Comparison of the Virtual Synchronous Generator and Droop Control Techniques to Cater the Unexpected Ingress and Egress of EVs at the CS

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***Abstract*—In the current scenario of power system, deviations in frequency is the main issue in micro-grids (MG). These frequency deviations can be eliminated by minimizing the gap between load demand and power generation. In this paper, electric vehicles (EVs) parked at the charging station (CS) has been considered as an energy storage system (ESS) to minimize the gap between load demand and power generation. Further, unexpected ingress and egress of EVs at the CS has been considered while supporting MG's frequency. For this purpose, one islanded MG in Kynthos has been considered. Frequency support to the MG has been provided using two different techniques. One is the VSG control technique and other is the droop control. Comparison of both the techniques has been done and from the results, it has been observed that VSG technique is better to maintain the charging and discharging rate of EVs while providing the frequency support to the islanded MG.**

***Keywords—Charging station, Electric vehicles, Energy storage system, Micro-grid*.**

I. Introduction

In today's scenario, distributed energy sources (DES) are playing an important role to manage the load profile of microgrids (MG). In case, load demand of the MG differs from the power generation then problem of frequency deviation arises in the MG. However, this deviation in frequency can be supported by DES. These sources can deliver or absorb the required power in order to minimize the gap between load demand and generation. Energy storage systems (ESS), diesel generators, fuel cells etc., all act as DES. In case power generation is more than the load demand, excess power can be absorbed by ESS to diminish the gap. On the contrary, ESS and other DES can deliver the power if the generation is less in comparison with the load demand of MG. However, maintenance cost of the battery's ESS is very high, therefore, alternative solution is required which can act both as load as well as source of power. In the recent trend, electric vehicles (EVs) are behaving as an ESS and act as DES for the MG. Fleet of EVs parked in the parking lot of charging station (CS) can behave as an ESS for the MG. DES and EVs are a perfect combination to accommodate load profile of islanded MG as well as to reduce the emission of gases. However, with the increase in penetration of EVs in the market, unexpected ingress and egress of EVs at the CS will increase. With this increase in unexpected ingress and egress of EVs, it will be difficult to regulate the frequency of MG.

Several investigators have concentrated on the concept of frequency regulation in islanded MGs. They have implemented numerous techniques to regulate the MG's frequency. Out of these techniques, droop control is most commonly used in MG operations to provide the voltage and frequency support [1]. Bevrani and Shokoohi implemented the droop control strategy to regulate voltage and frequency of the MG [2]. However, some authors have implemented the virtual synchronous generator (VSG) control to regulate the MG's frequency. [3]. Matos et al. [4] discussed about the power management in islanded MGs using the ESS as well RES. They have explained that ESS deliver or absorb the power to regulate MG's frequency. Serban and Marisnescu [5] have demonstrated that frequency of the islanded MGs can be controlled by including the virtual inertia component with the droop control method. Soni et al. [6] have mentioned the importance of virtual inertia in MG to provide the frequency stability. Katiraei and Iravani [7] demonstrated various techniques to manage the flow of power within MG using droop control technique. Usunariz et al. [8] have designed a modified droop control method to provide stability to MG. Authors have further described the role of ESS to accommodate the load profile of islanded MG. Reihani et al. [9] have applied the droop control method for regulating the frequency of MG by considering batteries as an ESS for the MG. Several authors have opted for droop control and VSG control to manage MG's frequency. However, the above-mentioned researchers have not considered the EVs as an alternative ESS to the battery bank system in MG.

Ma and Mohammed [10] explained that with the use of centralized aggregators of EVs in a proper manner, frequency of MG can be regulated. However, authors have discussed only about the charging process of EV batteries. Gouveia et al. [11] discussed the role of EV batteries to provide primary frequency regulation to MG. Authors have explained the role of EV's battery to support frequency of MG by applying droop control method. Mortaz and Valenzuela [12] have discussed that load demand of the MG can be met by the EVs. Authors have considered the intermittent RES as well as variable load profile of MG to illustrate the importance of EVs as an ESS. In [13] authors have used the combination of battery ESS, EVs and renewable energy sources (RES) to support the MG. Farrokhabadi et al. [14] elaborated the frequency regulation of islanded MG by regulating its voltage through droop control technique. Jin et al. [15] discussed about the optimized charging of EVs using RES. Several authors have considered EVs as an ESS to provide support to the MG. However, they have not considered the unexpected ingress and egress of EVs at the CS while supporting MG's frequency. In this paper, unexpected ingress and egress of EVs has been taken into account while providing the frequency regulation to MG.

A. Motivation

Several researchers have investigated the idea of frequency control of islanded MGs. Some investigators have regulated the frequency using the controlled co-ordination of ESS and RES. Further, for this controlled coordination authors have applied the various types of techniques. Several authors have adopted the droop control strategy for regulating the frequency of MG [1]-[2]. Few have implemented the VSG control technique for the same purpose [5]-[6]. However, these authors have used battery banks as an ESS for MG to illustrate the frequency regulation process. None of them, considers the EVs parked at the CS for frequency regulation purpose. In this paper, EVs parked at the CS have been used as an ESS for the MG. Moreover, unexpected ingress and egress of EVs at the CS has been considered while supporting the MG's frequency. Comparison of the droop control and VSG control techniques has been done while providing the frequency support using EVs as an ESS for the islanded MG.

B. Contribution

- In this paper, comparison of droop control and VSG control technique has been done by considering the EV batteries as an ESS for the islanded MG.
- Unexpected ingress and egress of EVs at the CS has been taken into account while providing the frequency support to MG.

C. Organization

The other sections of the paper are summarized as follows, Section II demonstrates the proposed work. Section III represents the mathematical formulation of the work. Results and discussions have been shown in Section IV. Conclusion of the work is mentioned in Section V.

II. Proposed Work

In the proposed work, one CS has been considered to balance the load profile of islanded MG and consequently to regulate the MG's frequency. In the considered system, CS, PV array and diesel generator are connected in parallel to accommodate the load profile of MG. As the power supplied by PV array is irregular and dynamic characteristics of the diesel generator have slow response, EVs parked at the CS can participate to regulate the frequency of MG. Frequency support to the system has been provided by using two different techniques. One is the droop control technique and other is the VSG control.

Frequency of the system can be supported by using both the techniques. However, virtual inertia cannot be feed to the system through droop control technique. Therefore, in order to bring virtual inertia to the system, VSG control method is proposed to regulate the frequency of MG. The VSG concept relies on the emulation of inertial characteristics by the power converter in MG with the coordination of ESS. Using VSG technique, power converter can manage the flow of active power like a synchronous generator. Comparison of both the methods has been done to observe the effectiveness of applied technique to regulate the frequency of MG. The energy stored in the dc link (DL) capacitor can be used to provide the virtual inertia. This virtual inertia assists to minimize the change in frequency due to sudden changes in load. In this work, EVs parked at CS are assumed as an ESS for MG. In order to manage the load profile of the MG, these EVs can be charged and discharged at the frequent intervals. In case of VSG control, virtual inertia is imitated from the energy stored in the DL capacitor.

Fig. 1 illustrates the diagram to accommodate the load profile of islanded MG using CS and PV array, where CS consists of fleet of EVs and buck boost converters.

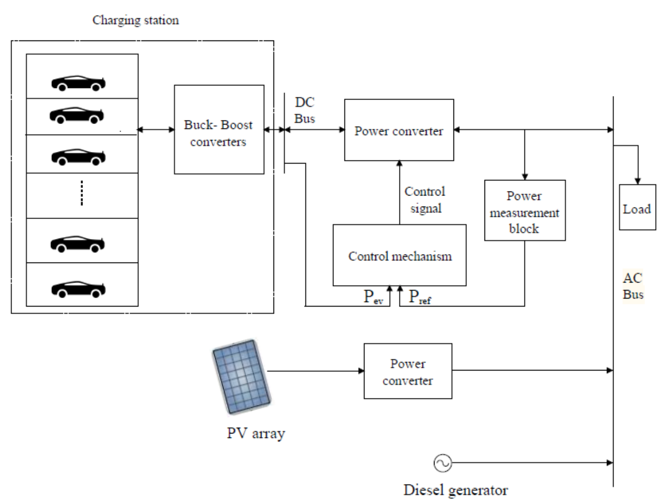

Fig. 1. Generalized diagram of the proposed system

In this work, EVs of various battery voltage ratings has been considered while the output voltage of each buck-boost converter is kept constant. The EV battery charges during the buck mode of dc-dc converter, while it begins to discharge during boost mode. These buck-boost converters are connected with common dc bus.

III. CONTROL STRATEGY

Basic motive of applying the VSG technique is to provide the frequency regulation to the system in an effective way. This frequency regulation is provided by minimizing the gap between load demand of islanded MG and power generated by RES. This mismatch is reduced by providing the active power to the MG by emulating the virtual inertia from energy stored in the battery of EVs. Depending on the amount of energy stored in the EVs which are parked in the parking lot of CS, active power can be delivered to the MG. Further, remaining part of the energy stored in the EVs can be used to emulate the virtual inertia. Active power is controlled in a bidirectional way using power converter. VSG mechanism to control the bidirectional flow of power is based on the following swing equation.

$$P_{ref} - P_{ev} = J w_r \frac{dw_r}{dt} - D\delta w_r \tag{1}$$

Where P_{ref} is the required output power and P_{ev} is power consumed or released by the EVs parked at the CS. J is the virtual inertia of the system and D is the damping factor. Where, net P_{ev} can be represented by the following equations,

$$P_{ev} = \sum_{k=1}^{r} P_k \tag{2}$$

$$P_{ev} = \sum_{k=1}^{l} P_{disc} - \sum_{k=l+1}^{r} P_{char} \tag{3}$$

Where, r represents the total number of EVs. l and $r - l$ indicate the number of vehicles in discharging and charging mode respectively. By taking the Laplace transform of the Eq. (1) the following equation can be obtained as,

$$P_{ref} - P_{ev} = Jsw_r - D(\mathrm{w}_o - w_r) \tag{4}$$

Further, virtual angular velocity w_r can be calculated by using Eq. 4

$$w_r = \frac{Dw_o + (P_{ref} - \mathrm{P}_{ev})}{Js + D} \tag{5}$$

Using Eq. 3, the Eq. 5 can be rewritten as follows,

$$w_r = \frac{Dw_o + P_{ref} - (\sum_{k=1}^{l} P_{disc} - \sum_{k=l+1}^{r} P_{char})}{Js + D} \tag{6}$$

In case of droop control method, inertia J is not taken into account. So, equation for droop control method will be

$$P_{ref} - P_{ev} = D(w_r - w_o) \tag{7}$$

$$w_r = w_o + \frac{(P_{ref} - \mathrm{P}_{ev})}{D} \tag{8}$$

$$w_r = w_o + \frac{P_{ref} - (\sum_{k=1}^{l} P_{disc} - \sum_{k=l+1}^{r} P_{char})}{D} \tag{9}$$

w_r is calculated in both the cases, which is further used to obtain the rotor angle.

Depending upon the gap between the load demand of MG and power generated by RES, P_{ref} changes. This P_{ref} is managed by the power delivered by the EVs parked at the CS. The w_r is responsible to control the power converter, which further manages the output power delivered by the CS.

IV. RESULTS AND DISCUSSION

In this section, simulations have been performed by considering the unpredictable load demand of MG as well as unexpected ingress and egress of EVs at the CS.

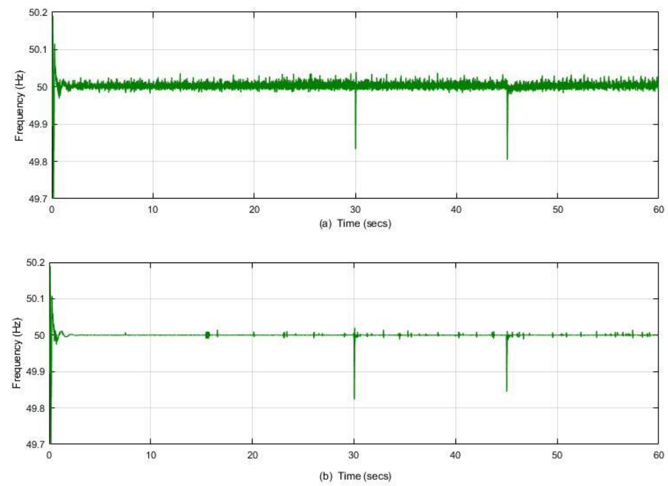

Fig. 2. Frequency of MG (a) Droop (b) VSG technique

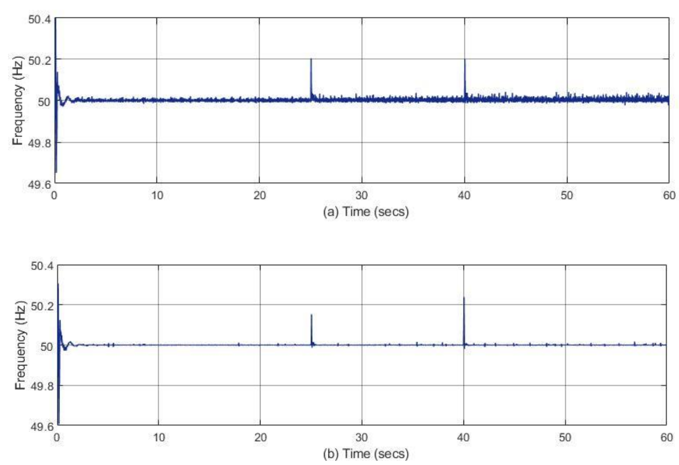

Fig. 3. Frequency of MG (a) Droop (b) VSG technique

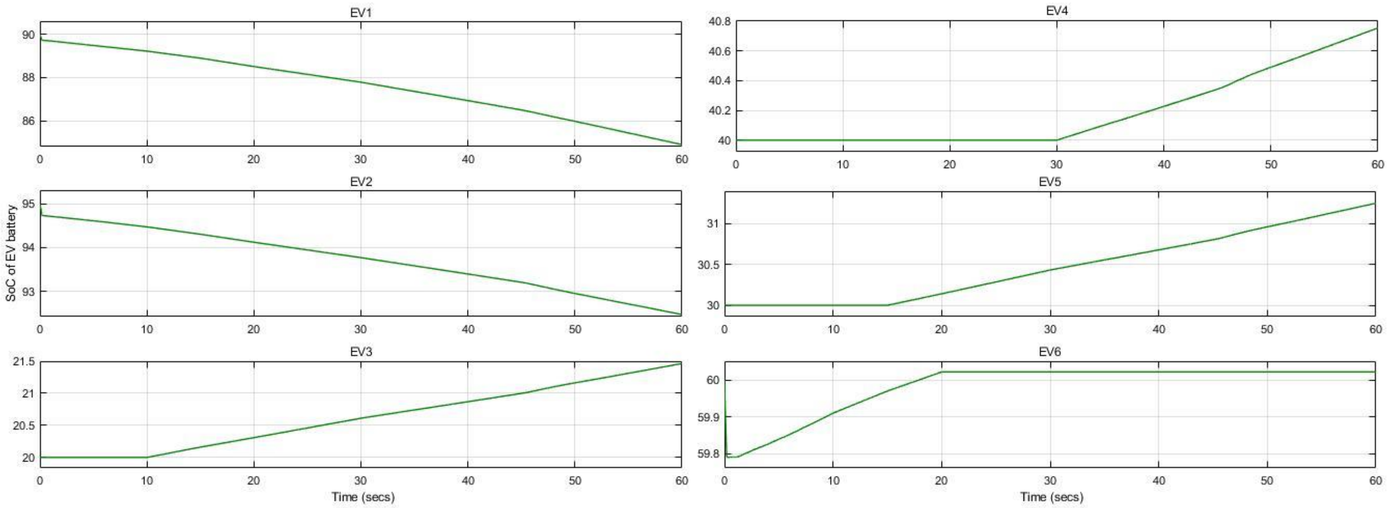

Fig. 4. SoC of the EV batteries parked at the CS through droop control

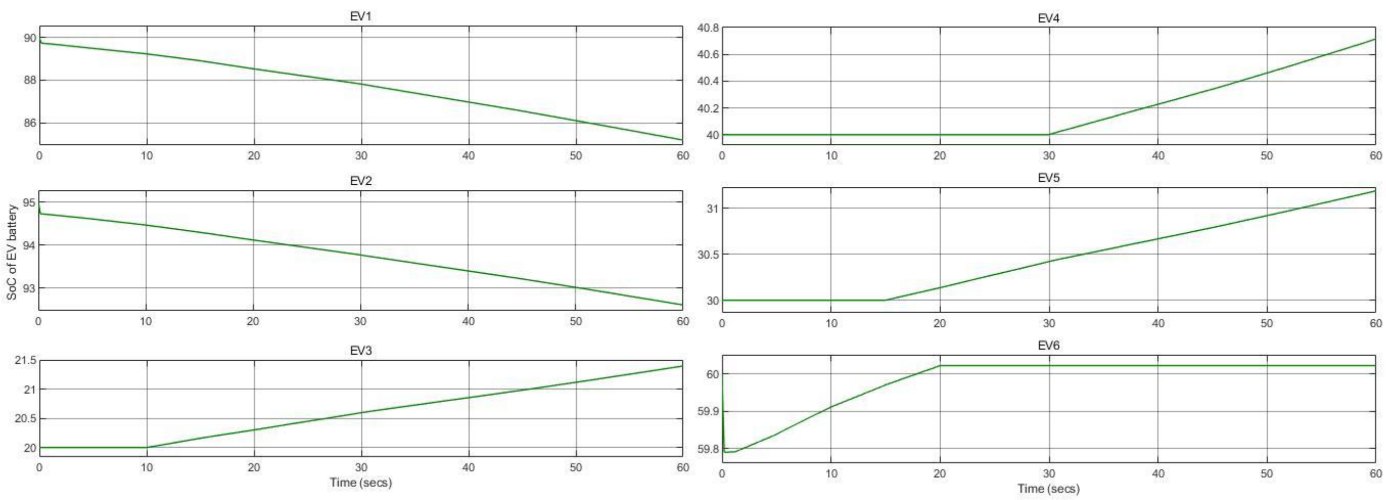

Fig. 5. SoC of the EV batteries parked at the CS through VSG control

In this system one CS, PV array of 10.7 *kW* and diesel generator of *5 KV A* ratings have been used. Comparison of the droop control and VSG control techniques has been done by considering EVs as an ESS for MG. In this system total number of EVs considered are *r = 6 (EV1 to EV6).* Out of these, the number of EVs that remain parked at the CS for long duration to participate in discharging process of batteries are considered as *l = 2* (*EV1 and EV2*). Rest of the EVs, *r - l = 4 (EV3 to EV6)* arrive and depart from the CS at different intervals of time.

Simulations parameters of the system are shown in Table I. Load demand of the MG is met by both the CS as well RES available at the MG. As illustrated in Fig. 2(a), there is large disturbance in frequency of the system, when droop control technique is used to regulate the frequency of MG. However, as per Fig. 2(b), frequency gets stabilized in an effective way by using the VSG control technique. Further, as per Fig. 3(a), there is large deviation in the frequency of system while using the droop control technique. On the other hand, as depicted in Fig. 3(b), frequency of the MG gets stabilized easily using VSG control. Based on these results it has been analyzed that VSG control can manage the MG's frequency in a better way.

Moreover, the comparison of VSG and droop control method has been drawn by taking into account the unexpected ingress and egress of EVs at the CS. As depicted in Fig. 4 and Fig. 5, *EV1* and *EV2* having SoC level of 90% and 95% respectively are already parked at the CS to participate in the discharging process of EV batteries. On the other hand, *EV3, EV4* and *EV5* having SoC level of 20%, 30% and 40% respectively arrive at the CS at *t* = 10, *t* = 30 and *t* = 15 sec and *EV6* depart from the CS at *t* = 20 sec. As soon as the EVs such as *EV3, EV4* and *EV5* arrive at the CS the charging commences. However, when the load on the MG is increased at *t* = 45 sec, there is a small change in the charging and discharging rate of these EVs as shown in Fig. 4. On the other hand, as per Fig. 5, there is very slight change in the charging and discharging rate of EVs by using the VSG control mechanism. From these results, it has been observed that charging and discharging rate of EVs parked at the CS can be maintained easily by using the VSG control, even when load on the MG changes.

V. Conclusion

EVs parked at the CS are capable of eliminating the observed deviations in frequency of islanded MG. Moreover, they can be used as movable ESS. It has been observed from the results that frequency regulation of MG can be obtained through EVs even when they arrive and depart from the CS at unpredictable intervals of time. From the results it is very clear that frequency of islanded MG can be regulated in an effective way by implementing the VSG control technique. It can be concluded that disturbance in MG's frequency is reduced to a large extent through VSG control. Moreover, charging and discharging rate of EV batteries has been sustained through VSG control, even when the load demand of MG changes.

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TABLE I. Simulation Parameters

	Parameter	Value
Buck-boost converter control	Proportional and integral gains for dc link voltage control	K_{pv}=0.005, K_{iv}=0.004
	Proportional and integral gains for battery current control	K_{pi}=0.0001, K_{ii}=0.0009
	DC link voltage V_{dc}	600V
	DC link capacitor C_{dc}	1000μF
VSG control	Line voltage V_L	400V
	Base power S_b	10e3
	Moment of inertia J	56.3 $kg\ m^2$
	Damping constant D	4.5
Droop control	Proportional gain parameter K_{pp}	0.0001
	Integral gain parameter K_{ip}	0.00004

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