Power Quality Improvement and Sustainable operation in A Standalone Micro Grid by Regulating Frequency in A Deregulated Market

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Abstract. Cooperative decision-making has always benefited from achieving objectives subjected to system constraints in a microgrid. This paper considers the power balance between generation and load as a significant power quality issue. Hence, frequency regulation is regarded as a primary challenge in the system. When the system operator works towards profit for the power producer, an integrated operation provides a solution. The sources considered in this system are Solar PhotoVoltaics (SPV), FuelCells (FC), Diesel Generators (DG) and Battery driven Electric Vehicles (BEV), where the BEVs operate in Vehicle microgrid mode. A central controller and local controllers are present to operate the generators at desired levels. A cascaded fuzzy controller is designed that chooses the best suitable BEV to be connected to the microgrid. The system is implemented in a MATLAB Simulation environment, and various scenarios and cases have been considered for evaluating the system response and its sustainability.

1 Introduction

Integrating distributed resources in the microgrid system introduces many power quality issues. System parameters like the quality of voltage supplied to the loads and the frequency response of the supply power delivery management issues must be addressed by the system operator. Various researchers have suggested an approach involving optimised control of the resources in the system and compensation techniques to overcome the issues of operation of renewable energy in the system that can be reduced. The collective operation of these resources is analysed under different economic considerations too. The participation of electric vehicles as a power source in the system has been considered in great scenarios. However, significant research is yet to be available in the context of microgrids and its sustainability. The contribution of our exchange between batteries of electric vehicles and microgrids for frequency regulation in the system is a significant consideration given the

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increasing availability of battery-driven electric vehicles in the system. A typical 100-kilowatt pic power management system is needed in which the source of power generation includes distribution like solar wind fuel sales, diesel generators and electric vehicles. Battery-driven electric vehicles are available in the market, ready to participate in the power exchange. The microgrid scenario limits the usage of locally available vehicles. The coordination between these vehicles is implemented using a synchronous mode of operation. The coordinator approach of the vehicles during a contingency has been discussed in [6] and [7] but without integrating other resources.

The load considerations in the literature are limited to the step inputs to study the study state response of the system. The real-time changes in the lords of our system are considered to be included in the study. During the load changes, the system's frequency should be regulated between 49.9 Hertz to 50.1 Hertz according to the grid code standards. In the literature, more importance should be given to these regulations and many results violate them. Electric vehicles' participation in frequency regulation in a grade scenario has long been discussed, but introducing microgrids is a new area of research. This paper must consider the scope of our transfer from the microgrid to the vehicles since it is assumed that the vehicles get charged off the grid from a source such as solar photovoltaics. Many private players are coming into the market in this sector to charge electric vehicles with the solar power available. The vehicle owner can schedule the availability of the vehicle at the parking station, which is interconnected to the microgrid. Hence, the microgrid operator has information about a BEV's incoming and outgoing time [8]. The vehicles in the pool are selected based on different approaches, such as (a) equal division of the discharge rates irrespective of their battery capacity. (b) proportional division of discharge rates based on battery capacities.

These methods are available for distributing the required power demand among electric vehicles. The state of health of the batteries shall not be considered in this case and may be considered in the future. The benefit of transferring power to the micro grade is also not considered in 9. In the first approach, the control operation of the power flow from the vehicles needs to be checked. If all the vehicles available in the microgrid deliver power, then control over the tower generation is not obtained. This can be achieved through a mechanism widely used in the literature, using a fuzzy logic controller [10]. Some authors have considered optimising operation costs to the BEV owners using a mathematical approach. Nontraditional methods like black hole algorithms are implemented in [12] and [13] for a microgrid scenario. The reserve power availability in the system needs to be discussed. The coordination between the sources needs to be considered. An aggregator-based communication is set up to use the power at BEV parking stations.

The rest of the paper is organised by presenting how BEVs are included in the microgrid system in the next section. It is followed by the implementation methodology of a cascaded fuzzy controller to decide which BEV to be connected to the microgrid optimally. The following section showcases the simulation results and analysis of different scenarios and cases considered in the microgrid operation. The conclusion is presented at the end of the paper with the cited references.

2 BEV-based Frequency Regulation in a Microgrid without Storage System

A distributed generation system needs an efficient management scheme so that the interlinked parameters can be optimally controlled under the given constraints. The primary concern of the system operator is to increase profits while effectively utilising available resources. A storage system (usually a battery) increases the system's reliability. A few drawbacks have been identified in the system considered.

They are:
• The solar power reserve shall only be available during the daytime, while this facility is unavailable at night.
• The reserve power obtained from solar is not used during the off-peak load period, which brings loss to the operator or a burden to other generators.
• The electric vehicles in the system, which can exchange power with the microgrids, are not considered here.

The microgrid considered in the paper consists of SPV, FC, DG and BEVs. The system includes a central controller to do the power scheduling operation. Depending on the load changes and the frequency deviations occurring in the system, each distributed power generator must adjust its power output. A local controller placed near the generator site does this power output adjustment. A typical PI controller converts the power change signal to respective parameter changes depending on the source. The modelling of different sources and loads is mentioned in previous works [18]. This paper contributes by addressing issues like managing the fleet of electric vehicles and coordinating with other generating sources in the microgrid. A group of BEVs send information such as SoC and the battery's discharge rate to the BEVs' aggregator. This aggregator analyses the information and sends data to the central controller regarding the current power supply and the total capacity of the fleet of BEVs connected to the microgrid. Depending on the load condition, the central controller sends a signal to all the resources regarding the power schedule for that time.
A PI controller is designed to convert the power generation signal (scheduled) to the battery discharge rate equivalent. The tuning of proportional and integral gains is done to obtain a faster response and avoid overshoots. Each power source has a controller to convert the power schedule signal to the power generation command and send it to the respective generating unit. In the case of SPV, a neuro-fuzzy-based approach is used to decide the voltage level at which the DC-DC controller should operate so that the reserve can be changed based on the requirement. FC's control unit changes the amount of fuel input, i.e. controlling the volume flow rate of hydrogen and oxygen into the chambers. For DG, a PI controller decides the amount of diesel input into the IC engine coupled with a synchronous generator. In this way, the local controllers will coordinate with the power-scheduled signal operating in an integrated way. There may be a change in load and steady-state error in the system's frequency despite the unit commitment and scheduling of the power from the central controller. Hence the change in frequency signal obtained from the power system transfer function block is taken as a feedback signal and given to the local controllers through the central controller. This feedback signal obtained is scrutinised further and sent to the central controller only if a certain threshold of frequency violation is observed. This value is considered as ±0.02 Hz in this work to obtain a smooth generating unit operation. The system parameters are presented in Table 1, where M1, M2, M3, and M2G are the vehicle categories [18]-[21].

Table 1. Distributed Generation Source Parameters considered.

	DG	**FC**	**SPV**	**M1**	**M2**	**M2G**	**M3**	**M3**	**Total**
Minimum power (pu)	0.1	0.1	0	0	0	0	0	0	0.2
Maximum power (pu)	0.3	0.3	0.29	0.1	0.125	0.1625	0.3	0.3125	1.89

Table 2. Battery Electric Vehicle Parameters considered.

VT	NS	NP	SOCmin (%)	NC (Ah)	TC (ms)	SOCIn (%)	DT(s)	Power (W)	Power @ 0.9C (pu)
M1	15	15	20	5	25	66	20	800	0.1
M2	19	19	20	5	25	89	60	1000	0.125
M2G	22	15	20	4	25	74	0	1300	0.1625
M3	40	40	20	5	25	78	0	2400	0.3
M3	42	42	20	5	25	42	70	2500	0.3125
Total								8000	1

Distributed Generation Source Parameters considered are shown in Table 2, with the keywords mentioned as Vehicle Type (VT), No of cells in series (NS), No of cells in Parallel (NP), SoC Minimum value set (SOCmin) in %, Nominal Capacity (NC) in Ah, Time Constant (TC) in ms, InitialSOC (SOCIn) in %, Dead Time (DT) in s, Power in Watts, Power @ 0.9C in pu.

Based on the input signal received from the central controller, local controllers shall ensure power generation from the units committed. The SPV, FC and DGs used in the simulation work are lumped units; hence, power obtained as an output is the aggregated value, and the central controller does not have individual access to the internal units. This is considered a drawback in the work done by [18]. Hence in the proposed work, the additionally included power source of BEV is designed so that individual units, i.e. each vehicle battery, can be connected or disconnected from the microgrid based on the power schedule requirement. However, this scheme is introduced in later stages of the work. Initially, the power from BEVs is lumped for ease of control. Every vehicle owner can decide whether to connect their battery to the microgrid. This decision introduces various scenarios of simulation that are possible. Every possible scenario should be considered to prove the feasibility of the study. Hence in this paper, there are three scenarios considered. The following aspects are included in the scenarios—load variations for every 60 seconds. Vehicle SoC variations are considered due to the different driving cycle patterns of the owners—extreme loading conditions.

The main challenge here is maintaining the system's frequency within the operating limits. The additive adaptive algorithm needs to continuously check the frequency change in the system and use the priority-based technique to commit the units and schedule the power. Different from traditional generators, there is little choice in the selection of generators since the availability of the source decides the priority. The load is categorised as critical and non-critical. The critical loads include computers, medical equipment, street lighting, etc., accounting for 0.1pu of the total load. The maximum load on the system is expected to be 150kW. The base value of power generation is 100kW, and in this study, it is assumed that the maximum load is 1.55pu levied on the system.

In contrast, the total generation capacity of the system is 1.79pu, which includes BEVs. The maximum generation capabilities of SPV are 0.29pu, while the reserve considered here is 10% and hence the usual operating point would be 0.26pu. Figure 1 shows the simulation environment considered. Three blocks highlighted with the star mark correspond to the contributions done in this work, while the others are taken from various references. Four scenarios have been considered with the following parameters.

• Scenario-1 Step load change
• Scenario-2 Load considered varies from 1.2pu to 1.35 pu and EV power output varies with load
• Scenario-3 Extreme load conditions are considered and EVs taken out based on SoC
• Scenario–4 SPV Power variation

In this [18] work carried out; certain aspects need to be considered, affecting the real-time implementation of the proposed concept. The daily power consumption/load curves provided by the load dispatch centres show that the variation in the load values is continuous. The average load demand curve is found by removing the higher order frequency terms to get a smooth waveform. Inspired by this, the traditional step change signal applied for the small signal stability analysis of the power system is mixed with another high-frequency signal to resemble the daily load curve variations. Private people own the BEVs, and if the owner wills to participate in the V2mG energy transfer, there should be a common place where this connection facility (infrastructure) is available. Hence in this study, two parking stations are considered, where the vehicle owners can park their vehicles and connect to the microgrid, as shown in Figure 2. Figure 3 showcases the cascaded fuzzy logic controller proposed and used in the Electric vehicle selection.

Based on scheduling, the parking lots get a signal to generate power, which is equally distributed to BEVs. Suppose total vehicles are connected to the microgrid. In that case, the infrastructure shall fail since the power transfer capability of parking lots has a maximum value, limitation of the number of vehicles that can simultaneously pump power can be regulated to five.

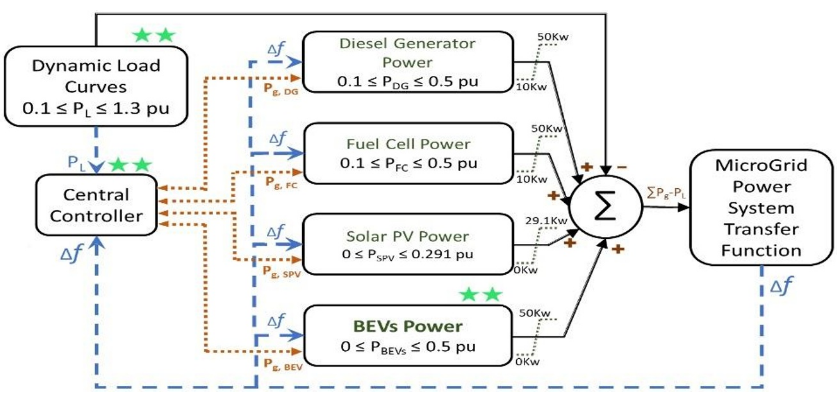

Fig. 1. Simulation model developed.

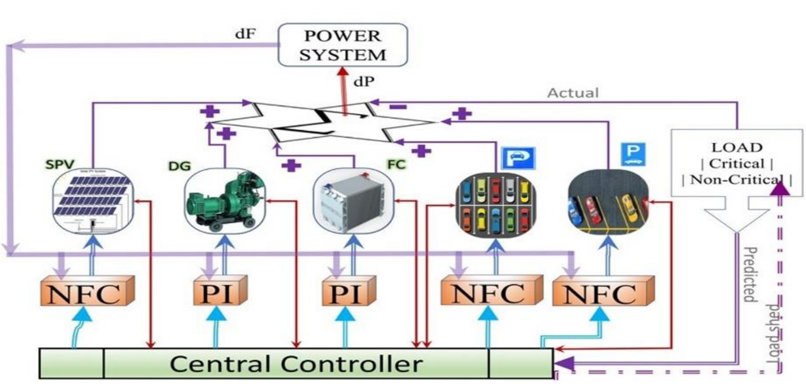

Fig. 2. Simulation model developed.

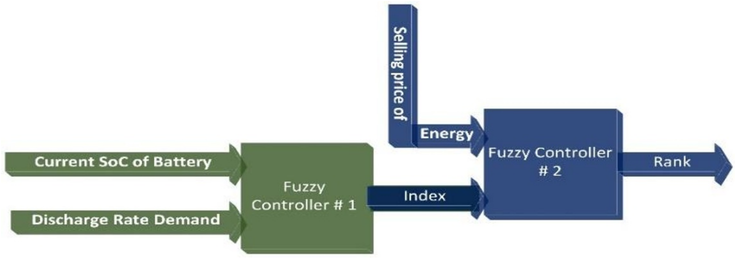

Fig. 3. Cascaded fuzzy-logic block diagram representation.

3 Simulation Results

The variable parameters identified in the simulation are related to the distributed sources considered for power generation and the load. As the load changes insteps, the generation tries to adjust to maintain the power balance. These BEVs are assumed to be parked in two parking lots and ready to supply power to the microgrid. The amount of power that can be pumped into the microgrid from a source is limited based on the current ratings of the infrastructure available. The variable parameters identified with the BEVs are listed below.
1. The availability of the vehicle during the simulation period
2. SoC of the vehicle battery
3. Cost of power exchange

Different scenarios are considered in the paper while increasing the complexity of variable changes in the system. The central controller continuously monitors the frequency in the system, and the frequency deviation is communicated to the sources if the deviation is beyond a threshold value of ±0.02Hz. The limits considered in the paper for maximum frequency deviation are ±0.05 Hz, and the fundamental frequency considered is 50Hz. The system is considered to have low inertia since there is only one synchronous generator, i.e., DG. The communication between the local controllers at the generation, central controller and load is assumed to be based on fibre optic communication since it is the most reliable, fastest means of data transfer available and that is currently being used. During the result analysis, the focus shall be on the allotment of an available BEV to supply power to the microgrid and the coordinated approach by all the generators to respond to the load changes in the system. Other simulation aspects are mentioned in [19], and this paper extends the previous works.

The scenario is considered to check whether the fuzzy logic controller designed can select the best suitable BEV to be connected to the microgrid. This is based on the current SoC of the battery, the discharge rate demand by the central controller and the selling cost chosen by the owner of BEV. For simplicity, the load assumed is constant throughout the simulation time. Two cases are considered in the scenario.

3.1.1 Case-1

In this case, the randomly chosen SoC levels of the BEVs and different selling costs of the BEV energy are given in Table 3. The load considered in this case is only 0.75pu. The system's frequency response is shown in Fig. 4. Since the system starts from an initial condition of zero, the initial frequency response of the system can be neglected. It can be observed that the frequency is within the limits of ±0.05 Hz and the percentage deviation during the overall simulation time of 480s is less than 1%. The overall share of each generator during the simulation time is given in Fig. 5. At time t=180s, the load of 0.75pu is divided by the central controller among the sources, as shown in Table 4, as per the priority-based algorithm. The load to be shared by the BEVs together is 0.315 pu divided among the BEVs, as shown in Fig. 6. The first fuzzy logic controller gives a priority number based on the current SoC of the battery and the current discharge rate demand. This priority number is sent as input to the second fuzzy controller, which decides the final ranking of the BEVs based on the cost. Ranking of BEVs is done on a scale of 0 to 10. The minor scale value corresponds to a higher ranking. The local controller then performs a sorting operation to list the BEVs in ascending order. Based on the total power to be shared by all the BEVs in parking lots, vehicles having a higher ranking will be connected to the microgrid. The BEV selection for the constant load considered is given in Fig.7 and the ranking of BEVs is shown in Fig.8.

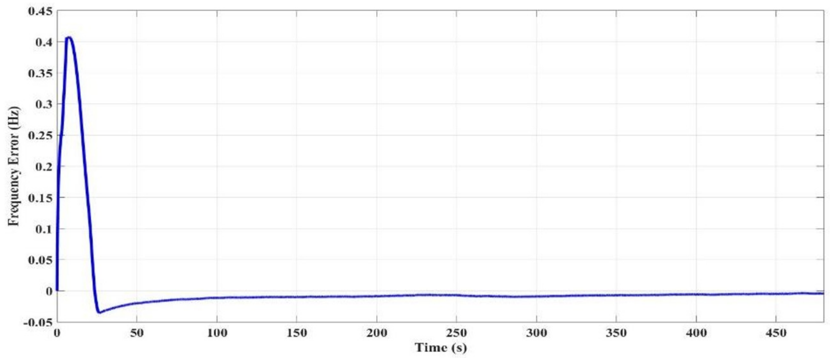

Fig. 4. Frequency error obtained for case 1.

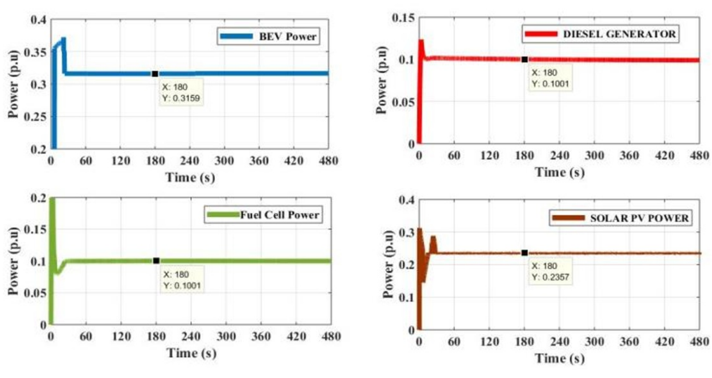

Fig. 5. Power generation done by each generator.

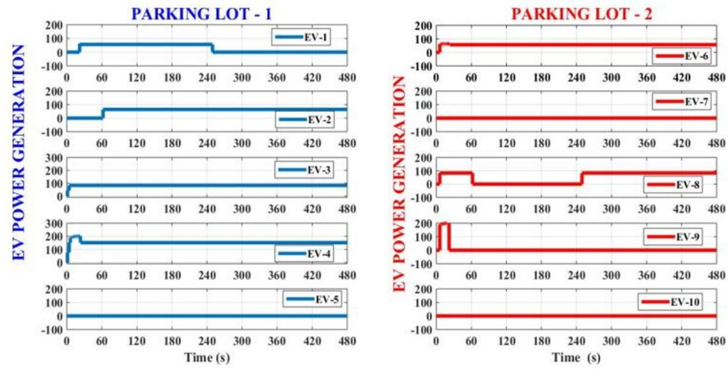

Fig. 6. Load sharing by BEVs in parking lots for case-1.

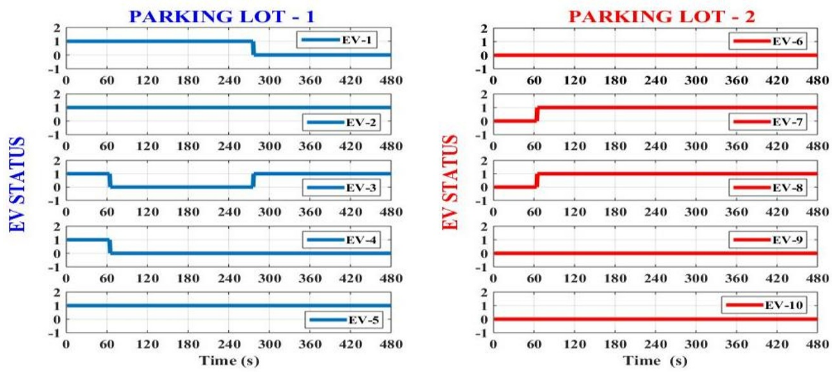

Fig. 7. Selection of BEVs in parking lots based on fuzzy controllers for case-1.

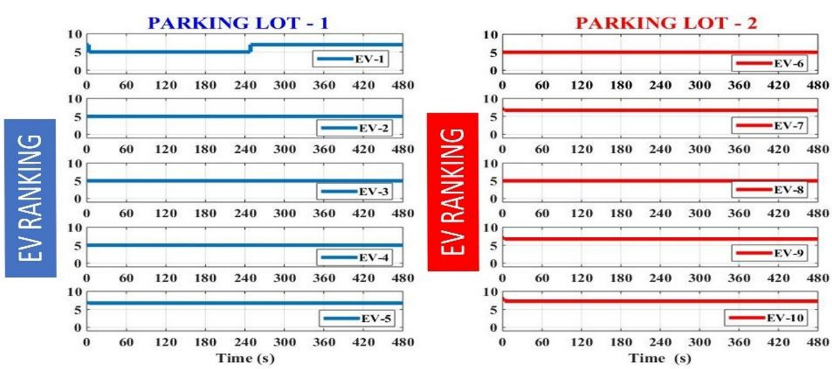

Table 3. Selling prices considered for the vehicle to microgrid energy transfer.

Parking Lot No. 1			Parking Lot No. 2		
EV No:	**SoC**	**Price (Rs.)**	**EV No:**	**SoC**	**Price (Rs.)**
1	50	5.025	6	50	5.04
2	50	1.675	7	50	5.574
3	50	3.35	8	50	4.884
4	50	4.623	9	50	1.524

5	50	5.963	10	50	1.458

3.1.2 Case-2

The load considered in this case is 0.95 pu which is close to the base value of the power demand expected. This value is chosen to test the ability of fuzzy controllers. The overall power-sharing by all the generators is given in Fig. 9. The BEVs generate enough power to keep the frequency within limits, as shown in Fig. 10. Here, the load share of BEVs is now 0.335pu. The sorted ranking order for this load share is shown in Fig. 11. The discharge rate requirement, in this case, is higher than the previous one. Hence the priority has changed. The frequency regulation, in this case, is shown in Fig. 12.

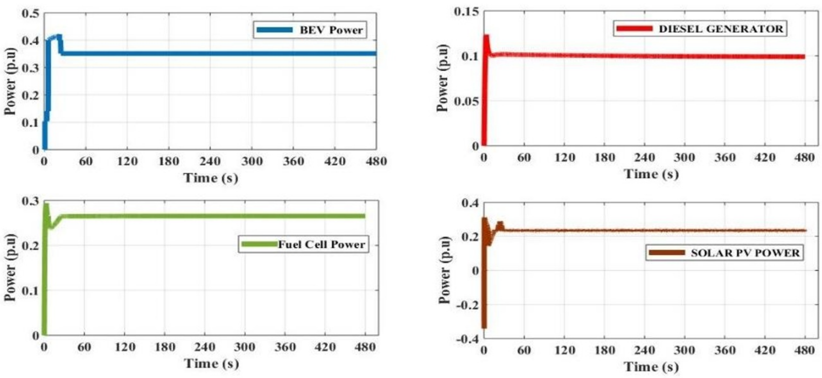

Fig. 9. Load sharing by all the generators for case-2.

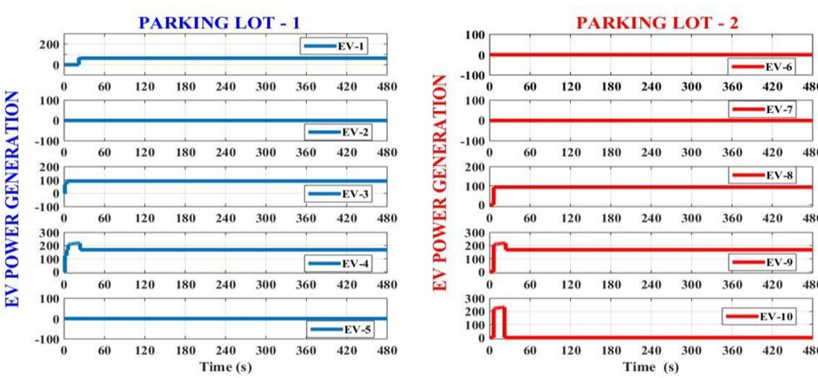

Fig. 10. Load sharing by BEVs in parking lots for case-2.

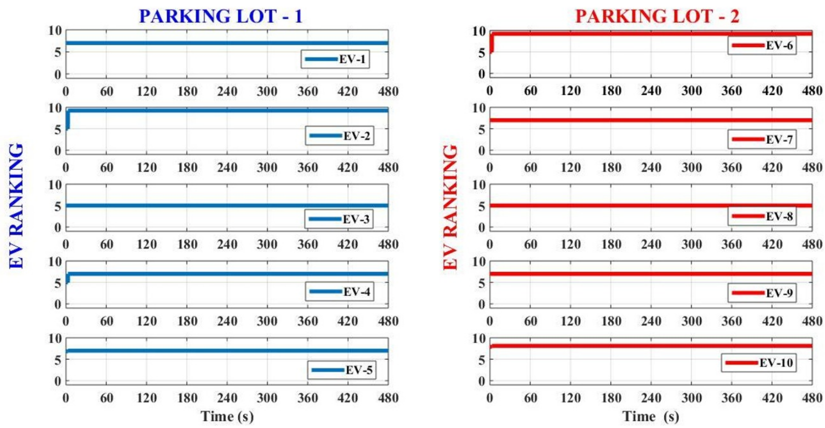

Fig. 12. Selection of BEVs in parking lots based on fuzzy controllers for case-2.

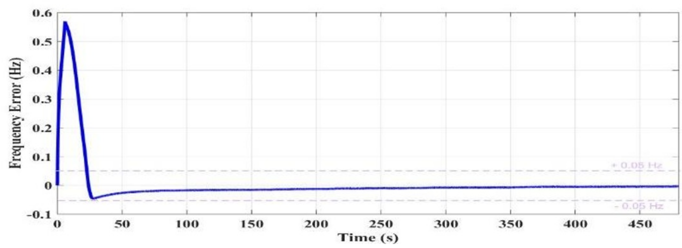

Fig. 13. Frequency error obtained for case-2.

Conclusions

The variable parameters in a deregulated power system where renewable sources are used for power generation, the system operation and power quality of supply in an autonomously operating microgrid with sustainability are maintained. Distributed resources are operated together to maintain a balance between generated powers to maintain power quality (frequency regulation) and satisfy dynamic requests of loads (active) to improve reliability (for sensitive/critical loads) and sustainability. A control strategy that can address the needs of every generating source and coordinate well with other parts of the system has been developed. In this paper, the power quality in frequency regulation is considered necessary for the system operator, and a novel system design has been proposed by including BEVs in a microgrid environment.

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