D-STATCOM in Electric Vehicle for Mitigating Power Quality issues in Grid

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Abstract

With the increased focus of the government on green mobility, we can expect the EV sector to flourish in India. Electric vehicles are becoming more efficient due to new battery technology and power electric converters. All most many electric vehicles are left idle in the parking lots and used for traveling only for a short time. Many grid services can be provided when electric vehicles are not used for transportation. It is possible to use EV as a storage device and also restore power to the grid, especially during peak hours. The ability to provide both harmonic and reactive power to the grid is possible by combining the DSTATCOM and Shunt Active Power filter. To control the amount of reactive power in a D-STATCOM and providing the amount of harmonic current to the grid is possible with the help of a controller. The main objectives of this paper are the development of three-phase grid-connected voltage source inverter control in dq frame. Development of charging/discharging control of EV battery connected to the DC link where EV battery will be represented using a constant DC voltage source. Modify control to incorporate D-STATCOM function and to develop the control to add active filter features to the converter. Here in this work, the EV connected D-STATCOM can improve the quality of the distorted grid. As a result, the devices connected to the grid will not be affected by the connection of a nonlinear load.

Index Terms—Phase Locked Loop (PLL), Low pass filter (LPF), D-STATCOM, Shunt Active Power Filter (APF), d-q frame, Hysteresis controller, PI controller

I. INTRODUCTION

In recent years the penetration of electric vehicles into the grid greatly increased. New battery technology and power electric converters have led to more efficient vehicles. According to Government of India (GOI), manufacturing of EV increased by 30% in India. TATA has invested 1120 cr in making EVs. Therefore, we can save 7 billion of oil purchases. With the government focus on green travel, we can expect the EV sector to flourish in India. Electric motors work very well due to the new battery technology and power converter. For most of the electric vehicles are left idle in the parking lot and used for traveling only for a short time. Also, many grid services can be provided when EV's are not used for transportation. It is possible to use EV's as a storage device and also restore power to the grid, especially during peak hours. For renewable resources, it can be used as external storage. The ability to provide both harmonic and reactive power to the grid is possible by combining the D-STATCOM and Shunt Active Power filters. Controlling the amount of reactive power in a D-STATCOM and providing the amount of harmonic current to the grid is possible with the help of a controller. [1] Necessary support for real power integration and efficient operation is provided by storage tools and similar STATCOM compensation devices. High power costs for similar devices STATCOM limits its widespread use in grid support. This literature analyses the actual and effective power support provided to the plug electric vehicles for smooth integration of wind power in the MMC-STATCOM is connected to the grid, parameter sensitivity analysis is performed in detail, which shows that the MMC-STATCOM based method works well in pressing the LFO, no matter how it changes the system boundaries. Imitation results confirm stability analysis and active LFO pressure in the vehicle grid system. In the next literature Modification and control of STATCOM are performed using the hysteresis control system. The results show that architecture can successfully produce and consume the need for active energy depending on the demand of load at the end of the industrial load and THD analysis is also done. [2] The main focus of this paper is Development of three phase grid connected voltage source inverter control in d-q frame, Development of charging/discharging control of EV battery connected to the DC link where EV battery will be represented using a constant DC voltage source, modify control to incorporate D-STATCOM function and develop the control to add active filter features to the converter. But for the time being here the main objectives that we found by the work till is to maintaining the DC link voltage constant irrespective of current flowing to the inverter and to measure the amount of harmonic current and reactive power. Also, to provide the switching pulse in such a way that required amount of harmonic current should be given by the filter [3]. The main objectives are to make the dc voltage across the capacitor constant, to provide the harmonic current required for the non-linear load by D-STATCOM Also to develop a three-phase grid connected VSC control in d-q frame. Lastly to develop the charging/discharging control of EV battery connected to the DC link. In this paper first section is the introduction then comes the Methodology then follows the Simulink diagram and results. Then it is followed by a conclusion. As the STATCOM plays an important role in supporting the reactive power compensation as it is a shunt compensator. It is mainly used for the generation and transmission side. In conventional system uses PI controller to generate the reference voltage with the sinusoidal PWM pulse. Controlling is based on pulse width modulation. Sinusoidal PWM signal is mainly used to decrease the reactive power loss. For getting a sinusoidal PWM signal we are using IGBT switches. IGBT switches are more reliable for high-speed operations. A DC capacitor is used to maintain stable power in the STATCOM installation. Here Voltage Source Converter (VSC) act as fully controlled. The voltage source should match the voltage in the system phase, frequency and amplitude. The main function of the STATCOM reducing the harmonics present on the side of the grid, improving the power factor and the loss of reactive power can also be reduced. Voltage variation is also reduced. [4] STATCOM on the distribution side is known as DSTATCOM. It provides both voltage sag and reactive compensation. It uses a multi-functional device called the Switched Filter Compensator (SFC), which can increase a wide range of power quality issues. It helps in mitigating harmonics present in the line as well as helps in the voltage stabilization. It works as the trial-and-error tunning for a specific operating condition. A modification is done in the conventional SFC and named a new device called adaptive switched filter compensator (ASFC). PID controller is used here to improve the overall dynamic performance of the microgrid. PID controller gain is optimized with the help of Grasshoppers Optimization Algorithm (GOA). GOA parameters are used to ensure control of the controller by searching for PID controller benefits for minimizing total time error (ITAE) error. It helps to achieve faster processing and more accurate output than that of standard test and error. The main advantage of the ASFC is, that it provides more converging result at less computation time. From the reference [5], it says as D-STATCOM can act as an alternating device for improving the power quality of microgrid. It is also altered to be self-tuned and to get a good result. As Static Synchronous Compensator (STATCOM) is mainly used to eliminate the harmonics in the power system. But the main factor that stops this ability is the amplitude of the voltage. As a result, it weakens the forced oscillations (FO) which are driven by external forces. So, to eliminate this problem an energy storage unit is included in the STATCOM, and there obtained the device E-STATCOM. Which increases the control degree of freedom as a result there gives possible outcomes for forced oscillations. The main advantage of ESTATCOM is its unique capability of supplying both active and reactive power in real-time. A control algorithm is used to eliminate all the forced oscillations. The resonant controller is used in the system to give the power which is needed to the system. The main function of the resonant controller is to give a closed-loop control to the power system. This method can be used in the complex meshed systems, but the disadvantage of this method is the location and the coordination of multiple equipment's is not considered here [6]. A Vector Current Controlled (VCC) was obtained from a Direct Power Control (DPC) for the three-phase VSI. The d-q current axes control is obtained from the DPC method. This method has more advantages such as increased performance because it considers the slow dynamics of PLL and there is a decrease in the computational burden in comparison with the conventional PCC due to the missing of Park transformation and PLL. This method combines the benefit of both DPC and the conventional VCC [7]. It can also sprightly control the current to get a high-quality outcome which is useful to the industrial customers. Here's a simple controller with feedforward and feedback to compare output performance to standard VCC. This control can sync VSI to the grid using the DPC method instead of the standard PLL system. As the grid voltage is distorted and unbalanced, requiring additional digital filters. The PLL system may not adjust the correct phase voltage of the grid during a short period or disrupt the system in a weak grid. This method strengthens the weak grid connected to the VSI system. It also has a faulty ride-through operation. This method is not evaluated for performance and stability using a band pass filter [8].

II. METHODOLOGY

Here models the D-STATCOM with a capacitor is used as the energy storage. The D-STATCOM act as a shunt active power filter. The harmonic elimination and reactive power support property of the D-STATCOM is considered here. Analysing the effect of D-STATCOM in a distribution system when a non-linear load is connected in the system. Then the capacitor in the D-STATCOM is replaced by the battery, ies here it is demonstrated to show the EV. By replacing the capacitor with the DC link is to provide the active support. The predefined values we are setting the reference. This study is only conducted when EV is connected to the grid. The EV concept is in the sense that uses the charging and discharging of the EV battery. The EV owners will program the circuit in such a way that he/she need to get charged the vehicle on non-peak hours. The discharge of the electric vehicle to grid will happen at peak hours and as a result incentive will get. The controller used here is the DQ frame controller. The PWM signal is generated by the hysteresis controller. Thus, a D-STATCOM in electric vehicle is used to mitigate the power quality issues in the grid. The figure 2 shows the block diagram of the model.

A. D-STATCOM

It is a shunt compensator. STATCOM plays a key role in supporting the compensation of reactive power in the generation and transmission system. The STATCOM used on the distribution side is known as D-STATCOM. The D-STATCOM system consists of three main components: Voltage Source Converter (VSC), set of coupling reactors and controller.

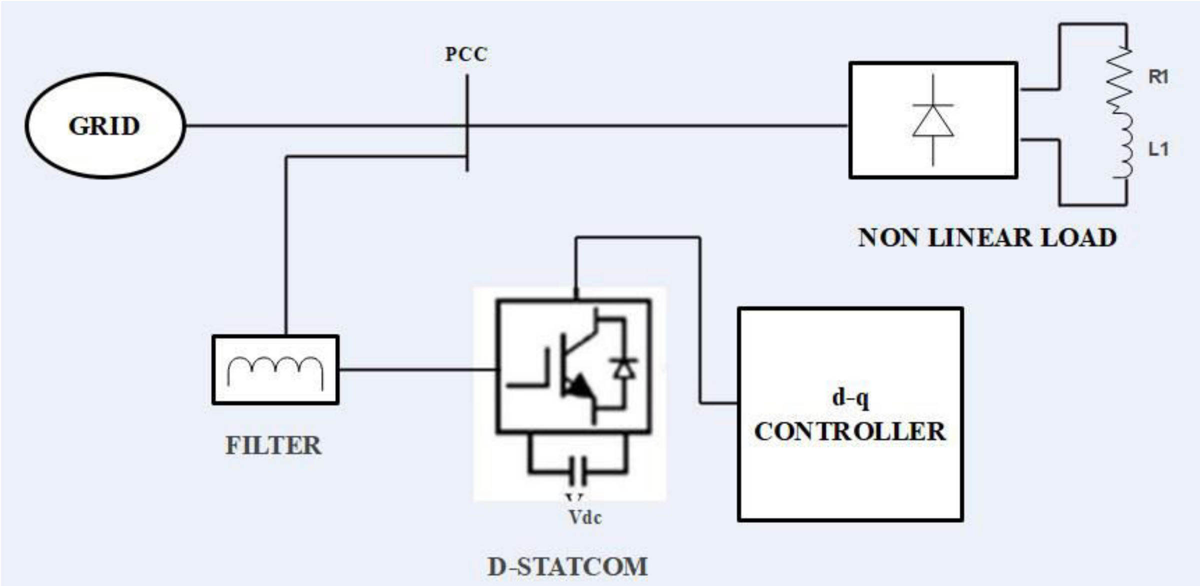

Fig. 1. Block Diagram of the model

They have a multilevel voltage source converter design. where (Insulated Gate Bipolar Transistor) IGBT or Gate Turn off Thyristor (GTO) is used for the switching operations. But for advanced operation IGBT is preferred for the reliable high speed operation. Control is based on the concept of pulse width modulation. Here the voltage source converter act as a fully controllable. The source voltage should match the system voltage in phase, frequency and with amplitude. In order to reduce the reactive power loss, the PI controller is used here. The main purpose of the PI controller is to generate the reference voltage with the sinusoidal PWM pulse. The DC capacitor is used to maintain the constant energy at the input of the STATCOM. Fig 1 shows the pictorial representation of the D-STATCOM. [9]

There are two control purposes used in D-STATCOM. Another ac voltage control of the bus power system to which D-STATCOM is connected. And another dc voltage control on all capacitors within D-STATCOM. It is widely known that an effective shunt power injection can be used to control the bus voltage. In a standard control system, there are two electrical controls designed for these purposes. AC voltage regulator to control bus voltage and dc voltage regulator to control capacitor voltage. In simple terms, both controls are not proportional integral (PI) type controls [10].

Here algorithm is mainly done using park transformation. This is mainly used for converting the phase current and phase voltage (abc) to rotating dqo reference frame.The below equations shows:-

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \\ i_{L0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{1}$$

This modification is done because in the corresponding reference framework the basic component becomes a fixed object which can be the lower level is filtered leaving behind high frequency components that can be easily removed.

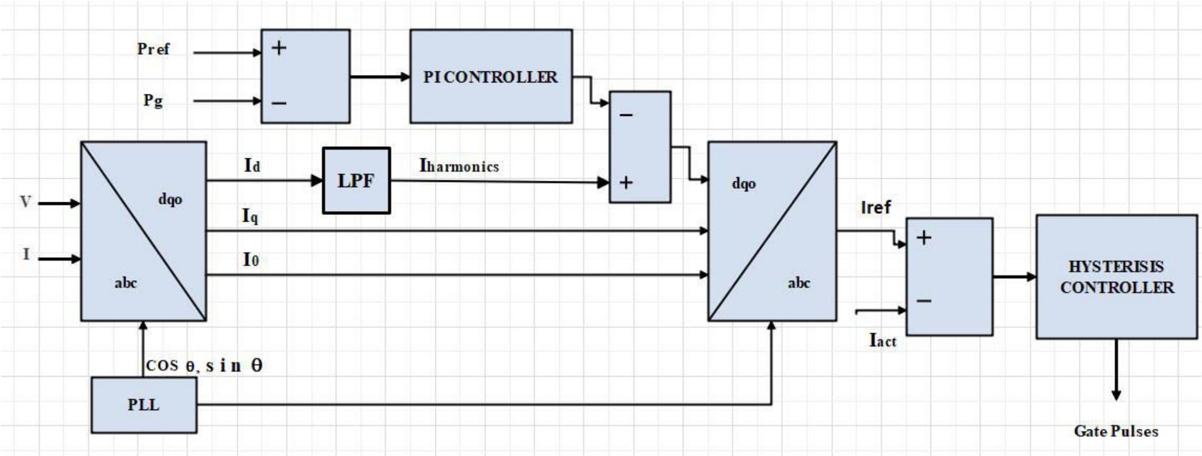

Fig. 2. Block Diagram of d-q controller

Also, filtration of low-pass DC section does not cause any category error in the signal which may be a problem when the High Pass filter is applied. In this way, the current volume is first converted from three phases to the d-q reference framework. Thus, the d-q currents obtained included the AC and DC components. I the primary current component is represented by the fixed DC component and the AC component represents the harmonic component. D part is transmitted with a low pass (LPF) filter. This component contains a basic and consistent component. LPF is the second order a filter called butter worth filter, its termination frequency is selected as 50Hz to extract the harmonics of the higher order. Therefore, the basic frequency is the output of the low pass filter. This is subtracted from the real d part for the maximum frequency parts. The q section represents the harmonic component. It is therefore used directly. The opposite of the park changes then performed to detect harmonic symptoms of three stages. [11]

$$\begin{bmatrix} i_{a*} \\ i_{b*} \\ i_{c*} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos\theta - \frac{2\pi}{3} & \sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\theta + \frac{2\pi}{3} & \sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \quad (2)$$

This is a harmonic extractor. It estimates what amount of harmonics filter should be compensated for. Determines all multiples components of current frequency or voltage. The extracted harmonics therefore became the reference circuit of the controller. There various techniques or algorithms used in the calculation of reference currents in the Instantaneous Reactive active filter. Power Theory (d-q theory), Unity Power Factor method, Fast Fourier Technique, One Cycle Control, etc. The paper is very descriptive the most common method used to produce harmonic i.e., the Synchronization Reference Framework (SRF) to produce three-phase reference waves. (ia *, ib *, ic *) used active power filters. [12]

III. WORKING OF THE MODEL

Grid basically is a three-phase voltage source followed by voltage and current measurement from which we can see the source current and source voltage. It is connected to a nonlinear load where NL load is observed as a diode bridge rectifier followed by the RL load. In the dc side has some amount of current and positive half cycle current won't be perfectly sinusoidal. It is non sinusoidal that mainly depend upon the load connected to the DC side. The AC side won't be perfectly sinusoidal. If the D-STATCOM didn't connect to the grid then whatever current needed by the load will be taken from the grid. Load requirement has harmonics because bridge rectifier is using here. If there is no additional arrangement for the current then the harmonics current will be taken from the grid as a result power quality condition of current will decrease. Because there is only small value for resistance and reactance on the transmission line. NL current in the impedance causes NL voltage drop. That results in the distortion of power quality of both voltage and current. So, to provide the harmonic current D-STATCOM is connected to the circuit. It can provide the required amount of reactive power to load. [13]

Here D-STATCOM will also act as an Active Power Filter (APF). It is modelled in such a way that whatever may be the amount of harmonic current needed will be provided by the APF. Remaining sinusoidal signal will be taken from the grid. So, when we looking through the side of grid it will be a sinusoidal signal. Thus, the power quality of voltage and power will be improved. There are two major huddles we are facing. In D-STATCOM we have an inverter consist of universal bridge with six switches. For switching IGBT and MOSFET can be used. IGBT is mostly preferred because of its high-speed operation. At the dc side of inverter capacitor is placed. APF is connected to the grid in shunt with the system. Energy will flow from ac side to dc side and vice versa. Some cases charge stored in the capacitor may be rises or reduces. As a result, voltage across the capacitor keep on vary. According to the working principle of inverter, if we want to maintain the ac side voltage constant (as ac side connected to the grid) so, corresponding dc link voltage should be constant.

The major objective of this model is to maintain the DC link voltage constant irrespective of the current flowing to the inverter. The second objective is to measure the amount of harmonic current and reactive power required by the load. The ammeter or kind of special meters cannot be placed across the load or in some cases the load destination will be far from the filter also there is lack of adequate communications. The only measurement can take is the voltage and current at the point of common coupling. The second objective is to measure the amount of harmonic current and reactive power. Also to provide the switching pulses in such a way that the required amount of harmonic current should be given by the filter. If linear load is there instead of non-linear load, then the source current will be perfectly sinusoidal. The wave shape of id and iq once the transferring of current from abc to dq0. Phase displacement angle θ can be obtained from the phase locked loop. In dq the specific value of Vd will be a dc voltage then Vq will be the zero voltage. This is for phase ’a’. If the signal is change to 120 degree, then the Vq will get a specified voltage and Vd=0. If both the Vd and Vq have oscillations that result in the abc signal have harmonics and non-linearities.

In the Phase locked loop (PLL) first senses the load voltage is converting or using the PLL are used for getting the sin, cos wt. Sin or cos are used for converting the abc to dq reference frame. As a result, id, iq and i0 will be get. id will be having non-linear current ie having the oscillating quantity not dc. A LPF of critical frequency 25 Hz result in the sinusoidal signal. If the frequency is less than 25 Hz then it allows to pass through filter (dc or 0 Hz). Oscillations in the id will be in the order of 100 Hz, if your abc current and voltage are 50 Hz. It consists of oscillating component and dc component that causes non linearity in the system. To maintain the dc link voltage constant so by predefined the value of Vdc at 700V According to linear modulation range,

$$V_{d,ref} = 415 * 1.6867 = 700V \quad (3)$$

The Vdc, ref should be greater than the above value. So, it is taken as 700 V.

The ref value and actual value is compared and the error signal is given to the PI controller. But the output of PI controller will be the amount of which is added with the oscillation of id. If the load is balanced, linear and phase shifted to 120 degree then iq and i0 will be always zero. Whatever amount of current absorbed by the load corresponding iq and i0 should be provided by the filter in such a way that iq and i0 should be zero from the grid side. Now the objective is to switch the inverter in such a way that ac side current of inverter should exactly track the ref current. With the help of hysteresis controller actual current and ref current are comparing. The band limits are given and the switching input are generated. Here hysteresis band width is selected of value 0.02. If very low value of hysteresis band, then the tracking accuracy increases but switching frequency will increases. If very low value of HB, then the tracking is not much efficient. As a result, we are taking an average value of 0.02. Then the signal is directly given to the pulse is given to the control. The result is given in the next chapter.

IV. SIMULATION MODELLING AND ANALYSIS

The major objective of this work is to maintain the DC link voltage constant irrespective of the current flowing to the inverter. The second objective is to measure the amount of harmonic current and reactive power required by the load. The ammeter or kind of special meters cannot be placed across the load or in some cases the load destination will be far from the filter also there is lack of adequate communications. The only measurement can take is the voltage and current at the point of common coupling. The second objective is to measure the amount of harmonic current and reactive power A lso to provide the switching pulses in such a way that the required amount of harmonic current should be given by the filter. A. Simulation Setup Here when we are connecting a non-linear load which is taken as a diode bridge rectifier followed by a RL load. Because of the NL load connected in the DC side result in the non-sinusoidal pulse at the AC side. This is mainly due to the harmonic generation by the nonlinear load. If there is no arrangement then the harmonics will be taken from the grid. As a result, the power quality of the grid will be distorted.

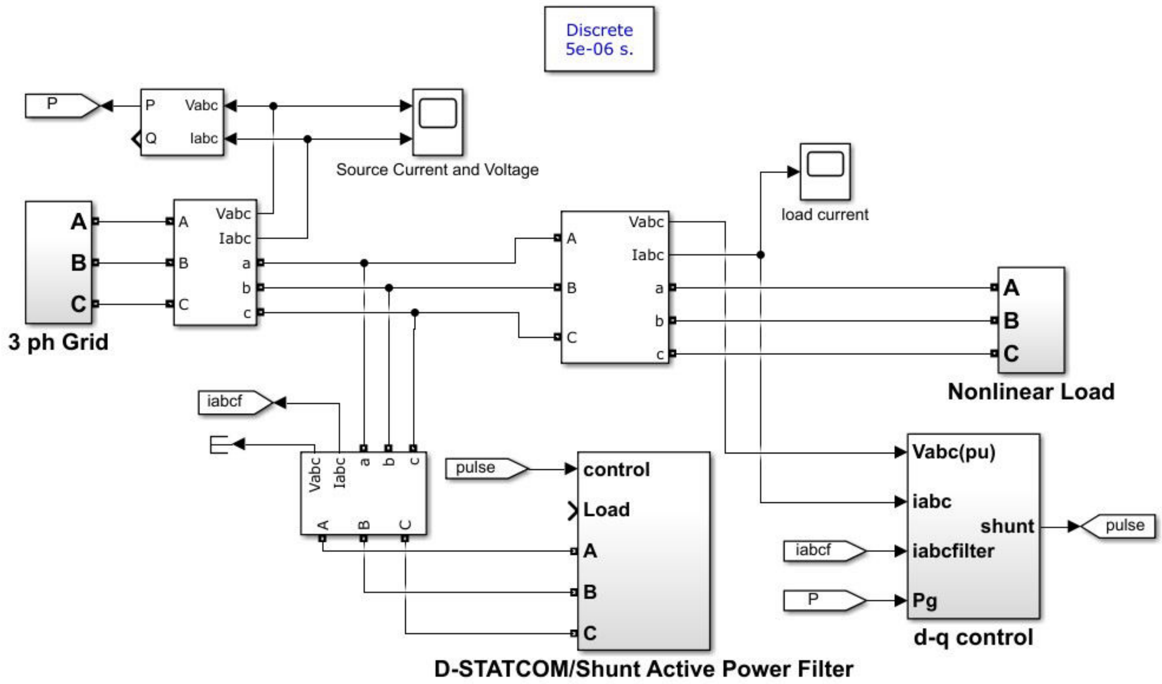

Fig. 3. Simulink Model considering the D-STATCOM

So, to avoid this here a D-STATCOM is adding in between a source and a load. Which provide required amount of reactive power to the load. Here STATCOM will also act as an Active Power Filter (APF). It is modelled in such a way that whatever may be the amount of harmonic current needed will provide by the APF. So, by the usage of the D-STATCOM it provides the harmonic current and as a result grid can see a perfectly sinusoidal signal. This difference can be seen by comparing a model without using D-STATCOM with the model used here. Here to maintain the DC voltage across the capacitor to be constant PI controller is used. For converting the model park transformation is done followed by the Phase Locked

Loop. In order to get a DC component a LPF is also used. To switch the inverter of D-STATCOM in such a way that AC side current of the inverter should exactly track the reference current. So, for this purpose a hysteresis controller is used.

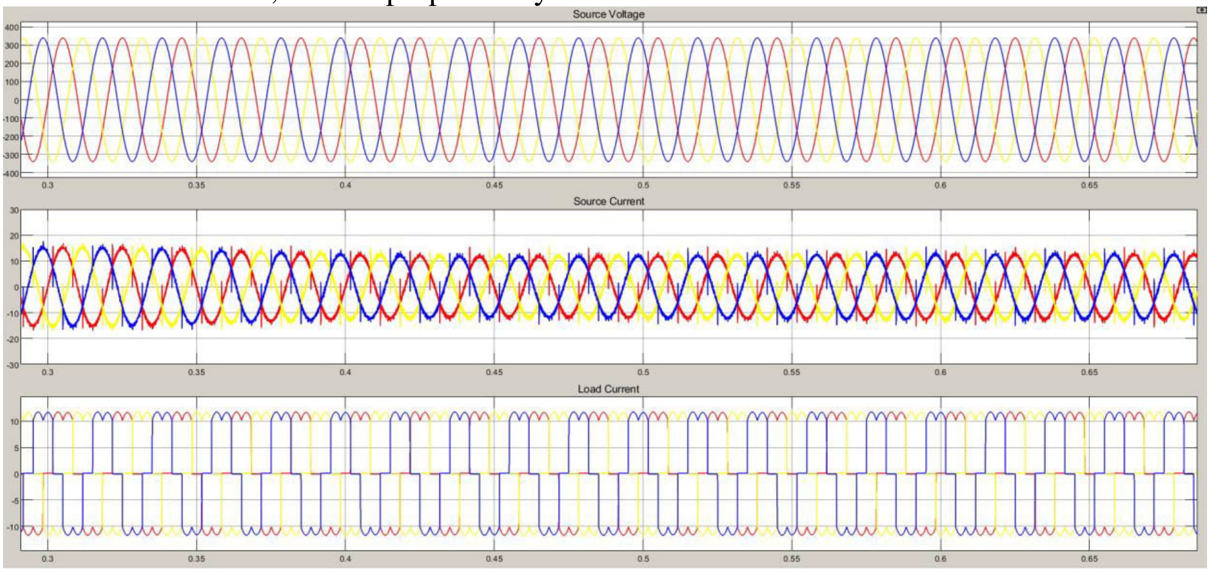

Fig. 4. Simulink waveform when D-STATCOM is connected

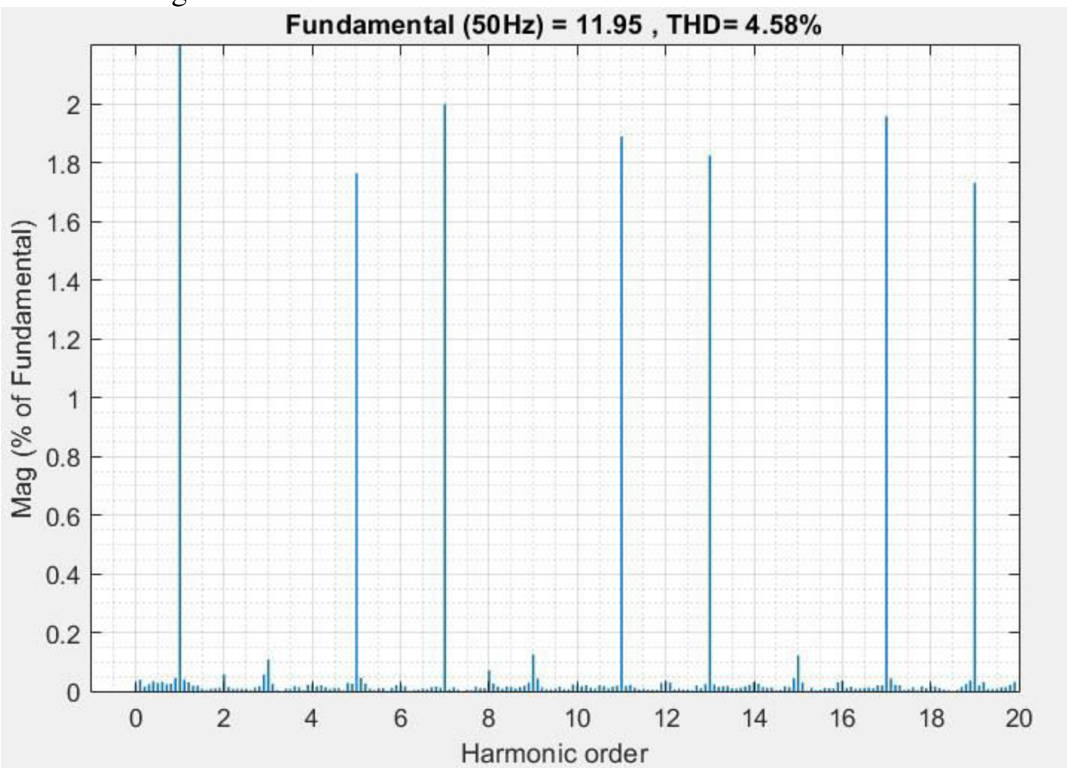

Fig. 5. THD waveform when D-STATCOM is connected refers the charging.

V. RESULT AND GRAPH

This section shows the result of the Simulink diagram model which discussed in the previous section. Figure 4 shows the waveform when D-STATCOM is connected. Here first graph shows the source voltage and second graph shows the source current which is almost a sinusoidal wave by looking from the grid side. Third waveform shows the Load voltage which is distorted by the non-linear load. Also here load current phase is different in that of the source current which means the reactive power compensation has taken place correctly. Figure 5 shows the THD result when D-STATCOM is connected. Here the THD value of the source current is around 4.58% which is nearly a distortion less waveform. Figure 6 shows the Simulink waveform without connecting the D-STATCOM. Here the source current is also distorted like the load current due to the non-linear load. The THD of the source current without connecting the D-STATCOM is shown in the figure. The THD is around 28.55.%. When comparing it with the THD waveform of D-STATCOM is connected the THD is reduced from 28% to 4.58%. Thus, the distortion of the DSTATCOM is very much reduced. In the figure 8 shows the waveform of Pref where we connected the as 1000W. This Figure 9 shows the Pref as -1000W and thus shows the discharging of the circuit.

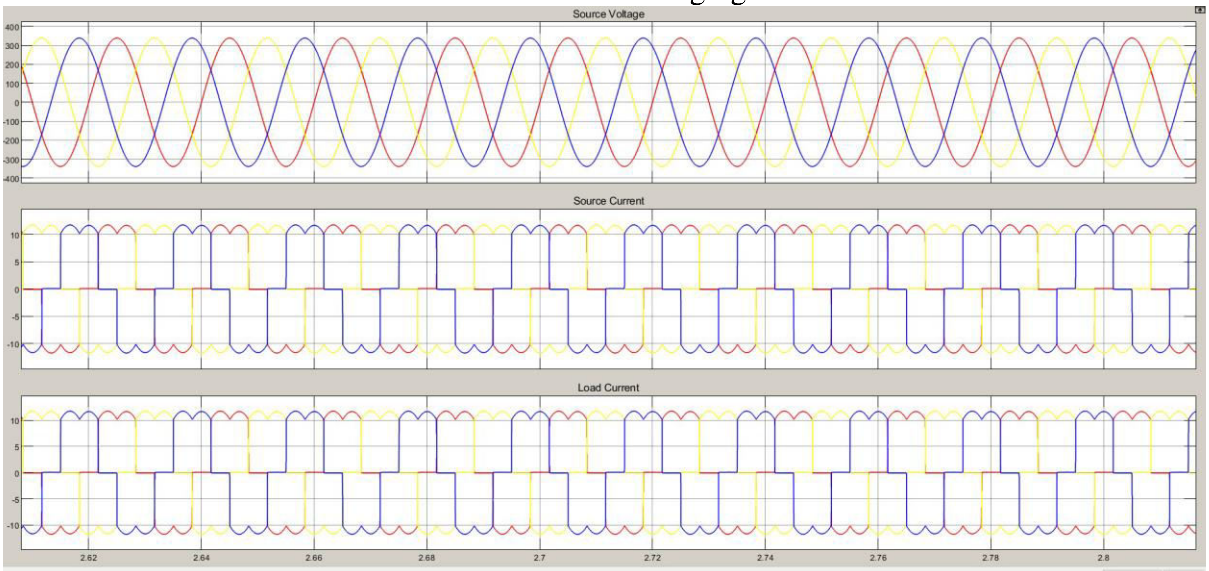

Fig. 6. Simulink waveform without connecting D-STATCOM

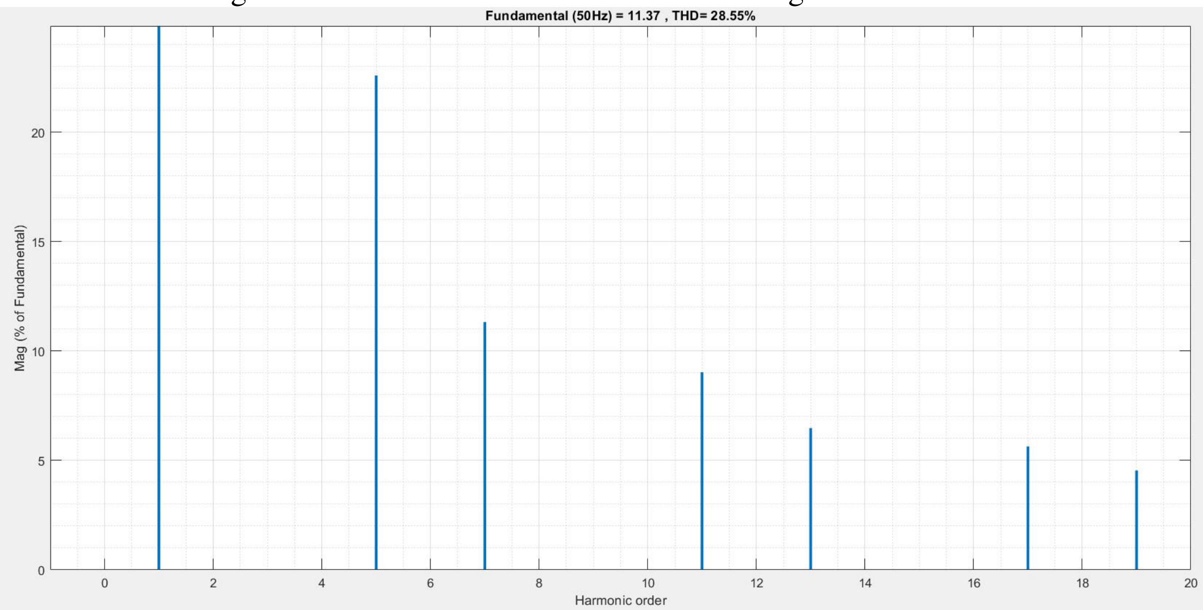

Fig. 7. THD waveform without connecting D-STATCOM

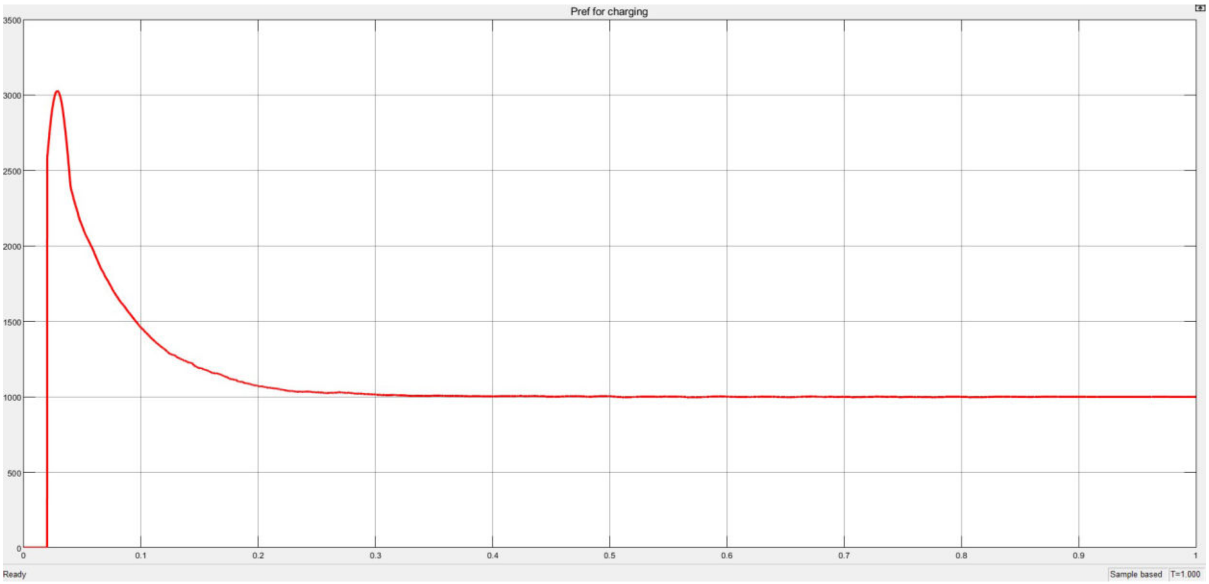

Fig. 8. Waveform of Pref for Charging

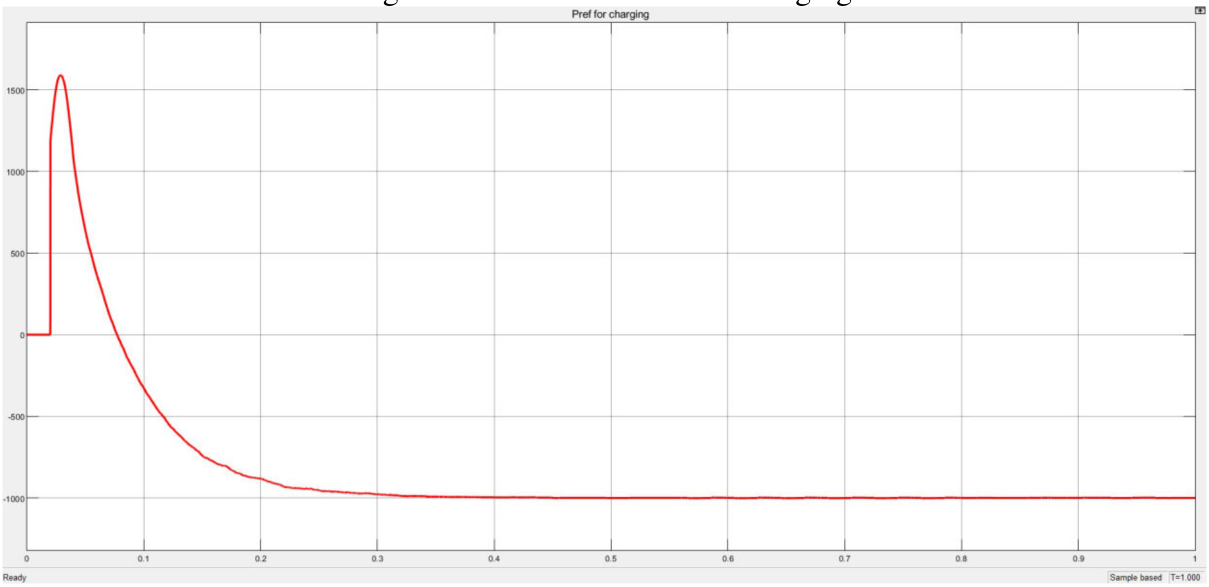

Fig. 9. Waveform of Pref for discharging

VI. CONCLUSION

The main aim of doing this work is when an EV linked D-STATCOM is connected to a distorted grid due to the connection of the non-linear load can improve the grid performance. Here the D-STATCOM controller is modelled. Source current of the D-STATCOM connected grid has a THD of less than 5%. THD of the model without compensation is around 28%. Thus, the THD is very reduced to the desired value so the power quality is improved. DC voltage across the capacitor was able to make a constant of around 700V. Charging and discharging the EV as a battery is also done by keeping 1000w and -1000w. Charging and discharging with the pref set as a 1000w for charging and -1000w for discharging. The simulation waveform of the charging and discharging of pref is obtained.

As a future scope SOC model for the above Simulink diagram so that the consumer can set the charging battery level of the EV. This is not shown here due to the duration of simulation time increases. Also, in the next stage integration of RES (wind, PV) to the grid as an energy integrated storage system in STATCOM (E-STATCOM) can be done. Here are this paper reactive power compensation and harmonic current elimination is only considered but the unbalancing condition can be considered. Here battery is shown as EV but as the next step EV modelling can also be consider.

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