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Installation of an Electric Vehicle Charging Station Using a Diesel Generator and Solar PV Batteries

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Abstract: In this study, continuous charging in islanded, grid-connected, and DG set connected modes is made possible by a battery, a diesel generator set, a battery energy storage system, a solar PV (Photovoltaic) array, and a grid-based EV charging station (CS). The primary function of the charging station is to use a solar photovoltaic PV array and a BES to recharge the electric vehicles (EV) battery. However, if the storage battery is empty and the solar PV array power is not available, the charging station intelligently draws electricity from the grid or a diesel generator set. However, the power from DG sets is drawn so that it always operates at 80–85% loading to achieve optimal fuel economy under all loading conditions. Furthermore, the generator's voltage and frequency are managed by the charging station in tandem with the storage battery, eliminating the need for a mechanical speed governor. It also ensures that the power drawn from the grid or DG set is at unity power factor (UPF) even under nonlinear loads. The PCC (Point of Common Coupling) voltage is synchronised with the grid/generator voltage to provide continuous charging. The charging station also carries out active and reactive power transfers from cars to residences, the grid, and other vehicles to increase its operational efficiency. The functionality of the charging station is experimentally examined using the lab-developed prototype.

Index Terms: DG set, electricity quality, solar PV generation, and EV charging stations.

I. INTRODUCTION

Because they do not emit any emissions from their exhaust, electric vehicles (EVs) are currently thought to be among the most efficient modes of transportation. Three million electric vehicles (EVs) have already been registered on the road because of their benefits, and 100 million are expected by 2030 [1]. However, the implementation of the recommended approach necessitates a significant amount of electrical power and infrastructure for charging. Furthermore, electric vehicles (EVs) may only be considered sustainable if the electricity required for charging them comes from renewable and sustainable sources. But producing electricity from fossil fuels doesn't reduce emissions—it just moves them from cars to the power plant. Therefore, producing electricity from renewable energy sources can reduce emissions and improve the environment. Out of all the renewable energy sources currently available, solar PV based generation is the most practical option for EV charging because it is almost always accessible, regardless of one's location—rural or urban. Other examples of renewable energy sources include wind, hydro, fuel cell, and solar PV arrays [2]. It is practically year-round accessible in the Indian subcontinent. Unlike solar PV arrays, wind and hydro energy is location-specific. The area along the coast gains the most from wind The area along the coast gains the most from wind.

The most sensible alternative for EV charging is to use renewable energy-based charging stations; however, adding a new power conversion stage to the existing charging system makes it more complex and results in more power loss. Furthermore, a controller specific to each conversion stage must be connected to the current control. Consequently, it is critical to design an integrated system that can function in several modes, necessitating centralised control and coordination amongst the various sources.

There has been a lot of interest in the creation of a renewable energy-powered charging station. Grimier et al. [3] have discussed the importance of renewable energy for the sustainability of the EV charging station. Mouli et al. [4] have utilised solar energy to charge EVs using a high-power bidirectional EV charger. However, AC charging is not supported by the designed charger. A three-port converter has been introduced by Monterio et al. [5] for the purpose of linking a PV array with an EV charger. However, the current distortions the charger introduces into the grid current are not considered by the proposed charger. Singh et al. [6] have proposed a modified z-source converter for the development of a PV array/grid connected EV charger. However, the island style of operation is not meant for the charger. It cannot, therefore, enable EV charging in the absence of a grid. Chaudhari et al. have discussed a hybrid. The battery storage is managed by an optimising model to maximise the output of the solar PV array and minimise the operational expenses of the charging station. Keavy et al. [8] recommended combining the EV charging station with the on-site PV generated power (installed on the business building) for maximum solar PV array utilisation (under uncertainty) with little grid effect. Zhang et al. conducted study on the optimal scheduling of EV charging stations with dual charging modes at workplaces. To minimise the impact of charging on the grid and provide the best possible service at the lowest possible cost, the PV array-powered charging station (CS) should be deployed onsite [10]. The demise of a storage battery utilised with solar PV array technology deployed on commercial buildings has been investigated by Kandasamy and others [11]. EVs can benefit from the wind energy driven charging station (CS) since it is available day and night. In this field, many papers have been written [12]– [14].

Owing to the massive amount of energy that EV batteries can store, EVs are already used as a distributed energy resource to provide a wide range of ancillary services. Singh et al. [15] have described a PV array-based CS that may provide charging capabilities in addition to vehicle-to-grid reactive/active power, active power filtering, and vehicle-to-home. Saxena et al. [16] installed a grid-tied PV array system for usage in EV and residential applications. Razmi et al. [17] have developed a home integrated PV-storage battery system with multi-mode control that can operate both islanded and grid-connected. Erdinc et al. and Kusto et al. Hafiz et al. [20] have presented the smart home operation where EV can be used as a store to provide the vehicle-to-home and vehicle-to-grid operation for the benefit of both the utility and the customer.

A detailed analysis of the reviewed literature reveals that research on renewable energy-based charging stations has mostly concentrated on optimising different aspects of charging, such as the size of the storage unit, the size of the renewable energy source, the driving patterns of the vehicles, the charging time, the cost, the scheduling of charging, etc. However, the charging station employing renewable energy has only been implemented in a small number of publications. Furthermore, there is less consideration of the practical performance of charging stations.

Furthermore, most of the literature primarily addresses how well CS performs in islanded or grid connected modes. Due to the single mode of operation in grid linked mode, the solar PV panel is rendered worthless even in the presence of the sun (solar irradiance) if the grid is unavailable. In the same way, irregular solar radiation interferes with PV electricity when it is operating in island mode. Therefore, to lessen the effects of fluctuating solar irradiation, a storage battery is required. The maximum power point tracking (MPPT) must be disabled when the storage battery is fully charged to prevent the storage battery from being overcharged.

The study provides a grid, energy storage, and DG set supported CS to maximise the PV array energy under all operational situations. This CS can operate in grid-connected, DG set-connected, and islanded modes.

Several studies [15] have discussed both grid-connected and islanded models. However, these two modes are managed independently; automatic mode change is not offered. As a result, the PV array power needs to be cut off, and without automatic mode switching, the EV cannot continue to charge. This work provides an automatic mode switching logic to enable the controller to automatically switch between different operating modes based on the power generation of the PV array and the need for EV charging.

Because the PV array is sporadic and not available at night, storage batteries combined with PV arrays are used to provide the consistent and reliable operation of CS. However, because of the limited capacity of the storage battery, it is not possible to provide backup continuously. Because of this, the CS require grid backup if both the electricity from the PV array and the energy storage are depleted.

To maintain the constancy of charging, isolated locations may need to use the DG set due to limited grid availability. However, the DG set performance is not fully utilised and is affected by the type of loading. DG sets are frequently designed to withstand extremely low load harmonic current [21]. Because EV chargers frequently use rectifiers, power factor correction circuits, and DC-DC converters for step-down, the performance of DG sets is damaged greatly by EV charging due to the presence of harmonic

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currents in EV current. Nonetheless, because the voltage in this investigation is such that the DG set is always loaded to at least 80% of its rated value, since the voltage source converter (VSC) supplies the harmonics and reactive current needed by the EV charger.

The important contributions of the paper are listed below.

Grid-integrated CS, which provides continuous DC and AC charging for electric vehicles, was made possible by the design and experimental verification of the energy storage, DG set, and PV array.

• The development of a single VSC and no hardware changes necessary for the charging station to operate in islanded, grid-connected, and DG set-connected modes thanks to a single controller.

• Creating an algorithm for mode switching that enables the charging station to smoothly change modes to offer continuous charging.

• The creation of control strategies for vehicle-to-grid (V2G) power transfer for grid support and vehicle-to-vehicle (V2V) power transfer for EV charging.

*To minimise harmonic grid currents and guarantee that the power exchange takes place at unity power factor, the charging station is equipped with an active power filter. For the charging station to comply with IEEE-519, this is required.

• DG sets the frequency and uses an automated mechanical voltage regulator to regulate the voltage.

• A plan is in place to feed any excess power produced by the PV array into the grid to prevent the storage battery from being overcharged.

II. SYSTEM DESCRIPTION

The suggested charging station, shown in Fig. 1, charges the electric car and powers the load connected to it using a solar PV array, a storage battery, a DG set, and grid electricity. The solar PV array is connected to the voltage source converter (VSC) DC link through a boost converter, and the storage battery is connected directly to the DC link. An EV, a single-phase SEIG (Self Excited Induction Generator), a nonlinear load, and the grid are all connected by a coupling inductor on the AC side of the VSC. The grid and generator currents at PCC are converted from switching harmonics to sinusoidal currents using a ripple filter. The excitation capacitor is connected to the SEIG's auxiliary winding. Furthermore, a small capacitor is connected across the primary winding of the SEIG. A synchronising switch is used between the grid/DG set and PCC to allow for regulated connection and disconnection of the charging station from the grid and set.

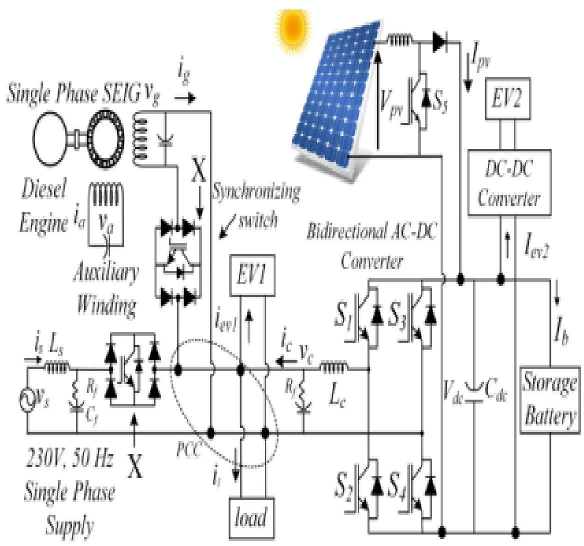

Fig. 1 Topology of charging station

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III. CONTROL STRATEGIES

Various control strategies used in the CS are discussed here.

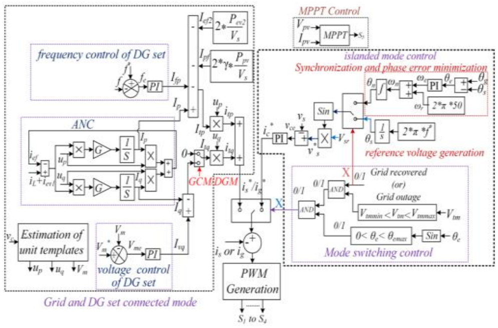


Fig.2 Unified control of VSC for standalone and grid and DG set connected mode

A. Control of VSC in Islanded Mode (Absence of DG Set and Grid)

Because of its islanded control, the CS can operate steadily even when the grid is unavailable, maintaining solar electricity output and EV charging in both AC and DC modes. With few adjustments to the control, the storage battery can regulate both DC charging and solar PV generation. But since the grid is necessary to access any voltage reference, an independent VSC controller is needed for AC charging to produce the local voltage reference. As a result, the islanded controller generates an internal voltage reference of 230 V and 50 Hz using the logic depicted in Fig. 2, which generates the reference voltage by multiplying the frequency by sin. The reference converter current is obtained by comparing the generated reference to the converter's terminal voltage after the voltage error is minimised using a proportional integral (PI) controller. The error minimization and current generation reference might be expressed as,

$$i_c^*(s) = i_c^*(s-1) + z_{pv}\{v_{ce}(s) - v_{ce}(s-1)\} + z_{iv}v_{ce}(s) \qquad (1)$$

The reference current generates the converter's gate signals once it has been compared to the measured the reference current generates the converter's gate signals once it has been compared to the measured.

B. Control of VSC in DG Set or Grid Connected Mode

The controller determines how much electricity will be traded with the grid when it is in grid connected mode. To improve fuel efficiency, the DG set operates in constant power mode when in connected mode. However, the controller needs to compensate for the EVs' reactive and harmonic current demands in both scenarios. It uses the EV current to estimate the grid's or the DG set's reference current to accomplish this. Only the active current of an EV is used to determine the reference current when it is connected to the grid. On the other hand, the reference DG set current in DG set connected mode is determined using both the EV's reactive and active currents. The controller determines how much electricity will be traded with the grid when it is in grid connected mode. To improve fuel efficiency, the DG set operates in constant power mode when in connected mode. However, the controller needs to compensate for the EVs' reactive and harmonic current demands in both scenarios. It uses the EV current to estimate the grid's or the DG set's reference current to accomplish this. Only the active current of an EV is used to determine the reference current when it is connected to the grid. On the other hand, the reference DG set current in DG set connected mode is determined using both the EV's reactive and active currents.

Presently, when connected to the grid, the total active and reactive currents are as follows:

$$I_{sp} = I_p - I_{ef2} - I_{pf} \quad (2)$$
$$I_{sq} = 0$$

Only an EV's active current is considered, with the reactive current being considered as zero, to achieve unity power factor functioning in grid connected mode. But when the DG set is connected, the EV's active and reactive current components are both utilised.

The connected DG set's current total active and reactive current is as follows:

$$I_{sp} = I_p - I_{ef2} - I_{fp} - I_{pf} \quad (3)$$
$$I_{sq} = I_{vq} - I_q$$

where Ip and Iq are the active and reactive currents of the EV, and Ief2 and Ipf are the feed-forward terms of the EV2 and the PV array, respectively. Ifp and Ivq are the designations for the voltage and frequency regulators utilised in the DG set connected mode. Ief2 regulates the EV's power transfer from the vehicle to the grid. Overcharging of the storage battery is controlled by the feed-forward term, or Ipf, of the grid-connected PV array. Since the energy storage is directly interfaced with the DC link, the storage battery cannot be charged in the CC/CV mode. However, it is feasible to ensure that there will never be an overcharge of the storage battery. In a grid-connected environment, feeding the grid with solar PV electricity prevents the storage battery from being overcharged. This is achieved by adding the solar PV array feed-forward term to the grid linked mode control, as shown in Fig. 2. A variable gain, "," is multiplied by the feed-forward term to determine the percentage of PV array electricity fed into the grid. The SOC data of the storage battery determines the constant """s range, which is 0 to 1. If the storage battery is fully charged, the " takes on the value of '1'. When the storage battery is totally depleted, the " turns into a '0'.

Lastly, the predicted reference current for the grid or DG set is as follows:

$$i_s^* or\ i_g^* = I_{fp} \times u_p + I_{tq} \times u_q \quad (4)$$

where the DG set or the grid voltage (vg or vs) synchronising signals are up and qp. As illustrated in Fig. 2, the switching signals are generated by a hysteresis controller that uses the grid/DG set's detected and reference currents.

C. DG Set Control for Voltage and Frequency

Through decoupled control of VSC, the frequency and voltage of the DG set are controlled to function at a single point. In a decoupled control system, active power regulates the frequency, while reactive power regulates the voltage. Two PI controllers are used to regulate voltage and frequency as a result. Here is the voltage regulation PI control:

$$I_{vq}(s) = I_{vq}(s-1) + z_{vp}\{V_{me}(s) - V_{me}(s-1)\} + z_{vi}V_{me}(s) \quad (5)$$

where Vme=Vm * -Vm and zvi and zvp are the gains of the PI controller.

Likewise, the differentiated expression for the frequency PI controller is as follows:

$$I_{fp}(s) = I_{fp}(s-1) + z_{fp}\{f_e(s) - f_e(s-1)\} + z_{fi}f_e(s) \quad (6)$$

where fe is the frequency error and zkfp and zfi are PI gains.

The outputs of the voltage and frequency controllers are integrated in grid-connected control, as shown in Fig. 2. However, in this mode, the outputs of these controllers become zero because the grid's voltage and frequency are still regulated when it is attached to the grid.

D. Control of EV2

The DC-DC converter connects an electric vehicle (EV) to the control technique, which is known as constant current/constant voltage (CC/CV). The EV charges in CC mode until the battery's terminal voltage reaches the value that indicates a complete charge. But after the EVs have almost reached the proper terminal voltage in a nearly full charge situation, the charging is switched to CV mode. As shown in Fig. 3, two PI controllers are utilised in this instance to control the CC/CV charging method. Because the outside voltage loop supplies a reference current for the current control step.

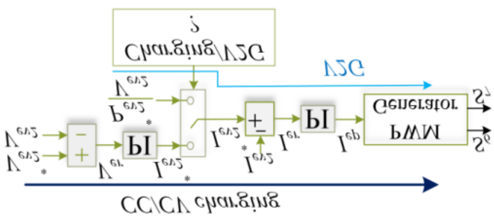


Fig. 3 EV2 control for CC/CV charging and V2G power transfer

The reference charging current that is anticipated is

$$I^*_{ev2}(s)=I^*_{ev2}(s-1)+z_{evp}\{V_{er}(s)-V_{er}(s-1)\}+z_{evi}V_{er}(s) \qquad (7)$$

where Ver is the EV battery voltage error and Zevp and Zevi are the controller gains. Using the reference and measured battery currents, the PI controller and PWM generator are utilised to generate the switching signals for the converter. The duty cycle calculation PI controller is expressed as,

$$d_{ev}(s)=d_{ev}(s-1)+z_{ep}\{I_{er}(s)-I_{er}(s-1)\}+z_{ei}I_{er}(s) \qquad (8)$$

where Ier is the battery current error and zep and zei are the controller gains.

Based on the reference power, the EV2 battery is used up for the V2G power transfer, and the controller takes the erroneous route shown in Fig. 3. Figure 3 shows how the EV2 feed-forward term is controlled by the reference power.

E. Synchronization and Switching Control

The charging station functions in multiple modes based on the generation and charging demand, necessitating the creation of a mode-changing strategy to ensure seamless mode switching and continuous charging. These scenarios involve being landed on a DG set and being landed on a grid connected. linked modes, for which the logic for mode changeover is developed. This method involves bringing the two voltages into phase for synchronisation, but not before the controller ascertains the phase difference between them. The PI controller does this by adjusting the frequency of the VSC generated voltage in an islanded condition using the logic shown in Fig. 2. The PI controller for phase minimization is expressed as,

$$\Delta\omega(s)=\Delta\omega(s-1)+z_{pa}\{\Delta\theta(s)-\Delta\theta(s-1)\}+z_{ia}\Delta\theta(s) \qquad (9)$$

Where is the phase difference, and what are the controller's tuning parameters, zpa and zia? Fig. 2

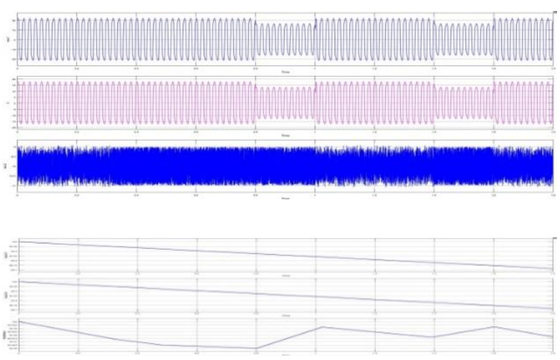
further illustrates the circumstances in which the CS operates in islanded mode and when a mode shift is required. When all synchronisation conditions are satisfied, the control logic generates the enabling signal X='1' for the synchronising switch.

IV. RESULTSAND DISCUSSION

Real and simulated results are utilised to analyse the performance of the CS.

A. Simulation Results

The simulation results shown in Figure 4 show that the CS is operating without interruption. When the CS is first operating in its islanded state, the PV array provides power to charge the EVs that are connected to the PCC. Since there is a greater need for EV charging than there is generation from the PV array, the excess generation is stored in the energy storage. In 0.32 seconds, the sun's irradiance drops from 1000 W/m2 to 300 W/m2. As a result, to sustain continuous charging, the storage battery starts to deplete and the PV array's output decreases. When the power of the PV array is cut to zero, the storage battery runs out in 0.48 seconds. The storage battery then fully enables charging if SOC > SOC min. When the battery is fully depleted, the controller synchronises the CS with the grid.



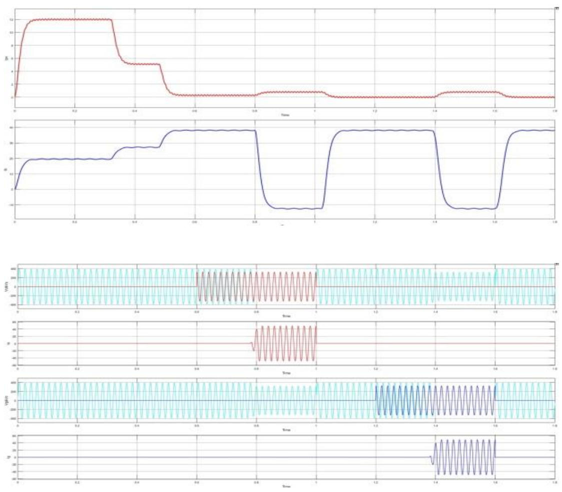


Fig. 4 Simulation results showing the different modes of operation

At 0.79 seconds, the CS started using grid electricity. After that, there is no longer any grid or storage battery power available, hence the DG set as shown in Fig. 4 supports CS. Based on generation and demand, the charging station automatically switches modes, as shown in Fig. 4.

V. CONCLUSION

A grid-connected DG set, storage battery, PV array, and charging station for electric vehicles have all been realised. It has been demonstrated that the CS can function in island operation, grid connectivity, and DG set connectivity modes all with a single VSC. The charging station has proven to function successfully in a range of steady-state conditions and dynamic scenarios caused by changes in solar irradiation level, EV charging current, and loading, according to test results. The charging station functions as a standalone generator with good voltage quality, as confirmed by the statistics displayed below. Test findings in DG set or grid linked mode have shown that the ANC-based control algorithm can maintain the power exchange with the grid at UPF or the optimal loading of the DG set. Additionally, islanded operation, grid linked, and DG set connected operations, along with automatic mode switching, have made it feasible for the PV array's MPP to work and for the DG set to be loaded optimally, increasing the charging reliability. The efficiency of the control is attested to by the charging station's IEEE-compliant performance, with voltage and current THD consistently less than 5%. Based on the assertion. With the control now in use, it can be deduced that this charging station can efficiently employ a variety of energy sources while giving EVs a consistent and reasonably priced charge.

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