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RELIABLE ENERGY SUPPLY AND VOLTAGE CONTROL FOR HYBRID MICROGRID BY PID CONTROLLED WITH INTEGRATING OF AN EV CHARGING STATION

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Abstract

The integration of an electric vehicle (EV) charging station into the DC-microgrid requires management control of the energy supply and the voltage variation. The hybrid energy sources of the microgrid consist of battery storage, wind energy, and photovoltaic (PV) energy sources. To optimize power generation from renewable energy sources such as wind and PV, the source-side converters (SSCs) are regulated by the leading edge intelligent PID technique. This strategy enhances the quality of power delivered to the DC-microgrid. The microgrid comprises AC/DC loads, battery storage, EV charging stations, backup power from the main grid, and renewable energy supplies comprising wind and solar energy. The proposed control system relies on monitoring the state of charge of the battery and utilizing renewable energy sources to supply loads efficiently. The final results of the simulation obtained from the simulation software MATLAB and Simulink are used to validate the effectiveness of the suggested energy control technique, which performs well in terms of accurate control and maintaining a stable energy supply even under various load and weather conditions.

Keywords: PID controller, DC Micro-grid, Energy supply reliability , Renewable energy system, EV charging station

1. INTRODUCTION

The invention of the vehicle has revolutionized transportation by simplifying people's lives and reducing travel time. However, the automobile industry is facing challenges, including oil dependence and greenhouse gas emissions, which are becoming increasingly scarce. To tackle these issues, the focus is shifting towards emerging technologies[1]. In order to provide electricity to rural and distant places where grid extension is challenging, hybrid renewable energy systems are now deployed [2]. Renewable energy-powered electric vehicles (EVs) have the potential to make a significant contribution towards sustainable transportation, minimizing Carbon dioxide emissions, and improving air quality. The growth rate of EVs, as depicted in Figure 1 [3], is currently increasing rapidly.

In just three years, the proportion of electric vehicles has tripled, with over 16.5 million EVs in circulation in 2021. The recent tightening of CO2 emission standards and rising gasoline prices are driving the expansion of EVs worldwide. The acceleration of tax incentives and purchase subsidies has also contributed to the increased sales pace [3].

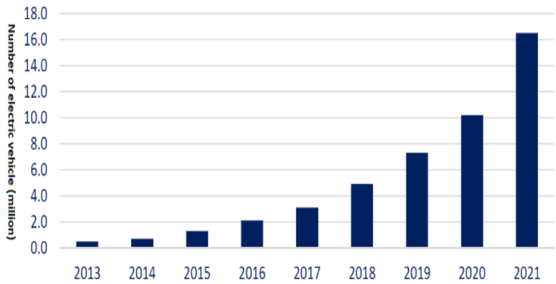

Fig. 1. Progress of EVs globally.

Due to the explosive rise of EVs, there is more of a requirement for power, prompting the development of various solutions to address this issue. These solutions include integrating EVs into microgrids [4], [5], (V2V) technology and (V2G) technology [6], [7], and managing EV charging in parking lots [8]. The amount of research on operating microgrids has significantly increased in recent years; this research mainly concerns the aspect of control, size, and energy management. To ensure safe, sustainable, and environmentally friendly energy for consumers, microgrid systems require an energy management system that controls the energy and power flow between sources and loads. The first part

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of this study tries to look into the integration of an EV charging system into the theory of microgrids. Microgrids are hybrid electrical systems operating at low or medium voltage that use multiple energy sources, often providing small clients in faraway regions with reliable power using energy from renewable sources [9]. Depending on their technical and financial capabilities, microgrids can operate in either an islanded mode or linked one [10].

The definition and concept of hybrid microgrids are evolving to offer customers sustainable options for renewable energy integration, grid dependability, flexibility, and affordability. Currently, there is an increasing interest in researching the incorporation of energy storage systems (ESS) and renewable energy sources in independent microgrids. To increase the maximum capacity of the ESS, sources of renewable energy, including tidal, wind, and photovoltaic power are often combined. The ESS typically consists of both supercapacitors and batteries, which work together to increase battery lifespan and provide a rapid system response to compensate for transients [11]. In the case where every energy source and battery storage system are interconnected, supercapacitors can be replaced by an AC grid, as suggested by [12]. DC and AC microgrids differ in terms of their structure, integration, and controllable parameters. DC microgrids have a simpler structure and are easier to integrate, which is why they are preferred over AC microgrids. However, control design is made more complex by the requirement for frequency and reactive power coordination in AC microgrids. Despite this, the latest power electronics advancements can operate AC microgrids at their peak efficiency. In contrast to AC microgrids, the stochastic nature of renewable energy sources in autonomous DC microgrids requires the addition of an energy management system to ensure continuous power transfer to loads. While numerous control strategies are available for AC microgrids, they cannot be used for DC microgrids due to significant differences in dynamics. For controlling the DC-link's voltage as a DC microgrid's load converters, the energy sources are linked in parallel, and energy is supplied or consumed via the DC-link, It is essential for the system to operate reliably and effectively. [13], [14]. However, previous studies on DC microgrids did not consider the integration of EV charging stations. Most EV drivers are willing to use intelligent charging stations for recharging their EVs from microgrids, according to research on the social acceptance of EV charging stations in microgrids [15]. Therefore, the authors of this work aim to simulate a microgrid and develop a control strategy that can manage energy supply and demand effectively under various loads, including the presence of electric vehicles, and different weather conditions. Several control solutions have been proposed in the scientific community, this issue of DC hybrid microgrid maintenance of voltage is discussed, including fuzzy logic control with fewer rules [16], integrated fuzzy controller and voltage control[17], and hybrid microgrid architecture[18]. However, none of these solutions specifically address the incorporation of EV charging stations, which is the focus of this work.

The present study proposes the use of a PID controller to address the limitations of traditional integer controllers in hybrid energy management. Specifically, the proposed controller is integrated into a DC-microgrid, which includes multiple sources and essential DC loads, alongside an energy management system. The energy control system functions as a high-level controller, providing the PID controller's recommended references and keeping track of power production and consumption. The PID controller therefore performs the function of a low-level controller, regulating the energy balance of the system and maintaining stable operation under different load situations.

To summarize, this paper aims to achieve several goals. Firstly, it proposes the use of a PID controller in combination with an EV charging station to effectively control the source-side converters and maximize power generation from wind and solar renewable energies. Secondly, by using an energy control unit to regulate reactive power and DC-link voltage in accordance with their respective references, it seeks to enhance the DC microgrid's power quality. Finally, the paper's unique contribution is in real-time regulation of the energy supply dependability of the DC microgrid while incorporating EV charging stations. In this study, a framework is proposed to control energy usage and develop an energy management strategy that considers various energy exchange scenarios in a DC microgrid system. The system includes a photovoltaic system, an EV charging station, an energy storage system, AC loads, and the electrical power grid. The key objective of the suggested energy plan is to optimize the usage of the maximum power available from the PV system, wind resource, and ESS while also taking into account the possibility that the EV owner may require emergency usage. The structure of this paper is organized as follows: Section 2 presents a hybrid microgrid concept that includes both an EV charging station and an energy management system. Section 3 presents the PID control scheme for the microgrid. In Section 4, results, a detailed analysis, and a discussion of the simulation are given. Section 5 summarizes the paper.

2. MICROGRID MODELLING INTEGRATING AN ELECTRIC VEHICLES CHARGING STATION

The design of the electric vehicle charging station relies on the utilization of a DC microgrid topology, as demonstrated in Figure 2a [19], [20]. The proposed local DC microgrid technology involves integrating a PVA, a public grid connection, electrochemical storage, and batteries from PEVs, all of which are linked to the DC grid. Additionally, this technology can be seamlessly integrated with car parking, creating a local grid connection, where sun-shading roofs can be equipped with PV panels, as illustrated in Figure 2a. The sources of DC microgrids are typically connected to a shared DC bus, which facilitates the efficient distribution of electricity. The PV-generated electricity is mainly used for charging EVs. In addition to PV sources and the public grid, storage provides a backup energy source that can be used to power EVs or store excess electricity from solar energy sources. The public grid serves as a backup power supply, allowing for the sale of surplus electricity generated by the PV sources. When the PV-generated electricity is not enough to meet the EV charging demands, the storage system supplies most of the extra power, followed by the public grid. Conversely, any excess energy is typically stored before being exported to the public grid, as stated in the aforementioned studies [20], [21]. In the PEV charging station's system, EVs alone are the loads, as depicted in Figure 2b

Fig. 2. (a) Graphic design of the grid

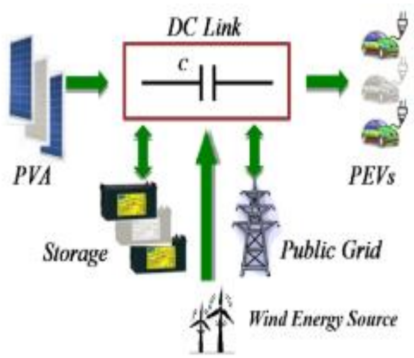

Fig. 2. (b) DC microgrid for an EV charging station.

2.1. PV System

For the solar system Figure 3 illustrates a boost converter ,a photovoltaic cells panel, as well as the MPPT (maximum power point tracking) controller

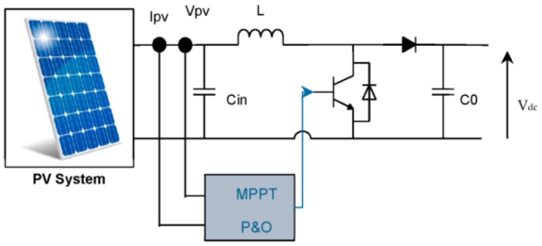

Fig. 3. Solar energy system with controller.

To ensure that the maximum power generated by photovoltaic (PV) generators is collected and efficiently transferred to the load, a DC/DC power converter, also known as a static converter, is utilized as an interface between the two. In order to fully utilize the available capacity of solar power systems , the MPPT method are employed, specifically the PV array's operating point at its greatest power point using the perturb and observe (P&O) algorithm [22], [23]. To achieve maximum power efficiency at all times, an MPPT controller regulates the boost converter.

The basic objective of this strategy is to keep PV power generation below or near its highest peak power point. In order to do this, the PV generator's output current (Ipv) and voltage (Vpv) values are measured, and the power is determined. The position of the point (Vpv(t),Ppv(t)) on the PV curve is then determined by analyzing the variation of power (Ppv) and voltage (Vpv). When the power derivative is positive, the operating point is getting close to the MPPT. Then The voltage fluctuation sign must be assessed to determine the search direction. The pulse width modulation (PWM) control signals are modified to either increase or decrease the duty cycle depending on the direction of the search. The program uses an iterative approach that adheres to a particular algorithmic procedure, as seen in the diagram below:

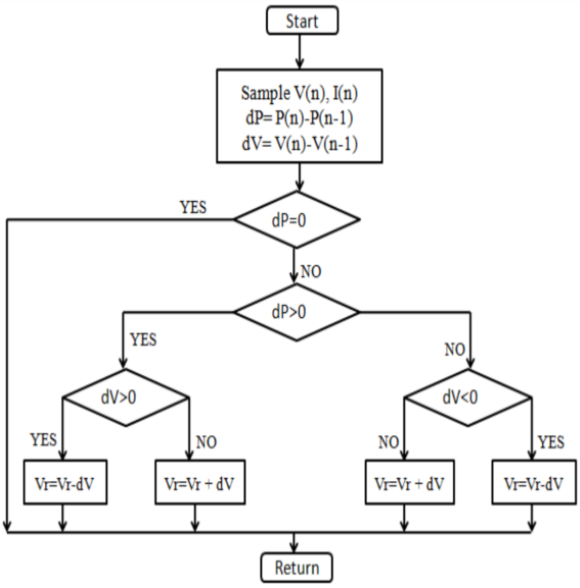

Fig. 4. Flowchart of MPPT algorithm

2.2. Wind system

Systems for wind turbines are a promising and easily accessible source of electricity. These systems provide mechanical energy for the operation of turbines that rotate, which is later transformed into electrical power via generators for power. The total amount of energy supplied is directly influenced by the wind speed, and the maximum power point, depending on the wind speed, controls how the MPPT management unit works. [24]. A typical WES is depicted in Figure 5 and consists of a turbine for wind power, a synchronous permanent magnet power source, and a power converter that makes use of the MPPT algorithm to get the most power possible out of the wind generator. The following is a representation of the wind energy converter model [25] :

$$\frac{dV_w}{dt} = \frac{T_w}{C_w} - \frac{I_{L_w}}{C_w} \tag{1}$$

$$\frac{dV_{dc}}{dt} = (1 - U_1)\frac{I_{Lw}}{C_{dc}} - \frac{I_{L_w}}{C_w} + D_1 \tag{2}$$

$$\frac{V_w}{L_w} = \frac{dI_w}{dt} + (1 - U_1)\frac{V_{dc}}{L_w} + D_2 \tag{3}$$

$\frac{dV_w}{dt}$ represents the rate of change of wind velocity with respect to time (t). It denotes how the wind velocity V_w is changing over time. $\frac{dV_{dc}}{dt}$ represents the rate of change of the direct current (DC) voltage V_{dc} with respect to time (t). It denotes how the DC voltage is changing over time. The third equation suggests that the ratio of wind velocity V_w to the characteristic length L_w is equal to the sum of the rate of change of a certain parameter $\frac{dI_w}{dt}$.

In the wind energy converter model, the symbol I_w represents the rectified wind current, while L_w denotes the inductance. I_{LW} represents the current flowing through the inductor, and V_w stands for the rectified input voltage. The control signal is represented by U_1, while V_{dc} represents the link voltage. T_w represents the wind torque acting on the wind energy converter (WEC), it is a measure of the rotational force exerted by the wind on the WEC. C_w represents a constant or coefficient associated with the wind dynamics or characteristics. C_{dc} represents a coefficient associated with the electrical dynamics or characteristics of the DC voltage. The energy stage parameters' dynamical variability can be identified by the numerical values D_1 and D_2.

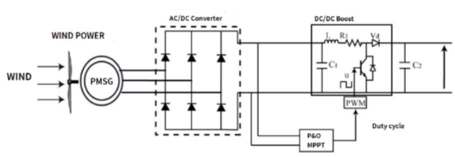

Fig. 5. System for generating wind power

Wind energy is transformed into electrical energy by the wind turbine. The following formulas can be used to determine the wind turbine's output power [26]:

$$P = \frac{1}{2} A \rho_a v^3 \tag{4}$$

Where A: the swept area of the blades, ρ_a: specific density of the air, and v is the wind speed.

2.3. Battery storage system

When renewable energy sources (RES) are unable to fulfill the energy demand or when there is an excess of energy, the battery storage system (BSS) steps in to maintain system equilibrium. A lithium-ion battery, a charging and discharging management system and a bidirectional DC-DC converter make up the battery storage system (BSS), which is shown in Figure 6.

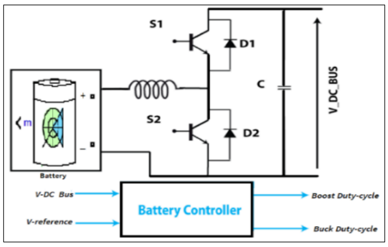

Fig. 6. Battery system with a bi-directional inverter

Bidirectional DC/DC converters, as shown in Figure 6, allow electricity to be transferred from the battery to the microgrid. The study used bidirectional converters with a half-bridge IGBT topology that run in continuous conduction mode. By modulating the current flow's direction while keeping each position's voltage polarity constant, these converters are becoming more and more common for controlling battery charging and discharging. The converter works in boost mode to store extra energy on the DC bus while it works in buck mode to supply power to the battery. While in buck mode, Energy is delivered to the battery through S1 and D2, during boost mode, current flows to the DC bus via S2 and D1.

2.4. EV charging station system

To charge the battery of a battery electric vehicle (BEV), the charging converter is equipped with constant-voltage and constant-current control. Fast charging is achieved through inner current loop control, while the outer voltage loop control utilized for constant-voltage charging is illustrated in Figure 7. Charging occurs when the current flowing into the battery is positive ($I_{batt} > 0$), and discharging occurs when the current is negative. Based on the battery current's direction (I_{ref}), the EMS controller generates controlled power for the battery.

State of Charge (SOC) and reference current (Iref) Direction are two variables that affect how the charging converter operates. Depending on the control signal, the converter may function in either a constant-current or constant-voltage mode. The converter functions in constant-voltage charging mode when the switch is closed and constant-current charging mode when it is open.

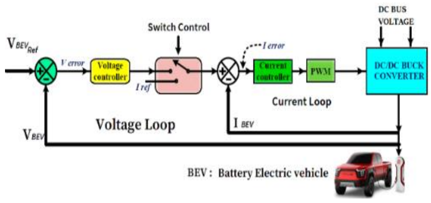

Fig. 7. Battery charging and discharge for BEVs

Equation (10) expresses the EV charging modeling equations, where v_{EVs} and $i_{L_{EVs}}$represent the voltage and current on the output side of the EV converter. L_{EVs} and C_{EVs} are the inductor and capacitor of the EV, respectively. The input current for EVs is represented by i_EVs, while v'_{EVs} $i'_{L_{EVs}}$indicate the voltage and current on the input side of the EV converter. The EVs are connected to the common DC bus via their dedicated static converters, which have a switching function of f_{EVs}. The control variable of electric vehicle energy supply is denoted by m_{EVs} [27].

$$\frac{dv_{EVs}}{dt} = \frac{i_{L_{EVs}} - i_{EVs}}{C_{EVs}} \tag{5}$$

$$\frac{di_{L_{EVs}}}{dt} = \frac{v'_{EVs} - v_{EVs}}{L_{EVs}} \tag{6}$$

$$\begin{bmatrix} v'_{EVs} \\ i'_{L_{EVs}} \end{bmatrix} = f_{EVs} \begin{bmatrix} v_{EVs} \\ i_{L_{EVs}} \end{bmatrix}$$

$$=> \begin{bmatrix} v'_{EVs} \\ i'_{L_{EVs}} \end{bmatrix} = m_{EVs} \begin{bmatrix} v_{EVs} \\ i_{L_{EVs}} \end{bmatrix} \tag{7}$$

$$m_{EVs} = \int_0^T f_{EVs}\ dt \quad \text{with} \quad m_{EVs} \in [0;1]$$

2.5. Energy Management System (EMS)

Figure 8 depicts the various power sources that constituted the microgrid utilized in this study. The proposed microgrid management technique is based on a PID controller. A DC/DC converter connecting the photovoltaic solar system to the DC bus is controlled by an MPPT block to maximize power output. A wind turbine is also connected to the DC bus using multiple converters and an MPPT block to extract the maximum available power. An AC/DC converter connects the primary grid to the DC bus, but it is only utilized during emergencies when renewable energy sources are inadequate, and the battery's state of charge drops below 20%. The battery system is linked to the microgrid via a bidirectional DC/DC converter, and its operation is controlled by a PID controller. The suggested energy management system seeks to satisfy the energy demand, control the voltage at 400 volts, allow the AC bus frequency at 50 Hz, while avoiding overcharging or undercharging the battery.

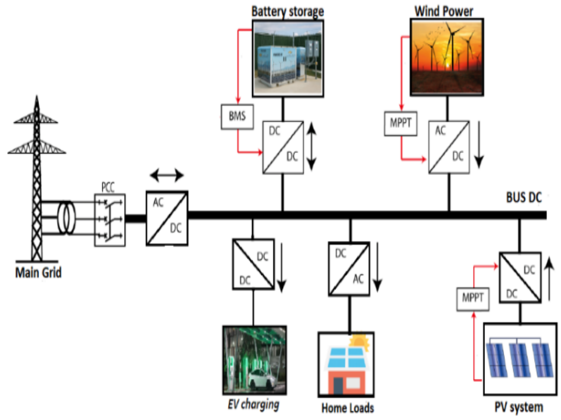

Fig. 8. Microgrid battery electric vehicle charging station suggested design

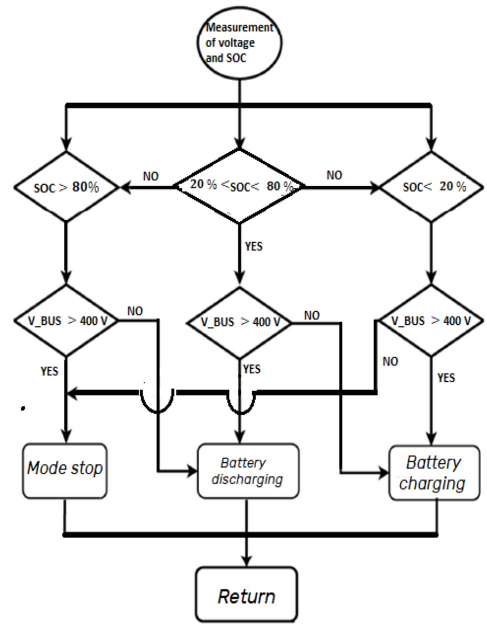

Fig. 9. Flowchart for the energy management plan

3. PID CONTROLLER DESIGN

Engineers and researchers in a variety of fields are increasingly turning to PID controllers because they enable error signals to be turned into input signals (I) combining an integrative action and a proportionate factor (P). These controllers detect false signals by contrasting the output signal with the reference signal that was intended. The difference between the observed voltage (V-DC-Bus) and the required voltage (V-reference) is amplified by the PID controllers to generate the error signal (e), which is intended to reduce the error signal. The bidirectional converter is used to balance the load output and consumption while maintaining a stable 400 V voltage. In this work, simulation was used, and Figure 10 shows the system's control method. Following comparison of the observed DC_BUS voltage to the reference voltage, the voltage of the bidirectional converter was adjusted. The duty cycle for each direction should be identified, the PID blocks examined the difference between these voltages. Based on the measured voltage and the battery's state of charge at the DC bus, the procedure for the proposed battery charger predicts the duty cycle value to operate the system converter using a PWM signal.

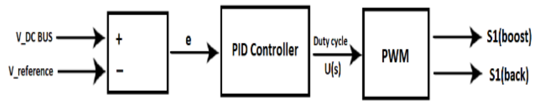

Fig. 10. The diagram illustrating the implementation of the PID controller

The PWM signal was adjusted by the controller output to minimize errors in power distribution between the battery and microgrid through the DC-DC bidirectional converter. A reference model of 400V was selected to ensure an optimal and comparable response to the reference input. The PID controller's output can be described as [24] :

$$U(s) = K_p e(s) + \frac{K_1}{S} e(s) + K_D . S . e(s) \qquad (8)$$

In this equation $U(s)$ represents the Laplace transform of the controller's output, which is the control signal applied to the system being controlled. The term $e(s)$ represents the Laplace transform of the error signal, which is the difference between the desired reference signal (Vreference) and the actual process variable (VDC_Bus). The three terms on the right side of the equation correspond to the three components of a PID controller:

- $K_p e(s)$ represents the proportional control, where the control output is directly proportional to the error.
- $\frac{K_1}{S} e(s)$ represents the integral control, which integrates the cumulative error over time to eliminate steady-state error.
- $K_D . S . e(s)$ represents the derivative control, which takes into account the rate of change of the error to anticipate future errors.

The transfer function can be written as follows :

$$H(s) = \frac{U(s)}{e(s)} = K_P + \frac{K_1}{S} + K_D . S \qquad (9)$$

Where $e(s) = |V_{ref} - V_{DC}|$

The last equation that express the transfer function of the PID controller, which relates the Laplace transforms of the control output $U(s)$ and the error signal $e(s)$. The transfer function $H(s)$ essentially characterizes how the controller responds to changes in the error signal. It's a representation of the controller's dynamics. K_P is the proportional gain, K_1 represents the integral gain, and K_D is the derivative gain. These gains determine how each component of the controller contributes to the control output. The term $\frac{K_1}{S}$ in the transfer function represents the integral action, which helps eliminate steady-state error by integrating the error over time. The term $K_D . S$ in the transfer function represents the derivative action, which anticipates future error trends by considering the rate of change of the error.

These equations are fundamental in the analysis and design of PID controllers, a widely used control strategy in engineering to regulate systems. The gains (K_P,K_1 and K_D) are adjusted based on system characteristics and control performance requirements to achieve the desired control behavior. In battery storage systems, maintaining a stable output voltage is crucial. The PID controller can be used to regulate the battery voltage to a desired setpoint. In summary, a PID controller with appropriate tuning of (K_P,K_1 and K_D) can effectively control the voltage of a battery storage system by continuously adjusting the charging or discharging process to maintain the battery voltage close to the desired reference voltage, V_reference.

4. SIMULATION AND RESULTS DISCUSSION

As depicted in Figure 11, this study suggests a smart DC-microgrid that is combined with a hybrid energy system. The hybrid energy sources, such as wind and solar energy, and a battery storage system (BSS), which each display their own converters and are coupled to the DC-link, make up the system's three primary parts. The power converters try to get the most electricity possible out of each renewable resource. The second component represents the loads, which include a DC electric vehicle (EV) charging station and a smart university with AC loads, such as laboratory experimentation benches, fans, and lights. The energy control unit calculates the energy consumption and production to select the appropriate control modes. The simulation of the proposed system is carried out using Matlab/Simulink.

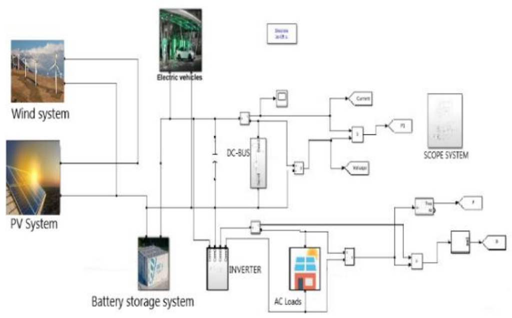

Fig. 11. Simulink model of the proposed Microgrid including EV charging station

The PV system has a maximum power output of 50 KW, while the PMSG wind turbine provides up to 10 KW. The reference voltage for the DC-link is set at 240 V. When the starting point of charge (SOC) of the battery storage system is 80%, a DC

EV charging station with a power of 12 KW is connected to the DC-link at a voltage of 400 V through two load-side converters. The load demand for the AC bus is 10 KW for one second, whereas the load demand for the DC bus is 10 KW at 400V. The simulation was run at a sample rate of one second to evaluate the degree to which the proposed energy control system performs in preserving microgrid balance during weather variations in comparison to each controller. In the proposed meteorological scenario, the power generated by the PV panels and wind turbines was observed to vary, as shown in Figures 12 and 13, respectively. Figure 14 displays the variation in power demand from the EV charging station.

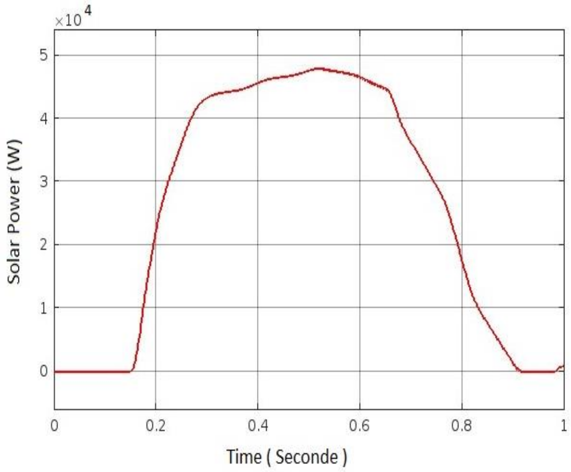

Fig. 12. The power generated by solar panels (W)

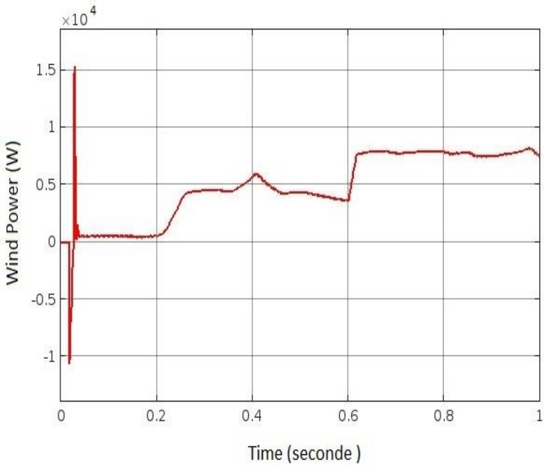

Fig. 13. The amount of power generated by wind turbines (W)

Between t = 0 and t = 0.2 seconds in the simulation, the total power required for the DC and AC loads of the EV charging system, as well as the total renewable energy generated, was less than 20 KW. The maximum energy output from the PV and wind sources was 12 KW and 1 KW, respectively. To maintain the power balance and supply both loads with electricity, the battery had to discharge since its state of charge was limited between 20% SOC and 80% SOC. According to Figures 15 and 16, the battery provided an energy range of 16 KW, it was established based on the decline in the state of charge spectrum, and a total of 18 KW of battery power. As a result, this issue with the DC bus's power requirements was fixed.

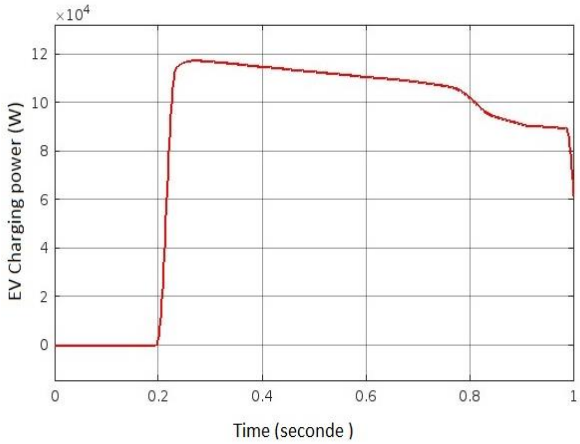

Fig. 14. EV charging station power (W)

Additionally, when the solar power increased by more than 45 KW, the wind power climbed by 5 KW, and the EV charging power increased by more than 11 KW, there was an excess of energy that was out of balance between t = 0.3 s and t = 0.5 s. As we already discussed, the battery is the key element in maintaining the equilibrium of the system. The battery conserved the additional energy to maintain a balance between power generation and consumption because its state of charge was within a safe range.

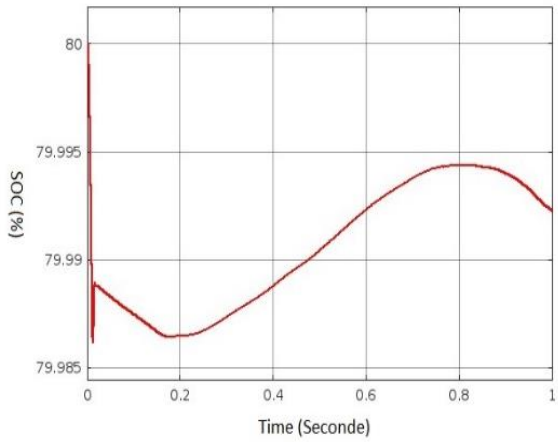

Fig. 15. State of charge of Battery storage (%)

At time t = 0.5 s, the AC bus was consuming 10 KW of power, while the solar output was at its maximum of approximately 45 KW, and the wind turbine was producing 7 KW. This led to a decrease in the battery's energy surplus compared to the previous interval, and the charging slope was also lower, as shown in Figures 19 and 18. At t = 0.6 s, once more, the irradiation frequency dropped, causing the solar system to become less effective as the primary source. By time t = 0.8 s, the total amount of renewable energy sources was insufficient to meet the loads' requirements, resulting in the battery being discharged once again to provide excess power to the microgrid. The battery's power output increased proportionally with the difference between the requested and produced power. This finding is important because it suggests that the gap between the two is widening. The objective of this research was to regulate the voltage and frequency on both the DC and AC buses and equalize energy in microgrid systems, as stated at the beginning. In contrast to Figure 19, which demonstrates the AC bus frequency fluctuation, Figures 17 and 18 exhibit the measured power and voltage values on the DC bus, respectively.

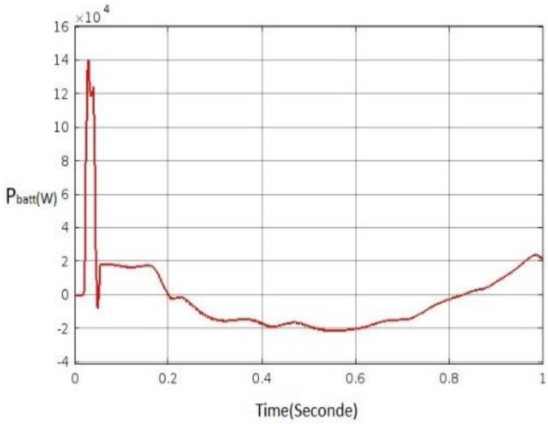

Fig. 16. Variation of the battery power (W)

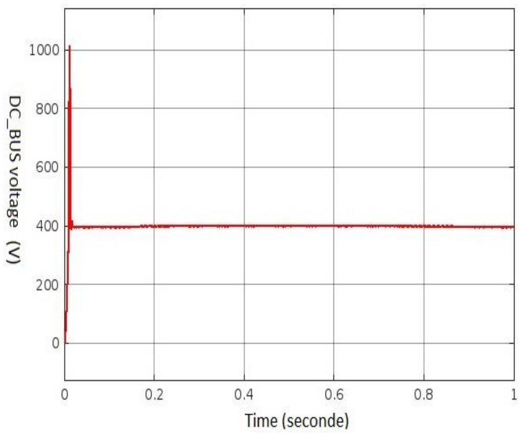

Fig. 17. DC_BUS voltage (V)

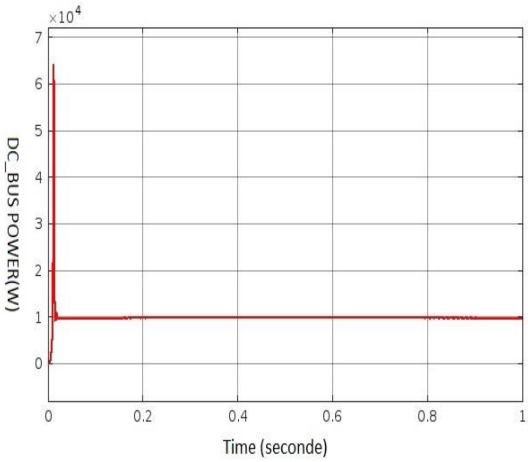

Fig. 18. DC_BUS Power (W)

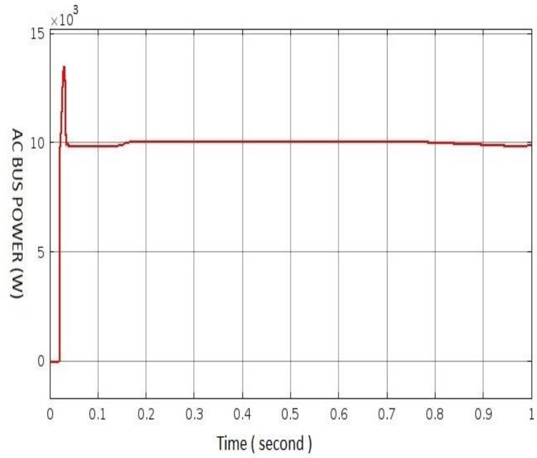

Fig. 19. AC_BUS power (W)

The AC load consumed 10 KW, and the DC load consumed 10 KW, between t equal to 0 s and t equal to 1 s, according to the power measurements on the AC and DC buses. The DC bus voltage was maintained at 400 V as needed at the start of the test. Figures 17–18 demonstrate the significant benefits of PID controller methods for maintaining power and voltage at the reference level. In Figure 20, it can be observed that the frequency variation of the the approache was 0.02, which was negligible, except for the initial transitory regime and by confirming the robustness of our results, we can compare this DC voltage and AC frequency stability with the study of the reference [28], who carried out this work without having integrated the electric vehicle charging station and having in the end the same level of stability in our case using different intelligent controller such us ANN and Fuzz logic controller. The PID controller demonstrated the least amount of frequency variation. Based on this, we can draw the conclusion that the PID controller was more effective in sustaining the microgrid's frequency, power, and voltage stability. The simulation results demonstrate how well the proposed EMS adapts to variations in load demand and weather conditions.

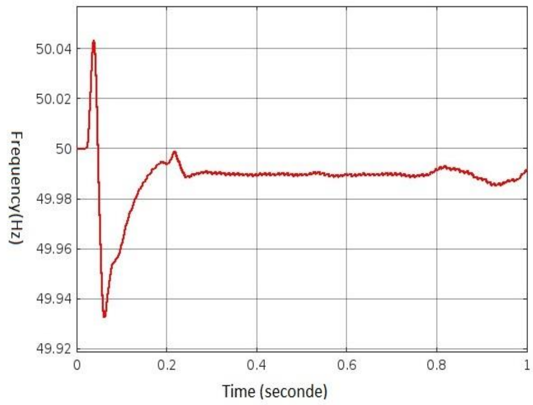

Fig. 20. Mesured frequency at the AC_BUS(Hz)

5. CONCLUSION

This study focuses on integrating various hybrid energy sources, including a battery storage system (BSS), wind energy, a photovoltaic (PV) energy source, and an EV charging station, into a DC microgrid. Intelligent PID techniques are used to regulate the source-side converters (SCCs) of the storage unit to maximize the amount of power generated by renewable energy sources and enhance the quality of the electricity provided to the DC microgrid. The innovation of this work is illustrated by the integration of an EV charging station while maintaining the DC bus voltage at 400V as required at the start of the test. Additionally, the AC frequency's stability is maintained within a deviation margin not exceeding 0.02.The energy storage system in the charging station provides uninterrupted EV-charging and ESS provides an option for effective usage of renewable energy sources. Utilizing PID control can enhance system reliability, by enabling the storage of surplus renewable energy during periods of low demand and subsequently providing it during high-demand periods. Our results are compared with those of the latest works in the literature, as discussed in the last part of the article, with the inclusion of an EV charging station in our case. The proposed control strategy's simulation outcomes, using Matlab and Simulink, demonstrate the effectiveness of the proposed system in balancing the microgrid and providing a stable power supply to the loads. Future research in this area will focus on integrating cutting-edge intelligent techniques, such as Artificial Neural Networks (ANN) and fuzzy logic control, into the overall management of the energy control system. This will include controlling the number of electric vehicles that can charge simultaneously and planning the charging system with optimal electric vehicle allocation. On the other hand, future work related to this topic will involve the integration of energy optimization, specifically focusing on CO2 emissions control, into the global management of the energy system.

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REFERENCES

1. Wu Y, Zhang L. Can the development of electric vehicles reduce the emission of air pollutants and greenhouse gases in developing countries? Transportation Research Part D: Transport and Environment 2017; 51: 129–45. https://doi.org/10.1016/j.trd.2016.12.007.
2. Atia DM, El-Madany HT, Atia Y, Zahran M. Real-time implementation of energy management for photovoltaic/battery/diesel hybrid system based on LabVIEW. International Journal of Renewable Energy Research (IJRER) 2022; 12(2): 1105–16.
3. Global EV Outlook 2022: Securing supplies for an electric future en OECD. Available: https://www.oecd.org/publications/global-ev-outlook-bdb28e12-en.htm
4. Integration of microgrids and electric vehicle technologies in the national grid as the key enabler to the sustainable development for Rwanda. Available: https://www.hindawi.com/journals/ijp/2021/9928551/
5. Liu Z, Chen Y, Zhuo R, Jia H. Energy storage capacity optimization for autonomy microgrid considering CHP and EV scheduling. Applied Energy 2018; 210: 1113–25. https://doi.org/10.1016/j.apenergy.2017.07.002.
6. Chaurasiya S, Mishra N, Singh B. A 50kW bidirectional fast EV charger with G2V & V2G/V2V capability and wide voltage range. 2020 IEEE 5th International Conference on Computing Communication and Automation (ICCCA) 2020: 652–7. https://doi.org/10.1109/ICCCA49541.2020.9250857.
7. Koufakis AM, Rigas ES, Bassiliades N, Ramchurn SD. Offline and online electric vehicle charging scheduling with V2V energy transfer. IEEE Transactions on Intelligent Transportation Systems 2020; 21(5): 2128–38. https://doi.org/10.1109/TITS.2019.2914087.
8. Alinejad M, Rezaei O, Habibifar R, Azimian M. A charge/discharge plan for electric vehicles in an intelligent parking lot considering destructive random decisions, and V2G and V2V energy transfer modes. Sustainability 2022; 14(19): 12816. https://doi.org/10.3390/su141912816.
9. Mahmoud MS, Azher Hussain S, Abido MA. Modeling and control of microgrid: An overview. Journal of the Franklin Institute 2014; 351(5): 2822–2859. https://doi.org/10.1016/j.jfranklin.2014.01.016.
10. Microgrid architectures for distributed generation: A brief review. Semantic Scholar. Available: https://www.semanticscholar.org/paper/Microgrid-architectures-for-distributed-generation%3A-Lede-Molina/6ac096c9288529c55c46b8e96db6017abe4a5f49.
11. Review of energy storage systems for electric vehicle applications: Issues and challenges Semantic Scholar. Available: https://www.semanticscholar.org/paper/Review-of-energy-storage-systems-for-electric-and-Hannan-Hoque/5ee3cb688cf8b0e018338ec2b96c9c5ae9e62eaa.
12. Overview on recent developments in energy storage: Mechanical, electrochemical and hydrogen technologies - ScienceDirect. Available: https://www.sciencedirect.com/science/article/abs/pii/S019689041631055X.
13. Energy management and control strategy for a DFIG wind turbine/fuel cell hybrid system with super capacitor storage system. Semantic Scholar.

Available: https://www.semanticscholar.org/paper/Energy-management-and-control-strategy-for-a-DFIG-Kadri-Marzougui/a78b1efa3c80f9ca2f655ffd6cdde6c6e8f96193.

14. Barik A, Das DC, Latif A, Hussain S, Ustun T. Optimal voltage–frequency regulation in distributed sustainable energy-based hybrid microgrids with integrated resource planning. Energies 2021
15. Social acceptance of microgrids dedicated to electric vehicle charging stations. IEEE Conference Publication IEEE Xplore. Available: https://ieeexplore.ieee.org/document/8566787
16. Arcos-Aviles D, Pascual J, Guinjoan F, Marroyo L, García-Gutiérrez G, Gordillo-Orquera R, et al. An Energy management system design using fuzzy logic control: smoothing the grid power profile of a residential electro-thermal microgrid. IEEE Access 2021; 9: 25172–25188. https://doi.org/10.1109/ACCESS.2021.3056454.
17. Distribution Voltage Control for DC Microgrids Using Fuzzy Control and Gain-Scheduling Technique. IEEE Journals & Magazine. IEEE Xplore. Available: https://ieeexplore.ieee.org/document/6297477.
18. Recent trends and development in hybrid microgrid: a review on energy resource planning and control |Semantic Scholar. Available: https://www.semanticscholar.org/paper/Recent-trends-and-development-in-hybrid-microgrid%3A-Barik-Jaiswal/a3503bc4489e85cc7144637ccea1f27f127da4dd.
19. Locment F, Sechilariu M, Forgez C. Electric vehicle charging system with PV Grid-connected configuration. 2010 IEEE Vehicle Power and Propulsion Conference 2010; 1–6. https://doi.org/10.1109/VPPC.2010.5729016.
20. Locment F, Sechilariu M. DC microgrid for future electric vehicle charging station designed by Energetic Macroscopic Representation and Maximum Control Structure. 2014 IEEE International Energy Conference (ENERGYCON) 2014; 1454–1460. https://doi.org/10.1109/ENERGYCON.2014.6850614
21. PDF Modeling and Simulation of DC Microgrids for Electric Vehicle Charging Stations. Semantic Scholar. Available: https://www.semanticscholar.org/paper/Modeling-and-Simulation-of-DC-Microgrids-for-Locment-Sechilariu/41eaadaaa794bc9957e7d4f394e188acc6cab305.
22. Thakran S, Singh J, Garg R, Mahajan P. Implementation of P&O algorithm for MPPT in SPV system. 2018 International Conference on Power Energy, Environment and Intelligent Control (PEEIC) 2018: 242–245. https://doi.org/10.1109/PEEIC.2018.8665588.
23. Bhattacharyya S, Kumar P DS, Samanta S, Mishra S. Steady output and fast tracking MPPT (SOFT-MPPT) for P&O and InC algorithms. IEEE Transactions on Sustainable Energy 2021; 12(1): 293–302. https://doi.org/10.1109/TSTE.2020.2991768.
24. Kushwaha A, Gopal M, Singh B. Q-Learning based Maximum power extraction for wind energy conversion system with variable wind speed. IEEE Transactions on Energy Conversion 2020; 35(3): 1160–1170. https://doi.org/10.1109/TEC.2020.2990937.
25. Kumar PS, Chandrasena RPS, Ramu V, Srinivas GN, Babu KVSM. Energy management system for small scale hybrid wind solar battery based microgrid. IEEE Access 2020; 8: 8336–45. https://doi.org/10.1109/ACCESS.2020.2964052.
26. Wagner HJ. Introduction to wind energy systems(*). EPJ Web of Conferences 2020; 246: 00004. https://doi.org/10.1051/epjconf/202024600004.
27. Wang D, Locment F, Sechilariu M. Modelling, simulation, and management strategy of an electric vehicle charging station based on a DC microgrid. Applied Sciences 2020; 10(6): 2053. https://doi.org/10.3390/app10062053.
28. Al Sumarmad KA, Sulaiman N, Wahab NIA, Hizam H. Energy management and voltage control in microgrids using artificial neural networks, PID, and fuzzy logic controllers. Energies 2022; 15(1): 303. https://doi.org/10.3390/en15010303.

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