchart - Over-load

- Scenario 2 : AP Less or equal EVs demand (Under-load).

We apply a similar rationale as in the preceding scenario. In this instance, our focus is on situations where the energy consumption from both DC and AC components surpasses the energy provided by Renewable Energy Sources (RES). In the absence of electric vehicles, we analyze the RES status modes to cater to AC and DC loads. Conversely, if electric vehicles are in play, a crucial examination involves determining whether the state of charge exceeds 80%. This assessment is pivotal for choosing between two modes: ESU to EV or ESU to AC and DC loads, and EV to ESU. The subsequent diagram illustrated in figure 3 succinctly illustrates the recommended modes for implementation in this second scenario.

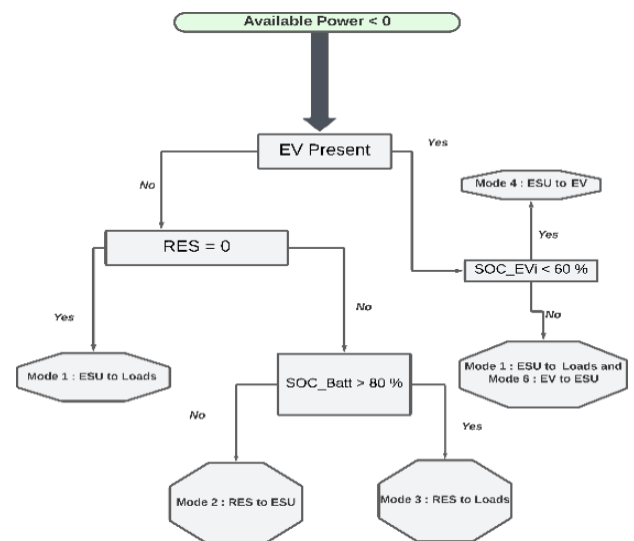


Fig. 3. Scenario 2 Flowchart- Under-load

➤ Scenario 3 : AP can cover a part of EVs (pseudo-over load)

This scenario represents the intermediate state where the available energy partially covers incoming electric vehicles at the charging station. In the absence of electric vehicles, there is a discussion about supplying energy to the DC microgrid. If electric vehicles are present with a state of charge exceeding 80%, we utilize their energy to power the storage system. However, if the state of charge is below 80%, the decision to charge electric vehicles from renewable energy sources (RES) or energy storage units (ESU) depends on the status of renewable energies. The diagram below summarizes all the modes associated with this scenario.

It appears that the system is designed to dynamically manage energy distribution based on the real-time conditions of available power, electric vehicle states of charge, and the status of renewable energy sources. The described scenarios in figure 4 provide a structured approach to decision-making within the Energy Management System of the microgrid.

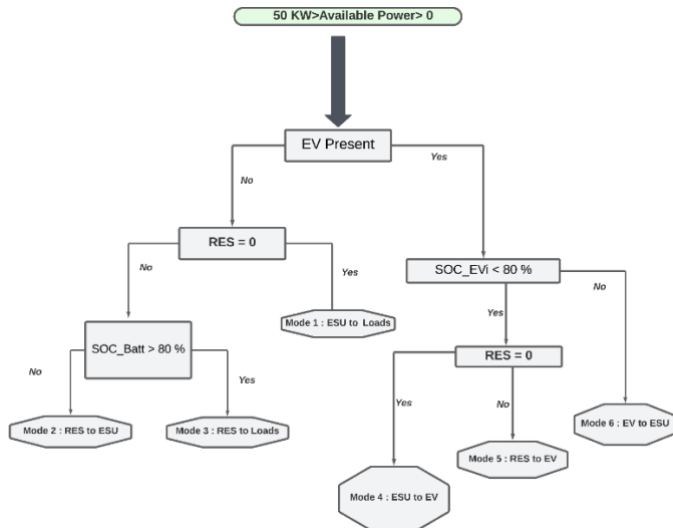


Fig. 4. Scenario 2 Flowchart - pseudo-over load

4. Controllers Design for the Hybrid Microgrids

4.1 Fuzzy Logic Controller Design for ESU

The Battery Storage System (BSS) acts as a crucial backup system, preserving system equilibrium in situations of energy surplus or when Renewable Energy Sources (RESs) fall short of meeting the load demand. The figure 5 illustrates the components of the battery storage system: a bidirectional DC-DC converter, a charging-discharging control system, and a Li-ion battery.

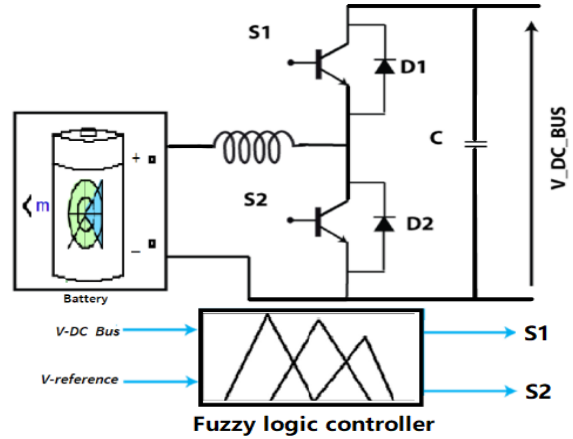


Fig.5.Fuzzy Logic Controller coupled with a battery storage system

To control the Bidirectional DC-DC Converter (BDC) on the vehicle and Energy Storage Unit (ESU) sides, a separate Fuzzy Logic Control system was created [17]. All direct current (DC) loads within the public charging station were linked to the typical DC bus voltage levels commonly found in DC microgrids within residential structures, in compliance with established norms and industry expertise. Typically, a distributed generator is positioned between these microgrids and the loads. Although literature suggests voltage values between 12 and 800 volts, the absence of standards has led to the establishment of standard voltage levels for DC distribution networks. These standard voltage levels have been adopted to minimize losses and simplify systems. The specified figures serve as a guide for the DC bus voltage, aligning with the current standard for electric vehicles that operate between 300 and 400 V. Despite ongoing efforts to establish guidelines, the DC bus voltage is firmly set at 320 V, adhering to previously established standards [18]. The output power serves as a reference in the control schemes for the power converters on the Energy Storage Unit (ESU) and Electric Vehicle (EV) sides. The primary objective of the fuzzy logic controller is to regulate the DC bus voltage and the State of Charge (SOC) of the ESU. Figure 6 illustrates the implementation of the fuzzy logic controller on the ESU.

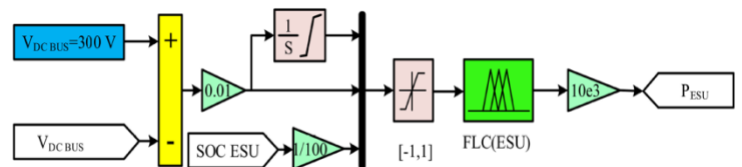


Fig. 6. Fuzzy Logic Controller (FLC) for Energy Storage Unit (ESU) power control.

The Energy Storage Unit's (ESU) State of Charge (SOC) and the cumulative error of the DC bus voltage are inputs into the fuzzy controller. The error is calculated by contrasting the observed value with the reference, with the rated DC bus voltage set at 300 V. The normalization range for the error and differential error inputs is -1 to +1,

equivalent to -30 V and +30 V, respectively. Additionally, the SOC of the ESU is normalized from 0 to 1. To maintain continuous balance in the microgrid, the fuzzy logic controller employs a set of fuzzy rules to calculate the battery's charging and discharging rates.

We use the fuzzy logic controller (FLC) commonly to obtain the MPP[19]. Because it identifies, resolves the problem of nonlinearity and gives a robust performance respecting the charge changes of the Li-ion Battery storage. We mentioned the implementation of control rules of FLC to calculate the difference noted in the equation () as well as adjusting the charging or discharging process to maintain the battery voltage close to the desired reference voltage, $V_{reference}$:

$$e(s) = |V_{ref} - V_{DC}| \quad (3)$$

The fuzzy logic controller (FLC) consists of three key components: fuzzification, a fuzzy inference system, and defuzzification. The procedure of fuzzification involves converting a precise input into a linguistic variable using membership functions. This process requires domain knowledge and often utilizes trapezoidal or triangular membership functions. The inference stage employs rule-based operations guided by trained awareness. Finally, the linguistic variable receives a clear value through defuzzification. Figure 7 in this study displays the membership functions used for the microgrid energy management input.

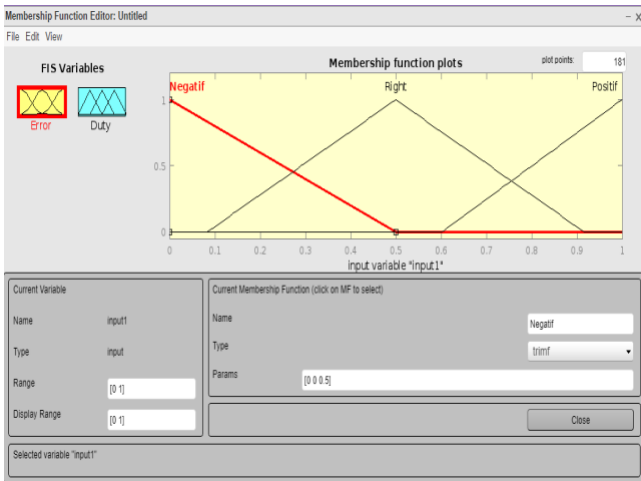


Fig. 7. Error signal membership functions.

By comparing the DC bus voltage with the voltage of reference, the method of control adopts an optimal switching pattern for the battery's charging and discharging. The fuzzy logic controller receives four inputs as a result of this comparison. The controller then provides the PWM block's duty cycle, as shown in Figure 8, so that a signal can be sent to the buck/boost converter.

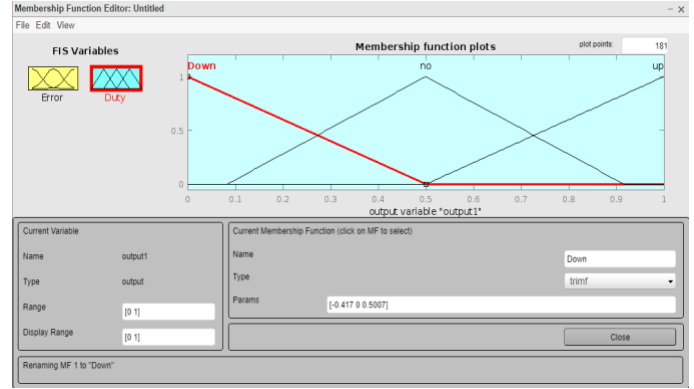


Fig. 8. Output function of membership

If the energy produced from the renewable energy sources is greater than the power consumed by the loads in the microgrid, the FLC will control the charging rate of the battery to store the surplus energy. If the amount of energy consumed by the loads in the microgrid is greater than the amount of power generated from renewable sources, the FLC will control the discharging rate of the battery to supply the microgrid with the required energy. The FLC uses a set of fuzzy rules to determine the charging and discharging rates of the battery based on the battery voltage and the power generated from renewable energy sources.

4.2 Charging and Discharging Controller for BEV Battery

Maintaining continuous voltage and current regulation during the charging process is essential for a Plug-in Electric Vehicle (PEV) battery. Figure 9 illustrates how the fast-charging method achieves a consistent voltage during the charging phase by employing both inner current loop control and outer voltage loop control. When the current flowing into the battery is positive ($I_{batt} > 0$), indicating a charging state, the battery is in this mode. Conversely, when the current is negative, the battery is depleting. The Energy Management System (EMS) controller ensures that the battery receives a regulated power supply based on the sign of the battery current (I_{ref}). A positive I_{ref} indicates a charging status, while a negative I_{ref} indicates a discharging state. The State of Charge (SOC) and the reference current's (I_{ref}) sign dictate which of the charging converter's several operating modes to use. The charging converter can function in constant voltage or constant current mode, depending on the switch control signal. Constant voltage charging mode is indicated by a closed switch, and constant current charging mode is shown by an open switch [20] [21].

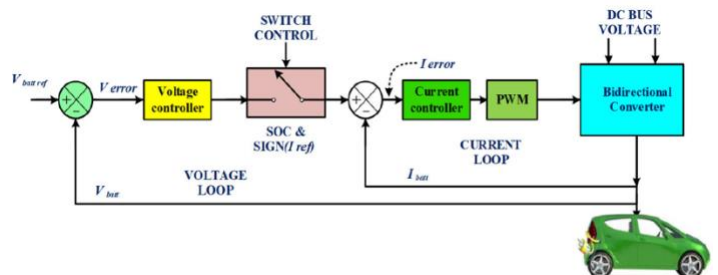


Fig. 9. Controller for Charging and discharging of PEV battery.

5. Results and Simulation :

5.1 Case of Microgrid Study in Fixe Data

In the initial phase of my research, I incorporated data from References [11] to preliminarily validate my model's performance. Utilizing simulation results from Matlab Simulink, based on our illustrated model (see figure), the AC load consumed 10 KW, while the DC load consumed 10 KW between $t = 0$ s and $t = 1$ s, as per power measurements on the respective buses. The DC bus voltage was maintained at 400 V initially. The Photovoltaic (PV) system could generate up to 50 KW, and the Permanent Magnet Synchronous Generator (PMSG) wind turbine provided up to 10 KW. The reference voltage for the DC-link was set at 240 V. At a Battery Storage System's state of charge (SOC) of 80%, a 12 KW DC Electric Vehicle (EV) charging station connected to the DC-link at 400 V via two load-side converters. The AC bus had a one-second load demand of 10 KW, while the DC bus had a 10 KW demand at 400V. Simulation was conducted at a one-second sample rate to assess the efficacy of the proposed energy control system in maintaining microgrid stability under varying weather conditions, comparing different controllers. Figure 10 highlights the significant advantages of Fuzzy controller methods in maintaining the voltage at the reference level. Conversely, Figure 11 depicts a negligible frequency variation of 0.02, except during the initial transition regime, confirming the robustness of our findings. Notably, these data focus on stability within the charging station and fixed radiations, without incorporating an energy management system capable of handling diverse microgrid component scenarios, which necessitates a comprehensive case study, discussed in the subsequent sub-chapter.

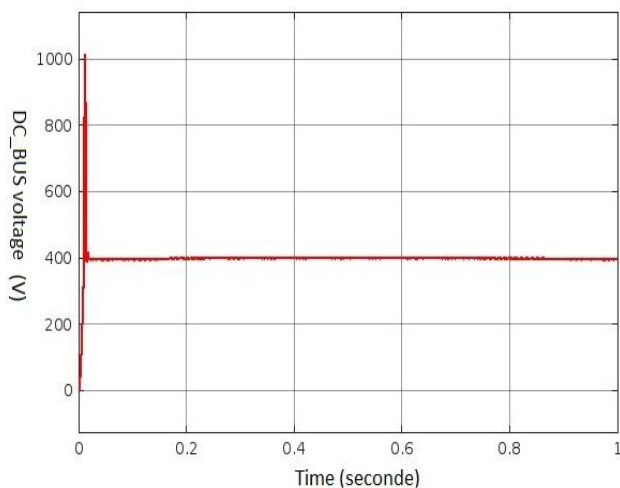


Fig. 10. DC_BUS voltage (V)

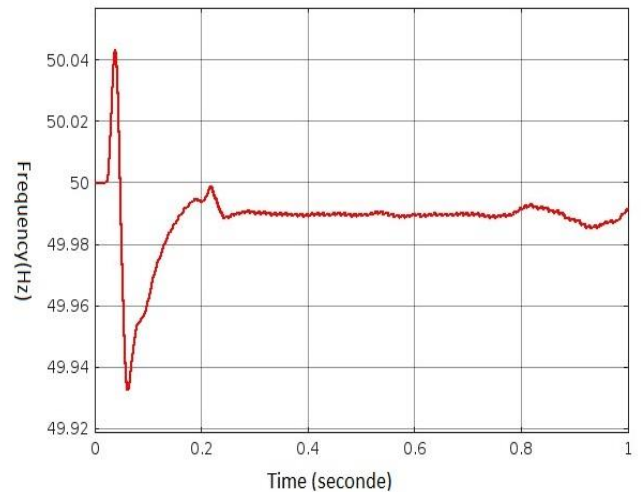


Fig. 11. Measured frequency at the AC_BUS(Hz)

5.2 climate data and microgrid components: Case Addis-Ababa Microgrids

In order to have an implementation of our model in the field, we proceed with the application of this model on a microgrid located in Ethiopia, specifically in its capital, Addis Ababa. This involves controlling the stability of the DC voltage of the network, in addition to ensuring the stability of the AC network frequency, all while managing the 5 electric vehicles in our case. We also control our storage system in correlation with the lithium battery used in the case of the microgrid studied in this simulation. The climatic conditions and parameters of the Addis Ababa microgrid will all be applied to our microgrid. In this study, the cities, Addis Ababa ($8^{\circ}58.8'N, 38^{\circ}45.5'E$), were chosen to analyze PV/Wind/ESS/EV charging station with the battery storage technologies Tesla Powerpack2 and controlled under the fuzzy logic controller. Figure 12 illustrates the geographical layout.

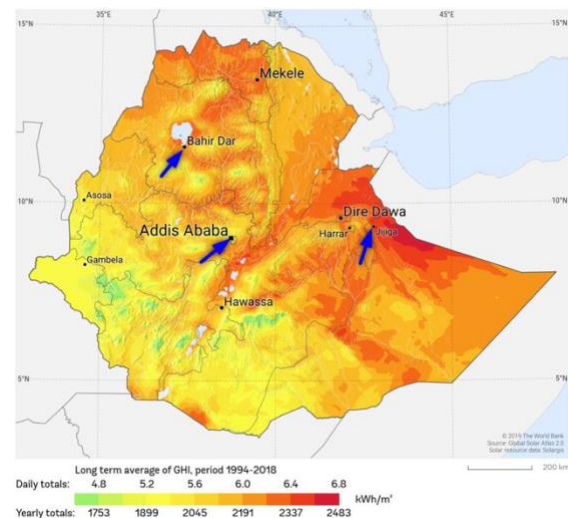


Fig. 12. the study locations in Ethiopia along with global horizontal irradiation data[22].

Although the size study was conducted for a specific area, the results and methodology can be generalized for application in different locations worldwide by adjusting solar and wind energy statistics. With only one charging station in Ethiopia, the country is still in its early stages of electric car adoption. Establishing a national plan for regulations, sizing, and other relevant aspects becomes crucial. To exemplify how to size EV charging station applications, three Ethiopian cities with the highest automobile density and significant potential for solar and wind energy have been chosen. In these cities, five electric vehicles are utilizing the microgrid operating under the proposed real-time energy management scheme. Simulations of all previously described scenarios verify the effectiveness of the suggested EMS and associated control measures. The findings are reported and examined, with a focus on the stability of the DC BUS voltage and AC BUS frequency during normal operation of the Addis Ababa Microgrids, which follow a charging schedule for electric vehicles. Choosing cities with lower car populations facilitates easier access to the charging station, making these locations ideal for installation. Figure 13 illustrates the city's solar energy potential, while Figure 14 depicts the potential for wind energy in these selected cities.

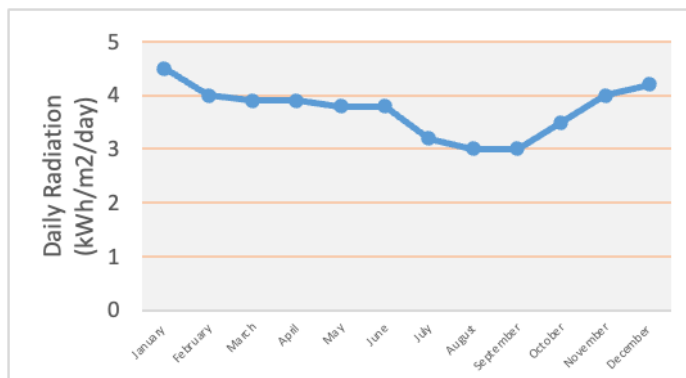


Fig. 13. Monthly average solar irradiation for Addis Ababa city

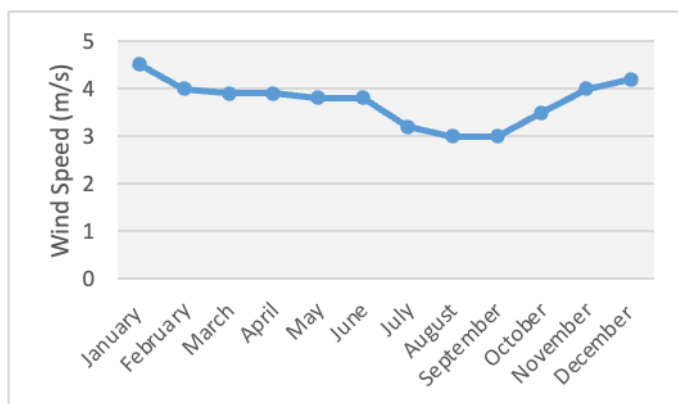


Fig. 14. Monthly average wind velocity of cities.

In this study, the wind system is presented by NPS100C-21 WT Northern Power, with a rated capacity of 100 kW, Photovoltaic modules with power outputs of 829

kW The storage system battery storage with outputs of 162 Kwh with the specification noted in the table below :

Table 1. system parameter

Parameter	Specification
Battery Name	Tesla Powerpack2
Battery Type	Li
Nominal voltage (V)	220V
Maximum capacity (Ah)	60
Nominal capacity (kWh)	13,2
Maximum charge current (A)	31,8

The EV charging station is designed with 5 charger , 172 KW power pick 3216kwh/d. the figure 15 below the simulink model of our study :

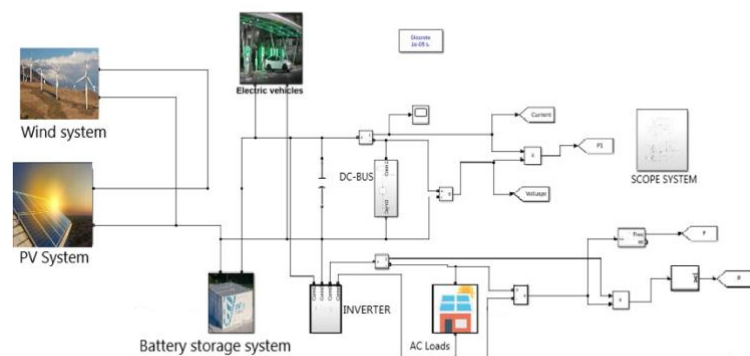


Fig. 15. Simulink representation of the suggested microgrid with an EV charging station

5.3. Result Analysis and discussion

MATLAB Simulink is utilized for simulating the hybrid microgrid and EV charging system models. The simulation aims to assess the capability of the EMS algorithm in ensuring a continuous charging process that enhances energy reliability, balances AC frequency, and stabilizes DC microgrid voltage. In Ethiopia, the only electric vehicle model is the Kona SUV, equipped with a 42 kWh battery, a range of up to 300 kilometers, and zero carbon dioxide emissions.

The quantity, capacity, and state of charge of electric cars upon arrival at a charging station determine the number of EVs utilizing it. The initial premise assumes no more than four car arrivals during early morning, midday, and evening hours, with the expectation that all cars will be fully charged. However, the charging station has a minimum arrival rate of two automobiles per hour. Our investigation is based on a station that has five chargers in our instance. The suggested system's simulation results are generated using Matlab/Simulink, and the specific parameters that were used are detailed in [23]. The unique aspect of our research lies in

the energy management system layout employed at the charging stations featuring five charging ports. Because of the sporadic characteristics inherent in renewable energy sources, variations occurred in the measured power of the wind and solar turbines. Consequently, the microgrid's power supply exhibited irregularities, at times generating excess power and at other times none at all. Figures 16 and 17 visually represent the measured power of the microgrid's DC and AC loads, respectively.

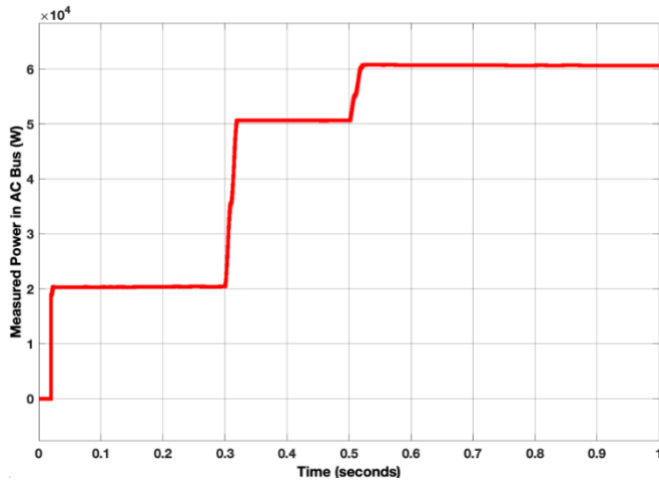


Fig. 16. Measured Power in AC load (W)

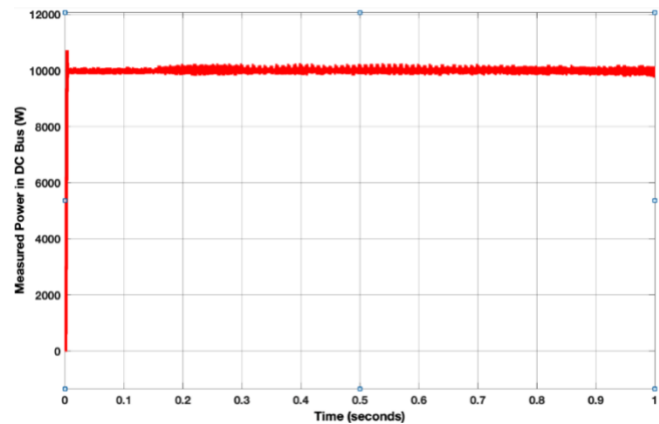


Fig. 17. Measured Power in DC load (W)

In the measured power of the DC and AC loads, as shown in Figures 4 and 5, it is evident that the generated power from the renewable energy sources is effectively meeting the power demand of the loads.

The surplus power was effectively managed by the energy management system, orchestrating the charging of the battery to store excess power for later use. Conversely, the shortage of power was addressed by discharging the battery to supplement the power from renewable sources. This approach resulted in a balanced power supply throughout the operation of the microgrid. Figures 18 and 19 visually represent the variations in the battery's State of Charge (ESU) and power.

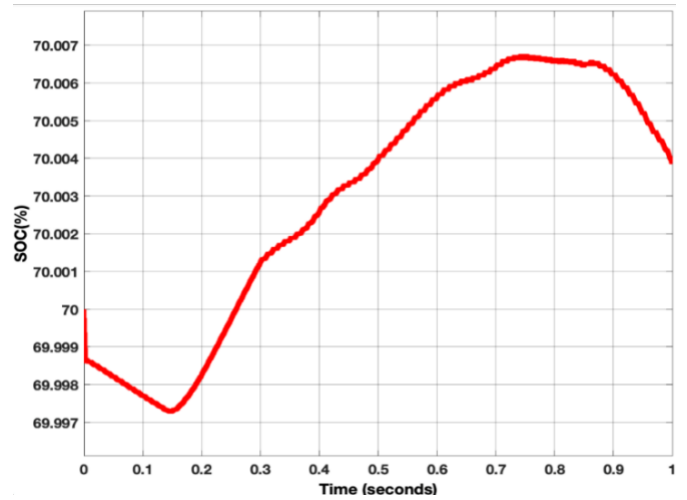


Fig. 18. Alterations in Battery state of charge (%)

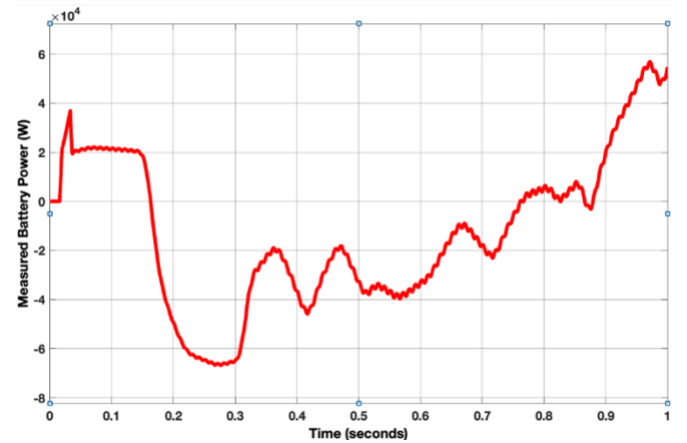


Fig. 19. Alterations in Battery Power (W)

Firstly, we carried out a validation of the performances of our where we note the maintenance of the performance of DC voltage and AC frequency, on the other hand the introduction of the EMS for the flow of electric vehicles ensures the stability of the Grid in this case study as noted in the figure 9-10. The fuzzy logic controller adeptly handles the charging and discharging of the battery, ensuring the equilibrium of the microgrid. As observed in the battery power graph, the battery discharges when renewable sources fall short of meeting the demand and charges when there is surplus power. The battery's State of Charge graph indicates that the battery is maintained at an optimal level. This efficient battery management significantly contributes to the stability and reliability of the microgrid system. In summary, the energy management system effectively balances the generation and demand of the microgrid, evident in the close alignment of the measured power of loads to the required loads demanded. This affirms the successful implementation of the proposed energy management strategy. The measured DC bus voltage and frequency are illustrated in the below figures :

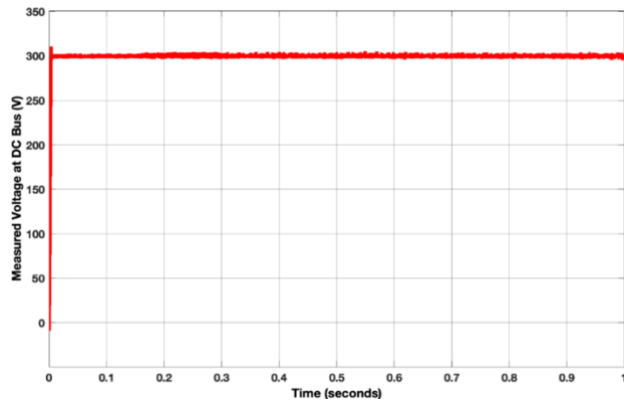


Fig. 20. Voltage Measured at DC Bus (V)

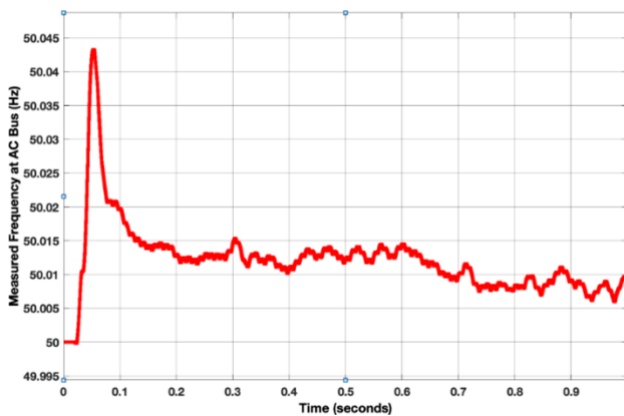


Fig. 21. Measured Frequency at AC Bus (Hz)

Ensuring the stability of the DC bus voltage and frequency is a crucial aspect of microgrid operation. As illustrated in Figure 20 and Figure 21, the proposed energy management system adeptly regulates the DC bus voltage and frequency, effectively managing variations in power generation from renewable sources and load demand. The DC bus voltage remains consistently stable throughout the simulation period, showing only slight variations. Similarly, the frequency of the AC output signal is well-controlled, with a variation of less than 0.02 Hz. These results strongly validate the efficacy of the proposed energy management strategy in ensuring a stable and reliable microgrid operation. The interpretation of these findings emphasizes the sufficiency and reliability of the EMS design, utilizing data from Adis Ababa Microgrids.

Our results can be compared with the study conducted by [24]. In their research, they developed a hybrid CNN-LSTM architecture to automatically classify the state of charge (SOC) of batteries for efficient energy management in electric vehicle (EV) charging stations. It's worth noting that our study does not cover wind energy, and the comparison metric is expressed in the time needed for the system to stabilize the DC bus voltage. Figure 20 indicates that this stabilization time is considered zero. However, the results from our comparison in [24] demonstrate a temporal delay that requires improvement to achieve voltage stabilization.

The reference [25] provides insights into analogous studies featuring diverse component configurations and grid architectures. These studies delve into examining a hybrid microgrid situated in Jazirat Al Halaniyat (Island) within the Sultanate of Oman, encompassing both technical and economic validation processes. Our forthcoming study aims to build upon this groundwork, focusing on achieving similar technico economics objectives.

6. Conclusion

The proposed real-time energy management plan has been successfully tested on the microgrid in Addis Ababa, Ethiopia. The results illustrate the effective stabilization of power supply to an EV charging station through the integration of a PV, WT, and ESU-based microgrid. Intelligent fuzzy controllers control the source-side converters (SCCs) of the storage unit, maximizing power from renewable sources and enhancing electricity quality in the DC microgrid. An algorithm is designed to handle various scenarios for energy flows and related modes within the microgrid. Notably, the integration of an EV charging station into the system is achieved seamlessly, maintaining the DC bus voltage at the required 300V. The AC frequency stability is also well-maintained, with a deviation margin of no more than 0.02 to accommodate different communication scenarios among the DC microgrid components. Implemented and simulated using Matlab/Simulink, the system utilizes data from the Addis Ababa Microgrid, an actual case in Ethiopia. The outcomes validate the effectiveness of the suggested Optimization of Scheduling for Electric Vehicle Charging Stations Integrated within a DC Microgrid in maintaining microgrid equilibrium and providing steady power to the loads. The power generated from solar and wind turbines closely matches the required loads, and the power and charge levels of the batteries are well-controlled. The frequency variation of the DC bus voltage remains below 0.02, ensuring stability. The fuzzy logic controller within the energy management algorithm efficiently handles the charging and discharging of batteries in various described scenarios. The next step in completing the study involves conducting a technical-economic analysis of charging electric vehicles in PV/wind/battery hybrid energy systems, considering various battery technologies.

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