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Implementation of PV Based DSTATCOM for Localized Distribution System.

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ABSTRACT: Photovoltaic (PV) energy is mainly used for producing large amount ofpower among different types of renewable energies. The efficiency of powertransfer canimproveby modellingand control of photovoltaicsystems ingridconnectednetwork.Distributionsystemisconnectedwithlinearandnonlinearloads and due to presence of nonlinear loads power quality problems areoccurredon the sourcesidewhichcanaffecttheperformanceofthesystem.When supplying both fundamental and ripple current to the nonlinear loadssource currents is to be disturbed. So that, we are placing shunt compensatorcalled as STATCOM (Static Compensator) which can be produces ripplecurrents to nonlinear loads. STATCOM is a static device which is connectedparalleltothesource. When the STATCOM is connected to distribution side it is called asDSTATCOM(D istribution Static Compensator).DSTATCOMhavingVoltage Source Inverter (VSI) and filter. VSI switches are semiconductor-based switches we are going to on &off the switches of the inverter using PWM(Pulse WidthModulator)processwith highswitchingfrequency.

During high switching frequency at the output of the inverter high frequencyswitching ripples are generated. In order to filter out the high frequencyswitching ripples generated by the Inverter can be filtered by using filters.Filters are classified in to L (inductor)/LC (inductor capacitor)/LCL (inductorcapacitor inductor). L filter is bulky and costly. So that, in order to make lesscostandforgoodworkingperformance weare goingtoLCLfilter. Inthisproject,thecontrolofgridconnectedinverterwith LCLfilterisstudied.The LCL filter is an effective solution for the interconnection of the RES tothe grid but suffers from the problem of resonance. To overcome the abovedrawback active and passive damping methods are proposed. And also, acontrol strategy to reduce the lower order harmonics is proposed. The proposed controlstrategyissimulatedin MATLABSIMULINKenvironment.

I. INTRODUCTION

1.1 OVERVIEW

Nowadays, the most common power quality issues like voltage sag, voltage swells, low power factor and harmonic distortion influence highly. Mostly, these issues are groomed due to the nonlinear behavior of the electrical loads. The growth of electronics utilities becomes the source of introducing lower order harmonics since; they use the nonlinear loads for power conditioning. Few of these non-linear loads are televisions, computers, printers, etc. Therefore, the increase in the use of such equipment becomes the reason of the high-power consumption and low power density. Besides, the market demands a power source of higher power density with a sensible price charge. Hence, DSTATCOM (Distribution Static Compensation) with suitable filtering method has been widely implemented in localized distribution system to limit the influence of lower order harmonics with maintaining the desired input unity pf (Power Factor).The DSTATCOM is a custom power device which is utilized to eliminate harmonics from the source current and also balance them in addition to provide reactive power compensation to improve power factor or regulate the load bus voltage.The key component of the DSTATCOM is a power voltage source converter (VSC) that is based on high power electronic technologies. The Fig.1.1 shows the single line diagram of the DSTATCOM connected to the grid in the PCC (point of the Common Coupling) the single line diagram consists of the DC voltage source behind self-commutated inverters using IGBT controller and coupling transformer.

The main focus of the placing the DSTACOM is that we are having the harmonics problem that is occurring in the system that are having the great loss to the system we have to decrease the THD (Total Harmonic Distraction) is to be reduced and make the system in the good performance so that placing the DSTATCOM. In the middle of the distribution system the importance of the DSTATCOM. The DSTATCOM is to obtain high power factor (PF) and also, the

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DSTATCOM can be improved to obtained high quality of power which is essential for the distribution system to satisfy IEEE std.519, IEC 61000-3-2.

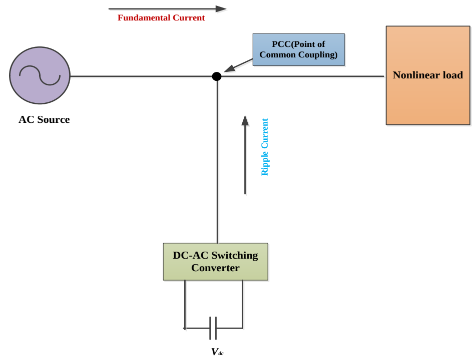

Fig.1.1. Single line Diagram of the DSTACOM

The Fig1.1 has the V_{dc} (dc link voltage) which is connected to the VSI the DC link is the supplying the voltage to the VSI. By the suppling to the power to the inverter the dc link is going to discharged at some time after this leads to the imbalanced of the system so that we are going to solve this unbalancing the problem by the introducing he continuous flow of the energy. So that we are able to be give non-interrupt current to the loads.

By the introducing the renewable energy sources Infront of the VSI can cause the system in the perfect manner so that we are selecting the one of the energy resources to the inverter as the input to the system. By taking the solar energy as the resource to the inverter for the improvement of the performance we are going for the PV(Photovoltaic) modules are attached to the Infront of the inverter and the check the THD values as shown in the chapter 4 can be shown the difference in the performance of the without the PV panel and with the PV panel can be clearly absorbed in the chapter 3 & 4 by seeing the THD values. The ac source is having the fundamental frequency which is to be send to the nonlinear loads.The power line frequency (fundamental) is 50 Hz or 60 Hz. In case the fundamental frequency is 50 Hz, then 5^{th} harmonic is 250 Hz, and 7^{th} harmonics is 350Hz, etc.

Non-linear loads are the main source of harmonics related problems. All electric loads are mostly non-linear loads and generate harmonics in the power system.These nonlinear loads draw only short pulses of current from supply network and combine with the source impedance resulting in distribution of the supply voltage. The modern power electronics provide suitable topology to mitigate the power quality problems. This chapter discuss about the harmonic distortion and its solutions based on the shunt active power line conditioner by the supplying the fundamental and the ripple current to the nonlinear loads the source current is to be affected. In order to protect the source current, we are placing the compensation in the point of the common coupling this can be discussed in this chapter and the importance of the compensation can be discussed in this chapter.

1.2 NONLINEAR FEATURE OF LOAD AND IT'S IMPACT

The distribution system has having the linear loads and the nonlinear loads the linear loads are not affects the grid. The nonlinear loads having the property of the source current has to send the fundamental and the ripple current to the nonlinear loads by the sending the fundamental and as well as the ripple current the source current has to be affected. The Fig 1.2 shows the source current connected to the nonlinear load as well as the Fig 1.2 shows the ripple current and the fundamental (50 Hz frequency is taken as per the Indian standard). This both are supplying the source current so that source current is going to affect more for the supplying the both. So that placing the compensation to compensate the problem that are affected in the grid. If we are not placing the compensation in the middle of the grid the grid has effects seriously in order to satisfy the nonlinear loads. So, that placing the compensation on the middle of the distribution system because the compensation has to supply the ripple current to the nonlinear loads this leads to the balancing the grid current.

In the Fig 1.1 we see the nonlinear loads are connected to the grid the source current is supplying the fundamental and the ripple current to the nonlinear loads. Due to nonlinear loads harmonics problems are to affected for the solution of this we are going for the compensation technique. The Fig.1.3 shows the simulation results of the nonlinear loads connected to each other without compensation. We are clearly observed that the source current is supplying the fundamental as well as the ripple current and, in the Fig.,1.3 also can be seen the load current also taking the both fundamental as well as the ripple current. By the taking of the both the source current is to affected so that we are going for the better option is that compensation technique.

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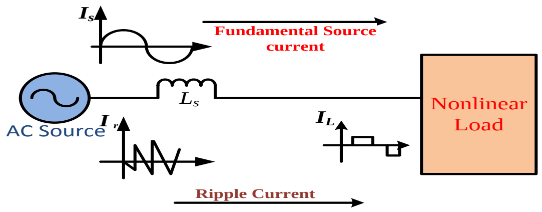

Fig.1.2. Representation of the nonlinear load without compensation

In the power system nonlinear is described by the introduction of a distortion due to their non-ideal characteristics. Distracted voltage and current are having much harmful effects, such as the resonance problems occur in between the supply Inductance (L) and Capacitance (C) leads to over currents and over voltage, this is the nonlinear loads whereas the Fig 1.2 shows the nonlinear load is connected with the AC source.

The nonlinear loads are connected to the AC source in which we want to satisfy the nonlinear property. In the Fig 1.2 the AC source is sending the Fundamental frequency and the ripple current the source current is to be in the unbalanced condition in order to overcome this problem we are going to the compensation. Due to the sudden change in the variation in the voltage and the current in the source side can cause to the blackout the grid so that we are taking care of the grid. The only solution for this problem is the compensation technique only.

The compensation technique we are having the series and the shunt compensation. We are taking the shunt compensation for the solution of the problem because of the we are handling the source current to be balancing the Fig 1.3 and the Fig 1.4 are the outputs of the nonlinear loads which is connected to the series with the grid. The Fig 1.3 &1.4 are the having the source current and source voltage in this work we are going the main focus on the source current in it the source current sending the fundamental and the ripple current to the nonlinear loads and making the power factor at the unity. So that the source current is to be balanced for that we are going to the place the shunt compensation to make the source current is to be balanced.

The output of the nonlinear load with the ac source can be shown above by using MAT LAB/SIMULINK the results are to be shown in below as per the results that we are absorb that the source current is to be affected because of the supplying the fundamental and the ripple current to the nonlinear load that the source current is to be unbalanced condition mode because of the supplying both fundamental and ripple current to the nonlinear load. For this type of the problem, we having a solution in which we want to do compensation. In the Fig.1.5 we are seen that the THD value is very serious comparing to the IEEE standards. We want to produce the compensation to the system.

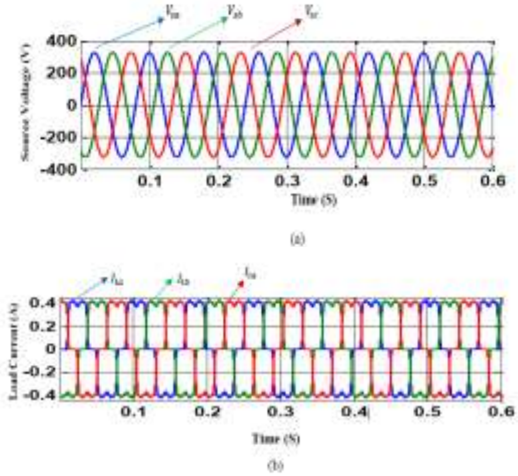

Fig.1.3. Source Voltage & Source current waveform of the nonlinear load :(a) source voltage (b) source current

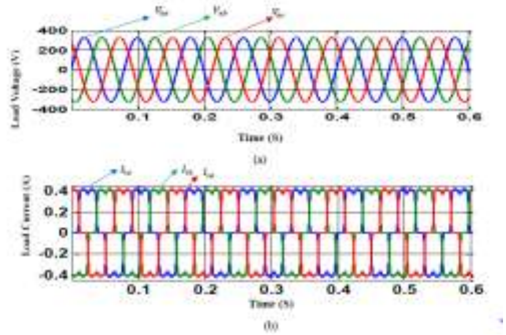

Fig.1.4. Load Voltage & Load Current waveform of the nonlinear load: (a) Load voltage (b) Load current

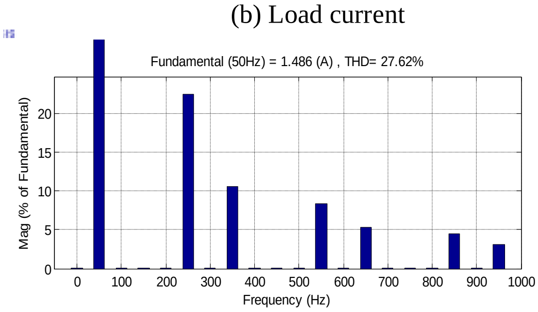

Fig.1.5. FFT Analysis describing THD of Source Current under nonlinear load without compensation

The compensation which is suited in this thesis is shunt compensation. the shunt compensation is placed at the center of the source current to the nonlinear load. This can be absorbed in the Fig 1.8 in this chapter that can be attached at the point called as the Point of Common Coupling (PCC). AC source is having the different kinds of the loads there are linear and nonlinear loads. The nonlinear loads like power converter and solid-state drives that use high speed are main source of harmonics in the power system. The harmonics in the system make disturbances such as the increasing the heating in the transformers, power factor is going to low, torque pulsation in motors, overvoltage by resonance, and the harmonic voltage and the current drops across the network, poor utilization of distribution plant also effect other loads connected at the PCC. Customarily, the passive filters are used in the compensation of the harmonics distortion in the distribution system.This type of the filters consist of the resistance, inductance, and the capacitance elements are adjusted to control harmonics. This filter is connected to the system in shunt with the distribution system and is adjusted to present low impedance to particular harmonic current. However, this filter is not frequently used for low voltage and the intermediate voltage applications since it is intricacy and dependability factors are matter of anxiety. It also receives several shortcomings such as ageing and modification problems, resonance that affects the constancy of the power distribution systems, bulky in size and also fixed compensation. To solve this problem, different configuration of static VAR compensation (SVC) has been projected. Unfortunately, some SVC causes lower order harmonics themselves and the response time of the SVC system may be too long to be suitable for fast fluctuating loads. Recent trends the Active Power Filter (APF) or Active Power Line Conditioners (APLC) are developed for the compensation of harmonics and reactive power instantaneously.

APF filter can be connected in the series and shunt and the combination of the both as well as the hybrid configurations. The shunt APF is commonly used than the series APF, because most of the industrial, commercial and domestic application need current harmonic compensation.

The main disadvantage of the AC source current connected to nonlinear load is

1. The main disadvantage is harmonic distraction because of the nonlinear characteristics.
2. One of the main draw backs is that due to the harmonic effect the THD (%) is high as per the IEEE standards > 5% makes the system collapse permanently with in the less time period.
3. Due to the supplying of the both fundamental and the ripple current the PF is not in the unity and makes the source current to be unbalanced.
4. The THD percentage can be seen in the Fig 1.5 can be seen as per the result we are going to compensation technique.

1.3 COMPENSATION TECHNIQUE

Now a days all electronics are nonlinear loads makes the entrance of the dangerous phenomenon of power quality problem in the electrical feeder networks, constructing distortions have created problems in the design of AC power system. Several technologies have been developed utilizing power electronics-based perceptions which are capable of mitigating the problems of power quality.

1.3.1 Passive Filters

Most commonly used method for the mitigation of harmonics is to install the passive filters in the DSTATCOM side. The passive filter is connected to the system in three-phase is connected after the DSTATCOM for the mitigation of the harmonics which are generated in the voltage source inverter (VSI) and tuned the system in particular frequency, thus provides the system in to the good solution because of their high efficiency, low cost and simplicity. This filter is used as either inject in series high impedance to block the harmonic current. Series connected filter are impetrated to full line current and has lower reactive power compensation. But the shunt filter makes more perfection to the system.

Whereas the LC filter are prone to the source sink resonance. LC filter attacks harmonic current from harmonic constructing loads and upbringing distortion of grid value. The Fig 1.6 shows the Block diagram of the passive filter in this Fig the passive elements are used to mitigate harmonics in the system the filter is three-phase connected to the DSTATCOM. In the passive filter R, L, C are used.

1.3.2 Active Filters

Comparing the passive filters, the Active filter makes the system runs more perfect. This filter has the capable of the eliminate the harmonics easy than that of the passive filter and also comparing to the passive filter Active filter has the low losses and also easy for the elimination of the harmonic distraction which is coming from the VSI [16].

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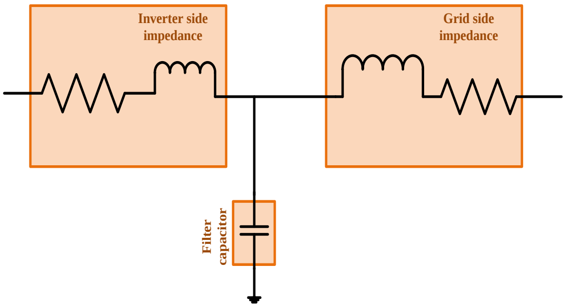

Fig.1.6. Block diagram of the passive filter

The active filter is the connection of the passive elements in the parallel to the filter and it is shown in the Fig 1.7 in this Fig the filter is having the parallel connection of the capacitance and the resistance to the LCL filter the main advantage to this filter is that we can get better performance for the correction of the harmonic's in the VSI the IGBT switches are used because the IGBT switches gives the turn off and the turn on in the particular time and it gives the best option to the VSI. The IGBT is a bipolar transistor so that it gives the switching.

Due to the high PWM switching frequency of the DC-AC VSI, the output of the inverter consists of equivalent high frequency pulses that contain a wide range of harmonic components. To prevent these types of the harmonics injected in to the distribution network, a passive low pass filter is placed at the output of the VSI to reduce the high frequency harmonic components. In the Fig 1.7 is the Block diagram of the Active filter which shows the parallel connection to the series passive element's this can be give the good performance and this can be described in the chapter 4 with MATLAB simulation results by using the Active filter we can be clearly absorbed.

1.4 Shunt Compensation With Filter

The shunt compensation is connected in the middle of the PCC to send the ripple current to the nonlinear loads it is seen in fig 1.8 shows the compensation technique in which the compensation has connected in shunt to the source current.

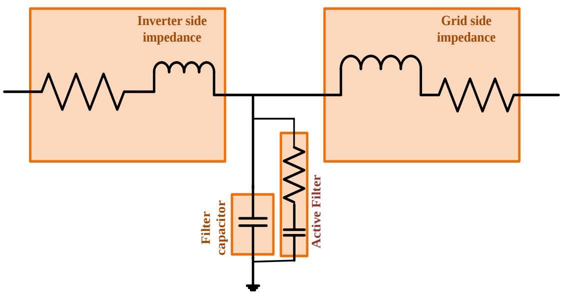

Fig.1.7. Block diagram of the Active filter

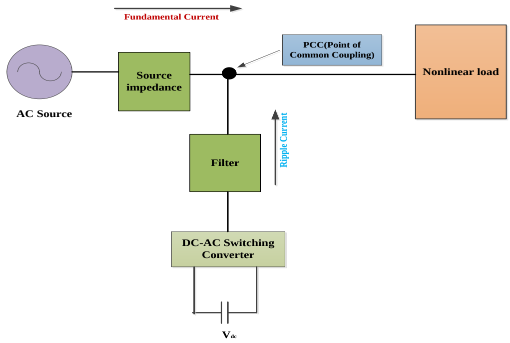

Fig.1.8. Shunt Compensation connected to grid

In the current controller PWM technique is used for the Switches to turn on & turn off. The SPWM technique is used in the PWM for the fast response in the two level VSI. The current controller is seen in the chapter 3 and 4 can be discussed and the intelligent controller is used for the reduction of the resonance peak that are occurred in the LCL filter. This occurrence in the passive damping method that can see in the chapter 2 the adding of the damping technique in the current controller the system performance and improves the fastness to the system and we can get the system in the perfect way but the failure of the DC link has occur for the sometime the DC link voltage works as the source to the VSI has discharged we want to replace the DC link this characters are seen in the chapter 4 so that for this we are going for the permanent solution so that by placing the continuous supplying to the VSI we are getting the best performance to the system that can be analyzed by the FFT the THD percentage has to decreased down comparing to the DC link this topic covered in the chapter 4.

1.4.1 SHUNT COMPENSATION WITH THE DIFFERENT FILTERS

To remove the AC components or filter them out in a rectifier circuit, a filter circuit is a device to remove the AC components of the rectified output, but allows the DC components.

The filters are classified in to the many types the few types are

- L (Inductance) filter
- Capacitor filter
- LC (Inductance capacitor) filter
- CLC filter
- LCL filter

In the above types of the filters, we are adding to the DSATCOM. The shunt compensation

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is part of the production of the ripple current in the grid as connected to the middle of the distribution system by the point of the common coupling whereas the DSTATCOM is called as the static device. The STATCOM is the static compensation which is the static device whereas the STATCOM is connected to the distribution system so it is called as the Distribution Static Compensation (DSTATCOM). DSTATCOM is very easy to handle so that we are taking for the compensation the current related problem.We are taking the compensation at the shunt because of the current related problem so that we are placing the compensation at the shunt which is connected to the distribution at the point of the common coupling (PCC) Fig 1.8 can be seen the connection of the DSTATCOM which is connected to the to the filter of the L (inductor filter basically the filters are placed after the voltage sourced inverter because of the high switching ripples are generated in the inverter due to the switches. The generated harmonics in the outside of the inverter can be compressed by the filter. So that we are selected the filter to place after the inverter for not to disturb the system performance. Here we can be seen that they are having the inductance filter after the inverter.

In this L filter is having the good performance but the main drawback to this type of the filter is that they have bulky amount of the inductance is required. The reason behind the bulky amount of the filter is that inductance has very much is used to decrease the harmonics generated by the inverter so that we are going for the improvised method. By placing the filter of the LCL we gating the good economic aspects and we can easily use and the bulky amount has to decreased so that our main motto to place good filter before the inverter to decrease the harmonics which are to be generated by the inverter switches.In the Fig 1.10 shows the LCL filter which is showing the good performance of the L filter but whereas the LCL filter shows the small problem related to the resonance peak is the problem identified in the system of the LCL filter usage. We are giving the solution to the LCL filter and make the LCL filter easier and we are using the LCL filter with best performance and we are going to the more focus on the filter of the LCL with the total harmonic distortion can be seen the difference with damping method is used for the resonance problem solution

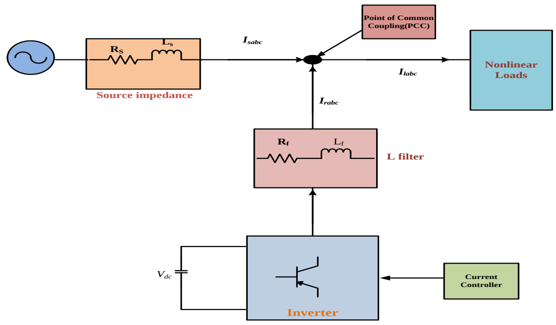

Fig.1.9. Block Diagram of the DSTATCOM with L filter.

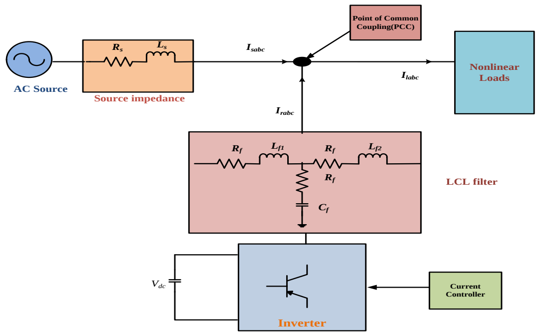

Fig.1.10 Block Diagram of the DSTATCOM with LCL filter

In our work we are going to extending the work to supplying the voltage to the inverter at the continuously without any interruption. We are placing the renewable energy source at in front of the inverter. In the Fig 1.10 can be seen the v_{dc} at the Infront of the inverter. Here the dc voltage works as the source to the inverter the dc link is the capacitor bank it works as the battery so that we are giving the continuously supply to the inverter.

In the Fig 1.11 shows the attachment of the renewable energy source in front of the DSTATCOM can be seen and also performance also improved according to the continues flow of the power.

1.4.2 PERFORMANCE OF THE DSTATCOM IN POWER SYSTEM

DSTATCOM is a shunt-connected custom power device. The primary aims of which are power factor correction, current harmonics filtering, load DC offset cancellation, load balancing.

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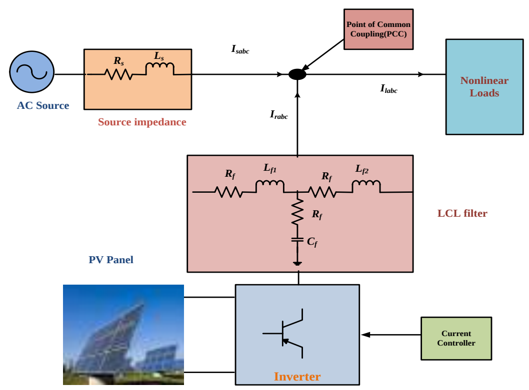

Fig.1.11. Block Diagram of the PV based DSTATCOM with LCL filter

It can also be used for voltage regulation at a distribution bus. Being an active filtering device connected in shunt with the harmonic-producing load, DSTATCOM is often referred as shunt or parallel active power filter. DSTATCOM consists of a voltage source PWM converter equipped with a dc capacitor as storage element, interface inductor and matching transformer.The shunt active power filter based on Voltage Source Inverter (VSI) structure is an attractive solution to harmonic current problems. The shunt active filter is a Pulse Width Modulated (PWM) voltage source inverter that is connected in parallel with the load. Active filter injects harmonic current into the AC system with the same amplitude but with opposite phase as that of the load.

The principal components of the APF are the Voltage Source Inverter (VSI), DC energy storage device, coupling inductance and the associated control circuits. The performance of an active filter depends mainly on the technique used to compute the reference current and the control strategy followed to inject the compensation current into the line. The use of two or more PWM voltage source inverters connected in cascade is an interesting alternative to compensate high power nonlinear loads. Connecting in cascade two VSIs with different rated power allows the use of different switching frequencies, reducing switching stresses, and commutation losses in the overall compensation system. Of these two VSIs, one compensates for the reactive power demand and lower frequency current harmonics, while the other one compensates only high frequency current harmonics. The first converter requires higher rated power than the second and can operate at lower switching frequency.

There are two major approaches that have been proposed in the literature for harmonic detection, namely, frequency domain and time domain methods. The time domain methods require less computation and are widely followed for computing the reference current. The two mostly used time domain methods are synchronous reference (d-q-0) theory and instantaneous real-reactive power (p-q) theory.

1.5 KEY ISSUES

- Various technical issues need to be addressed during the operation of a grid-connected PV system like power quality, grid synchronization.
- Generally, grid-connected PV system may be used as DSTATCOM for power quality improvement.
- Basically, DSTATCOM consists of voltage source inverter and filters.
- During the PWM switching operation of voltage source inverter high frequency switching ripples are generated.
- Conventionally L/LCL/LC filters are used after the voltage source inverter in DSTATCOM.
- Switching ripple attenuation capacitor of the L/LC filter is not up to the mark during the dynamic condition of DSTATCOM operations.
- LCL filter is alternative solution to filter out the switching ripple in the better way compared L/LC filter.
- The major problem associated with the LCL filter is the resonant peak at the resonant frequency which can affect the stability of the system.
- Basically, damping methods are used to damp resonant peak of the LCL filter.
- Designing active damping method for LCL filter along with current controller is one of the key issues in the PV based DSTATCOM circuit.

II. PERFORMANCE OF THE DSTATCOM WITH PASSIVE DAMPING

INTRODUCTION

In the before chapter, we are had a discussion on the overview and the performance of the filters. In which suitable filter is taken place for the good performance to the system for the satisfy of the nonlinear loads. Basically, nonlinear loads are having the property of the combination of the fundamental and ripple current. the source current is going to affect so that we are going to place a compensation technique called as the shunt compensation technique. In which this compensation is having the series and shunt compensation is having we are selected shunt compensation.The shunt compensation is also

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known as the STATCOM. It is the static compensation which is not a rotating part and the STATCOM which is connected to distribution side it is called as the DSTATCOM (Distribution Static Compensation). The DSTATCOM is a device consist of the VSI (Voltage Source Inverter) and DC link which is connected in front of the inverter. The DSTATCOM is connected parallel to the load at the PCC (Point of Common Coupling) through the interference filter the block diagram can be seen in the previous chapter 1 below we can see the shunt compensation and its parts by one by one with brief.

2.1 SHUNT COMPENSATION

The VSI based shunt APF is mostly used. It is connected parallel to the nonlinear loads. The APF is used for the mitigate the harmonics that are generated by the VSI. The Fig 2.1 block diagram of the shunt compensation that is sending the ripple current to the nonlinear load and it is attached to the PCC this is clearly seen in the Fig.2.1. shunt compensation is having the harmonic problem because of the continuous switching generated by the VSI we want to decreases the harmonic impact to the system so that there is no black out will occur if not the system is to be collapse so that proper filtering is to done to the shunt compensation. The filters we are taken is inductance (L), inductance capacitance (LC) and the inductance capacitance inductance (LCL) are taken for the improvement of the system performance.

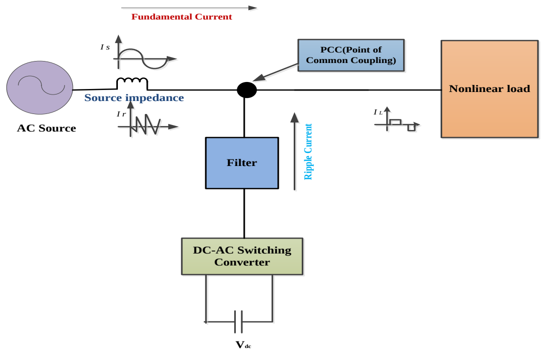

Fig.2.1. Shunt APF Circuit Diagram

2.2 CURRENT CONTROLLING IN DQ0 REFERENCE FRAME

The performance of the DSTATCOM depends on the control algorithm used for extraction of reference current components. For this purpose, many control schemes are reported in literature, and some of these are instantaneous reactive power (IRP) theory, instantaneous symmetrical components, synchronous reference theory (DQ) and the current compensation using DC link. SRF theory is most widely used for the current controlling technique.Synchronous reference frame theory also called as the DQ frame theory. the main advantages for the selection of the SRF theory is the number of the voltage equation are required. The time varying voltage equation become time invariant ones. Performance of the power systems and electric machines can be analyzed without complexities in the voltage equation. The reference current extraction method is classified into time-domain and frequency-domain. The time-domain method is used to extract the reference current from the harmonic line current with simple algebraic computation. The frequency domain based on Fast Fourier Transformation (FFT) method provides accurate individual and multiple harmonic load current detection. The merit of time-domain method has fast response compared to frequency-domain.

The time domain based synchronous reference frame theory is utilized to extract the reference current from the distorted line current. The SRF control strategy operates in steady-state as well as in dynamic-state perfectly to control the active power line conditioner in real-time application. Another important characteristic of SRF theory is the simplicity of the calculations, which involves only algebraic calculation.

A block diagram of the control scheme is show in below Fig.2.2. The load current (IL_a,IL_b,IL_c,), the PCC voltage (VT_a,VT_b,VT_c,), and DC voltage (V_{dc},) of the DSTATCOM are as feedback signals. The load currents from the a-b-c frame converted to the $\alpha - \beta$ frame and then to the d-q frame using the following formation.

$$\begin{bmatrix} IL_\alpha \\ IL_\beta \end{bmatrix} = {}^2/_3 \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -\sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} IL_a \\ IL_b \\ IL_c \end{bmatrix}$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

The PLL-circuit is provided that the vectorized fundamental frequency for synchronization. The i_d iq currents is conceded through a low pass filter to filter the higher order harmonic components and permit fundamental frequency components. The PI-controller is used to eliminate the steady state error of the dc-component and maintains the dc-capacitance voltage of the VSI. The proportional and integral gains determine the dynamic response and settling

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time of the dc-voltage respectively. To minimize the inverter losses by preserving the dc-voltage constant or within limits, the required current is added to the positive sequence fundamental frequency active component of the d q current. The desired reference current (a b c stationary frame) is calculated from i_d $i_q$rotating frame using inverse transformation.

The extracted reference current is compared with actual currents and hence generates the required switching pulses for the inverter using indirect PWM-current controller. However, the conventional-SRF control strategy requires a PLL-circuit based on the supply voltage for vector orientation.

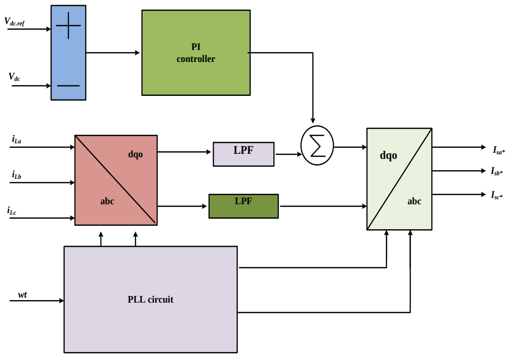

Fig.2.2. Block diagram of the conventional-SRF method

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta \\ \sin(\theta - 2\pi/3) & \cos(\theta - 2\pi/3) \\ \sin(\theta + 2\pi/3) & \cos(\theta + 2\pi/3) \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix}$$

But the design of a high performance PLL-circuit is difficult, when various non-idealizes like multiple zero crossing are occurring in the supply voltage. A simple and efficient method is used to calculate the unit vector, which is incorporated with the modified- SRF method.

2.3 PERFORMANCE ANALYSIS OF PASSIVE DAMPING IN L FILTER

Three phase DSTATCOM consisting of the VSI connected at the PCC through the inductance filter shown in below Fig. Filter is used for the reduce of the high switching ripples are generated by the inverter. The L filter has the no resonance property, but the first order L filter is bulky because it is required to have sufficient ripple attenuation.

The L-filter is a first order filter having 20dB/decade attenuation over the whole frequency range. So, this type of filter has its application with converters having high switching frequency where the attenuation is sufficient. The L-filter topology is as shown in Fig. 2.2 and the transfer function of the L-filter is-

$$f(s) = \frac{1}{LS}$$

Table1: System Parameters

Parameters	Value
AC source voltage and frequency	V_s=400 v, 50Hz
Line impedance	L_s=40mH, R_s=1.57Ω
Nonlinear load	R_d=125 Ω , L_d=30mH
Power converter	IGBT
Filter parameters	L Filter L=15mH LC Filter L=8mH, C=2.5μF LCL Filter L1=4mH, L2=2mH, C=2 μF
DC link	V_{dc}=550v C=3300 μF

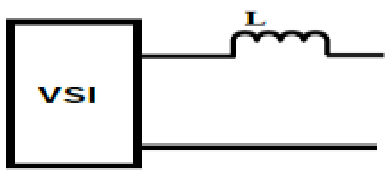

Fig.2.3. Equivalent circuit diagram of VSI with L filter

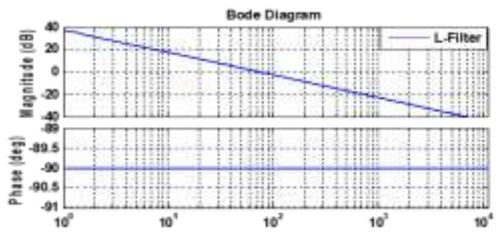

Fig.2.4. Transfer function of L filter

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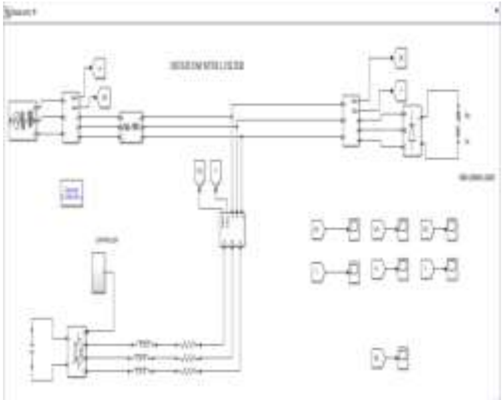


Fig.2.4.1 Simulink diagram of DSTATCOM with L Filter

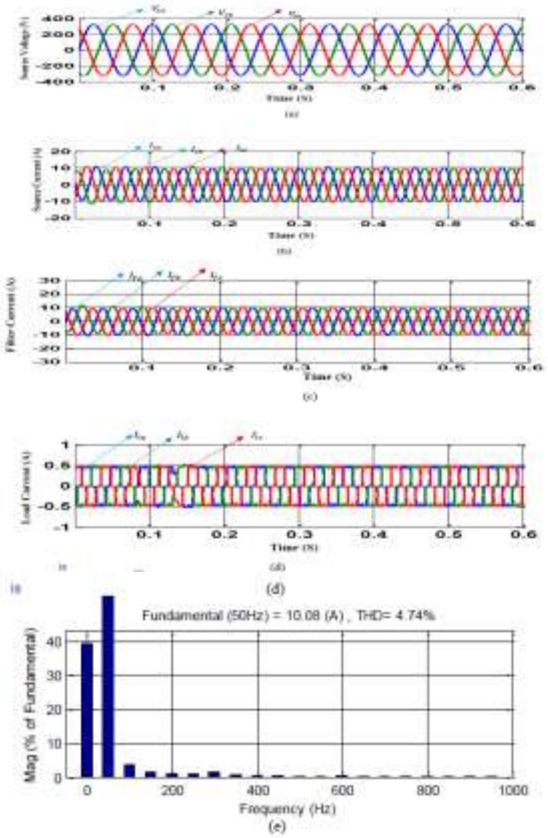


Fig.2.5 Simulink diagram of DSTATCOM with L Filter connected to the DSTATCOM: (a)Source Voltage (b) Source Current (c) Filter Current (d) Load Current (e)Source Current Total Harmonic Distraction (THD%).

2.4 PERFORMANCE ANALYSIS OF PASSIVE DAMPING IN LC FILTER

The LC Filter is a second order filter and it has improved dynamic performance than L Filter. Also, the LC filter shows good performance in terms of current-to-voltage conversion and noise damping. If the grid-impedance is high compared to $1/(2\pi fC_f)$. On the other hand, the filter capacitor may be exposed to line voltage harmonics, which result in large currents. The per phase equivalent model of the LC Filter is shown in Fig. 2.3

$$f(s) = \frac{1}{cLs^2 + RCs} \quad (2.8)$$

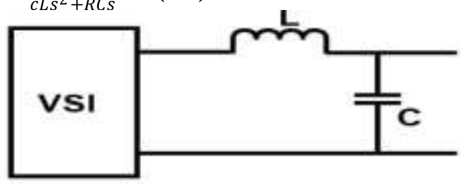


Fig.2.6. PWM VSI with LC-Filter

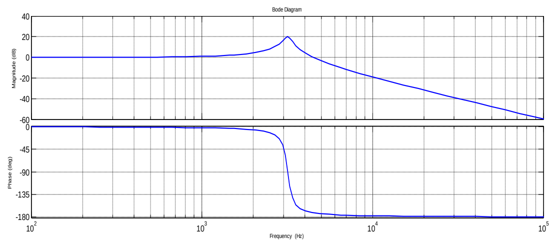


Fig.2.7. Bode plot of LC filter

This simple configuration is easy to design and it works mostly without problem. The second order filter provides 12dB per octave of attenuation after the cut-off frequency, it has no gain before cut-off frequency, but it presents a peaking at the resonant frequency. The bode plot of the LC-Filter is shown in Fig. 2.7. In order to suppress the negative behaviors near cut-off frequency the damping circuit is added to the filter. The damping can be either series or parallel. The own design of the filter is a compromise between the value of the capacity and inductance. The high capacity has positive effects on the voltage quality. On the other hand, higher inductance value is required to achieve demanded cut-off frequency of the filter. Connecting system with this kind of filter to the supply grid, the resonant frequency of the filter becomes dependent on the grid impedance and therefore this filter is not suitable too.

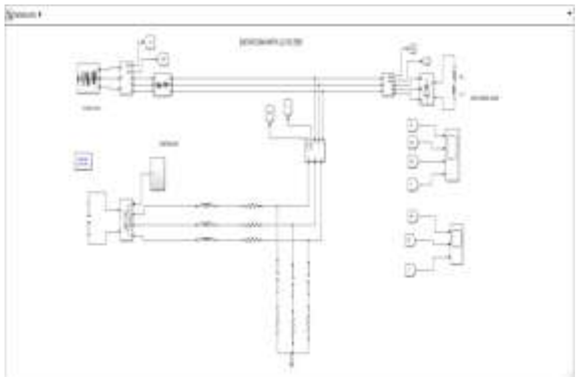


Fig.2.8 Simulink diagram of DSTATCOM with LC filter

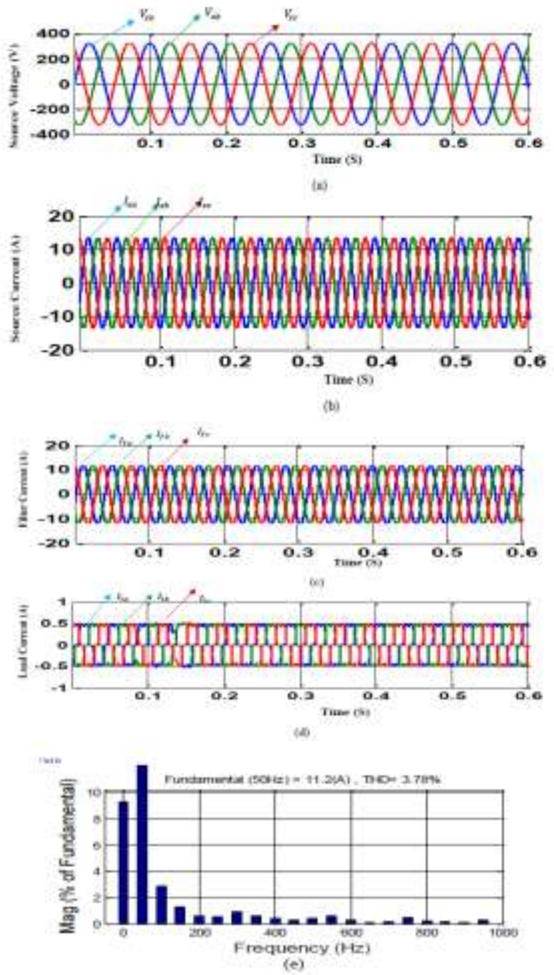


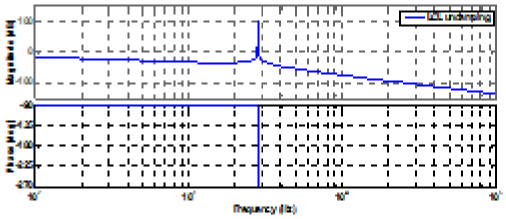
Fig.2.8.1 Simulation results of the LC filter with the passive damping: (a)Source Voltage (b) Source Current (c) Filter Current (d) Load Current (e)Source Current Total Harmonic Distraction (THD%).

2.5 PERFORMANCE ANALYSIS OF PASSIVE DAMPING IN LCL FILTER

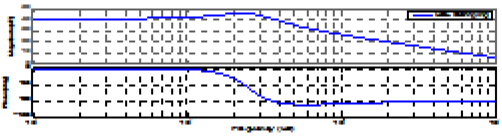
Commonly a high-order LCL filter has been used in place of the conventional L-filter for smoothing the output currents from a VSI. The LCL filter achieves a higher attenuation along with cost savings, given the overall weight and size reduction of the components. LCL filters have been used in grid-connected inverters and pulse-width modulated active rectifiers because they minimize the amount of current distortion injected into the utility grid. Good performance can be obtained in the range of power levels up to hundreds of kW, with the use of small values of inductors and capacitors. The higher harmonic attenuation of the LCL filter allows the use of lower switching frequencies to meet harmonic constraints as defined by standards such as, IEEE-519 and IEEE-1547. However, it has been observed that there is very little information available describing the systematic design of LCL filters. The attenuation of the LCL Filter is 60 dB/decade for frequencies above resonant frequency, so, lower switching frequency for the converter can be used. It also provides better decoupling between the filter and the grid impedance and lower current ripple across the grid inductor. The per phase equivalent model of the LCL Filter is depicted in Fig. 2.11 and the corresponding frequency response of the LCL Filter is shown in Fig. 2.11. The LCL Filter has good current ripple attenuation even with small inductance values. However, it can bring also resonances and unstable states into the system. Important parameter of the filter is its cut-off frequency. The cut-off frequency of the filter must be minimally one half of the switching frequency of the converter, because the filter must have enough attenuation in the range of the converter's switching frequency. The cut-off frequency must have a sufficient distance from the grid frequency too.

Transfer function of the filter with damping resistor is depicted in Fig. 2.9(b). The peak near resonant frequency has nearly vanished. This is simple and reliable solution, but it increases the heat losses in the system and it greatly decreases the efficiency of the filter. This problem can be solved by active damping. The resistor reduces the voltage across the capacitor by a voltage proportional to the current that follows through it. This can be also done in the control loop. The current through $C_f$is measured and determined by the term C_fR_{sd}. A real resistor is not used and the calculated value is subtracted from the demanded current. In this way the filter is actively damped with a virtual resistor without losses. The disadvantage of this method is that an additional current sensor is required and may bring noise problems because it amplifies high frequency signals. But this is a third order filter which is difficult to be stable and introduces resonance. Soto damp out the resonance active and passive damping methods are used.

The transfer Function of the LCL-filter with active and passive damping methods is given by Equations (2.3) and (2.4) respectively



(a)



(b)

Fig.2.9. Frequency response of the LCL filter (a) without damping (b) with damping

$f(s) = \frac{sL}{L_1L_2s^3+(L_1+L_2)s}$ (For undamped condition)

$f(s) = \frac{CRs+1}{L_1CL_2s^3+(L_1+L_2)s+(L_1+L_2)s^2RC}$ (For damped condition)

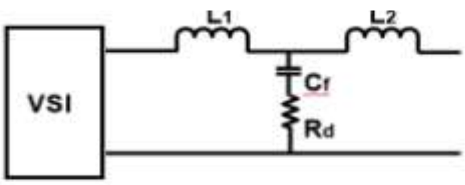


Fig.2.10. PWM VSI with LCL-Filter

$$f(s) = \frac{C_fRs + 1}{L_1C_fL_2s^3 + (L_1 + L_2)s + (L_1 + L_2)s^2RC_f}$$

In passive damping method an additional capacitor 'C' is connected in parallel with filter capacitor and resistor.

The bode-plot for different filter topologies is as shown in Fig. 2.9(b) From the bode-plot it is clear that the LCL-filter with active damping method has better performance characteristics when compared with other filter topologies.

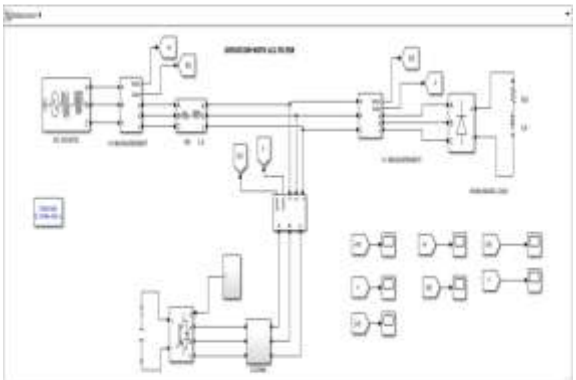


Fig.2.11 Simulink diagram of DSTATCOM with LCLFilter

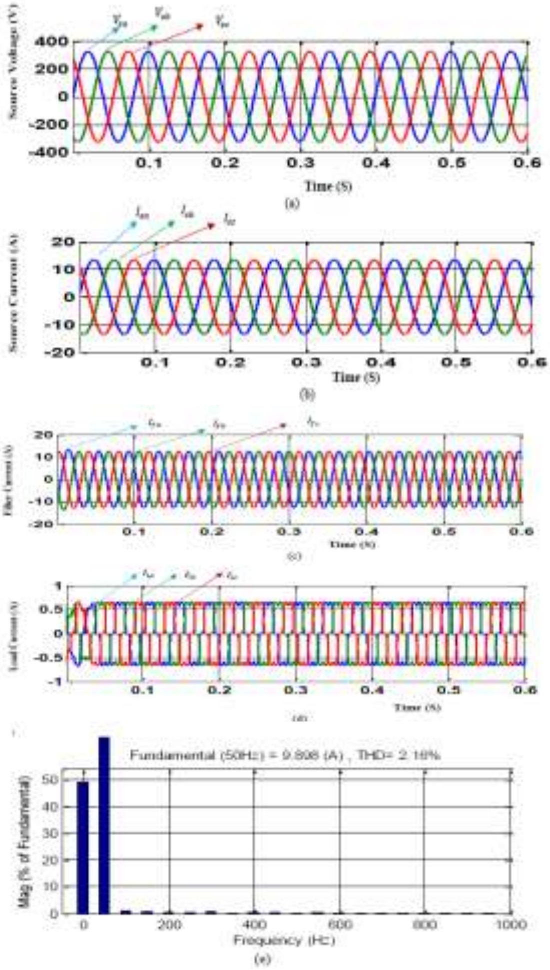


Fig.2.12. Simulation results of the LCL filter with Passive damping (a)Source Voltage (b) Source Current (c) Filter Current (d) Load Current (e)Source Current Total Harmonic Distraction (THD%).

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III. PERFORMANCE OF LCL FILTER WITH ACTIVE DAMPING METHOD

INTRODUCTION

In the previous chapter we are discussed about the Filters selection on which the output of the inverter having high switching ripples are generated in order to reduce this ripple we need proper filter so that we had a deep discussion on the filter selection.

In this discussion we had some important points related to the selection of the filter that is discussed in the previous section. Mainly L filter behavior is good and it doesn't have any ripple factor but it is bulky amount of inductance need for the decrease of the switching ripple generated by the inverter. This was the main drawback of the L filter. After that we had an LCL filter for making L filter disadvantage to advantage. In this filter it is easy and cheap cost and have better performance. But this have the only one disadvantage that is resonance peak at the resonance frequency. This disadvantage can be overcome by the active method. That can be shown below by using the active damping method.

3.1 CONTROL TECHNIQUE

Current controller is realizing in synchronous rotating dq0 reference frame in this study. The dq0 current controller of Fig.3.1 is shown below. This block consists of actual filter currents (If_d, If_q, If_o), capacitor current (Ic_d, Ic_q, Ic_o), PCC voltage (Vt_d, Vt_q, Vt_o) as the inputs and control signals (U_d, U_q, U_o) as outputs. This current controller consists of two feedback loops. One, inner capacitor current feedback loop with constant kc for resonance damping. This loop consists of cross coupling terms and voltage feed forward terms (V_{td}, V_{tq}), these terms help in decoupled control of d,q controller. The purpose of c_f in the actual physical system is to provide path for low amplitude switching current ripple.Therefore, the cross-coupling term introduced by c_f is neglected and those due to Lf12 are only considered. Seconded loop is actual injected filter current feedback loop. This loop consists of current regulator is PI regulator is used zero steady state error can be achieved by applying PI regulator. If the reference current is a dc quantity (i.e., fundamental frequency component of filter current, which appears as dc quantity in dq0 frame) given by

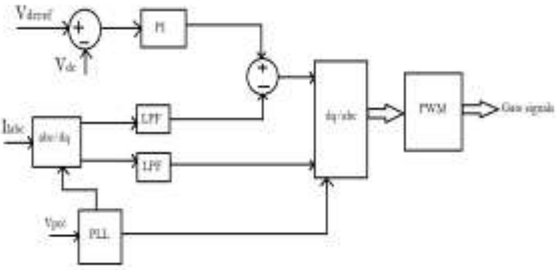

Fig.3.1. Active Damping method of synchronous reference frame theory

However, if the refence current is an oscillating signal (harmonic current, which appear as oscillating components in dq0 frame), the conventional PI regulator due its limited frequency of gain will cause steady state error.

The output of this PI is reference capacitor filter current, which is the input for the inner loop. The dq0 current controller results in the generation of the control signals U_d, U_q, U_o. These control signals rotating at w in dq0 reference frame, are transformed to stationary abc frame to obtain modulating signals V_{Ma}, V_{Mb}, V_{Mc} are given in the above equation. Switching signals of the Sa, Sb, Sc, Sa', Sb', Sc' are the top and bottom switches of the voltage source inverter (VSI) with respectively they are generated by the pulse width modulation of sine pulse width modulation (SPWM) strategy with modulating triangular carrier signals as inputs.

3.2 SYSTEM STUDIES WITH PIREGULATORS

According to the design procedure discussed in the chapter 1 the obtained parameters of L_{f1}, C_f, L_{f2} of LCL filter are presented in the block diagram in the chapter 1. here we are arranging the values of the parameters according to the system requiring. The objective of the DSTATCOM is to compensate up to 19th harmonic (n=19) in three phase 12.5kVA load ,400v, 50HZ system. The maximum current rating of DSTATCOM is taken as 25A (peak).

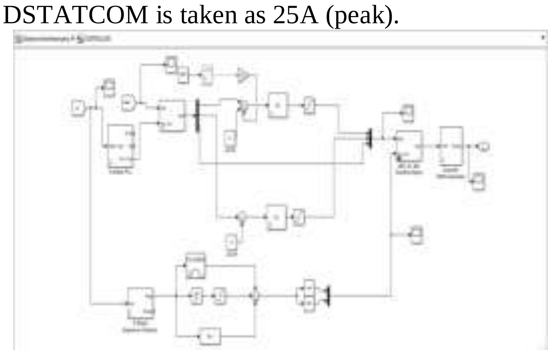

Fig.3.2 Control Scheme of the LCL Filter with Damping.

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Therefore LF1=4.5mH is obtained in the below equation

$$Lf_1 = \frac{V_{dc} D(1-D)}{f_{sw} \delta I_{p-p}}$$

Whereas the Vdc is the dc link, δI_{p-p} is the peak-to-peak inductor ripple current expressed as the percentage of maximum current through the inductor and fsw is the switching frequency of the triangular carrier signal at the 10KHZ is taken and the Vdc link at the 650 v is taken and the capacitor is taken at the 3300μF is taken here the duty cycle switch is at the worst case of the ripple is 0.5.Once the L filter is designed, LC filter is added to form the Third order filter, the aim of the LCL filter is to reduce the switching frequency ripple in source voltage and current. The below is having the simulation results of the Active damping of LCL filter that can show below.

The above THD value is 0.52%. there is improvement in the THD value where the resonance peak is decreased by using new technique called as the active damping method is used in the SRF theory. The resonance peak at the resonance frequency is to reduce by using the active damping method in the synchronous reference frame theory. That can be absorbed at the above the simulation. They have the difference in the Total Harmonic Distortion in the before THD we can absorbed the difference passive and active damping.

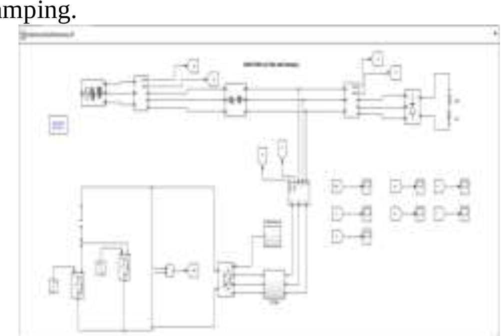
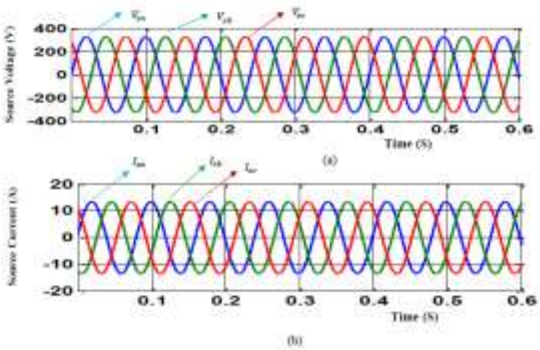


Fig.3.3 DSATCOM LCL Filter with Damping



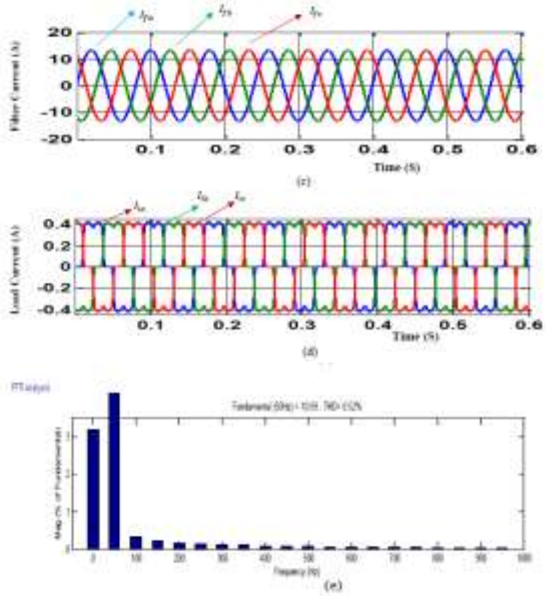


Fig.3.4. Simulation results of the Active damping of the LCL filter with the nonlinear load: (a)Source Voltage (b) Source Current (c) Filter Current (d) Load Current (e)Source Current Total Harmonic Distraction (THD%).

Present work of the project is that we want to take LCL filter for the economic purpose and to sort out the disadvantage of the LCL filter by using the active damping method.

IV. PERFORMANCE OF PV BASED LCL FILTER WITH ACTIVE DAMPING METHOD

OVERVIEW

In the before chapter 3 we had discussion on the Active damping method and on the performance of the LCL filter is seen in the before chapter. In the comparison of the passive method (shown in the chapter 2) and the Active method (shown in the chapter 3) of the damping methods we get a better performance in the Active damping method than that of the passive damping method.

By using the active damping method, we get a good performance in the power quality and by adding the renewable energy system like solar energy (or) wind energy etc..., can be taken as the power suppling to the DSTATCOM. By adding the PV panel in front to the DSTACOM can be get the continuous power supply to the DSTATCOM without any interruption to the system.

The main reason regarding to the adding of the PV panel (or) any type of the renewable energy resources is to continues supply without any interruption can be done in the convention method we are placed a capacitor as a supply to the

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DSATCOM. But the capacitor has the property of the discharging if any interruption is carried out in the shunt compensation, they have problem in the source current is to have damage. So that we are taking proper precaution on before any type of the damages occurring.

In this chapter we are going to discuss the importance of the renewable energy now a days and the PV panel properties can see below, and the simulation results are to be absorbed in below.

4.1 PERFORMANCE OF LCL BASED DSTATCOM IN DC LINK FAILURE

The performance analysis of the LCL filter from the chapter 3 we are having the good performance than before but the performance is good but the failure has come due to the discharging of the dc link in shunt compensation the Fig 4.1(a) shows the DC link is gone to turn off from the 0.3 to the 0.5 region this region the system is gone to be at unstable mode or unbalanced condition.

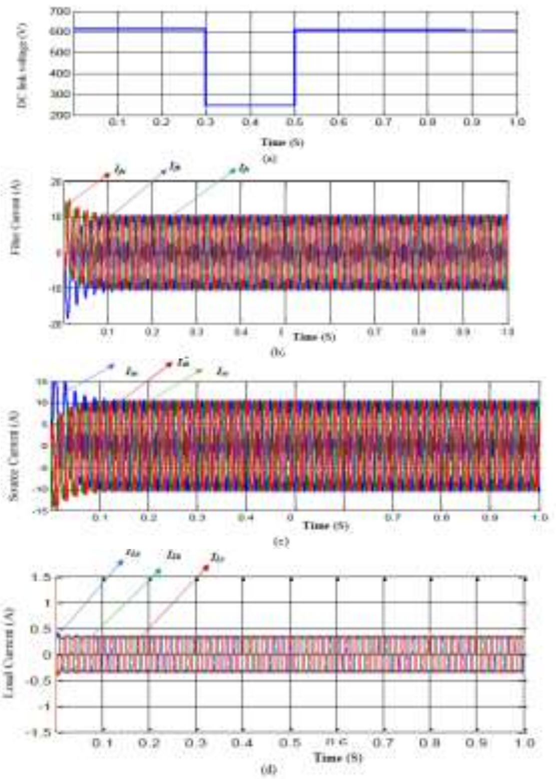


Fig.4.1. Performance of the DC link :(a) DC link (b) filter current (c) source current (d) load current

As per the study of the property of the battery it is going to be discharged after some time so that we ah veto replace always. For this we are going to place the permanent solution to this problem so that we can be overcome this problem.

So that we are taking the PV panel for the permanent solution of the discharging behavior of the DC link. By giving the PV panel the performance of the LCL filter with nonlinear load takes the best performance we can be seen in the Fig.4.3 that the FFT analysis have shown the better performance of the LCL filter in the Active damping method with PV panel.

4.2 PROPOSED METHOD OF PV PANEL WITH LCL FILTER:

The proposed method we are used the PV panel as the votage to the inverter as shown in the Fig.4.2 in the below Fig.4.2 we are placing the continuous flow of the voltage to the inverter. In this we are having the parameters are placed as per the Table 2.1 in it the source voltage and the source impedance are taken same and the filter parameters are taken as per the LCL filter parameters shown in the table 2.1. the PV panel gives the better performance as comparing of the LCL filter with Active damping method hence we are shown in the simulation results about the improvement of the performance. Hence the we are going to the PV panel for the best harmonic reduction in the system.

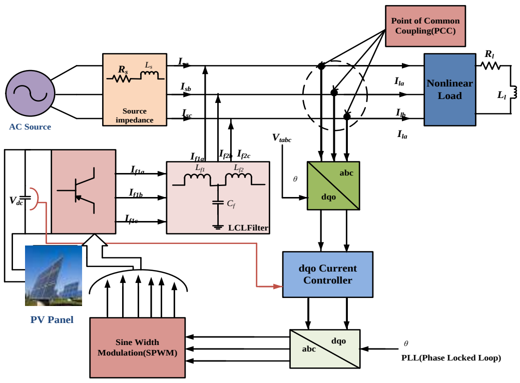
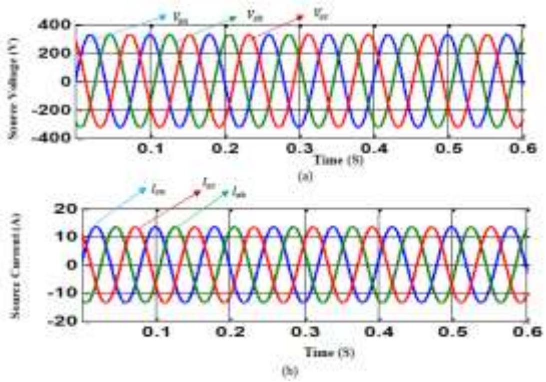


Fig.4.2. Block diagram of PV based DSTATCOM with LCL filter



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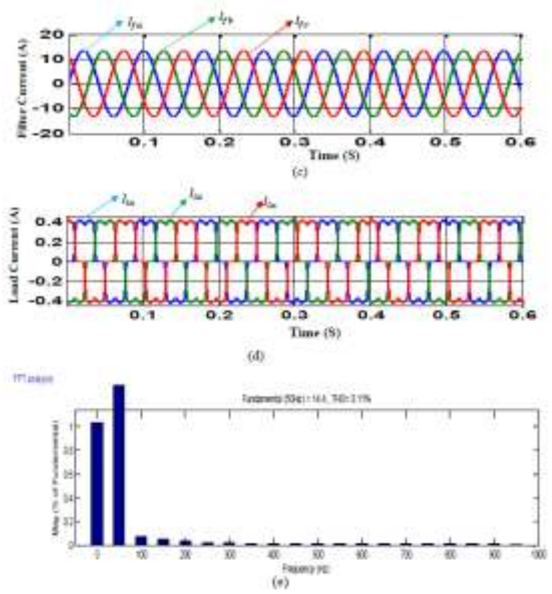

Fig.4.3. Simulation results of the LCL filter with Active damping with PV panel: (a)Source Voltage (b) Source Current (c) Filter Current (d) Load Current (e)Source Current Total Harmonic Distraction (THD%).

V. CONCLUSIONS

5.1 CONCLUSION

Now-a-days, the addition of renewable energy sources to the grid is one of the most deliberated subjects in power industry. There are plentiful issues and challenges concerning grid interconnection.

The harmonics present in the injected grid current is one of the major issues. To overcome these problems, LCL filter can be used which filters the harmonics. But it suffers from the resonance problem. In order to overcome these problems, active damping methods have been proposed in this project. And also, the control of grid connected inverter with LCL filter is studied and analyzed.

5.2 FOLLOWING WORK CARRIED OUT IN THIS PROJECT

- ❖ The grid connected RES system has been presented.
- ❖ The importance of the L, CL, LCL filter for grid interconnection and the advantage of LCL filter has been explained.
- ❖ The basic control strategy of grid connected inverter has been explained.
- ❖ Active and passive damping methods to damp out filter resonance have been proposed.
- ❖ A comparative study of dissimilar filter topologies has been made with the MATLAB/SIMULINK the succeeding simulations were done.

Simulation of 3-ϕ grid connected PV panel with shunt LCL filter under steady state and source dynamic forces conditions. From this simulation it is found that the shunt LCL filter has improved characteristics and suits well for grid interconnection as it rises the fundamental grid current inserted by the RES.

5.3 FROM THIS PROJECT THE FOLLOWING CONCLUSIONS ARE MADE

- ❖ Among the different filter topologies present in the prose, the LCL filter best suits for grid interconnection application.
- ❖ The active damping method of LCL filter has better reply with reduced THD of grid current which is in IEEE standards.
- ❖ The passive damping method of LCL filter is a low-cost solution and is used where effectiveness can be sacrificed slightly.
- ❖ The shunt connected LCL filter with sponging elements has better act than the series linked filter and increases the power inserted into the grid.

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