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Simulation on Consumers Mode of Operation on Electric Propulsion System

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Abstract- Electric vehicles (EV) have recently gained much popularity as a green alternative to fossil-fuel cars and a demand response tool to support high penetration of renewable energy sources in future smart grid. In this paper, the simulation of the grid-to-vehicle (Battery charging) is carried out. The power handling of Three-Phase AC/DC converter is 10kw, DC Bus Voltage is maintained at 800V, grid voltage of 415V(rms) and switching frequency of 10kHz. The DC-DC converter and AC/DC Converter with detailed control methodology have been done in simulation. The Control techniques used in paper are done by Clarke, Park, and Inverse-Park Transformation method. The passive LCL filters are used to reduce harmonic distortion in the Grid side of the converter. The PWM Technique are used to reduce the harmonics, in paper the THD comparison of the SPWM, SVPWM, DPWMMIN, DPWMMAX are simulated. The simulation results in this paper shows the consumer mode of operation on Electric Vehicle.

Keywords:- *Electric Vehicle, G2V, Park and Inverse Park Transformation, Clarke Transformation, Phase Locked Loop, SPWM, SVPWM, DPWMAX, DPWMMIN, Buck-Boost Converter, AC/DC Converter, Filters.*

I. INTRODUCTION

In this age of globalization, usage of IC engine vehicles has massive negative impact on environment. The problems With Fossil Fuel Powered Vehicles are as follows: (i) Fossil fuels are a scarce resource; (ii) Spilling of oil may be hazard-ous; (iii) It is very expensive now a days. Therefore, in recent days, due to the cheaper rate of electricity and zero pollution features, EVs are grabbing attention. In [2], the charging sch-eduling of the vehicle in the charging station is presented. The growing concerns over environmental impacts and energy security, governments worldwide are targeting for large pen- etration of electric vehicles (EVs) in the transportation sector. An increase in the number of EV will require intelligent cha- rging infrastructure. The goal of the intelligent or smart char-ging infrastructure will be to ensure that the grid is not over- burdened by EVs. This feature is commonly known as grid-to-vehicle (G2V) or Consumer mode of operation [1]. In [3], the real-life military application of V2V and V2G technolo- gy based microgrid system is described. The military application involving a V2V/V2G/G2V based microgrid clearly shows that the overall fuel economy be economy benefit of this system is significantly (which can be around 30% or even more depending on load power demand) better than the existing TQG-based standalone systems used in the military.

Vehicles have provided society a very convenient lifestyle. Personal vehicles are chosen over other modes for independ- ence, safety and luxury, while railways, airways, etc., are suited for travelling over larger distances. Without these, ani- mals would have been drawing carriages taking people around. From 1350, the earliest known record of railway, number of motor vehicles has reached to 1 billion, through inventions like mechanical vehicles, steam-powered vehicles, balloon vehicles, push bikes, flights, helicopters, aircrafts, etc. The sales of electric drive motors worldwide will rise from $965 million in 2013 to more than $2.8 billion by 2020 [5]. EVs are contributing towards grid support in SG. EVs operate in two modes: Consumers and Prosumers. In consu- mer's mode of operation, battery charging current is consum- ed from the utility and in the prosumer's mode, EVs inject power to the grid at the requisite time specified by the market operator or depending on the grid loading, such as lightly load ed or heavily loaded. In this paper the consumer mode of ope-ration is concentrate. Likewise, the energy rates are also affe-ctted by the a-fore-mentioned modes of operation. In the G2V mode, EV behaves as an electrical load [4].

The Paris declaration on Climate change and Electric vehicles (EVs) is an essential element in the change from bio -fuel-based vehicles to EVs, aiming to deploy 100 million EVs worldwide by 2030 [6]. India has set up a goal to achieve 30% roadside electric vehicles by 2030 and expected to save 5 crore litres fuel every year to reduce 5.6 lakh tonnes of annual carbon emission. smart charging is an excellent reso- urce in the grid due to its flexibility of varying the charging power, the ability to both charge as well as discharge, and in- telligent functionalities in a sustainable, low-cost, and effici- ent charging environment. It increases the flexibility of char-ging by controlling the charging power and its flow direction. In addition to charging EVs from renewable, it can be made more sustainable, and the rapid growth of V2G networks will increase the distributed storage capacity significantly.

II. CIRCUIT TOPOLOGY

In high-performance industrial applications, three-phase voltage source PWM rectifiers/Inverters are gaining wide po-pularity as compared to the conventional diode bridge rectifi-er and thyristors-based control rectifiers because of their no. of advantages like low input current distortions, improved

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po- wer factor, regulated dc link voltage, etc. Thyristor control- led rectifiers contain lower-order harmonics which increases the cost and size of the filter. Hence, a saturation of the tran- sformer takes place due to the presence of the DC component in the source current.

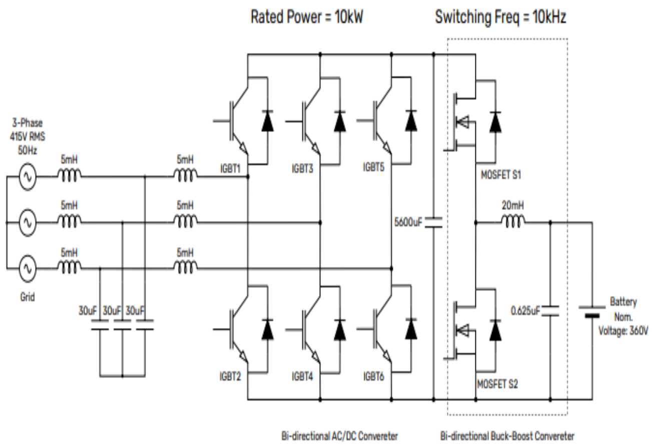

Fig 1 Circuit Topology

LCL Filter provides better filtering performance and reduces the size of the filter. Unity power factor is not ac- hieved in the case of diode bridge rectifiers and thyristor brid- ge rectifiers because large amounts of harmonics are present on ac side and due to uncompensated reactive power which is not the case with improved power PWM rectifiers. The main advantage of using PWM techniques is in the reduction of harmonics by using the proper no.of pulses per cycle hence the output voltage can also be controlled by adjusting the modulation index. Fig.1 shows the circuit topology of the operation of the EVs during the consumer's modes of opera- tion [6].

➢ *Specification of Circuit Topology:*

- Rated power: 10kw
- Switching frequency:10kHz
- Grid voltage: Three-phase 415V RMS, 50Hz
- Grid filter capacitor: 30µF
- Grid filter inductor: 5mH
- DC-link capacitor: 5600µF
- Switching frequency: 10kHz
- Battery Nominal voltage: 360V
- Battery side inductor: 20mH
- Battery side capacitor: 0.625µF
- SoC of Battery: 50%

➢ *AC/DC Converter:*

The circuit diagram of the three-phase voltage source PWM Rectifier is shown in Fig.1. The magnitude and phase angle of the currents flowing through the ac side is regulated by using a current control loop. The current control loop has three controlling parameters. They are i.The currents flowing through ac side, ii.The line voltag- es on ac side and iii.The voltage at the dc side of the frontend rectifier. Using these three controlling parameter values the controlling deci- des the switching pulses to be applied to the three-phase PWM rectifier. PWM rectifiers have a total of 8 possible switching states out of which the first 6 states are active and are used for providing dc output voltage to the load and for triggering the pulses to turn on/off the respective switches. The sinusoidal pulse width modulation technique is used and its performance analysis is shown. By using a closed loop, the output dc voltage of the PWM active rectifier can be set to desired value [14].

➢ *Buck-Boost Converter:* The use of a bi-directional DC-DC converter in motor drives devoted to the propulsion of EVs allows suitable control of both motoring and regene- rative braking operations. The topology used in fig.1 is deriv- ed directly from the traditional buck-boost scheme by introd- ucing a dual switch-diode. The MOSFET s_1 and s_2 are never operated at the same time, being switch s_2 always off during the consumer's mode of operation. In consumer's mode of operation the buck-boost converter circuit states respectively when the switch $s_1$is in the conduction state, battery and the output capacitor supply energy respectively to the inductor L and to the machine load or battery. When the switch s_1 is off, the Diode is directly biased and the output capacitor and the load receive energy from the inductor. Thereby, the voltage V_o at the output capacitor terminals can be regulated accordingly with the Battery charging by adjusting the duty cycle of the switch s_1 [8-9].

III. CONTROL TECHNIQUE

➢ Phase Locked Loop:

In order to send active power to the load, the currents flowing through the grid side have to be in phase with the grid side voltages. To send this Current, PLL will generate a reference signal and that signal should be in- phase with the actual voltage.Similarly to send reactive pow- er to the load, PLL will generate a signal which is 90º out-of-phase with the actual voltage. Hence PLL is used to generate reference signals and those signals are used as a reference for the implementation of the current controller in a grid connec- ted system. There are 2 methods for the implementation of PLL.Open loop and closed loop PLL, In this paper, the closed loop PLL is used.

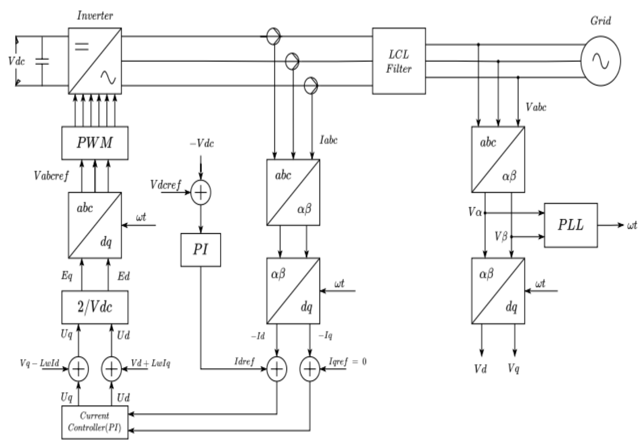

Fig 2 Control Block Diagram of AC/DC Converter.

➢ Control logic of AC/DC Converter:

The Controlling Block diagram of the Active Front-end Rectifier is shown in Fig.2.5. In this closed loop operation, the abc coordinates are transformed to dq coordinates by using Park's transformation to achieve two components of current Id and Iq and angle ωt is obtained from Phase Locked Loop (PLL).

$$Id = I\alpha^* \cos(\omega\, t) + I\beta^* \sin(\omega t) \qquad 1$$

$$Iq = I\beta^* \cos(\omega\, t) - I\alpha^* \sin(\omega t) \qquad 2$$

In order to control dc ouput voltage, the error obtained by comparing the actual dc output voltage Vdc with Vdc reference of 800V is fed to PI controller. The output of PI co-ntroller is taken as Id current reference and compared with the d-component of input current (Id). The q component of input current (Iq) is set to 0 for maintating unity power factor. The errors obtained from both the components of current are fed to their respective PI current controllers and output of both the controllers are scaled and fed to PWM scheme. After applying inverse Park's transformation we get Va*, Vb* and Vc* [14].

$$V\alpha = Id^* \cos(\omega\, t) - Vq^* \sin(\omega t) \qquad 3$$

$$V\beta = Vq^* \cos(\omega\, t) + Vq^* \sin(\omega t) \qquad 4$$

From the above equations 3 and 4 Va* , Vb* and Vc* are calculated.

$$Va^* = V\alpha \qquad 5$$

$$Vb^* = (-V\alpha + \sqrt{3} * V\beta)/2 \qquad 6$$

$$Vc^* = (-V\alpha - \sqrt{3} * V\beta)/2 \qquad 7$$

➢ *PWM Techniquie:*

Sinusodial pulse width modulation is one of the simplest and efficient PWM method used for gen-erating the gate pulses of the switches used in converter. In this method a high frequency triangular carrier wave is com- pared with modulating refernce wave of desired frequency. The intersection of both these waves determines the switch- ing instants and communication of the modulated pulse. The SPWM method is linear between *0* and 0.*785* of six-step voltage value [9]. Therefore, there is poor voltage utilization. Employing the zero-sequence signal injection technique, King developed an anolog hardware-based PWM Method and illustrated the method is linear between *0* and 0.*907* of six-step voltage value. Thus, King's method, is termed as space-vector PWM (SVPWM) method, significantly improv-es converter voltage utilization. [10-12].

- *Sine Pulse Width Modulation (SPWM).*

Sine PWM refers to the generation of PWM output with sine wave as the mosulating signal. A low frequency sin-usoidal waveform is compared with the high frequerncy tri-angular carrier signal. The sinusodial reference signals have 120° phase difference with each other. When the sinusodial reference signal intersects the triangular wave switching gate pulse is produced at that time. Fig.3 shows the refernce signal of the SPWM.

- *Space Vector Pulse Width Modulation (SVPWM):*

It is a technique used in the final step of field-oriented control (FOC) to determine the pulse-width modulated signals for the inverter switches in order to generate the desired three-phase voltages to the motor. Field oriented control with space vector pulse width modulation. The SVPWM strategies is based on the injection of the zero sequence components U_0 in reference waveforms (V_{aref} , V_{bref} and V_{cref}),

$$V_{max} = Max(V_{aref}, V_{bref}, V_{cref})$$

$$V_{min} = Min(V_{aref}, V_{bref}, V_{cref})$$

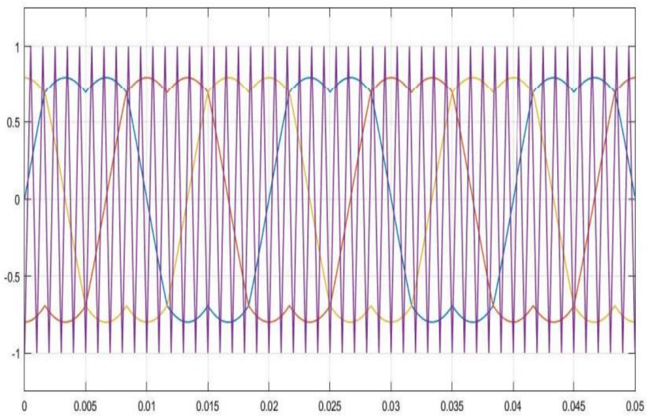

Fig 3 SVPWM Reference Signal

In SVPWM technique the periods of use of zwro vectors T_0 *and* T_7 are equal, therefore a factor corresponding to a distribution of these periods is defined as $K = \frac{T_7}{T_0+T_7}$. If k=0.5, this factor results in the technical SVPWM, because the time of use of the zero vector T_z is also distributed at the beginning and at thr end of timing ($T_0 = T_7$). The zero sequence componets of the SVPWM techniques as follows:

$$U_0 = -\frac{V_{max}+V_{min}}{2}.$$

- Discontinuous PWM (DPWMMIN and DPWMMAX):

DPWMMIN: When k=0, in this case, $T_7 = 0$ and $T_0 = T_z$, one of the pole voltage is conducted to the negative DC bus clamping the pole voltage during 120° while the other two phases modulate. So the zero sequence components is as follows:

$$U_0 = -(V_{min} + \frac{E}{2}).$$

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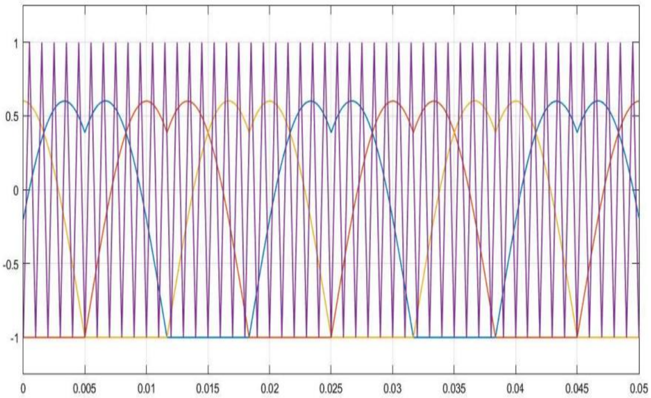

Fig 4 DPWMMIN Reference Signal.

- *DPWMMAX:*

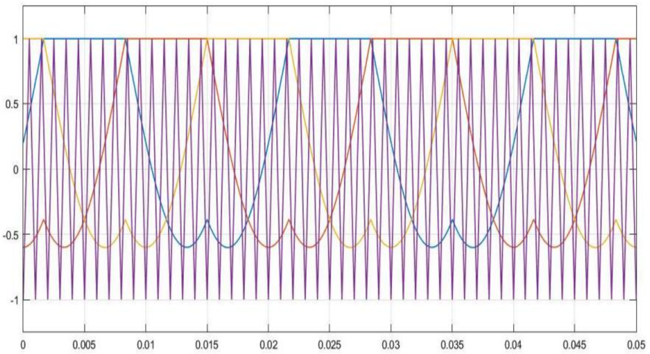

Fig 5 DPWMMAX Reference Signal.

When k=1, in this case, $T_0 = 0$ and $T_7 = T_z$, one of the pole voltage is connected to the positive DC bus clamping the pole voltage during 120^0 while the other two phases modulate. So, the zero sequence components is given as follows:

$$U_0 = -(V_{max} - \frac{E}{2}).$$

➢ Control Block Diagram for Battery Control:

The controlling of battery reference current we can control the battery charging/ discharging mode. In consumer mode of operation of the EVs the battery will charges by the -Ibatref as shown in Fig.6. In Control of the Battery charging/ Discharging, the PI controller is used. According to the duty ratio of the controller the PWM pulse are generated for the DC/DC converter. Fig.6 shows the control block diagram of the Battery.

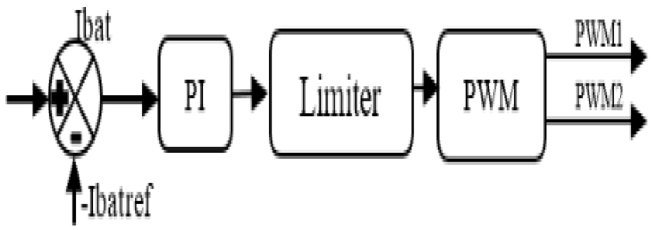

Fig 6 Control Block Diagram for Battery Charging.

IV. SIMULATION RESULTS

The simulation results of the consumer mode of operation on Electric Vehicles (EVs) are shown as follows.

Fig.7 shows the grid voltage and the current of the converter.

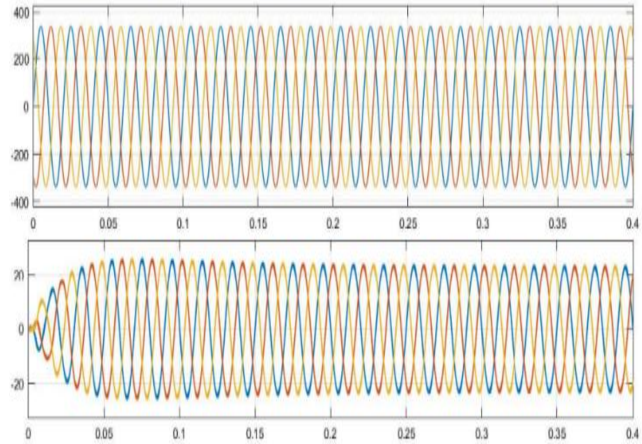

Fig 7 Grid Phase Voltage and Current

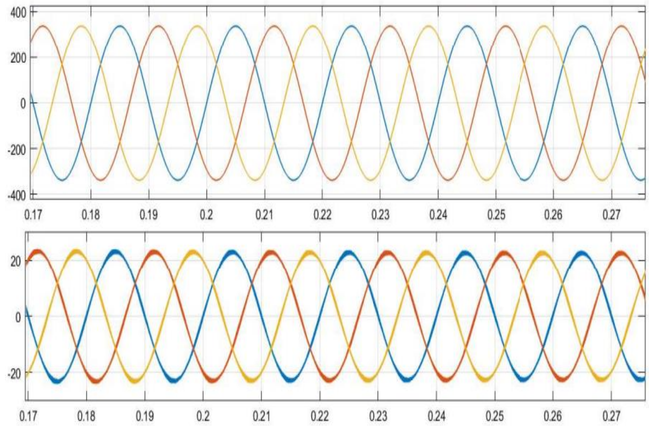

Fig 8 Three-Phase Grid Current out-Phase with Grid Voltage.

Fig.8 shows the grid voltage and the current are out-of-phase which means that, power flow direction is from Grid to the battery charging. Fig 9 show the DC bus voltage and current at AC/DC converter. The direction of the DC bus current shown in the Fig.9 is from the voltage source to the Battery.

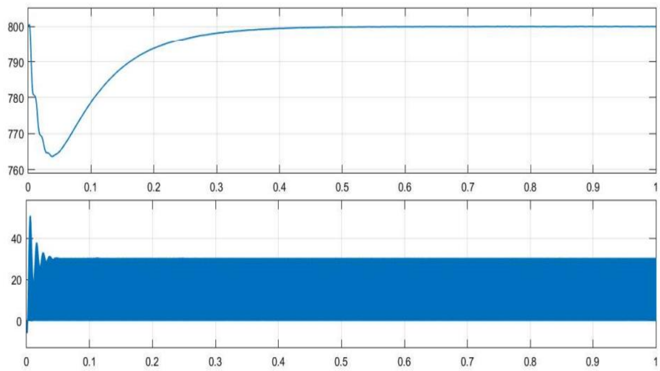

Fig 9 DC Bus Voltage and Current

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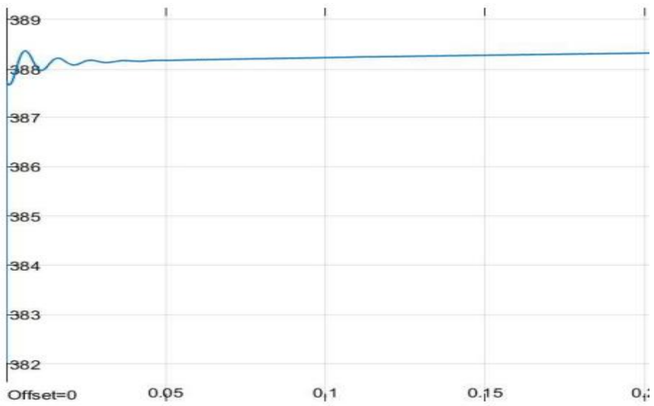

Fig.10 (a) Battery Voltage

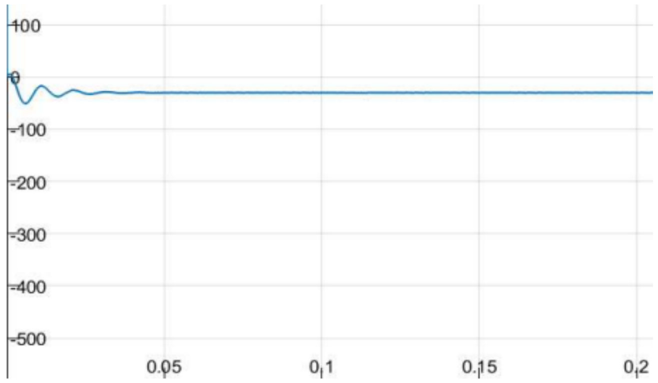

Fig 10 (b) Battery Current

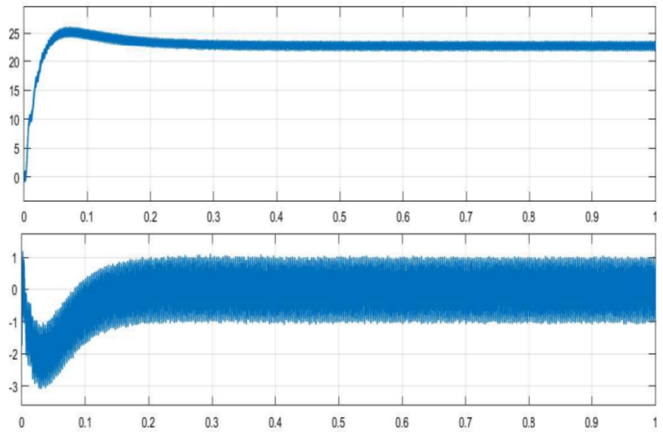

Fig 11 Converted Id and Iq Current

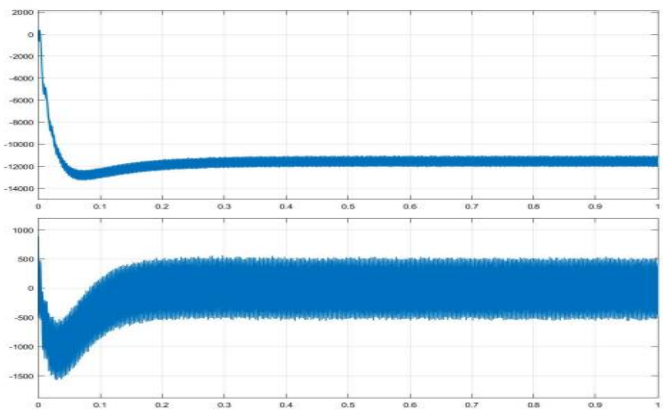

Fig 12 Grid active and Reactive Power.

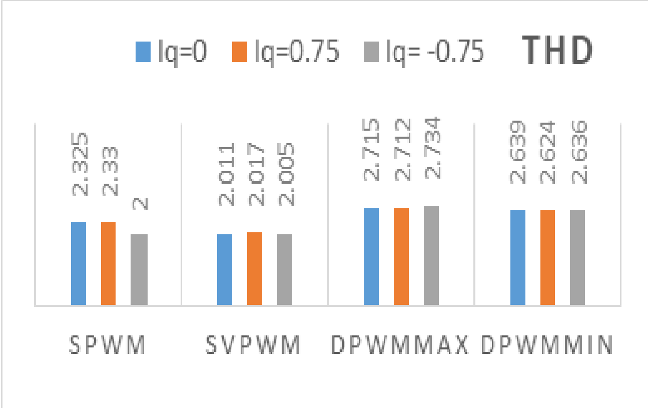

Fig 13 Comparison of Different PWM Technique THD (%)

The battery voltage and battery current during the battery charging is shown in Fig.10. The converted controller Id and Iq current of the converter is shown in Fig.11.The active power and reactive power of the converter of Grid while charging the battery is shown in Fig.12. It represents that, active power is taken from the Grid supply for the battery charging. The reactive power is controlled by the Iq reference current. The simulation result of the Consumer's mode of operation on EVs are presented in paper are of the SPWM technique results. The Fig.13 and 14 shows the comparison of the THD and power factor of the three-phase supply during the consumer's mode of operation, when subjected to the different PWM techniques.

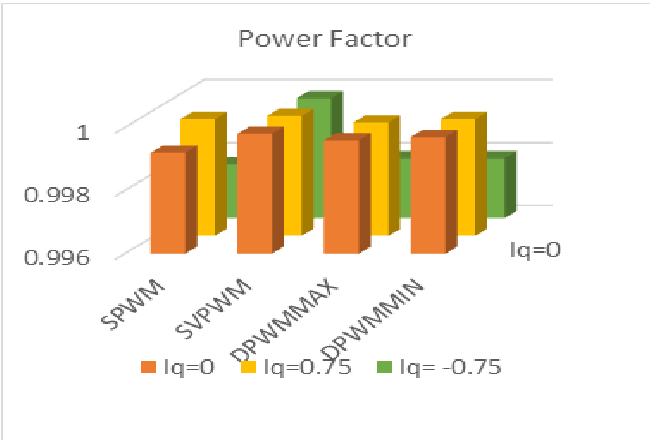

Fig.14: comparison of Power factor.

V. CONCLUSION

In this paper, the simulation results of 10KW Power converter for the Battery Charging with maintaining the DC Bus voltage of 800V. The SPWM technique simulation results are presented in this paper. The simulation results concludes that the THD of the different PWM is almost similar, but the SVPWM will give the less Total harmonic Distortion (THD). The power factor of different PWM techniques is almost similar and around 0.99. The major disadvantage of the converter is the power factor maintains when subjected to the loads, in this paper we can control the power factor and the reactive power of the load by controlling the Iq current in the AC/DC controller. The simulation results concludes that the SVPWM will gives the better performs of the conversion, which reduces the THD and maintain the good Power factor of the three-Phase power supply. The SVPWM and Discontinuous PWM are used for the reduction of the switching losses of the IGBT in the converter.

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