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Design, Analysis and Implementation of Fuzzy Logic Controller based Grid/PV-BESS/Diesel Generator-integrated EV Charging Station

Y. Lavanya[1], Giribabu Katta[2]
[1]M.Tech student, EPS, J.B Institute of Engineering and Technology, Hyderabad, India
[2]Assistant Professor, EEE Department, J.B Institute of Engineering and Technology, Hyderabad, India

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ABSTRACT

This research works mainly aims to provide the continuous power supply in the Electric Vehicle (EV) CS (charging station). For this a solar PV-Battery and Diesel Generator set is employed. Whenever the power supply is unavailable from solar and battery the DG set or 3-phase grid will provides the continuous power supply in the charging station to charge an Electric Vehicle. Mainly 3-modes are considered over here namely grid connected mode, islanded mode or DG set mode. To achieve the maximum fuel efficiency from the DG set and its operation capacity is equal to 85% app. The voltage and frequency will be regulated by the CS (Charging Station) in coordination with the storage system. A voltage source converter is used to renovate the DC power to AC power. In this PI controller is employed to control the reference current by giving voltage and reference voltage as inputs. But by implementing the PI Controller will have less speed response of the system and less power quality also. In order to overcome these issues in this work PI controller is replaced with Fuzzy Logic Controller (FLC) to regulate the current in grid and DG set connected mode. MATLAB/SIMULINK 2018a Software is used to validate the performance of the flc based system.

Keywords: Battery, Solar PV array, Diesel Generator set, Voltage Source converter, FLC, Step up Converter, Electric Vehicle Charging Station.

I. INTRODUCTION

A global challenge is lowering CO_2 emissions to stop global warming. By 2040, electricity will make up almost a quarter of global energy consumption [1], therefore the power industry must lead the way in developing a decarbonized energy system. Electric versatility makes a huge commitment to expanding the manageability and effectiveness of the transportation business, including the utilization of electric vehicles (EVs), hybrid EVs, power device vehicles, and electric bikes [2]. To eliminate power quality issues, optimize EV interaction with other electrical appliances, and benefit from their use in the innovative approaches of microgrids, smart grids, and smart homes, the massive introduction of EVs into the electrical grid should be

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monitored [3]-[4]. Electric vehicles (EVs) are evolving as an ecofriendly solution to the issue of rising carbon emissions in terms of load. While using EVs to address environmental issues has advantages, they also have a number of disadvantages for electrical power systems. EVs are regarded as a load on the distribution grid. Nonetheless, the simultaneous charging and discharging of a large number of EVs may endanger the grid's overall stability and power quality. Due to the increment in the power losses the behaviour of the EVs will also changes their behaviour in the DS (Distribution System), which cause prices to rise and reserve margins to decline. As proposed in [5]-[6], without considering any preventive measures, the increase in the harmonic content, no balance between demand and supply, and occurring the disorders in controlling the voltage are happened due to the disorganized behaviour of the EVs. The article's authors proposed using an aggregator-run EV charging system. Aggregators should manage EV charging to increase revenue while decreasing grid impact. In these cases, renewable energy sources (RESs) such as solar and wind energy production are effectively used for EV charging, lowering costs while reducing the grid's negative effects. However, in the case of a V2H system, discharge management has also been considered in terms of managing the energy at home, as per human activity and electricity costs [7]-[8]. [9] Outlines a grid-associated SPV structure with two power-handling stages that boost power from the SPV exhibit while supplying steady power to the network. The framework that balances power with meticulously planned control has the advantage over the two-stage geographies currently in use. As a result, the PV inverter has the ability to act as a VSC and delivers steady power to the lattice. This has an impact by reducing the PV vacillations that affect matrix power and increase effectiveness. New net metering features shorten the amount of time required for restitution, elevating this location above others. Aside from that, the system's reliability is enhanced, particularly for critical loads, by the accessibility of power during peak load demand periods and the lack of solar energy [10]. For the advancement of EVs, CS are a fundamental auxiliary organization. The charging load is an illustration of an indirect liability. The continued construction of the charging station will introduce significant consonant contamination, which will alter the nature of the force and the ability of the power system to function consistently [11]. While the number of charging stations is currently on the rise, there aren't many centers that focus on the analysis and management of sounds [12] MG is defined as a collection of stresses and dispersed ages to meet a substantial burden inclusion at the lowest conceivable activity cost in both structure associated and independent modes (DGs). A type of force circulation system known as an independent MG can make use of a variety of DG, particularly renewable energy sources (RESs), and is inaccessible to the utility network [13]. When the power supply from the grid is absent the DG cannot supply the required amount of power to the loads. So, in order to overcome this issues the microgrids [14] are employed which consists of the energy storage systems. This will acts according to the demand for power supply and generated power. For improving the power quality in the system many controllers like PI, SMC and FLC based topologies are employed in the VSCs. But as proposed in [15], the FLC has evaluated the best results than the other controllers. The THDs are in reduced count. The design and implementation is shown in this paper. This paper is formulated as follows: Introduction and Literature review is explained in the section-I, description of the system is depicted in section-II, strategies involved in the controlling topology is explicated in Section-III, the implementation of proposed FLC topology is described in section-IV, the description of simulation based results obtained is depicted in section-V. The conclusion of this work is explained in section-VI.

II. DESCRIPTION OF THE SYSTEM

In order to provide power supply to the Electric Vehicle Charging Station a solar PV, DG Set and a 3-phase grid, battery is employed in the system as shown in the below figure-1. The step up is connected to the solar PV to increase the magnitudes of PV Voltage. A battery is integrated across the solar PV. The obtained DC power from Dc sources is given to the DC-AC converter through a DC link. The VSC is fed to the grid and SEIG, an Electric Vehicle unit and a load that is non-linear through a coupling inductor. For reducing the harmonic contents that are obtained in the grid currents and generator a ripple filter is implemented at the PCC. The excited capacitor will consists of coupling of SEIG with the auxiliary winding.

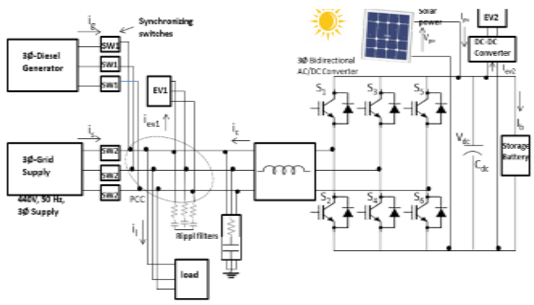

Figure 1: Proposed System

For disconnecting or connecting the charging station a switch (synchronizing switch) is employed. The SEIG primary winding can be crossed by a tiny capacitor.

III. STRATEGIES OF THE CONTROLLING TOPOLOGY

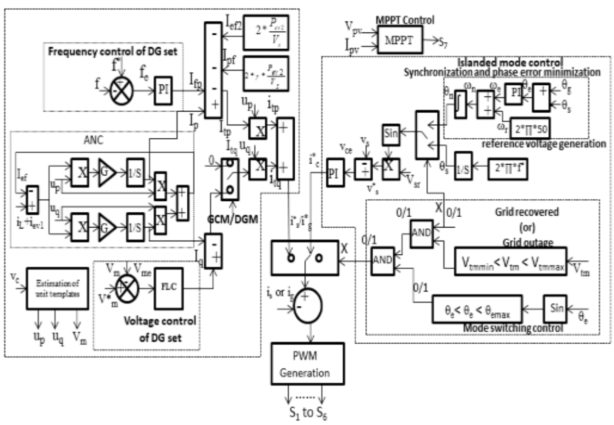

Figure 2: Proposed controlling topology for VSC (Grid connected and standalone mode)

A. VSC Controlling topology in Islanded mode:

In this controlling topology the power supply from grid is absent but the charging station need the continuous power supply at the same time the solar and EV should not affected. So, by this time the power supply can be considered from the solar, as well as battery will gets charged. In the voltage mechanism of DG set the voltage and reference voltage is given as input to the FLC to generate the reference currents. The equation for minimization of error and reference currents production is given as follows:

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

The comparison of reference currents and measured currents and passing them through the controller known as hysteresis controller will generate the required pulses to the VSC.

B. Controlling topology of VSC in Grid Connected mode or DG Set:

The determination of finding how much of electricity is transferring to the grid is the main aim of implementing this controller. For achieving the maximum fuel efficiency the DG will be operated in constant power mode. The active current of EV will leads to finding of the reference current in the grid connected mode. An ANC (adaptive notch filter) is used for extracting the fundamental frequency of the electric vehicle. In grid connected mode the calculation of reactive and active currents can be depicted as follows.

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

$$I_{sq} = 0$$

In the mode of grid connection the unity power factor should be equal to one. In this case the active power should need to consider whereas the reactive power should be kept to zero. This related equations are depicted below:

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

$$I_{sq} = I_{vq} - I_q$$

From the above equation the EV's active and reactive currents are denoted by Ip and Iq, the pv array and ev feedforward terms can be denoted by Ipf and Ief2. In DG set connected mode the voltage and frequency terms can be denoted by Ivq and Ifq. The excess charging of the battery can be controlled by the PVs feed forward term in the grid connected mode is denoted by Ipf. In CC/CV mode the storage battery cannot be charged due to energy storage is coupling to dc link. The power from solar is fed into the grid for not exceeding the charging of battery. Figure-2 depicts about the feedforward term of solar pv in the mode of grid connected. γ which is known to be variable gain is multiplied to the feedforward term of PV array. If the battery is get drained or become empty the value of γ will becomes zero and if the charging of the battery is happened then the value will be equals to 1. The equation of the current will be as follows:

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

The grid voltage's synchronizing signals can be denoted by using q_p and u_p. As shown in figure-2, by using the hysteresis controller the creation of switching signal is happened.

C. Frequency and Voltage Control of DG set:

The frequency and voltage should be monitored/regulated for operating the DG set by using the vsc's decoupling capability at a single point. In this coupling method the control of voltage will be done by the reactive power and the controlling of frequency can be done by using the active power. For controlling the frequency and voltage the PI and FLC controllers are employed. The regulation of voltage can be done by the FLC.

Where $V_{me}= V_m{}^*-V_m$ and the FLC is used. In the similar manner the frequency can be controlled by using PI. The equation can be depicted as follows.

$$I_{fp}(s) = I_{fp}(s-1) + z_{fp}\{f_e(s) - f_e(s-1)\} + z_{fi}\, f_e(s) \qquad (5)$$

In connected mode which is depicted in figure-2, the outputs of voltage and frequency can be combined.

D. Topology of Switching control and Synchronization*:*

On the demand basis of charging and generating the charging station will be operated in many modes. So, there will be necessity of mode changing capability. By consuming this capability power the charging will be remained unchanged. The regulation of voltage in the islanded mode can be done by the FLC. This related equation can be depicted below for minimizing the phase synchronization.

$$\Delta\omega(s) = \Delta\omega(s-1) + Z_{pa}\{\Delta\theta(s) - \Delta\theta(s-1)\} + Z_{ia}\Delta\theta(s) \qquad (6)$$

For the settings of the controller are denoted by Z_{pa} and Z_{ia}. Where phase difference is denoted by Δθ.

- **EV2 Controlling topology:**

The controlling of EV can be possible in CV/CC (constant voltage/constant current) which is at the DC-Link through the boost converter. The charging of EV will be in charging upto the terminal voltage is reached to the condition of full charging position of the battery. Once after completion of this reaching terminal voltage the charging of EV will change to mode of CV. This operation can be seen clearly in the figure-3.

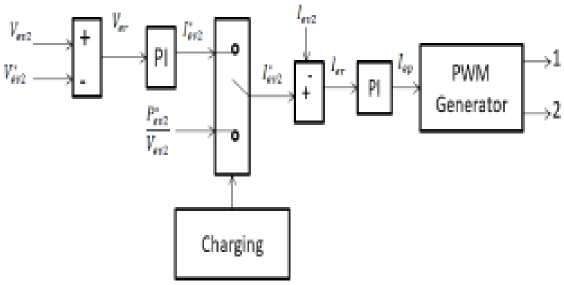

Figure 3: Proposed Controlling topology for EV2 (CV and CC Modes

The below equation depicts the charging's reference current:

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

From the above equation-7, the PI controller's gains are denoted by Zevi and Zevp and the error in voltage of EV battery can be denoted by Ver. By using the PWM technique and PI controllers the signals to the switches can be generated. The calculation of duty cycle can be formulated as below.

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

From the above equation the error in the current of EV battery can be denoted by Ier and gains of PI controller can be denoted by using Zep and Zei.

IV. Proposed Fuzzy Logic Controller (FLC) SYSTEM:

FLC, which operates based on logical rules formed by input and output arguments. And also it converts crisp values to fuzzy values (analog to logical). It is implemented by using the membership functions. The FLC system mainly compresses of 4 major parts known as fuzzification (converts fuzzy sets to crisp sets), rules base, inference engine and defuzzification (crisp sets to fuzzy sets) which can be depicted in below figure-6. This work related flowchart by using FLC is depicted below.

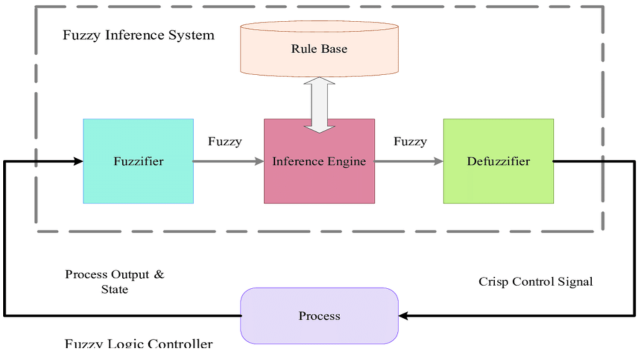

Figure 4: Schematic Representation of FLC

TABLE 1. Rules of FLC

$e\backslash\Delta e$	NB	N	Z	P	PB
NB	PB	PB	P	Z	Z
N	P	P	Z	Z	Z
Z	Z	Z	Z	Z	Z
P	Z	Z	N	N	N
PB	N	N	N	NB	NB

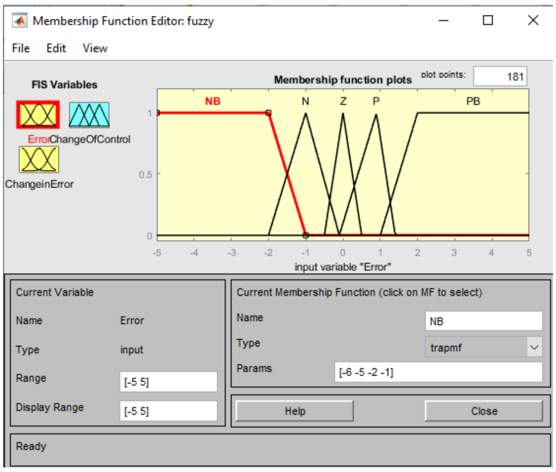

Fig 5: Input 1 MF (Error)

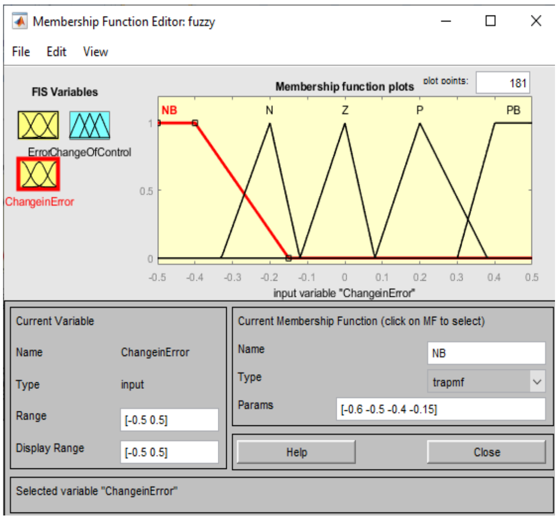

Fig 6: Input 2 MF (Change in Error)

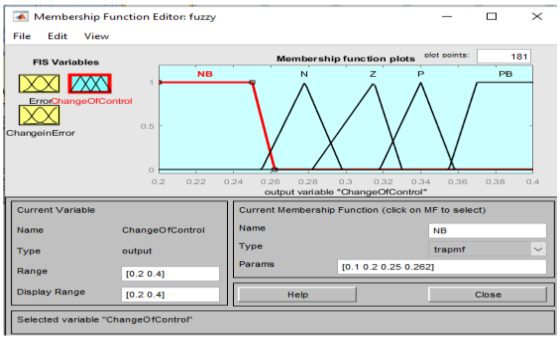

Fig 7: Output MF (regulated voltage)

The given inputs are error e(k) and change in error Δe(k) and then output is regulated voltage. Where the error (e) = Vmtref – Vmt. From the table-1, As 5 Voltage error variables and 5 change in Voltage error variables are taken as inputs, so that there will be a total of 25 rules, which will governing the decision making mechanism.

V. SIMULATION BASED RESULTS:

In this section, the simulation based results obtained by using both PI and FLC controllers in the controlling topology of VSC is evaluated. In this the controllers are used to regulate the voltage. The simulation based can be evaluated by using Matlab/Simulink 2018a Software.

1. Results with PI Controller:

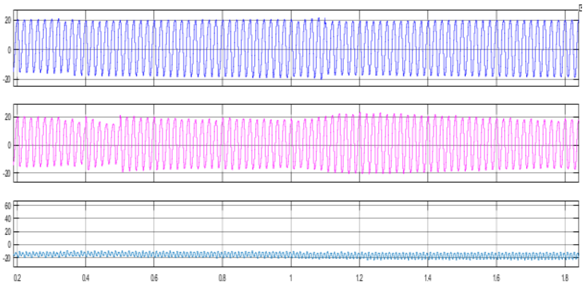

Figure 8: Ev1 current, load current, Ev2current

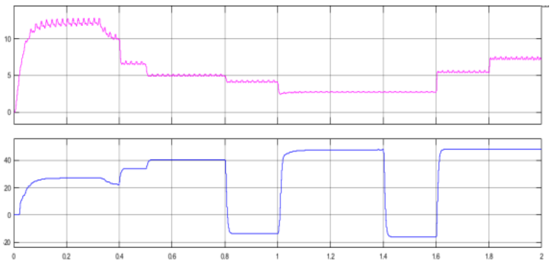

Figure 9: PV panel current (Ipv), battery current (Ib)

The above figure-8 and figure-9 depicts about the results obtained after system is affected due to synchronization and variation obtained in the irradiance. The currents obtained at ev1, ev2 and load is depicted in figure-8 whereas figure-9 describes the currents obtained at battery and PV panel.

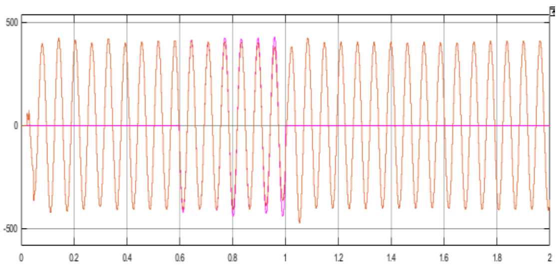

Figure 10: Grid (Vs) and AC link terminal Voltage (Vc)

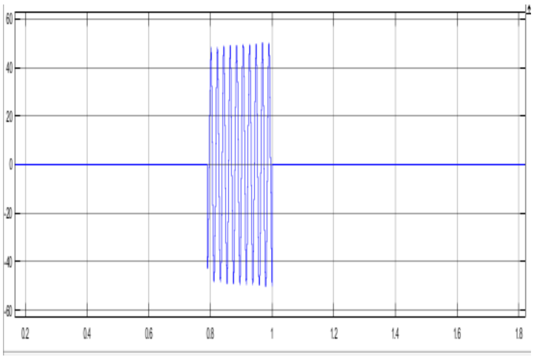

Figure 11: Grid current (Is)

Figure-10 and Figure-11 depicts the simulation results obtained in the absence of power supply to EV from solar. In this case the grid and battery will comes into act and provides the power supply. The grid will be in connected mode from 0.8 to 1s, whereas the battery will be in charging mode.

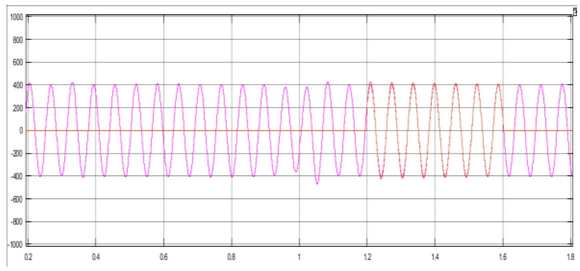

Figure 12: Converter (Vc) and dg set voltage(Vg)

As depicted in above figure-12, the DG set is in connected mode from 1s to 1.4s. At the same time the battery will be in the mode of charging and the rest of time will be in the mode of discharging. So, the DG current wave form is depicted in the above figure.

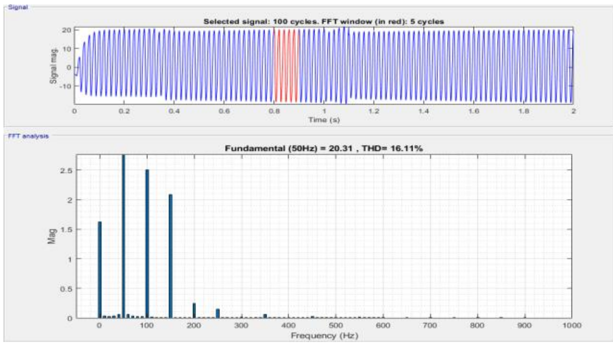

Figure 13: PI based Simulation result of THD

The above figure-13 will depicts about the THD obtained in the load current by employing PI controller for regulating the voltage. Therefore the value of THD obtained is 14.76%.

2. Results with FLC Controller:

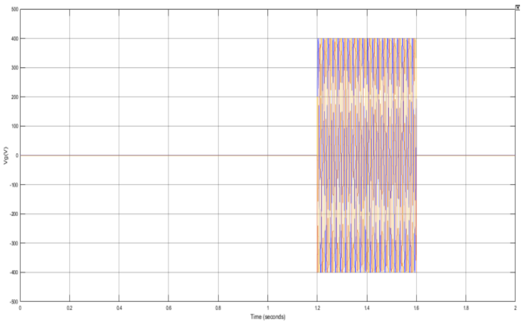

Figure 14: Output voltage (Vg) obtained at DG-set

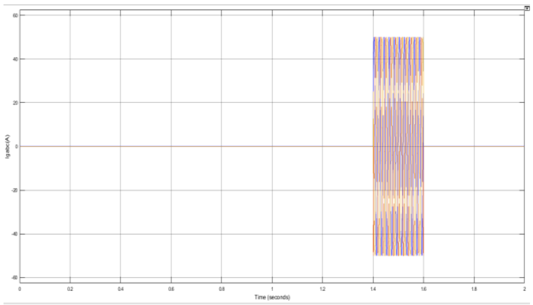

Figure 15:Current (Ig) obtained at DG set

In this the VSC is employed by using FLC to regulate the voltage. Due to the issues obtained by using PI controller, the PI controller is replaced with FLC. The above fig-14 and fig-15 depicts about the current and voltage obtained in DG set. The grid will be in the mode of islanded at initial state. The irradiance obtained will be varied from 1000-300 W/m2 at 0.32sec. As depicted in above figure-12, the DG set is in connected mode from 1s to 1.4s. At the same time the battery will be in the mode of charging and the rest of time will be in the mode of discharging. So, the DG current wave form is depicted in the above figure.

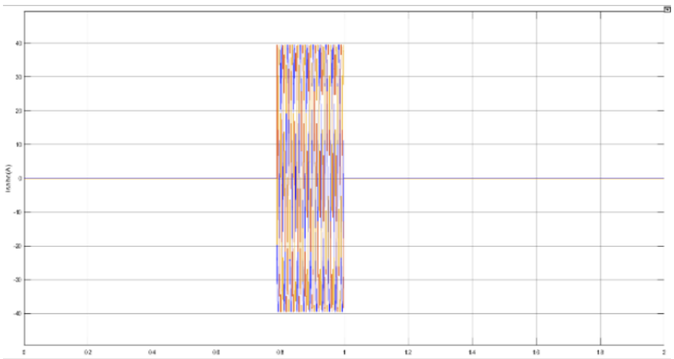

Figure 16: Source Current output (Is)

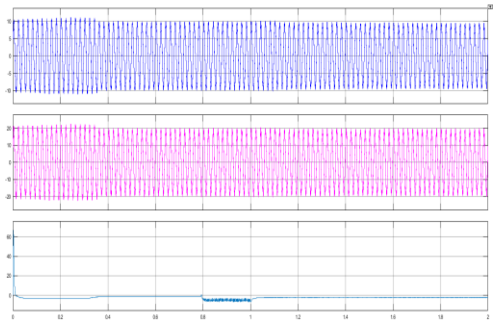

Figure 17: Current of electric vehicle 1(Iev1), load current (iL) and current of Electric Vehicle 2 (Iev2)

Figure-16 and Figure-17 depicts the simulation results obtained in the absence of power supply to EV from solar. In this case the grid and battery will comes into act and provides the power supply. The grid will be in connected mode from 0.8 to 1s, whereas the battery will be in charging mode. Hence this related results are shown below.

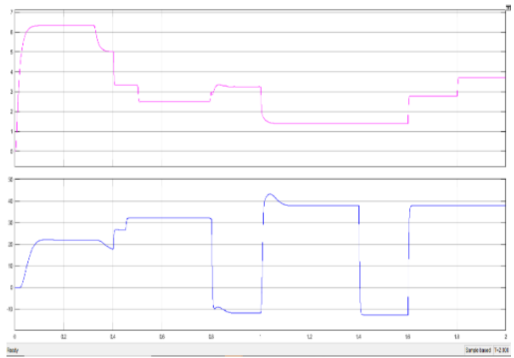

Figure 18: Ipv and Ib simulation results

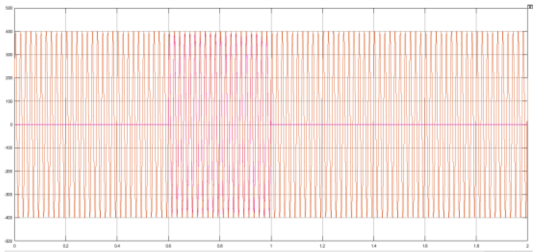

Figure 19: Vs and Vc related simulation results

The absence of power supply from the solar PV then discharging condition of battery will takes place. This related results are shown in the above figures 18 and 19.

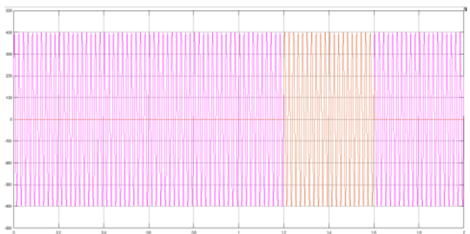

Figure 20: Simulation result of Vc & Vg

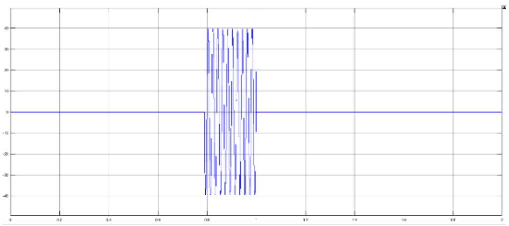

Figure 21: Simulation results of Is

The above figure-20 & 21 will depicts about the current and voltage obtained at the time of grid is in connected mode. In this scenario the DG set and grid will comes into act and supplies the required power in the CS due to absence of power supply from the Solar PV. It is happened from the time duration of 0.s to 1s. At this time the battery will gets charged.

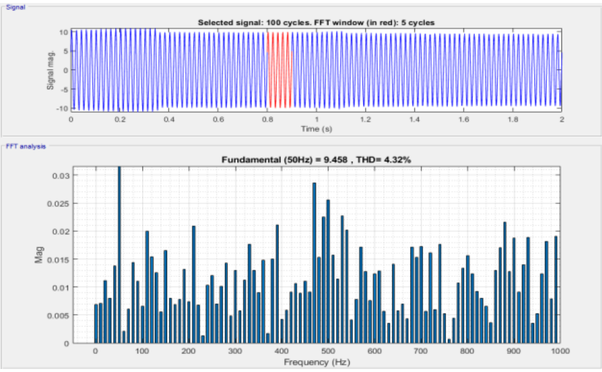

Figure 22: FLC based Simulation result of THD

The above figure-22 will depicts about the simulation result of THD obtained by using Fuzzy controller. The conventional PI controller will have disadvantages like less speed response of the system and high harmonic distortions. These issues can be overcomed by replacing PI with FLC. So, the THD is decreased from 16.11% to 4.32%. This evaluation can be seen in below table.

TABLE 2. THD Comparison

	PI controller	Fuzzy logic controller
THD (%) for load current	16.11%	4.32%

VI. CONCLUSION:

In this work, the performance analysis of 3-Phase Grid connected Solar PV-Battery and Diesel Generator based EV charging station by using FLC is evaluated. The continuous power supply in the CS to charge an EV is achieved. The operation of charging station in the three modes namely grid connected mode, islanded mode and DG connected mode possibility is evaluated by using only one VSC. The replacement of single phase grid with three phase grid can be used for three phase loads. Firstly, the controlling topology of VSC is employed by using PI controller. Later on, due to more harmonic distortions, PI controller is replaced with FLC. This controller has evaluated the best results than the PI controller and has less harmonic distortions. So, by using this these modified methods the power quality can be enhanced by providing the continuous power supply to the loads. The performance results of this is evaluated by using Matlab/Simulink 2018a Software.

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