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Research Paper

ANN-Based Energy Management Strategy For Grid-Interactive DC Microgrid EV Charging Station with Fuel Cell-Battery Coordination

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Abstract: *To ensure the consistent operation of renewable energy-integrated electric vehicle (EV) charging stations that are grid-interactive, efficient energy storage and coordinated power management are essential. Although large-scale energy storage technologies help to lessen the intermittent nature of renewable production, charging stations become considerably more reliable when combined with multi-source energy management and priority charging. An approach to decentralised energy management (DEM) that combines fuel cell (FC) and battery energy storage (BES) systems is presented in this publication. The technique makes use of an LRCD control mechanism that is based on rules. The proposed method substitutes an ANN-based controller for a conventional PI controller, providing intelligent and adaptive control under varying operating circumstances. By adjusting its parameters in real-time based on the system's behaviour, the ANN controller improves the system's transient responsiveness, resilience against nonlinearities and uncertainties, and the management of the DC bus voltage. Depending on the BES's state-of-charge (SoC), the droop control changes its gain to maximise power support time, decrease current stress under different capacity scenarios, and improve battery life. Additionally, fuel cells are quite stable across a wide range of charging circumstances, provided that they remain within their linear operating zone. The charging station keeps its power factor at unity and its current harmonic distortion at 5% while it operates independently and communicates with the grid. As an added bonus, it can handle supplementary loads. In both grid-connected and independent modes, the proposed technique successfully controls the DC bus voltage in response to variations in photovoltaic (PV) power and dynamic loads, proving the accuracy and reliability of the ANN-based control strategy.*

Keywords_ electric vehicle charging stations (FCs), power quality (PQ), unity power factor (UPF), harmonic distortion (HD), adaptive control strategy (ACS), linear regression control (LRCD), state-of-charge balancing system (SOSBS), DC bus voltage regulator (DC bus), and artificial neural networks (ANNs).

I. INTRODUCTION

The relevance of energy security and grid resilience is growing as power networks are becoming more electrified and dispersed. A lot of noise is being made in the energy and transportation sectors due to the increasing popularity of electric vehicles (EVs), which are similar to conventional automobiles driven by internal combustion engines. Innovations in fuel cell and battery technologies have allowed for longer intervals between charges and greener modes of mobility. The integration of large-scale electric vehicle charging stations with existing grid systems is hindered by many technological challenges, including grid stability, infrastructure preparation, and coordinated energy management. Grid operations are increasingly depending on renewable energy sources like wind and photovoltaic (PV) electricity as a backup to fulfil the rising demand for charging electric automobiles. The distribution networks are already straining under the weight of electric vehicle charging chaos and the unpredictability of renewable electricity, despite the fact that renewable energy offers many benefits. When there is a lot of EV use, the power quality drops, especially during peak demand periods, and problems like voltage fluctuations and harmonic distortion might arise. The inability of the power grid and electric vehicle charging stations to communicate worsens these concerns and might even make them useless.In this regard, the development of multipurpose, grid-independent charging stations could be a viable solution. Important considerations for the design of such a system include control mechanisms, energy management, reliability, safety, and cost. Create a workable substitute by creating a hybrid system that uses fuel cells (FC) and battery energy storage (BES). The two technologies complement each other well because to their numerous similar characteristics, such as high energy density, scalability, and operational flexibility. Fuel cells are able to maintain a constant rate of power production throughout time, in contrast to batteries, which may react rapidly to variations in demand. Two major problems that have not yet been resolved are running fuel cells inside their efficient region and properly monitoring the state-of-charge (SoC) of batteries.

Proton exchange membrane fuel cells (PEMFCs) are eco-friendly as they can provide steady-state electricity with zero emissions. Their fundamental electrochemical and thermodynamic dynamics render them sluggish and transitory when subjected to dynamic load situations, severely restricting their independent use. These components, when integrated with battery systems, enhance the system's efficiency and reliability. Both optimization-based and rule-based EMS are often used in the design of BES-FC hybrid systems. Since rule-based methods are more accessible, require less resources, and provide superior outcomes, most people prefer them over optimization-based ones. The latter are more complex and expensive. However, we have a long way to go before we achieve robust control structures, scalability, and plug-and-play functionality. The potential for decentralised control algorithms to improve the scalability and reliability of distributed energy systems is attracting the attention of many academics. Accurate load sharing and DC bus voltage regulation are both compromised by the use of traditional droop control in decentralised power sharing DC microgrids. Errors in power-sharing due to line resistance effects further degrade the system's performance. Updated droop control algorithms are used by contemporary systems to tackle these issues. Nevertheless, these approaches often result in more intricate systems with unbalanced system-on-a-chip (SoC) batteries. This research proposes a decentralised system that uses fuel cells and battery storage to regulate energy use at DC microgrid-based charging stations for electric vehicles. The goal is to avoid these limitations. An LRCD control mechanism based on rules is designed to regulate the DC bus voltage, improve power-sharing accuracy, and guarantee reliable operation under dynamic grid and load scenarios. The system's adaptability, responsiveness, and nonlinearity resilience are all enhanced when an ANN-based controller is used in place of a conventional PI controller. Intelligent decision-making in response to current system circumstances is enabled by the recommended ANN controller, which increases system efficiency and stability. The following fields are primarily aided by this endeavour: A decentralised power management system is developed to guarantee that BES, FC, and the grid all get the energy they need in all conceivable operational scenarios. 2. A complete fuel cell model and LRCD-based control maintain this system running efficiently. 3. By controlling the depth of discharge (DoD) using a system-on-chip (SoC) based technique, the battery lifespan is increased. To improve robustness and dynamic performance, the fourth stage is to switch out the old PI controller with one that is based on artificial neural networks. Fifth, the recommended approach will improve power quality and guarantee constant operation of your electric car charger regardless of your grid connection.

II. ARCHITECTURE DESIGN AND MODELING OF EVCs

Figure 1 shows the many functions of electric vehicle (EV) charging stations. This system includes components that power electric vehicle charging stations (EVCSs) using renewable energy sources, such as photovoltaic (PV) generation, fuel cells (FC), and battery energy storage systems

(BES). Electric vehicles will be consistently and effectively charged by this hybrid design regardless of fluctuations in the production of renewable energy sources, system disruptions, or fluctuations in demand. The front-end converter (FEC) uses a two-level, three-leg voltage source converter (VSC) configuration to link the DC microgrid to the AC utility grid. Bidirectional power interchange between the grid and electric car charging stations is made feasible by the FEC's flexibility to shift between grid-forming and grid-following modes; this exchange does not result in a loss of unity power factor or worse power quality. Switching between island and grid-connected modes is a breeze, even when the power goes out. By connecting the BES to the shared DC bus, a bidirectional DC-DC converter may be used to charge and discharge the battery. The BES is a crucial part of any system that aims to stabilise DC bus voltage, deal with transient loads efficiently, and reduce variations in renewable power. The charging and discharging of the battery are regulated based on its state of charge (SoC) to ensure that it does not undergo excessive charging or deep draining, hence extending its life. To connect to the system's DC bus and produce power in just one direction, fuel cells (FCs) use a boost converter. An FC is a typical backup power source to keep the power running when renewable power generation isn't enough and the battery isn't charged. Continue to operate the fuel cell inside its linear ohmic region for the best performance with the least amount of degradation. The common DC bus coordinates all energy sources and storage units, and stable voltage levels ensure that auxiliary loads and electric car chargers obtain power on a continual basis. Decentralisation of control reduces the need for communication lines while increasing system reliability, scalability, and plug-and-play capability via the use of local controllers for each source. The electric car charging station is well-designed so that it can improve its energy efficiency, manage electricity properly, and endure both typical and out-of-the-ordinary grid conditions.

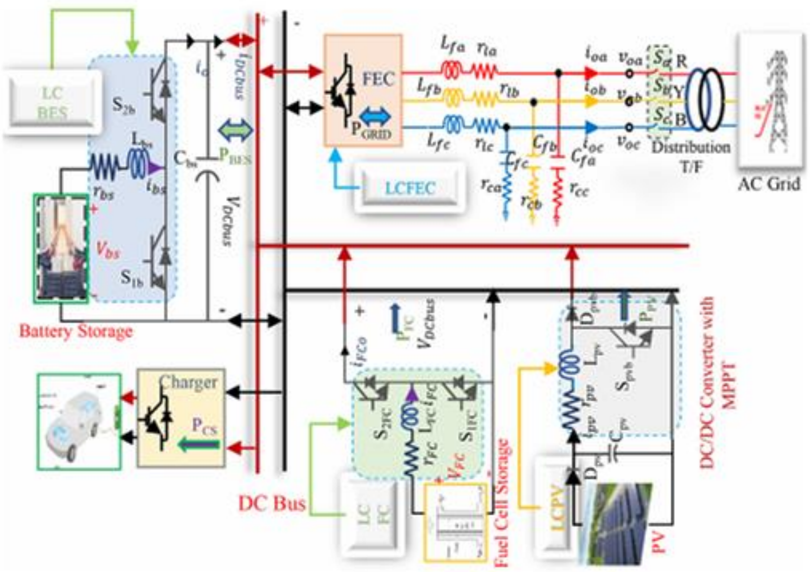


Fig. 1. Grid interactive DCMG architecture for the electric vehicle charging station.

The DC microgrid coordinates the integration of various energy sources and storage devices by using a constant voltage level, V_DCbus. The system is able to manage its activities independently of centralised communication since it uses a distributed local control technique. Therefore, it might function well in both grid-connected and autonomous (islanded) modes. Using a local controller at each source allows for autonomous regulation of power contribution in response to real-time operating circumstances, which improves system stability and scalability. Solar panels with 280 V open-circuit voltage and 25 A short-circuit current are part of the system's photovoltaic (PV) arrays that use DC-DC boost converters. When these converters are in their normal operating mode, they are set to maximum power point tracking (MPPT) mode, which allows them to capture the most power possible from the sun. Switching the PV converters to voltage management mode may help preserve DC bus stability during grid islanding or periods of surplus power. In order to avoid DC bus overvoltage, PV management is designed to be flexible, which allows for optimal use of renewable energy. The BES's local controllers make it possible to charge and discharge. This innovation permits two-way power transfer by use of DC-DC converters. A bank of 228 V and 42 Ah PbO_t batteries powers the BES devices, allowing them to smooth out oscillations brought on by intermittent renewable power sources and manage short bursts of electricity. The system's overall efficiency and battery life are both enhanced by algorithms that are dependent on the battery's charge state. This prevents the battery from being dangerously over- or undercharged.

Even if the power is off for a lengthy time, the fuel cell (FC) unit can keep providing aid with unidirectional power flow. Thanks to its unidirectional boost converter connection to the shared DC bus, it has the potential to provide the electric vehicle charging station with peak current enough to satisfy all of its essential requirements. A fuel cell's slower dynamic response makes it ideal for steady-state power needs, but a BES excels at handling quick transients. When BES and FC work together, they make it possible to adapt to changing circumstances and provide energy both now and in the future.

A well-designed DC microgrid that includes photovoltaics, battery storage, fuel cells, and the grid interface can charge electric cars reliably, transmit electricity consistently, and manage the voltage on the DC bus. To evaluate the system's responsiveness in different circumstances, the following sections discuss the microgrid component models. These models include converters, storage systems, and control algorithms.

III. CONTROL ARCHITECTURE

Fuel cells, solar panels, and batteries are the three energy sources that make up a charging station (CS), and their relative importance is determined by the load-sharing algorithm. This design relies on a photovoltaic (PV) system as its primary energy source due to its clean and sustainable nature. Due to its ability to manage transient load demands and its rapid response time to power changes, the BES is selected as the main backup source. If PV output is insufficient and the BES state of charge remains below the defined threshold for a long time, the FC unit will provide a constant flow of power as an additional backup source. Each part of the CS may operate autonomously thanks to a decentralised local control technique that allows for coordinated power sharing apart from communication links. Improved utilisation of renewable energy sources, longer battery life, and more reliable grid-interactive EV charging stations are just a few of the many advantages of this priority-based load-sharing approach.

In developing the algorithm, we aimed to accomplish the following: first, to establish a priority system among the BES, FC, and grid; second, to enable grid-supported electric vehicle charging stations that use PV-Battery and fuel cell storage to access the power of the BES through its System on a Chip (SoC). Further features include FC optimisation of operation, battery dominance degree optimisation, stable DC bus operation during grid landing, and transient power control via the BES. The control diagram of the system is shown in Figure 2. Management of reactive power and frequency constitute the ACMG droop. Since a little change in frequency may significantly impact the active and reactive power, we look at the system's sensitivity to get the droop coefficient. A DCMG also makes advantage of a power-voltage droop. The typical droop with virtual resistance for controlling the current flowing across several DC sources is as follows:

$$Vj = Voj - Rdj \times isj \quad (1)$$

With j = 1, 2, 3,..., the virtual droop resistance or gain (Rdj) and the no-load terminal voltage (Voj) are defined in equation (17). Choosing droop gain requires thinking about the system's overall stability as well as the maximum permissible variation in the DC bus voltage (VDCbus). This formula may be used to get the BES's maximum charging/discharging current (Imax):

$$Rdj \leq VDCbusimax \quad (2)$$

Given two sources, the current sharing ratio may be expressed as in Equation (17) as i

$$s1 \times Rd1 = is2 \times Rd2 \quad (3)$$

An inverse connection between source droop gain and load distribution is desired.

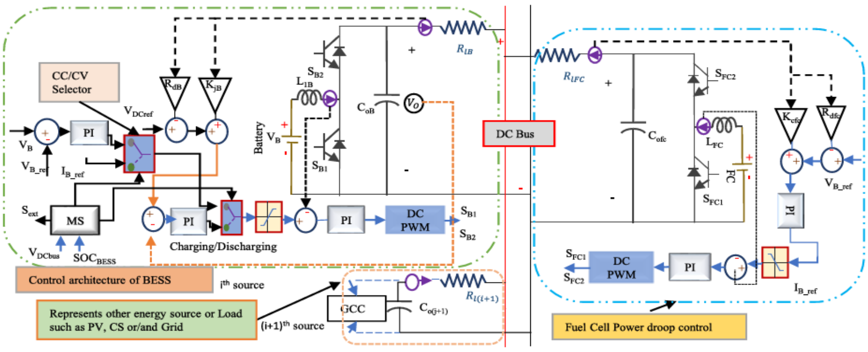


Fig. 2. Detailed control architecture of various power sources and loads.

Equation (18) shows one limitation of droop gain; line resistance should only be considered when droop resistance is much more than Rdj>>Rlj. Modifying the line inductance solves the problem of uneven reactive power distribution in ACMG. In a similar vein, DC droop communicates actual power via LRCD.

IV. ANN CONTROLLER

In contrast to the more traditional Proportional-Integral (PI) controller, this project employs an ANN-based controller to regulate the converter system's output voltage and current. In contrast to conventional PI controllers, artificial neural network (ANN) controllers are able to learn and adapt to non-linear dynamics by training on system input-output data in a variety of load and grid configurations. instrument for control. A single output layer, ten hidden layers, and two input levels make up the suggested controller for artificial neural networks. Both the original and updated error signals, which quantify the discrepancy between the real and reference values in the d and q coordinate systems, are sent into the ANN controller. A key principle of an ANN controller is to maximise accuracy while simultaneously minimising error. The work of converting the dqo data to abc format is being carried out by the ANN controller. Figure 3 shows that the ANN controller's performance is measured by the mean square error, which is the difference between the input and target values.

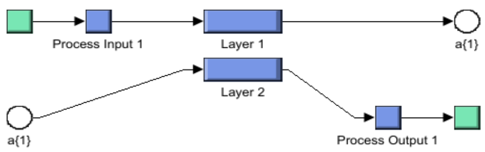


Fig. 3. Typical Structure of ANN control

V. RESULTS AND DISCUSSION

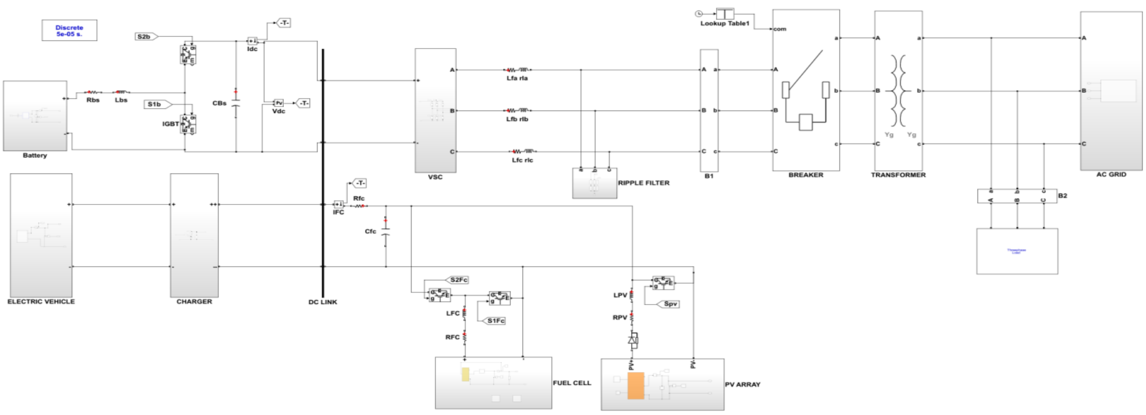
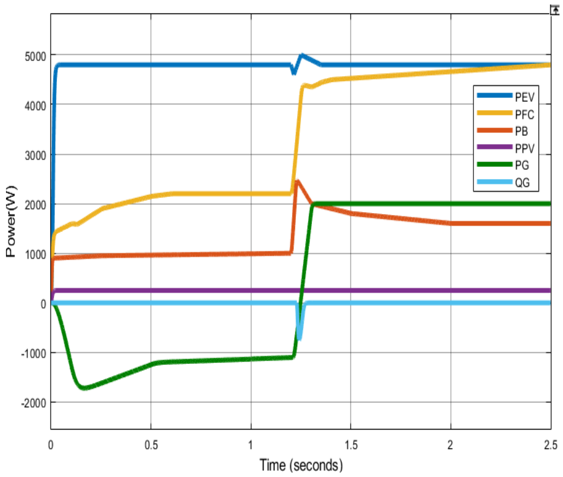
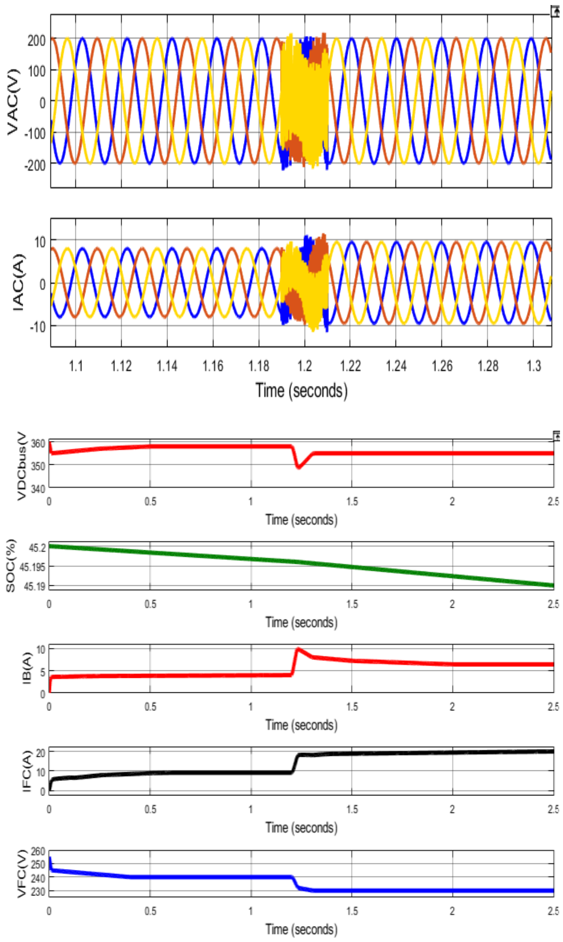


Fig. 4. The electric car charging station's proposed grid-interactive DCMG architecture's MATLAB/SIMULINK circuit.

A) PI CONTROLLER



(a)



(b)

Fig. 5. (a)Transferring power from grid-connected to off-grid modes for various units (b) MG performance with the recommended DEM in both modesVoltage and current in the ff-grid, including those of the FEC, the DC bus, the BESSoC, and the FC.

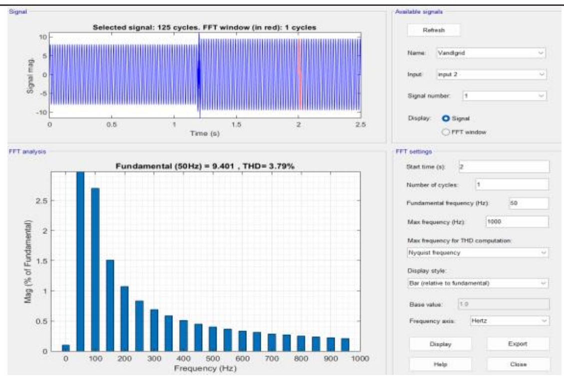
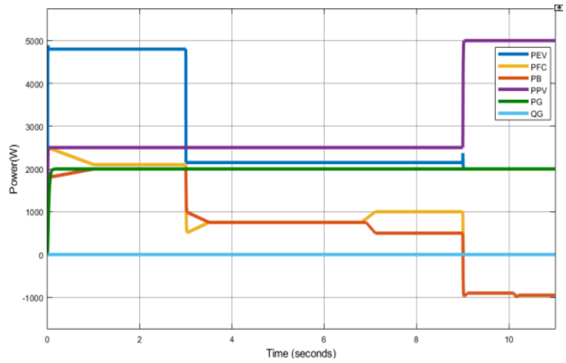
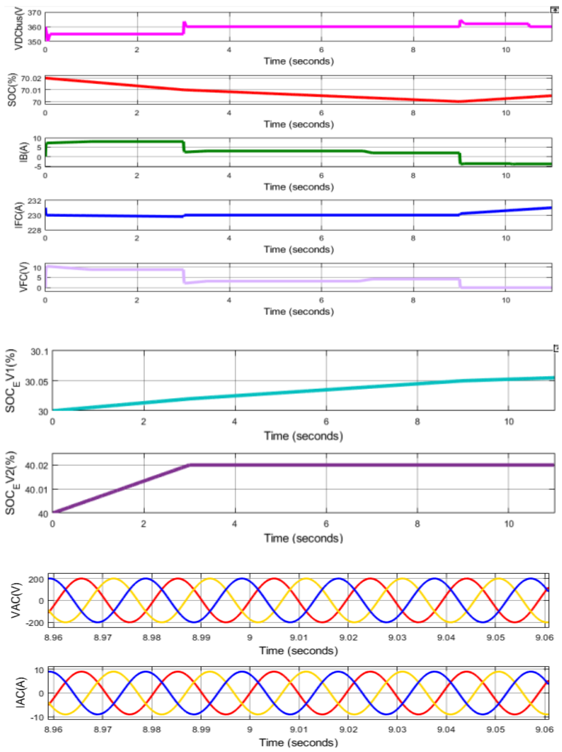


Fig. 6. THD% of grid current



(a)



(b)

Fig. 7.(a) During power changes, (a)the system ensures smooth operation; (b)during transitions, the voltage and current on the DC bus, the BES system on a chip, and the FC current are monitored.

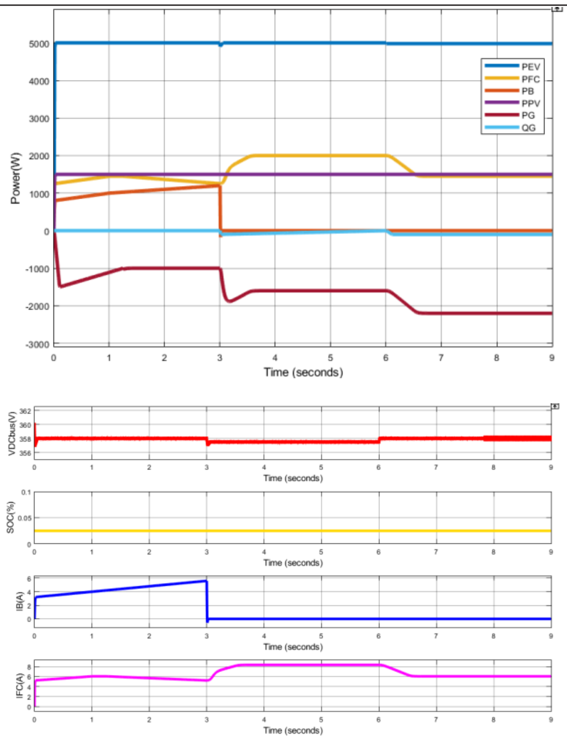
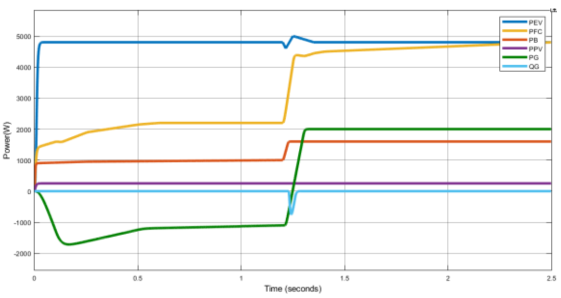
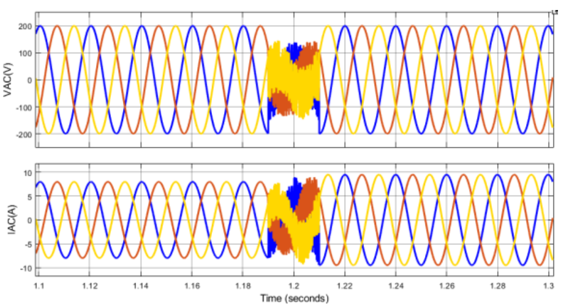


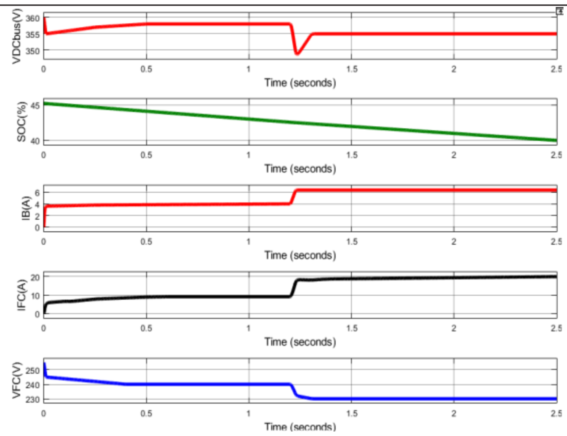
Fig. 8. (a) Unmanned grid power transitions will be performed by all units that are impacted by changes in load and source. (b) The DC bus voltage, BES system on a chip current and voltage, FC current, SoC of electric vehicle load, and FEC electrical current and voltage are the following characteristics that characterise the MG's off-grid performance with the suggested DEM.

B) ANN CONTROLLER



(a)





(b)

Fig. 9. a)Power transmission from grid-connected to off-grid modes for various units (b) MG performance with the proposed DEM from grid-connected to off-grid modes (FEC voltage and current, DC bus voltage, BESSoC current, FC voltage and current).

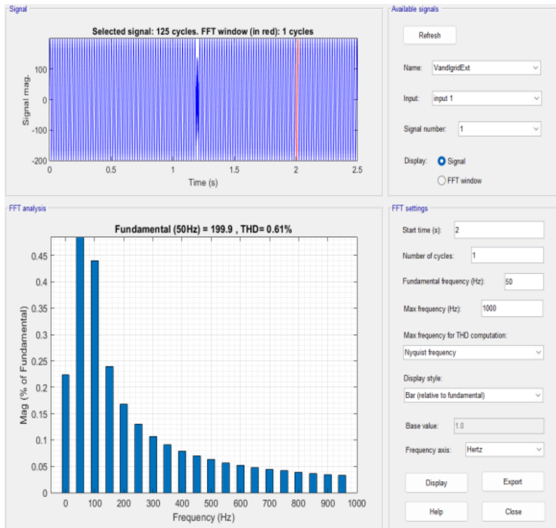
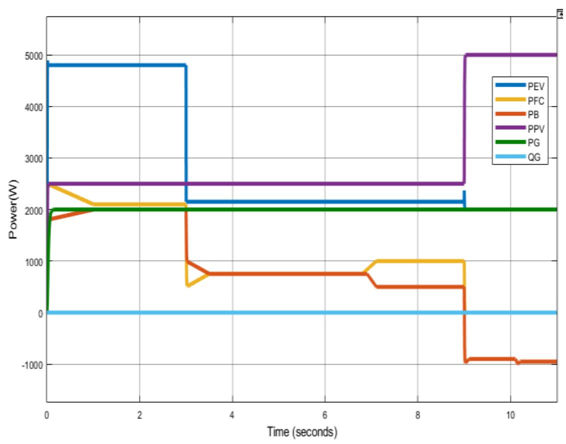
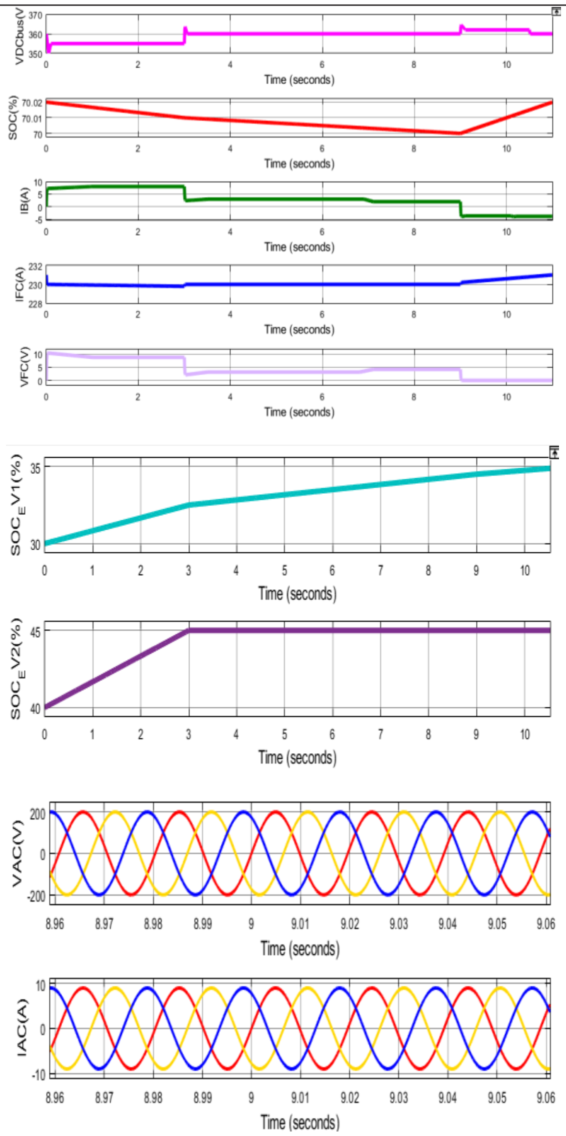


Fig.10 THD% of grid current

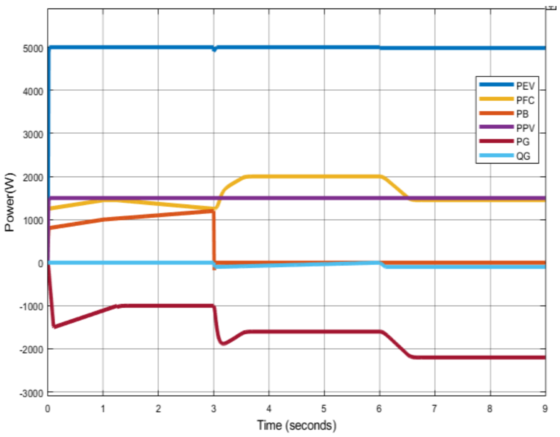


(a)



(b)

Fig. 11. When the power goes off, (a)everything runs well, and (b) during the changeover, we keep an eye on the FC current, the BES system on a chip, and the DC bus voltage and current.



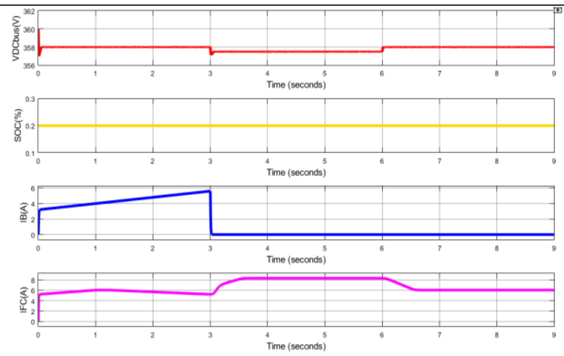


Fig. 12. (a) Autonomous grid units' power transitions caused by variations in load and source (b) MG's off-grid performance using the suggested DEM: DC bus voltage, BES system on a chip current and voltage, FC current, electric vehicle SoC load, and FEC voltage and current.

Comparision Between PI and ANN Controller

Parameter	PI Controller	ANN Controller
DC Bus Voltage Deviation (V)	±15V	±3V
Settling Time (sec)	0.6 sec	0.2 sec
Overshoot (%)	15 %	5 %
Dynamic Response	Moderate	Fast
Power Transition Smoothness	Slight oscillations	Smooth & stable
Battery SoC Fluctuation (%)	High variation (±8–10%)	Controlled (±2–3%)
Grid Disturbance Handling	Average	Excellent
Load Variation Response	Slower	Faster
Control Complexity	Simple	Moderate (training required)
System Stability	Good	Very High

CONCLUSION

Using solar photovoltaic (PV) electricity and the utility grid, this paper describes an electric vehicle (EV) charging station that integrates a BES-FC system as an example of a decentralised energy management framework. The DC microgrid must be designed with a control method known as line resistance compensated droop (LRCD) to guarantee efficient operation in both grid-connected and islanded modes. When compared to more conventional control methods, the use of an ANN-based controller yields better results. Our ability to swiftly adjust to changing operational conditions is a direct result of this. An accurate evaluation of performance is possible by include fuel cell electrochemical dynamics in the system model. This includes the behaviour of thermodynamic systems and the impacts of many charge layers. Operational reliability and longevity are improved by controlling fuel cell operation and regulating battery power sharing according to state-of-charge (SoC) trends. Hydrogen consumption efficiency is maintained. The proposed droop-based coordination method gives precedence to the utilisation of preexisting energy sources to guarantee that the charging station gets continuous and uninterrupted power. The control structure ensures that the hybrid storage system will operate smoothly in all operating scenarios, regardless of the grid's availability. The results show that at the point of common connection, the power factor is one, and thus the electric car charging station may depend on a continuous power supply independent of load or producing circumstances.

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