Self-adjusting Inertia Emulation Control in V2G Application

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***Abstract*—in this paper, we propose an improved control mechanism for a microgrid. This happens through adding a controlling measure and algorithm one step ahead of the combination of inertia emulation control technique and droop control. This controlling step is a self-adjusting control system designed for a stable electrical grid model. This control technique applied to a home that is furnished with Photo-voltaic (PV) system and Vehicle to Grid (V2G) capable Electric Vehicle (EV). This control could run in both grid-connected and islanded modes in a microgrid application. The model is used to achieve an improvement in frequency over the standard droop/inertia emulation control method, in case of load changes and faults. The provided control system can handle different scenarios such as sudden load changes and transient conditions through dealing with the power of the battery and PV to regulate the voltage and frequency in this microgrid system. This control technique will achieve a better result compared to the standard control technique. Both models are implemented in MATLAB/Simulink. The results for the simulations are presented, showing the improvements over the fixed values of the controller.**

Keywords—Microgrid, Inertia Emulation, Droop, Sweep, V2G, V2H, Simulink.

I. INTRODUCTION

A microgrid can be described as a group of interconnected loads and distributed energy resources (DER) that can operate independently or link to the power grid. A microgrid is an integrated solution to overcoming the problems of combining distributed energy units with renewable energy resources and power systems. Nowadays, various types of DERs in the communities are having increased penetration. Electric vehicles (EVs) and solar panels are seen more often in a household that is the manifestation of the desire of the nation to switch towards more sustainable energy systems. Solar, tidal, and wind are the most common renewable energy sources. While moving for greater integration of renewable energy sources into the power systems, we can anticipate many benefits as well as operational challenges. Renewable sources of energy will reduce the household reliance on conventional power systems, but they can also be very challenging to predict and control since they have much less inertia comparing to conventional power systems that using the massive spinning generators to supply their energy. Generally, renewable sources of energy can be classified into three categories: high-frequency ac (i.e. microturbines), low-frequency ac (i.e. wind energy) and dc (i.e. solar) energy sources[1].

Of the many renewable sources used in microgrids, PV and wind power are the most common ones. Nonetheless, these two sources do lack consistency and reliability in generating power, although usually a storage unit is required [2]. A battery system is a reliable solution to the problem of fluctuating power generation among the different types of storage units available these days [3]. Yet finding a balance between optimal battery size and the cost of using the storage system can be challenging. Especially when one considers rare events like blackouts. EVs, which are equipped with high-capacity batteries, are rapidly becoming popular around the world. The projected increase in the number of electric vehicles has altered the perception that they are seen only as big changes for the electric grid. The key reason for changing this perspective is the charging and discharging flexibility of the EVs in modern electric cars fitted with CHAdeMO or CCS chargers [4].

Nowadays, electric vehicles have been considered capable storage units which can provide important advantages in favor of electrical grid services such as ancillary services, spinning reserve, inertia improvement, peak shaving, frequency stabilization and storage [5][6].

In the case of special situations such as short-circuit, faults, blackouts or even a hurricane or tornado, the power systems may fail to provide reliable energy to all grid areas. In this situation, the microgrid will keep the local grid alive during the disaster. Charging/discharging a vehicle from and to the grid is a decision that helps to balance the system and improves the reliability of the local power grid while providing an emergency source of energy for a household.

The growing number of EVs makes the use of these storage units in the power systems particularly desirable. EVs are capable of charging and discharging the battery at different times of the day and under different circumstances to improve the power system voltage and frequency control [7]. In a configuration like V2G (Vehicle to Grid) or V2H (Vehicle to Home) in the local grid power networks, this important feature plays a major role in fulfilling the requirements for grid load. The electric car's battery can be used as a source for supporting local charges within the microgrid during special events (e.g. earthquake, tornado, etc.) EVs batteries have the capacity to charge and discharge the battery in different moments of the day and conditions to enhance the power system's voltage and frequency stability. This functionality plays an important role in the design of Vehicle-to-Grid (V2G) to help the local power system to fulfill the grid requirement and meet the load requirements. During the power shortage, the electric car's battery can be used as a source to support local loads in the microgrid. At the request of its user, the V2G system should be able to charge and discharge the EV the standards required for these applications are IEEE1547a (Standards for Distributed Energy Resources Interconnection and Electricity Grid Interchangeability), IEC62109 1 (Safety Standard), IEC62109 2 and UL1741 (Standard for Use With Distributed Energy Resources Inverters, Converters, Controllers and Interconnection Systems)[8].

Mentioned specifications are the basic requirements that can be implemented to share the energy with the grid depending on the requirements. Considering that the EV can be described as a DG system by Solar and Load. We must, therefore, understand the active and reactive power-sharing. To ensure the MG's reliability and performance, the active and reactive power of the DG units should be shared appropriately. Droop Control methods are modern, communication-less methods for controlling power in a microgrid, but they have several weak points. Another way of mimicking the swing equation's constant status and transient characteristics called the Virtual Synchronous Generator (VSG). While the inertia of DG units may be enhanced compared to droop control, the active power output of VSG is oscillatory, and dynamic power-sharing among DG units would be inefficient and slow, particularly in a weak microgrid situation. The use of the enhanced droop control method is therefore still popular for the sharing of active and reactive power between DG units in isolated MGs. In order to ensure the state optimization of a complex MG, the accuracy and dynamic performance of an active power-sharing should be considered. A static droop compensator is used for active power-sharing in [9]. In [10] it is proposed an improved droop regulation with a transient droop output. Improving the active and reactive power decoupling capability with a virtual output impedance is indicated. Nevertheless, the low-frequency dynamics of the inverter are not improved in [11] due to a time-scaled separation of power, voltage, and current dynamics. This optimizes the dynamic stability of the active power-sharing with a droop-control and balances a dynamic power-sharing output with a decentralized adaptive power-sharing system, which doesn't affect the efficiency of the dynamic energy-sharing system[12].

In addition, a hierarchical strategy for active power management is introduced to share active power under complex load conditions. Although there has been active power-sharing and the dynamic response of the microgrid is guaranteed, complex feeding impedance and costs are not taken into consideration for generating microgrids. Though there is still an unresolved reactive power distribution process and DG units can demonstrate harmonious power under uneven impedances of the feeder and non-linear load conditions [13][14].

In this paper, we provided a control technique that can further improve the responses from previous research work in [15]. It will automatically adjust two main coefficients of the controller based on the upcoming situations.

The rest of this paper is organized as follows. Section II describes the idea of the self-adjusting control unit. In Section III the model is proposed. with concluding remarks and results made and compared in Section IV and conclusion in section V.

II. SELF ADJUSTING CONTROL

A. *Vehicle to Grid Connection*

A power system to achieve the mandatory frequency and voltage regulations should make a balance between energy production and energy consumption. A Microgrid as a part of a power system in order to operate independently, it must keep its demand and supply in a stable condition in order to prevent voltage and frequency fluctuations. The generation and monitoring demand can be controlled. The frequency of electricity will change naturally once demand and supply are imbalanced. By adding synchronous generators, the variation will alter the concept of inertia derives from the total kinetic energy available in the microgrid spinning. Inertia means the sensitivity of the frequency to the inequality between supply and demand.

The system can not provide robustness in the production of energy as a conventional power system based on a lack of availability of inertia in a microgrid where the main source of energy production is photovoltaic (PV) systems generation. Due to the lack of inertia and sudden changes in voltage and current, it is much harder to control autonomous microgrid under a high photovoltaic generation. We get the power generation from renewable energies, it's still necessary to raise the microgrid's inertia deliberately to achieve a controllable device. The lack of adequate inertia due to the PV generation was resolved in [15] by adding the virtual inertia and coefficient of damping to the droop controller of the EV. This controller is able to restore the frequency and maintain it within the desired range. Excessive power is sent to the EV battery by using a bi-directional converter. The EV inverter is operated to provide a shortage of energy for the load induced by the irradiance reduction (W / m2).

The controller used in [15] uses two different types of controllers, the first being the droop control, which is commonly used in microgrid systems and is usually used to normalize the frequency and voltage in the device that this control system can be used to regulate voltage and frequency in parallel operation. The principle of droops can be considered; this helps to regulate frequencies if power is controllable. On the other hand, if you can regulate the reactive power, you can also regulate the voltage, which leads to equation (1). Droop control is used to achieve system stability and the other purpose is to achieve a proportional power-sharing, whereas there is more than one system of distributed generation (DG). As described above the voltage is linearly related to the system's reactive power. On frequency and power, the same principle applies (2).

$$V_{ref} = V_0^* - n\,(Q - Q_0) \tag{1}$$

$$f_{ref} = f_0^* - m\,(P - P_0) \tag{2}$$

The second control method that has been utilized in [15] is the inertia emulation control, the idea of the inertia emulation is around for a while. In the conventional power system, the heavy spinning rotors of the generator are producing the power. Therefore in case of sudden load change or a temporary fault, the system will not get affected. On the other hand, by increasing the penetration of renewable energies especially PV, since they have zero inertia in their systems, controlling these systems can be challenging.

Power systems that utilize synchronous generators have high inertia therefore, they have a robust system to avoid the fluctuations instabilities. Systems with high inertia are more capable of dealing with instabilities and frequency changes.

On the other hand, by increasing number of the renewable energy sources, renewable energy penetration percentile will increase and, the higher quantity of renewable energies especially PV can cause issues in the control systems and they are very susceptible in case of fluctuations or instabilities. Since, PVs do not have any inertia in their systems, controlling these power systems can be challenging. As mentioned, Systems with high inertia are more capable of dealing with instabilities and frequency changes. Therefore, we have some methods like virtual inertia that makes a PV system less susceptible to control failure. This method mimics the spinning rotor action with the control of the inverter. The virtual control is utilizing the buried capability in a microgrid to decrease the problem of lacking a synchronous generator or a grid. Besides, to expand the autonomous regulation capability, minimize in the system while irradiance or AC load varies.

B. Unified Control

In [15] we utilized an equation that we are trying to modify and optimize in this paper (5). By adding a gain (multiplier) to D_ω and K_d , we can further improve the responses of frequency and voltage to the faults, sudden load changes, Connection/disconnections from the grid and irradiance changes. The virtual inertia is implemented for frequency regulation.

The equations (5) that describe the unified control, composed by droop and virtual inertia, are presented and discussed. The virtual inertia is implemented in the frequency regulation.

$$H = \frac{1}{2\ \omega_c\ D_p} \tag{3}$$

$$K_d = \frac{1}{2\ D_p} \tag{4}$$

$$2\,H\,\dot{\omega} = \frac{p^* - p}{\omega} - \alpha \times D_\omega\,(\omega - \omega^*) - \beta \times K_d\,(\omega - \omega_g) \tag{5}$$

The above equations are dependent on ω_c and D_p. H is the inertia of the system. ω_g is the grid frequency, D_ω is the droop coefficient and the K_d is the damping coefficient. α is the coefficient determined for the droop control and β is the coefficient of damping part of the equation.

In this paper, a new technique is proposed to improve the frequency response of a controller, by the means of defining a delay function, etc. in the algorithm three constraints are implemented as the following. The sum of each coefficient should not exceed 2 and each coefficient receives a value between 0.1 and 1.9. Thus, applying these three constraints guarantees the stability of the system. In the controlling block, the input is the frequency and the three outputs (ya yb yc) sweep the values based on different conditions. At the first step of optimization, the value of ya varies from 0 to 2 with a step size of 0.1. In the next step after obtaining the optimized value of ya, the value of yb is swept between 0.5 and 1.5. After getting the optimized value of yb we move to the next step. The value of yc same as ya and yb swept between 0.01 and 0.05 with a step size of 0.01. In every situation, we will have certain parameters of ya, yb and yc. This controller does this for each step and provides a better result than a fixed value in [15]. These parameters can change the coefficient and delay time therefore we can achieve better responses in frequency and voltage. Playing with these two coefficients can improve the transient frequency response. There are some constraints that we are considering (6)(7)(8). These constraints are necessary for optimized values. These constraints and algorithms give better frequency responses.

$$\alpha + \beta = 2 \tag{6}$$

$$1.9 \geq \alpha \geq 0.1 \tag{7}$$

$$1.9 \geq \beta \geq 0.1 \tag{8}$$

The (5) are dependent on ω_c and D_p. H that is presented in the model is inertia. ω_g is the frequency of the power grid, D_ω is the gain of the droop control unit, and K_d is the factor of damping. The damping factor can help with decreasing the transient effect on the frequency for better frequency response in the system. The equation above has two different parts: $\alpha * D_\omega(\omega - \omega^*)$ is the droop control, and $\beta * K_d(\omega - \omega_g)$ is the inertia emulation. Here α and β should not be fixed since in some situations we better have a higher coefficient of droop control and on the other hand some moments that we need the higher impact of inertia emulation. The diagram of the self-adjusting inertia emulation with droop control is demonstrated in (1).

III. MODEL

In this paper, the Matlab Simulink model includes the Power Grid, an EV with V2G / V2H capacity and a PV system that uses an MPPT system modified to test the system and to reproduce the situation in the real world. The modified control unit EV's inverter has proposed to improve the results of [15]. We add an additional control unit to the inverter controller, which is provided with the frequency input in this model. This unit assesses the condition on the basis of the frequency deviations. By applying the sweeping method for three different variables within the control unit, a control unit will decide which coefficients depend on the changes in frequency, if necessary, either the effect of droop control or the emulation of inertia will increase. In this paper, our model has a PV system with a controller that tries to minimize the reactive power and extract the maximum real power to provide it for the microgrid system. In our system model (i.e.

Mitsubishi Highlander PHEV and Nissan Leaf), some EV or PHEV equipped with CHAdeMO or CCS charging capable of V2G / V2H are available. The system V2G / V2H uses two-head DC / DC conversion systems in various scenarios to charge and discharge the battery. Adding the control unit to the previous controller from [15]. We can achieve better responses to challenging conditions, including changes in irradiance, initialization, and changes in load. In this paper, we're focusing on both transient and steady-state situations. Droop and inertia emulation controls, which were unified in a single control system, both have advantages.

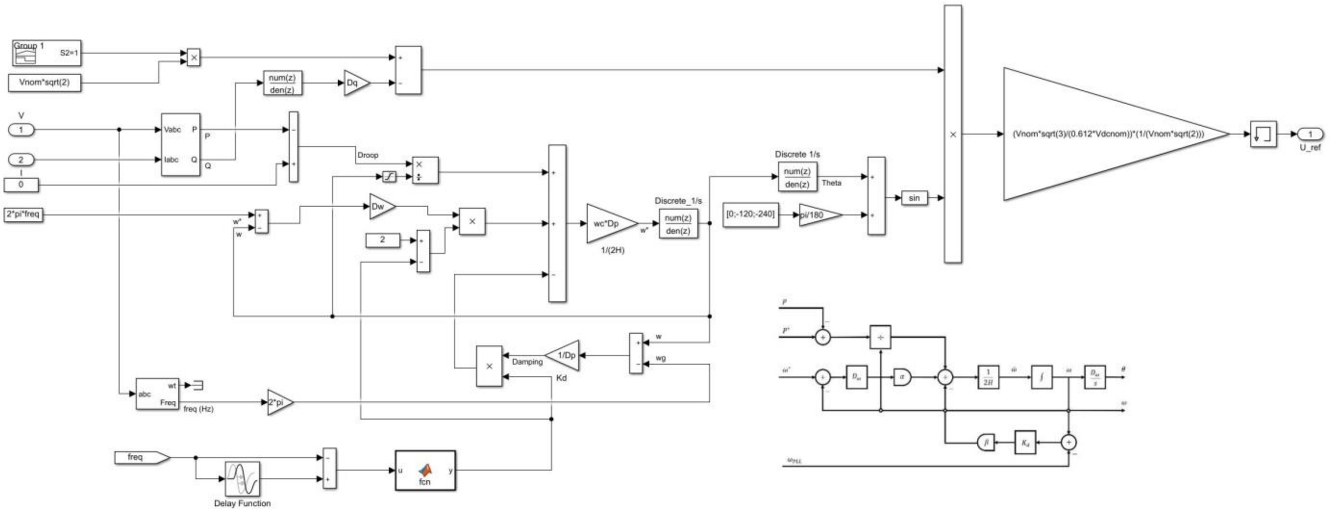

Fig. 1 EV's self-adjusting control scheme in Simulink/Matlab

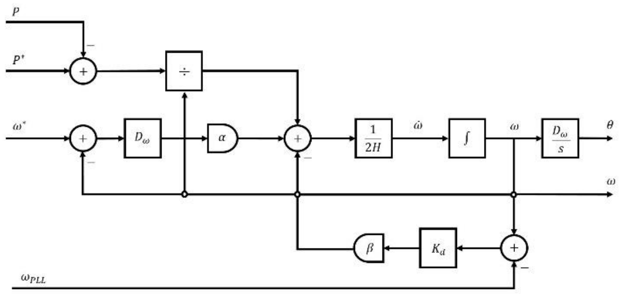

Fig. 2 Diagram of the self-adjusting inertia emulation controller with droop control

Their coefficient and their effect ratio have not been calibrated on the basis of various situations, and this added control unit will provide a better transient response to fluctuations and changes using provided algorithms and control units. Therefore, we can enhance the transient and steady-state response in the load change base or connect/disconnect the household EV and PV from the grid. worth mentioning, We use the PQ controller for grid-connected mode. This device is simulated for various situations: the transition from grid connection to islanding mode, connection and disconnection from the EV battery, adjustments in irradiation, and connection and disconnection. This simulation was built in Simulink/Matlab.

IV. RESULTS

In this part, we present the results obtained by simulating the model in islanding mode and with loading variations. Load and battery parameters can be fined from Table.1. Load_1 is a constant load and it will remain until the end of the simulation. Load_2 is transient and we added to the system with an immediate connection from t=[1 4]s. Load_3 is also a transient load we are added immediately by a switch from t=[2 3]s. Irradiance change in the system will occur from t=[5 6]s and it will lose 30% of the insolation in 1 second. We are comparing the results of [15] with this developed control unit for both voltage and frequency.

Worth mentioning, the results are very similar for other cases such as Power and Reactive Power.

A. Frequency Comparison

In Fig.3, we can observe an improvement in the frequency in the PCC, initialization is always a major challenge for any control in power systems. We can observe an enhanced initialization of the PCC frequency. Fig.4 shows the fault response of both systems, there is not much difference between the two, but we can see that after clearing the fault the orange line (proposed controller) gets to a steady-state faster than the default control.

An apparent improvement in frequency response can be seen in Fig.5 that we are having a transient load. The deviation of the proposed method is slightly lower than the standard model. Fig.6 shows two completely different responses to the irradiance change which also shows the controller activation to reach 1p.u. There is a comparison between these to the controller for initialization of the system which is showing in Fig.7. There is a slight improvement in voltage response to a sudden load change in Fig.8.

B. *Voltage Comparison*

Besides the frequency we compare the voltages, the initialization is easier for the optimized system with an orange-colored line, the fluctuations are lower and the peak-to-peak value is less than the standard model in Fig.7. The parameters for the controller is from Table.1.

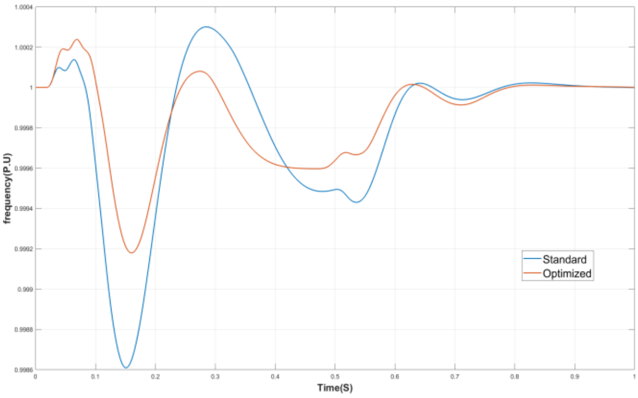

Fig. 3 Frequency response in PCC in case of initialization

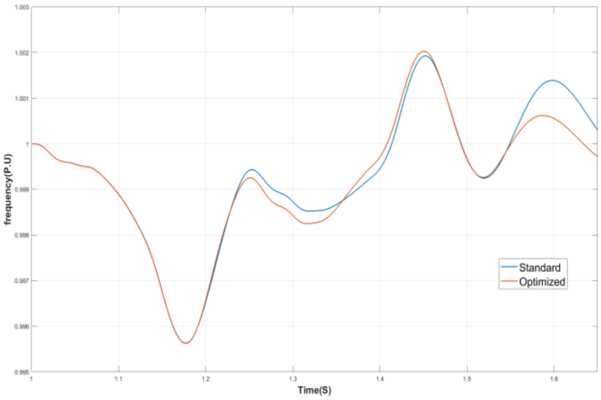

Fig. 4 Frequency at fault

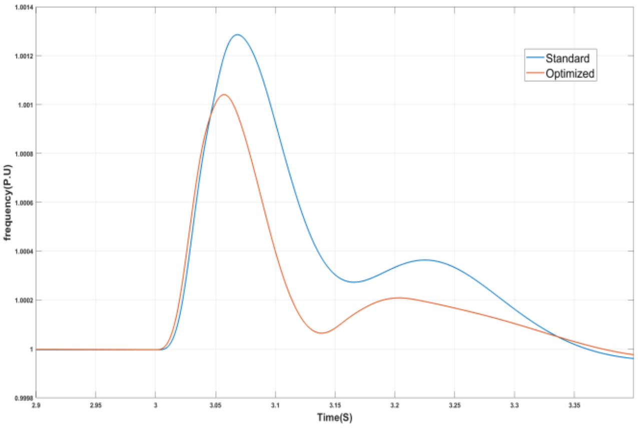

Fig. 5 Frequency of PCC adding Load

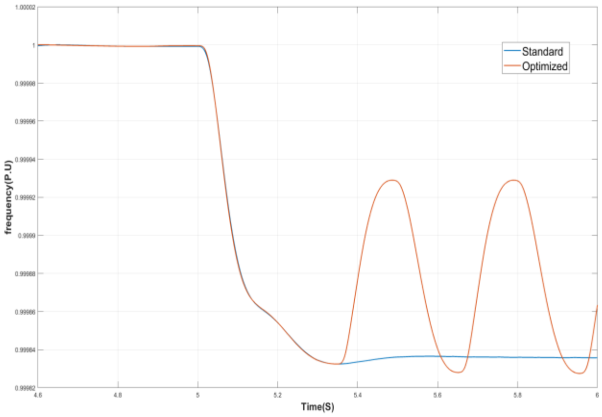

Fig. 6 Having the irradiation change

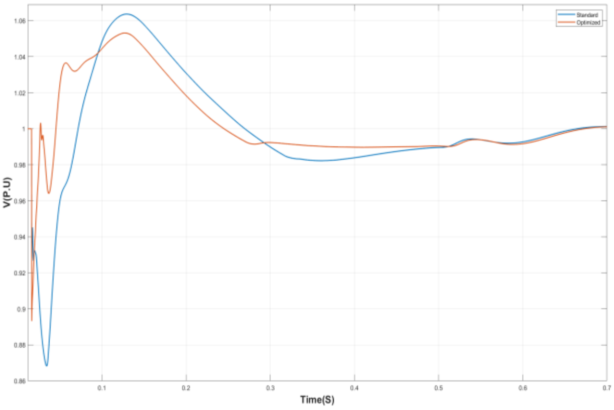

Fig. 7 Voltage initial at PCC

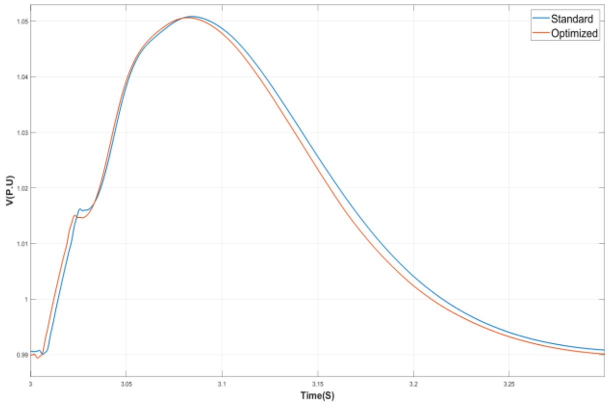

Fig. 8 Voltage in the load changing

TABLE I. PARAMETERS

Object	Value
Grid Voltage Battery Voltage	Vn = 120v Vn = 350v
Load	Load_1 Real Power = 5 kW Load_2 Real Power = 0.5 kW Q = 90 var Load_3 Real Power = 2 kW
Electric Vehicle	Battery Capacity = 40kWh Initial state of charge = 50 %

CONCLUSION

In this paper, we presented a modification to a control technique and we compared the results to witness the improvements in frequency responses. This model is added to inertia emulation and droop controls that are connected to each other in a unified manner, by adding the proposed control unit. we achieved better frequency and voltage Responses in Point of Common Coupling (PCC) for initialization and transient situations. This control model applied to a home equipped with EV. These results are demonstrating an improvement to previously proposed controller.

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