International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 08 , August - 2026

Analysis and Critical Review of Electric Vehicle Integrated Microgrids for Stability Challenges and Advanced Control Solutions

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***Abstract* - Due to the increasing population, the load requirement is also growing further and further. So nowadays researchers are focusing on integrating the EV with microgrids. Integration of EVs with the microgrid is a solution for peak demand. However, the integration of EVs with the microgrid is creating a big impact like voltage and frequency fluctuations, optimum power scheduling, peak load management, etc. The inertia of the microgrid is very low compared to the normal utility grid such that frequency control is essential for microgrids. Charging of EVs into the microgrid creates negative impacts like voltage fluctuation hence voltage controller is also required in an EV-integrated microgrid. So, this paper reviews the various issues related to the voltage and frequency stability in EV-integrated microgrids. Also, this paper reviews the various voltage controllers like ADRC, MGCC, and NDCS, three-layer coordination, and frequency controllers like MADB, CDM, AGPSO, PSO based PID. Also discussed in detail for EV-integrated microgrids from various literature. In line with all issues, this paper also focuses on the recent research problem and possible solutions in the area of EV-integrated microgrids.**

Keywords - EV (Electric Vehicle), Renewable energy resources (RERs), Voltage stability, Frequency stability, BESS (Battery Energy Storage System), Microgrid (MG), Solar power generation (SPG), MADB (Maximum allowable delay), AGPSO (Autonomous group of particle swarm optimization) , ADRC (Active disturbance rejection control), NDCS (Need-based distributed coordination strategy), Three Layered coordination, MGCC (Microgrid central controller), CDM (Coefficient diagram method), PSO (Particle swarm optimization), PID (Proportional integral controller).

I. INTRODUCTION

Nowadays quick upgrading of the countries has enormously increased the electricity demands. Conventional energy sources are unable to provide the load requirements due to the rising demand for electricity. Additionally, the environment is negatively impacted by these resources. In order to meet the load needs, researchers are switching from traditional sources to renewable sources based on generation The popularity and efficacy of using renewable energy sources (RERs) have increased as a result of the increasing number of technologies being produced [1]. Additionally, [2] of the top 10 nations for greatest power generation with (RERs) mentions a few statics. . Conventional energy sources are unable to provide the load requirements due to the rising demand for electricity. [3]. The penetration of non-conventional sources with the conventional grid is results in the distortion of the generation of preliminary source of grid and due the utilization of the traditional transmission and distribution lines system makes the system less reliable [4]. The expansion of the MGs with renewable energy sources and ESS (Energy storage system) with batteries. So, the numerical survey in [5] are represents that the utilization of MGs is growing nowadays. A combination of traditional sources and renewable sources with a BESS is called the “microgrid”. The primary purpose of a microgrid is system reliability and stability during disturbances [6]-[9]. In a conventional grid, there is only unidirectional flow of power (i.e., from source to load). But in an MG, there is the capability for bidirectional power flow (i.e., from loads to sources). The battery energy system also acts as a source with some bidirectional converters in the microgrid. These days, the MG also uses other sources, such as electric vehicles. EVs are used in the market as a result of growing strain on fossil fuels. During some peak hours of the production station, EVs fulfil the load requirement. Additionally, they have a decent charging profile and storage capacity, making them a useful mobility load [10]. The smart operation of EV with MG is not only increases the reliability of the system but also minimizes the cost of electricity. Utilization of EVs into MG with a proper energy management system will shave of peaks and improve the load curves [11]. Now implementation of the EVs into microgrid has a good advantage like earn the profit by sharing the extra energy to the grid, people can become a self-energy producer etc. But also has some issues related to frequency stability and voltage control, EV uncertainty (When a group of the EVs are available), optimum power scheduling, and cost optimization problems. Also, various researchers implemented various controllers for all these issues.

This paper reviews the technical challenges related to the EV-integrated MG. In [12] the issues related to the voltage stability in EV-integrated microgrids. Also, in [13] the frequency deviation in EV-integrated microgrids was explained. As a part of the solution in [14]-[16] the controllers for the voltage stability and in [17]-[19] frequency stability were designed. Also, in [20]-[25] controllers for the optimum power management and peak load management were implemented in EV-integrated microgrids. Also, in other literature, various work was done for EV-integrated microgrids. But that is limited to some extent. In the case of microgrids due to low inertia frequency control is very important. And the penetration of EVs into the microgrid is creating voltage stability issues. In microgrid, frequency control is a big issue in the islanded mode. Also, some controllers for voltage and frequency control were

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 08 , August - 2026

discussed in detail and provided the new research direction from the comparative review. However, the tunning of various controllers is a big issue. And in-line with this issue of frequency control the issues related to the optimum power management and clustering of large EV data in grid-connected microgrids are also studied in this paper. So, this literature survey gives further direction to the researchers to work in the area of the EV-integrated microgrid.

This paper contains various sections. In which the section-1 contains the introduction, section -2 Important problem in EV—integrated microgrid, section-3 contains the various stability issues. section-4 contains voltage controller technique review in the EV-connected grid, section -5 contains frequency controller technique review in the EV-connected grid MG, section 6 is the research direction and discussion.

II. PROBLEM AND EXISTING SOLUTIONS FOR EV INTEGRATED MICROGRID

Table 2.1. represents the various problems occurs in EV integrated microgrid with their existing solutions from the various kind of literature study. In table 1. it can see all issues in EV integrated microgrid was studied from various kinds of literatures and then discuss and review the all literatures in brief. After brief review it was observed that the frequency and voltage control in EV integrated microgrid is very important. However other problems should be solved in microgrid. But stability of voltage and frequency is primary important in microgrids. So, in further sections all voltage and frequency controllers was discussed in brief.

Table I. Problem and Existing Solution

Sr No	Problems	Existing solution
1	Frequency stability	In [22] the feed-forward-based fuzzy logic controller is implemented with an under-frequency relay (UF) relay. Also, Particle swam optimization is implemented in [18] which is PI-PD based. Also, an AGPSO-based algorithm is implemented for frequency control in [21]. A novel CDM controller is also implemented in [20] for frequency control in an islanded microgrid. Controller in [21] very effective than [20] in case of frequency deviation. Also, in islanded mode use of virtual synchronous generator is very effective for frequency deviation as in [57].
2	Optimum power scheduling	Also, in [53] peak shaving algorithm was implemented for reduction in peak valley difference in EV -integrated microgrid in case of sudden removal of any generating source
3	Co-ordinated charging /discharging	K-means clustering algorithm is implemented in [55] for counting the EV uncertainty effect and coordinated charging and discharging is done in vary easy way by making the group of EVs of same characteristic. Also, in [56] distributed control algorithm with battery degradation cost was considered for optimize power and cost in case of numbers of EVs are available in microgrids.
4	Cost of Microgrid	A mixed linear integer programming (MILP) is implemented in [32] And also, some parameter of this algorithm is solved by the CPLEX algorithm. So, this algorithm calculates the cost of the microgrid. Also, the quadratic programming algorithm is implemented in [27] to obtain the optimum EV cost in microgrid charging.
5	Voltage stability [14]-[17]	An active disturbance rejection-based (ADRC) control algorithm was implemented in [14] for voltage as well as reactive power control. Also in [15] MGCC controller was implemented for voltage control in different situations of EVs. Also in [16] –[17] three layered coordination and need based active control algorithm was implemented. Which considered the all situation of the solar PV generation and random load demand.

III. MICROGRID STABILITY

The combination of all micro sources and loads with each other is called the microgrid. In other words, it is nothing but the “integrated energy source.” As it is a combination of all the energy sources and loads, it is affected by some stability issues. In microgrids, various stability issues occur as explained in [12]. Especially when EV is used in microgrid than stability issues for the microgrid is an important point. EVs is generally used in microgrids as a source or load. When it is used as a source then the stability issues are related to the voltage and frequency fluctuation. So, this paper is focused on the review of various voltage and frequency stability issues. So, voltage and frequency stability issues are explained below,

A. Voltage Stability

The voltage stability issues in a microgrid are occur due to many reasons. And integration of EVs can lead to voltage stability issues in microgrids. So, this problem is generally associated with reactive power compensation, Load shedding, voltage unbalance, etc. When EV is supplying the grid then the reactive power compensation is the biggest issue which is related to the voltage stability in the microgrids. Also, it refers to the DC link voltage stability. A reactive power is a function of load voltage and terminal voltage. Also, three voltage stability criteria are explained as below, condition-1 is, if $\left(\frac{dQ_G}{dQ_L}\right) > 0$ then the system is stable, where Q_G=Reactive Power Generation, Q_L = Reactive Power Consumption. Condition-2 is, if $(\frac{dQ_L}{dV}) > (\frac{dQ_S}{dV})$ then the system is stable, Q_S = Reactive at S point. Condition-3 is, if $(\frac{dV_{cf}}{dV})>0$ then the where, V_{cf} = Capacitor filter voltage.

Above all condition shows the criteria for terminal voltage stability with respect to the load voltage. Now, the key issues in

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 08 , August - 2026

voltage stability are (1). Reactive power control; (2) Load shedding; (3) Tap changers and voltage regulators (4). Load dynamic. As, discussed earlier EV integrated microgrid stability of voltage is generally associated with under-voltage load shedding and reactive power control. The low-voltage microgrid system with EV integration is represented in [12]. In this system, the effect of voltage instability is observed with the different penetration levels of the EVs and DGs. The whole system is modeled using MATPOWER which is available in MATLAB.

The simulation of the low voltage benchmark microgrid system is mentioned in the [12]. In which the lower limit is 0.94pu and the upper limit of the voltage is 1.1.pu. Here fluctuation in the voltage is between the 15:00 to 18:00 hours. Here variation in voltage is from 0.99 pu to 0.93pu. variation of the voltage indicates the change in load or generation. This analysis is done with the different penetration levels of EVs and DGs. For example, here 25% to 30% penetration of the EVs are considered. And 150% penetration of the DGs are considered. So here it can be seen from the figure that 100% Ev penetration in microgrid has a larger voltage variation than 0% penetration. So due to this variation in voltage microgrid required a voltage controller. So, in this paper, section 4 explains the various methods for voltage control as explained in literature [14]-[17].

B. Frequency Stability

An MG can work in either grid-integrated or island mode. So, in grid-integrated mode there are many generating stations are connected in parallel so synchronism of all generating stations is necessary. However, in island mode frequency regulation is more complicated. The synchronization is related to the system inertia constant [13]. So, in the case of a conventional power system having enough kinetic energy from a synchronous generator can maintain the system's stability in case of large and sudden disturbances. But RERs-based microgrid systems require added inertia with the help of the V2G concept or ESS (Energy Storage System). The smaller number of generating units in microgrids may go under a large risk in the event of cascade tripping. This will impact negatively on microgrid stability. The AC/DC hybrid microgrid is simulated in [13]. In [13] the whole microgrid system is simulated using MATLAB Simulink in [13]. It is mentioned that the how frequency variation is done at the time of the increase in the load demand..

the variation in frequency between 4000 seconds to 6000 seconds. In which deviation in frequency is due to high power generation. While between the 85000 to 10000-second drop in frequency is from 60Hz to 59.90Hz due to increment in load demand. So, EV -an integrated microgrid requires the frequency controllers. In that case, conventional controllers are not sufficient for controlling the frequency in EV integrated microgrid. So, in section -5, some methods for frequency controls are explained as in [18]-[21]. microgrids should consider all types of faulty situations.

IV. VOLTAGE CONTROL

Voltage control is an important need of a microgrid. So, in this section, various methods of voltage control are discussed and compared. Every method has its features as well as limitations. Many researchers have worked on voltage control for microgrid systems. But the penetration of EV with microgrid is affecting on voltage stability.

A novel ADRC algorithm is implemented in [14]. This algorithm is very helpful in balancing the reactive power within the limit using DC-link voltage control. A basic structure of the DC microgrid with PCC is explained in [14]. A modelling of the battery and bidirectional converter is represented in [14]. The voltage-oriented control (VOC) based ADRC algorithm which is given in [14]. The proposed structure of the microgrid and control algorithm in [14] is simulated using MATLAB Simulink software. As in [14] it can be seen that using the controller in voltage at the DC link is exactly matches with a reference value of 850Volt DC. It can be seen that the value of voltage at dc_link is kept constant with the help of the proposed controller in [14]. However, at 0.5 seconds and 1 second negligible variation can be observed in voltage at the dc link. The control in voltage at the dc_link is indicating that the effectiveness of the proposed controller in [14] during external disturbance.

The typical microgrid system of 0.4KV Siemens benchmark as represented in [15] to prove the proposed method. The MGCC algorithm is verified using MATLAB Simulink software in [15]. In which two mode of operation are considered (Grid connected and islanded). Three scenarios are considered for simulation as in [15]. In which scenario-1 is without EV, scenario-2 is EV (Uncoordinated charge/discharge), scenario-3 (Coordinated charge/discharge). In which it can be seen that the maximum variation in the voltage is 0.005pu at node-5 in scenario-1 (Without EV). In scenario-2 (With EV uncoordinated charge/discharge) the variation in the voltage at node-5 is 0.009pu which is increased by 0.004pu than scenario-1 (Without EV). While in scenario 3 variation in the voltage is 0.002pu. Which improved than previous scenarios. So, it’s proved that the proposed controller in [15] is very effective. So, it can say that the controller in [15] is successful in case of scenario-3 (i.e. with controlled charging/discharging).

A novel type three -layered coordinated control algorithm is implemented for voltage & frequency control in EV-integrated hybrid (AC/DC) microgrid in [16]. However, four quadrant vehicle- grid operation is considered in [16]. A standard test microgrid system is considered in [16]. And using MATLAB Simulink simulation of controller is validated in [16]. Using this controller the dc bus and ac bus both voltages maintain the constant at 1.0pu.

Also, in [17] a novel need-based distribution coordination strategy (NDCS) algorithm is implemented for voltage control. In which MATLAB Simulink software is used to validate the controller in [17]. In which simulation is done in different cases. All cases are done in islanded mode of operation of microgrid. Those cases are like, step load change, variable PV irradiation, time delay etc. For all cases the controller is shows its effectiveness during operation to maintain voltage within desired limit.

Now after a discussion of the all-voltage controllers, the advantages and disadvantages of all controllers is mentioned in table-2. from table-1 it can see that the NDCS controllers for voltage control [17] is showing better performance among the all controllers.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 08 , August - 2026

Table II. Advantage and disadvantage of the voltage controllers

Name of Controller	Advantages	Disadvantages
ADRC [14]	It is very effective for controlling of reactive power and dc link voltage in case of any types of external disturbances.	Less effective when group of EVs are connected in microgrid
MGCC [15]	It is very effective for both mode of operations of microgrid (Grid connected and islanded). It can resolve the cost issues along with the voltage control.	Not considered the variable irradiation of solar PV on microgrid.
Three -layered coordinated [16]	A V2G capacity of 3-phase and DC EV charging station is used. Four quadrant V2G operation can done. Synchronization in grid can possible also along with voltage controller. It considering the effect of variable irradiation of solar pv.	It requires to reduce communication dependency. Also, it is not effective for grid connected mode.
NDCS [17]	Very effective in case of different situations like step load change, under any fault at dc bus, communication delay, variable irradiation and also EV owners having independency to disconnect the EVs without any notification signal	The controller performance is only evaluated for the islanded mode of operation.

However other controllers are also good but they are limited to any specific conditions. For example, ADRC [14] control is effective for dc-link bus voltage control in case of any type of external disturbances. But the NDCS controller [17] also controls the voltage in case of random load variation and different conditions of solar irradiations. Also, it controller in [17] considers the various types of faulty conditions like step load change, and any type of dc bus voltage fault also it has the advantage of four quadrant bi-directional converters. So advanced controllers for voltage control in EV -integrated microgrids should consider all types of faulty situations.

V. FREQUENCY CONTROL

Frequency control in microgrids is very important, so this section explains various methods for frequency control are discussed. However, frequency control in the islanded mode of microgrid is very important rather than the grid-connected mode due to inertia issues. So, in this section various methods from [18]- [21]. In [18] a robust controller PID controller is designed for frequency control in EV integrated microgrid. In [18] the different operating conditions for the start-stop of controllers are considered. Tuning of the PID controller parameter is done using the PSO (Particle swarm optimization). From the simulation result, it can be said that with the help of the controller in [18] the fluctuation in frequency is damped out more successfully than the conventional controller. In [19] the frequency control is done by the maximum allowable bound algorithm (MADB) which is solved by LMI (Linear matrix inequality). Basically, this algorithm is related to the delay-dependent system. In LFC (load frequency control) the time-delay calculation is very important. Because of any delay between the removal of any generation (Due to any peak load condition or due to the occurrence of fault) and the pentation of the backup source creates frequency instability issues. So, the appropriate value of the delay bound for load frequency control of a microgrid is obtained by this algorithm. This algorithm is solved by LMI (Linear matrix inequality). Now the complete Island microgrid system is simulated using MATLAB Simulink software, which is mentioned in [19]. Which studies the effect of time delay on frequency deviations. The allowable values of time delay for different combinations of kp and ki are calculated using the MADB algorithm [19]. It can be observed from [18] that with kp= -0.32 and ki= -0.32 allowable delay time is 2.0951 seconds. It means that the microgrid can wait for 2.0951 seconds to switch the backup generation in the microgrid at the time of peak load condition or any other faulty condition.

In [20] a new robust CDM (Coefficient diagram method) controller is implemented for frequency control in EV-integrated microgrids. In [20] also multiple operating conditions were considered for different controllers. Using MATLAB Simulink software the proposed controller is validated in [20]. The simulation is done for different cases like for case -1 nominal parameters were used for simulation and the simulation was carried out under random load and PV output fluctuation, in case 2 parametric uncertainty was considered, and in case 3 system was tested under multiple operating conditions. So, in all cases, the deviation in frequency is reduced more effectively than the CDM controller in [18].

In [21] the PSO (particle swarm optimization) algorithm is somewhat modified. The position of the particle is modified from conventional PSO which is known as an AGPSO algorithm. The AGPSO (Autonomous groups particles swarm optimization) is implemented in [21] to control the frequency of EV-integrated microgrids. In which values of Kp, Ki, and Kd are determined by the AGPSO algorithm. Conventional PSO algorithms have the disadvantage of a slow convergence rate. So due to this problem, the PSO algorithm is somewhat modified in [21]. In the AGPSO algorithm, the particle position (x) and velocity (V) are updated than the conventional PSO algorithm. The velocity (V) and particle positions are updated in each and every iteration. A MATLAB simulation of the entire system is represented in [21]. This simulation is done with random solar power generation and random load patterns. Which is divided into different scenarios. Each scenario has a different condition for parametric uncertainty. Each scenario has a random load pattern and generation. A detailed analysis of the simulation is explained here as in [21]. Using the AGPSO algorithm which is explained in [20] parameters for the PID controllers are tuned. And by integral square error method (ISE) the PID controller's parameters (For EV model, HP model, LFC method) are determined. [21]. In scenario 1, MATLAB simulation is carried out under normal conditions with considering random load demand and generation.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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It can be studied from [21] that the fluctuation in frequency is exactly zero with the help of the AGPSO controller [21]. These simulation results show less fluctuation than the CDM controller in [20]. From the above review of the various frequency controllers, the comparison between each controller can be represented in figure 1.

From figure 1. it can be seen that the frequency controller design depends on the controller parameter tunings. The robustness and accuracy of the controller can be improved by modifying the conventional algorithm. Also, consideration of parametric uncertainty is important for controller design. Like in [21] the author tries to consider the different starting and stopping times for each controller. Considering all type of uncertainty and different operating condition is also improves controller performance.

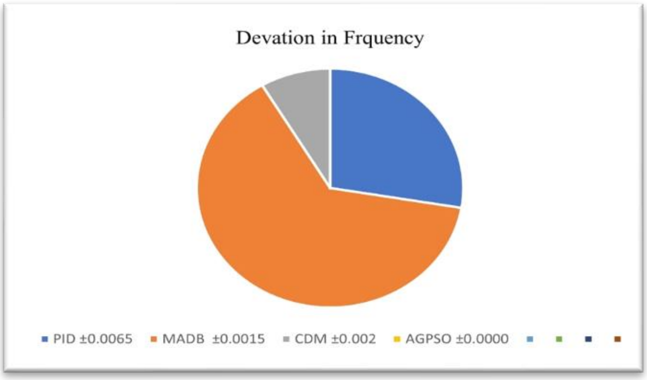

Fig. 1. Different values of frequency deviation of various frequency controllers)

VI. RESEARCH DIRECTION AND DISCUSSION

So, after studying all kinds of literature related to voltage and frequency control, and optimum power scheduling this paper will suggest the direction of the research in the area of the EV-integrated microgrid. The inertia of the microgrid is low due to less kinetic energy. So, frequency control in EV-integrated microgrids is very important. In islanded mode frequency controller is very necessary. However, in some literature like [14]-[17], and [18]-[21] the various types of controllers are designed for voltage and frequency control respectively in EV-integrated microgrids. But the proper tuning of the controller is more important. In an EV-integrated microgrid, each component should require the controller for frequency and voltage. So, coordination between all the controllers should be required. As an example, in [19]-[21] start and stop times are taken for each controller. Voltage stability in EV -integrated microgrid is also important while the EV is in charging condition. However, in [12] it explained how the EV penetration in microgrids affects the voltage. After reviewing all controllers for voltage and frequency in [14]-[21]. Further research should be done for the following purposes,

- As discussed in previous sections controllers for voltage should consider all types of effects like random load variations, fluctuations in solar PV generations, etc.
- The proper tuning technique of controller parameters is also helpful to reduce the variation in frequency and modification in the algorithms is required. For example, in [21] the AGPSO algorithm is a modified version of the conventional PSO algorithm.
- When the mass of EVs is available in the microgrid then it is necessary to coordinate charging and discharging between each EVs. As in [55] the K-clustering algorithm is implemented to co-ordinate the charge/discharge of an EVs.
- Also, proper delay bound calculation is very necessary in case of sudden removal of any generation in a microgrid. So allowable delay bound algorithm is implemented in [19].
- Optimum power scheduling and controlled charge/ discharge are necessary for EV-integrated microgrids. In [52] the distribution control algorithm was implemented to optimize the cost of EV -integrated microgrid by considering the battery degradation cost.
- Frequency stability in an islanded microgrid is difficult rather than the grid-connected mode. So, it can be compensated with the help of a virtual synchronous generator as implemented in [53] which is very successful in maintaining the frequency stability limit for islanded microgrids.

CONCLUSION

This paper reviews the various impacts of EVs on the microgrid. The integration of EVs into the microgrid has a lot of issues like voltage stability, frequency stability, reactive power injection, proper EV scheduling, peak load management, etc. So, in this paper review of the various issues and existing solutions to the above issues were discussed. Also, this paper gives the research direction in the particular area of the EV-integrated microgrid. And discuss the several controllers designed for voltage and frequency control in EV-integrated microgrids for an islanded mode of operation. Also, this paper provides the various challenges and solutions for optimum power scheduling and cost optimization algorithms from various literature. So, from the literature survey, it can be said that the various controllers are implemented for frequency control and voltage control. However, the main challenge for frequency control in an islanded microgrid is inertia. So, a virtual synchronous generator is very helpful for frequency control. Also, it can be observed that the controllers' parameters tuning is also necessary for EV- integrated microgrids. Also, tuning of the controller parameter is very helpful to reduce the fluctuation in voltage and frequency in EV-integrated microgrid. Proper coordination is required between the controllers in case of more than one controller is used.

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