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Original Article

A Multi-mode Operating Tri Port Based Electric Vehicle Charging Station

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Abstract - *This study aims at improving the continuity of power supply for electric vehicle charging service by operating the Charging Station (CS) in either grid connected mode, islanded mode or diesel generator (DG) set connected mode. This is achieved by the connection of power grid, Solar Photovoltaic (SPV) array, DG set and battery energy storage (BES) to an EV charging station. Primarily the charging station is designed to utilize the solar photovoltaic PV array and to make use of BES for charging the electric vehicle (EV) battery. The second priority is to charge the EV battery by the power from grid and the last option is the use of DG for the same purpose. The DG or charging from grid option is opted under the case that there is no power extracted by SPV and the BES is depleted. However, the load is maintained at 80-85% in order attain the peak fuel efficiency under all the load conditions, when the power is extracted from the DG set. In combination of battery storage, the control of voltage and frequency is achieved by the charging station. This coordination certifies that the power that is drawn from the grid or DG set is at unity power factor even when the loads are non-linear. The synchronization is done at the point of common coupling voltage to the generator/ grid voltage to obtain interruption less charging. The active/ reactive power transfer of vehicle to grid, vehicle to home and then vehicle to vehicle is done by the charging station for the reason to increase operational efficiency. This paper uses the fuzzy control technique to enhance smooth operation of the charging station, the results ae obtained through the use of MATLAB/Simulink software.*

Keywords - *Solar PV generation, EV charging station, Battery energy storage, DG set and power quality.*

I. INTRODUCTION

The electric vehicles now a days are termed as the most powerful type of road transportation with zero emission. In view of EVs with their merits, few millions of vehicles have already come into play. Anyways the implementation of proposed method challenges for large charging equipment and of huge electric power. Nevertheless, practicality of EVs is possible when the charging power is from green energy resources which do not produce greenhouse gases. Anyhow, the utilization of conventional energy resources to generate electrical power, does not decrease green-house gasses emission. Thus, there is a need of utilizing the unextracted renewable resources of energy for generation of electricity which can greatly reduce the emission and gives survival benefit. Today there are many numbers of renewable sources of energy like geo thermal energy, wind energy, tidal energy, biogas plant, solar power, and many more, in list of all these generation based on solar is highly suitable to meet the purpose as it is abundant in nature [2]. In the place of India, its availability is almost throughout the year. When the wind and hydro energy are considered these could be only in selected regions.

Although charging the EV with the renewable source of energy is the best option, their incorporation with the present-day existing charging system raise the problem of extra power conversion system, which will in turn enlarges the difficulty and also there would be loss of power in the process. Furthermore, every conversion section requires separate control mechanism, that demands being consolidated together with ongoing controllers. Hence, there is a need to design the combined control having various functional and multiple modes of operation to serve the purpose of the combined mode of control and also there must be collaboration among various sources of energy.

Enormous studies are being conducted to make sure that electric charging stations are depending on pure green energy technology. Ref [1] discusses the significance of green energy resources as alternative energy source for the charging station. Ref [2] studies the solar power for the charging purpose of EV's which is making use of high power two directional EV charger, but devised charger would not be used for the AC charging. In the paper [3] had proposed a system which combines the of solar photovoltaic and the EV charging station. But the manufactured charging station did not take into consideration power quality issues those were present to grid system. When considered [4] have come up with novel Z-source converter to meet the purpose. But formulated charging station wasn't able to operate in islanded mode. Hence this, the charger couldn't provide charging in the off-grid condition. The ref [5] discussed the optimal organizing of the charging of EV station in the place of work in the two modes of charging. Ref [6] implemented the application of solar PV in designing the charging station. The paper [7] had examined loss of life of the battery storage when it is operated under the solar energy efficient based residential supported by solar system. Charging station based on wind energy system is also discussed in reference [8].

In present days EVs are operated as the distributed energy source for giving different extra services, in view of large amount of energy is available in the batteries of EV. Ref [9] had proposed solar powered charging station which is capable to perform vehicle to grid power interchange. Ref [10] discusses the solar powered residential electric vehicle charging station. The power handling strategy along with the multiple operation model regulation for combined household level solar PV and BESS for the two cases off grid mode and grid connected mode [11]. In the proposed paper [12], [13], [14] the residential functioning in a way which charging station is implemented for supplying power from EV to residence.

Likewise, in many of the papers, performance of charging station is explained in any one of the modes that is either grid connected mode or the islanded mode. But also, because of particular one mode of operation in the on grid solar system, in that situation the solar PV panel array becomes non-functional in the case if the grid is not accessible though the sun. In the same way, in the off-grid mode, solar power is disordered because of its intermittent nature is unpredictable. For this purpose, BESS is essential to increase reliability of the system. In the papers [15], [16] grid connected and off grid connected modes are mentioned. Although these two modes are controlled individually, but automatically switching between two modes is not presented. In the absence of automatic switching, the power from the PV is disturbed and there would not be incessant charging. In order to overcome this, an automatic switching logic is demonstrated, as an outcome controller inevitably switches among the various functioning modes simultaneously.

Considering the fact that, solar PV can't generate power at night also the intermittency nature of it, this necessitates to include battery energy storage in order to continuously supply the charging station. The use of solar PV and BESS alone demands high storage capacity, to solve this challenge it is required to mix with other energy resources like integration with grid and use of DG set for the case of emergency. The DG set is only used in the case when solar and grid are not available and the BESS is depleted. This method faces a challenge with current harmonic distortions [17].

Non-linearity of charging station caused by involvement of rectifier, filters buck converter highly affects the working of the DG set. This is because the rectifier, filters and buck converter act as non-linear load and cause current harmonics. On the other hand, because of harmonics current requirements, in this paper operation of DG set is always not less than 80% loaded.

In this paper, a charging station is designed to be operated without interruption by being supplied from solar PV, battery energy storage system, DG set and power from grid. This supports both DC and AC EV charging. The integrated control ensures smooth operation in both islanded and grid connected modes of operation. The control also enhance power to be transferred among vehicles and between vehicle and grid. In the voltage source converter, the fuzzy controller has been replaced, this gives the faster response.

The designed charging station layout is presented in the Fig. 1, made of three energy resources (Solar PV, DG set and grid power) and battery energy storage system. The

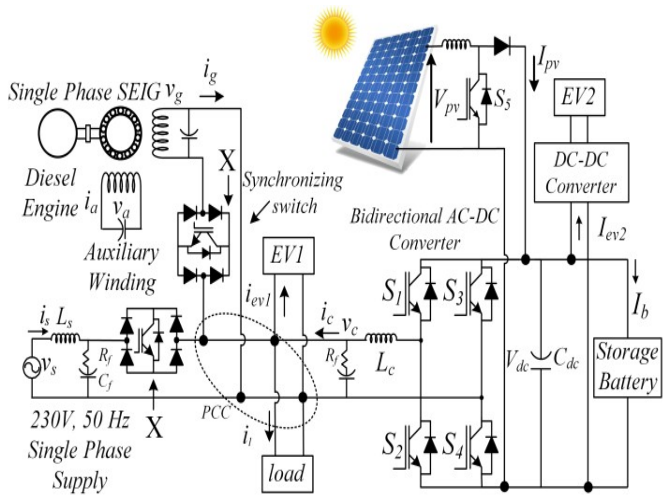


Fig. 1 Layout of Charging Station

system not only charges the electric vehicles but also intended to supply local connected load. The power from solar PV, BESS are in DC form, while that of DG set and power grid are AC. Thus, the AC power from grid and DG set are synchronized at point of common coupling and converted to DC power by means of bidirectional AC-DC converter. The AC loads are directly fed by the AC source or the power from DC sources converted from DC to AC by the help of bidirectional power converter. The common power DC is then supplied as input to the DC-DC converter which is a charger of the EV2.

II. CONTROLLING PROCEDURES

The different types of control strategies are explained below

A. VSC control in the islanded mode (without grid and DG set)

VSC control in the islanded mode, provides continuous supply of the energy to the EVs without the presence of grid power. That means both AC and DC power are being supplied by the solar PV and/or the battery energy storage system through power converters. The challenge with this mode is the lack of proper reference voltage signal in the absence of grid. Thus, a local reference is generated to make sure the voltage source converter follows that in order to safeguard the operation. A reference signal is compared with the generated feedback and an error signal is passed through PI controller so as to be minimized this is formulated as indicated in Fig. 2. Equation (1) below, is intended to express the reference signal and error signal to be minimized

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

The gate signals of the converter are produced after the reference current matched with the detected or sensed converter current only it is passed through the hysteresis controller.

B. VSC control in the grid connected mode or DG set mode

In this mode, the work of the controller is to estimate the power flow between the grid and the EVs. That means, power may flow from grid to vehicle or vehicle to grid, the controller will also decide the proper amount to be transferred. In order to maintain fuel efficiency, the DG set is operated in constant power mode. Nonetheless, both scenarios demand the controller to balance the harmonic and reactive current need of the EVs, obtained by which is obtained through calculating the grid or DG reference current with respect to Electric Vehicle current. This is as per equation (2)

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

For the case of grid tied mode, from the above mathematical equation (2) ensures operation at unity power factor. In the case of DG set connected mode equation (3), illustrates expression of active and reactive currents respectively.

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

where	I_p	= EV active current component
	I_q	= EV reactive current component
	I_{pf}	= feed forward signal for solar PV
	I_{ef2}	= feed forward signal for EV2
	I_{vq} and I_{fp}	= voltage and frequency feedback signals

Hence, grid or DG set reference current is computes as per equation (4)

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

Corresponding to above equation, the synchronizing signals of the DG set are expressed as u_p and u_q and the grid voltage by (v_g or v_s). By taking the reference current and the sensed current of the grid/DG set, the switching signals are produced by the hysteresis controller as shown in the previous figure.

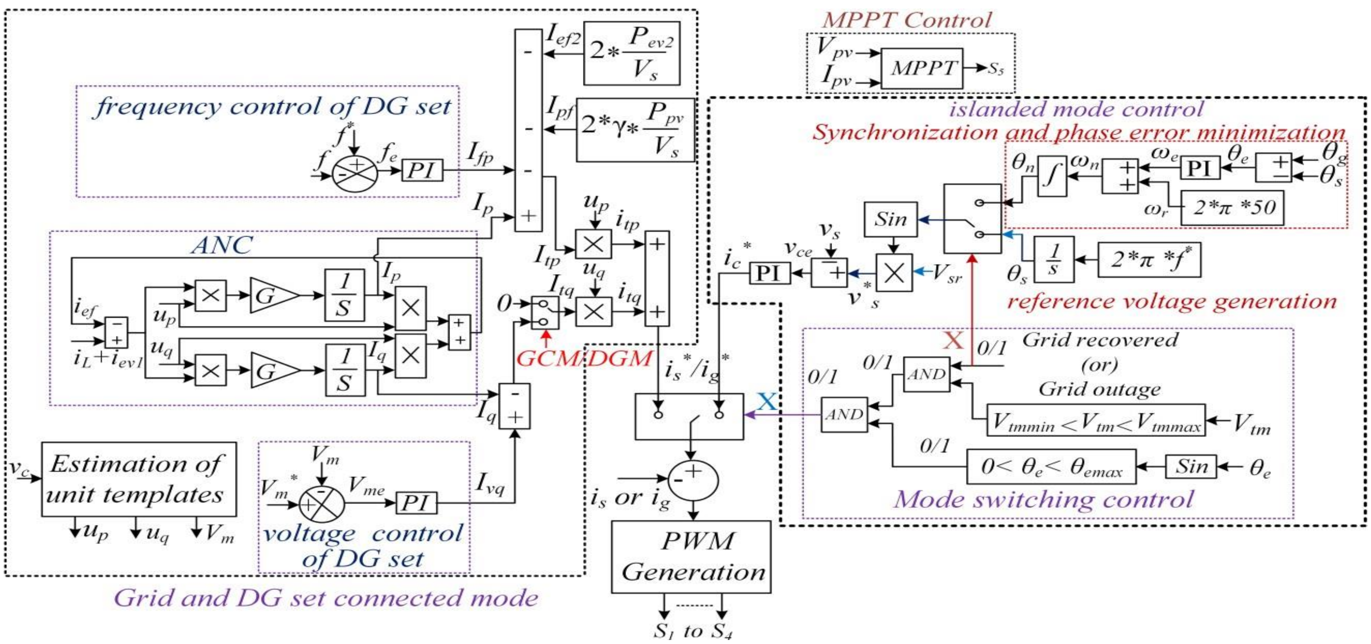


Fig. 2 Standalone, grid and DG set connected modes for the integrated control of VSC

C. Voltage and frequency control of the DG set

In order to operate the DG set, there is a need for decoupling the voltage and frequency control signals. By this approach the active power is used to dictate the frequency and the reactive power regulates the voltage. Mathematical expression for voltage control is formulated by equation (5)

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

in which, $V_{me} = V_m^* - V_m$ voltage error, z_{vi} and

z_{vp} gains of the proportional integral controller.

In the same way, the discrete expression of the frequency PI controller is given as,

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

Where f_e the error in the frequency, z_{fp} and z_{fi} are gains of PI. The final product of the voltage and frequency controllers are attached in the grid tied control put forward in fig 2. Moreover, these outcomes become null in the grid connected mode as the frequency and voltage remain regulated.

D. EV2 control

Battery charging mode is operated through two steps, the constant current (CC) followed by constant voltage (CV). For this purpose, A DC-DC converter is utilized for the connection of EV to the DC link in either mode till the battery is fully charged. Fig. 3 represents the CV/CC type of charging is regulated by the two PI controllers.

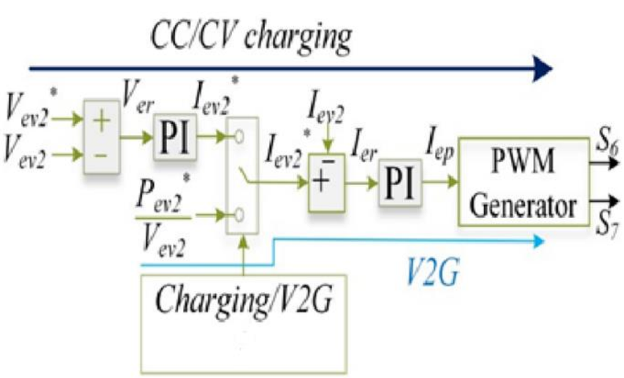


Fig. 3 Power transfer from vehicle to grid and the electric vehicle 2 control for CC/CV charging

The reference charging current is evaluated as,

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

In the above equation the vehicle's battery voltage error is given by V_{er} and the controller gains by z_{evp} and z_{evi} In the same manner, the sensed battery currents and the reference currents, by using the PWM generator and PI controller the signals of the converter are derived. The duty cycle of the PI controller computation is done by

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

Where the battery current error is represented by I_{er} and the controller gains by the z_{ep} and z_{ei}.

The power transfer V2G, on the support of the reference power and controller the electric vehicle 2 battery is discharged follows the alternate path as shown in above figure. In the EV2 the reference power controls feed forward term.

E. Switching Control and Synchronization

Based upon the charging demand and generation, the layout of charging mode strategy is necessary, because the charging mode operates in various modes, as the shifting from one mode to other one results in equal level and the charging remains level manner. The off grid to DG sets connected modes, islanded to grid connected mode are those such constraints where the switching logic is created. In this phenomenon, primarily the voltages phase difference is derived, the two voltages are brought up by the controller for the need of synchronization. The frequency of the voltage source converter evolved voltage manipulated by the PI controller in the islanded situation is displayed in the figure 2

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

In the above equation phase difference is given by $\Delta\theta$, the tuning parameters of the controller by the terms z_{pa} and z_{ia}. From the Fig. 2 it is much clear that under which conditions the charging station functions in the islanded mode and also depending upon which the transition of the mode is implemented. Upon approving, each demand required to synchronize the sources, the control logic produces an activating signal $X = 1$ to synchronization switch.

III. FUZZY CONTROLLER

This study, eproporses Fuzzy based controller in order to accomplish the multi mode operation tri-port charging station. This is having an advantage of low harmonic distortion as compared to conventional PI controller, also the control is robust and high system reliability.

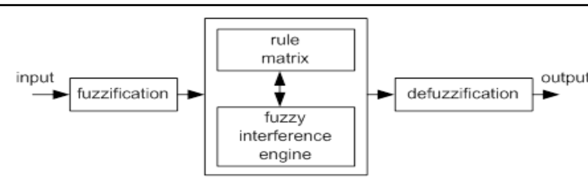


Fig. 4 Fuzzy logic controller structure

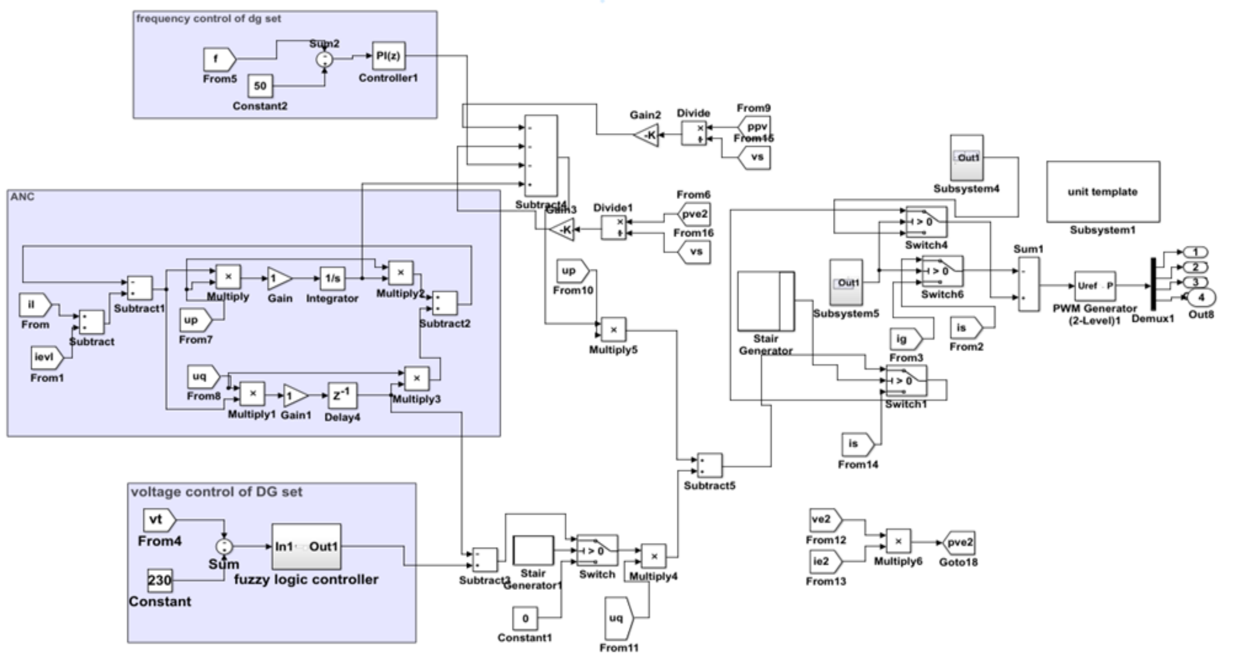
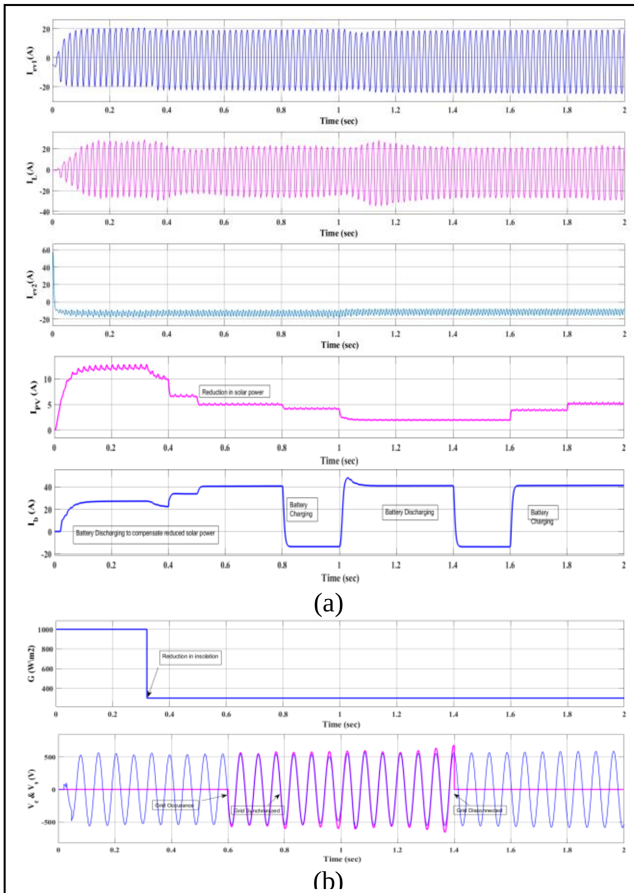


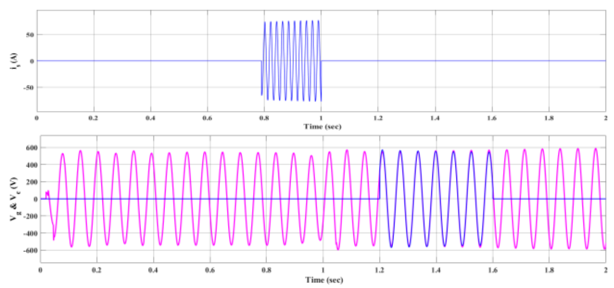
Fig. 5 PWM generation using Fuzzy logic controller

Usually fuzzy logic control system is created from four major elements presented on Fig. 4: fuzzification interface, fuzzy inference engine, fuzzy rule matrix and defuzzification interface. The overall operation structure based on fuzzy controller is shown in Fig. 5. The fuzzy logic controller is used to generate proper PWM signals which inturn dictates the switching pattern according to the fuzzy rules.

IV. RESULTS

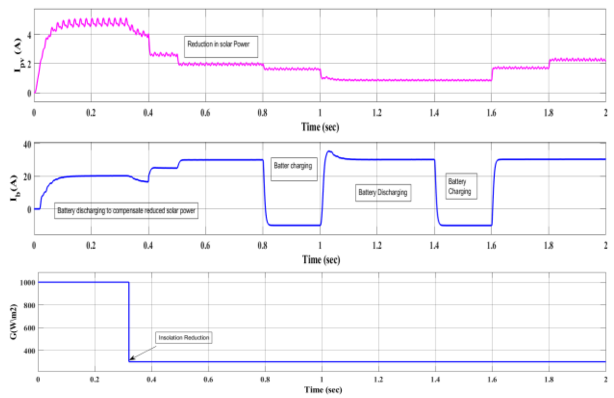
The simulation results are shown in the Fig. 6 and 7, the first with PI controller set up of the charging station and the second one with the fuzzy controller. A continuous supply of energy for charging station operation is achieved in both islanded and grid connected modes of operation. In the presence of enough solar PV power, the charging station operates with full of its power from solar PV. Whenever the solar power is in excess, then it is used to recharge the solar compensate the deviation. If the battery storage is depleted and the solar power is not enough then grid is used to compensate the loss and recharge the batteries. The worst scenario is when the solar power is not generated, the BESS is depleted and the grid power is faulted, then the DG set is used to supply power. All the time DG set is operated at its optimal load so that to maintain fuel efficiency, this is achieved by adjusting the charging of BESS and supplying to the charging station.



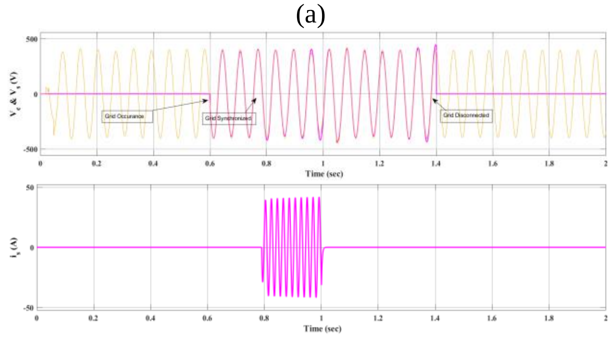


(c)

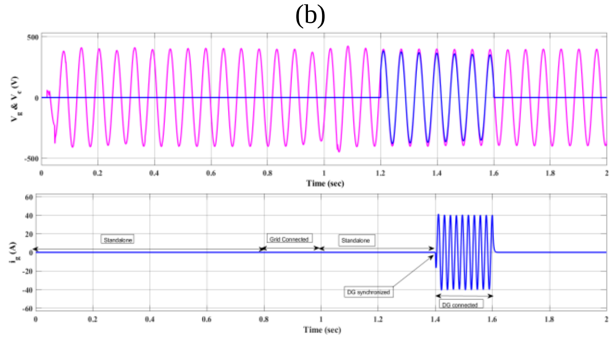
Fig. 6 Simulation results of PI Controller with (a) islanded mode (b) grid connected mode (c) DG set connected mode



(a)



(b)



(c)

Fig. 7 Simulation results of Fuzzy logic controller with (a) islanded mode (b) grid connected mode (c) DG set connected mode

Fig. 8 and 9 below shows the respective, THD for PI and Fuzzy logic controller based operation. It is vivid that, fuzzy has better performance than PI controller.

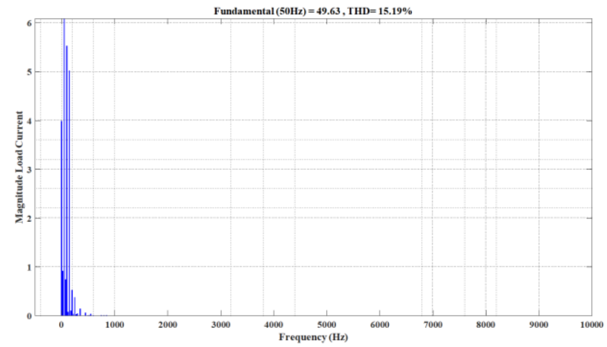


Fig. 8 THD for PI contrlloer

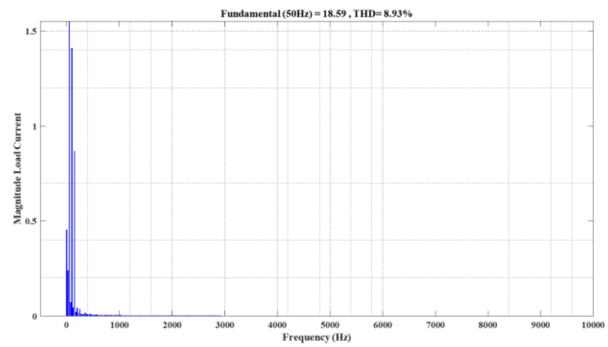


Fig. 9 THD for Fuzzy controller

V. CONCLUSION

The charging station which is connected to the PV solar array, grid, storage battery and the DG set has been accomplished for the vehicle charging purpose. The proposed results are been tested in the three modes of operation which are grid connected, DG set mode and off grid mode of the CS which is taking use of the voltage source converter. The results were verified by considering several working conditions, for example variation of load demand, variation of solar generated power over and below the demand and presence and absence of grid power. The control technique was able to adjust its control mechanism to balance between the load and demand.

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