# Active Power Controller based DSTATCOM Controller Scheme for Distorted Load Compensation

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***Abstract*** **- Most of the loads in steel plant and other major industries are arc welding, furnace and motor operating. These loads are in particular non-linear and very distorting in nature disturbs voltage or current or both. These disturbances are produced because of harmonics produced and also due to large reactive power demand. Such behavior leads to distortions in the source side and will damage all the sensitive loads like computers, lighting loads and other metering devices. Hence compensation of these harmonics plays a vital role. So, in this paper a shunt power quality conditioner called DSTACOM is used for compensation of current harmonics produced due to diode rectified based load. The control scheme adopted is an active power controller based with hysteresis current band. The results are observed in MATLAB/ SIMULINK environment and found the current is compensated effectively.**

***Index Terms*** **- DSTATCOM, Harmonics, current compensation, hysteresis current band control, non-linear load, total harmonic distortion.**

## I.INTRODUCTION

Most of the industrial loads are mostly motoring, lighting, heating and welding type. The steel plant and other metal industries in general use welding and electrical furnaces for heating to produce the desired final products. In this process, these equipment which are in general inductive in nature will draw large reactive current and also due to its non-linear nature will distort the source and load current waveform by injecting large current harmonic components into the system [1]. These harmonics will be fluctuating and will decrease the performance of lighting loads, motoring loads and other sensitive loads. If care is not taken, these harmonics will produce severe heat due to multiple frequencies in the waveform. Therefore the motor windings and chips in the lighting and sensitive loads will be damaged. To overcome this, different types of power quality conditioners are used. These distortions are to me monitored for future reference and suggestions by the electrical safety and maintenance experts [2-3].

The passive filters [4], active filters [5 and 6] are commonly used to improve the PQ. The shunt active power filter (ShAPF) topologies are classified based on the type of power sources (AC or dc, renewable), number of phases (1ph or 3ph), inverter topologies (VSI or CSI) [6]. They use of isolation transformers, use of neutral current compensation transformers, number of switching devices, advanced strategies (multi-level inverters) control strategy etc. The purpose is the cancellation of harmonic components through the generation of opposing frequencies that cancel out those produced by loads. Single-phase active power filters are classified into two topologies namely, current-source inverter (CSI) and voltage source inverter (VSI) [7]. CSI based APFs are inductor-based energy storage devices whereas VSI based APFs are fed from the energy stored in the capacitor. The performance of three phases three-wire VSI [8] and three-phase four-wire VSI [9, 10].

The remaining sections are planned as the Section II describes the topology adopted in the paper and the section III discusses the control scheme. The section IV describes the result analysis and discusses the operation of the proposed control scheme for a distorted load and the conclusions are discussed in the section V. The parameters adopted in the system are given in the appendix and finally references are at the end of the paper.

## II.TOPOLOGY OF THE PROPOSED DSTATCOM

The distribution static compensator abbreviated as DSTATCOM is used for low and medium power quality improvement operations when the load is mostly non-linear and distorted in nature. This DSTATCOM is a shunt device connected near to the distorting load to absorb the harmonics produced thereby the remaining part of the line from this point towards the source will be pure sinusoidal and least distorting. This DSTACOM is almost like shunt active power filter except few small topological differences observed. Different topologies are discussed in the literature and few are them are given in the references at the end of the paper [8, 9, and 28]. The topology proposed in this paper is shown in Fig.1.

The system contains healthy three phase three wire source represented as Ea, Eb and Ec voltage sources with respective internal impedance for the three phases as La, Lb and LC. The source is supplying power to the load given by Ia, Ib and Ic. The distribution line is represented as inductive with inductance Lla, Llb, and Llc and is connected to a diode rectifier based parallel RC load. This load to small extent distorts voltage waveform near the load and to a major extent current is getting distorted. This distorted load voltage and current will also distort the source and hence influences the loads connected to the source if any. To overcome this, shunt active compensator called DSTATCOM is connected in the shunt to compensate the source voltage and current distortions.

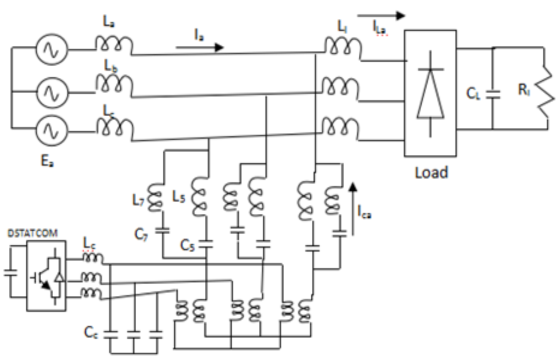


Fig.1 Topology of the proposed DSTATCOM

It can be observed that the DSTATCOM has a mixture of both active and passive filter components. Each leg of the DSTATCOM is connected with 5th and 7th order LC filters which are tuned based on the order of eliminating harmonics and works on the principal of series resonance. Later, the ends of the 5th and 7th order elements are connected to a back to bank inductors for voltage level boosting and current smoothening. A shunt capacitor is used as band-pass filter and also for reactive power support when the dc link capacitor at the end is with low voltage and also helps in quicker charging of the dc link capacitor. These back-to-back inductors and shunt capacitors also help in controlling sudden voltage or surge currents entering in to the voltage source converter (VSC).

The VSC contains a controllable IGBT switch and an uncontrollable diode switch for the three phases with total six switches in operation. When the power conversion is from ac to dc, it is done by the diode and the capacitor will get charged to a voltage of Vdc. The dc to ac is converted in a control fashion using IGBT firing control action. The VSC helps in maintaining constant voltage across the capacitor by charging and discharging through the switches and passive components. When the load or source point under reference is having harmonic component other than fundamental, the DSTATCOM acts like low impedance path because of 5th and 7th harmonic passive filter and higher order filtering with VSC operation. This harmonic current will reach towards the VSC and will be converted to dc with the help of diode bank and will charge the capacitor. This makes the source not influenced by harmonic currents because of distorted load. The charged capacitor will supply the voltage to the VSC and as is shunt connected with almost same voltage at the source or reference terminal, inject pure current which is called as compensating current. Thereby the proposed DSTATCOM will improve the source profile top the major extent by shunt current compensation and load current to a certain extent.

The DSTATCOM voltage (VDS) is given in terms of compensating current (ic) when passing through the passive resistive, inductive and capacitor elements R, L and C in time (t) dependant format is given by the Equation (1). Also the dynamic compensation current can also be represented using this equation can also be seen in this equation.

$$\begin{cases} V_{DS}(t) = i_c(t).R + \dfrac{di_c(t)}{dt}L + \dfrac{1}{C}\displaystyle\int_{-\infty}^{t} i_c(t)dt \\ \begin{bmatrix} \dfrac{di_c}{dt} \\ \dfrac{d^2ic}{dt^2} \end{bmatrix} = \begin{bmatrix} 0 & R \\ \dfrac{-1}{(LC)^2} & \dfrac{-R}{L} \end{bmatrix} \begin{bmatrix} i_c \\ \dfrac{di_c}{dt} \end{bmatrix} + \begin{bmatrix} 0 \\ \dfrac{-R}{L} \end{bmatrix} \dfrac{dV_{DS}}{dt} \end{cases}$$

The simplified compensating current neglecting the second order component is shown in Equation (2)

$$\frac{di_c}{dt} = \begin{bmatrix} 0 & R \end{bmatrix} \begin{bmatrix} i_c \\ \frac{di_c}{dt} \end{bmatrix} \quad (2)$$

The source current (I) is distributed to the load as load current ($I_L$) and the DSTATCOM compensation current ($I_C$) is given in Equation (3) and the reference compensation current can be derived due to the change in the dc link capacitor current ($I_x$) and source additional supply current ($I_y$) is given in Equation (4) as shown below

$$I(t) = I_L(t) + I_c(t) \quad (3)$$

$$I_c(t) = I_x(t) + I_y(t) \quad (4)$$

## III. PROPOSED ACTIVE POWER CONTROLLER SCHEME FOR THE DSTATCOM

The control scheme of the proposed active power controller is shown in the figure 2. The objective of the controller is to absorb the harmonic component produced by the distorting load and making the source voltage and current components to be as per the standards. Further control scheme developed is simple without much transformations and decoupling loops, faster in execution and easy adaptability. The reference dc link voltage, three phase source, load and DSTATCOM voltage and currents are the inputs to the controller and the pulses to the VSC are output. The reference dc link voltage is compared with the actual dc link voltage and the error between them is compared with tuned PI controller. The output from the PI controller is Ix. Next the three phase powers are calculated by product of voltage and current and the result is divided mathematically with the rms voltage of the three phases. The result of power by voltage gives current and this current is passed through a low pass filter to allow only the fundamental component of it. This reference current is denoted as Iy. Now, the scalar addition of these two currents (Ix and Iy) is given to the working or active current calculator to generate working or active reference current component. The load three phase currents are passed through the low pass filter (LPF) and comparing the reference active current with the actual load current. The error between these two currents is referred as error current (eabc) and is passed though a hysteresis band current limiter which is designed for each phase. If the error between these currents in any phase falls within the band, no pulses will be generated, otherwise pulses will be generated. The a-phase hysteresis band controller will generate pulses for a-phase, so will give pulse for switch S1 and a not gate will produce pulse for S4 which is also in the same leg. Similarly, b-phase produces pulse for S3 and with not gate switches switch S6. In the same way, c-phase give pulse signals to S5 and S2 respectively.

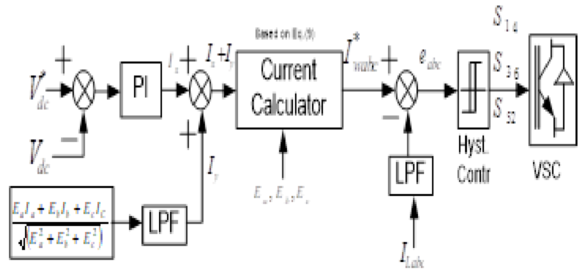


Fig.2 proposed Active Power Controller based DSTATCOM Controller for distorted and flickering type loads

$$i_{wa}^* = (i_x + i_y) * E_a$$
$$i_{wb}^* = (i_x + i_y) * E_b$$
$$i_{wc}^* = (i_x + i_y) * E_c \quad (5)$$

The design of inductance, dc link capacitance and dc link voltage parameters can be obtained as follows.

$$L = \frac{\frac{V_{dc}}{\sqrt{2}} - \frac{V_L}{\sqrt{2}}}{n.\omega.I_n} \quad (6)$$

where n is order of harmonics, ω is the angular frequency and $I_n$ is the harmonic current.

$$C_{dc} = \frac{\frac{\sqrt{3}}{\sqrt{2}} V_{ph}.I_{L\_rated}}{\frac{1}{2}(\sqrt{3}V_L)^2} \quad (7)$$

The dc link capacitor value can be obtained using the load voltage and load currents as given by Equation (7). If the line voltage is 440 volts and rated current is 15 amps, then the dc link capacitance value will be 900 microfarad and so the choice can be 1000 microfarad. The dc link voltage can be derived as

$$V_{dc} = \sqrt{2}\sqrt{3}V_{ph} \quad (8)$$

Based on the equation (8), the dc link voltage will be ( $\sqrt{2}\sqrt{3}*230)$ and hence will be 563 volts or the reference dc link voltage will be 600 volts.

In this from the voltage and current sensors, the source, load voltage and current and the dc link capacitor voltages are inputs to the control scheme. Their initial values and the samples at natural and all frequencies are collected. The scalar difference of reference and actual dc link voltages are given to the PI controller to get a reference current defined as Ix and using the source power to the source voltage rms values, we get another reference current (Iy). We then add analytically these two currents (Ix+Iy) is multiplied with the source voltage as given by the equation (9) to compute active current component which will be the reference current at the load terminal. So, the reference active current and the load current are compared and is passed through the hysteresis band. If the current is within the band, then there will be no pulse, otherwise pulses will be produced as discussed earlier in this section. This control method is independent phase control scheme and hence unbalance and distortion of different values in each phase also can be solved effectively.

## IV.RESULT ANALYSIS

The MATLAB/ simulink model of the test bed system is shown in Fig.4. A three phase healthy source is supplying power to the non-linear uncontrolled rectifier load and a three phase RL load and is supplied through certain small distance represented by the line impedance. The non linear load is a diode rectifier load containing parallel RLC elements as shown. This non-linear load is distracting type and will distort mostly the current waveform and to very small amplitude voltage. In this system, the DSTATCOM is connected near to the load and will absorb any other waveform other than fundamental current. For this tuned 5th and 7th harmonic passive filter are used as shown. Along with these harmonics, the remaining harmonics will reach the VSC and will charge the capacitor bank via diode switches of the converter as shown in Fig.5. The passive filters and RLC combinations shown in Fig.1 are placed in the subsystem of the Vi-RYB block. The inversion operation is controlled by switching logic explained in Fig.2 and with the help of IGBTs. The results of the system will be discussed as follows.

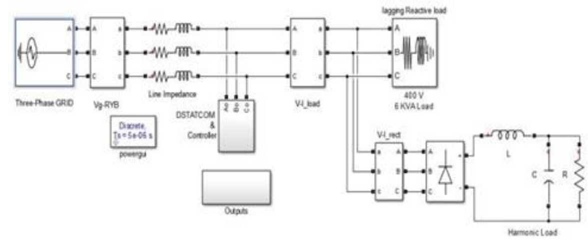


Fig.3 MATLAB based test system with DSTATCOM controller

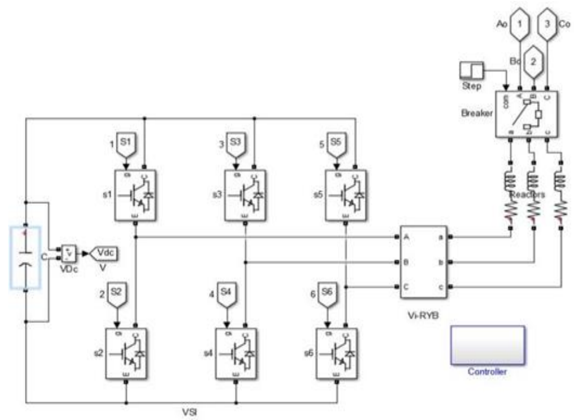


Fig.4 MATLAB based circuit diagram of the VSC

In the DSTATCOM and non-linear load system, the DSTATCOM is open circuit till 0.15 seconds and then immediately closed at this instant using a circuit breaker arrangement as shown in Fig.4. It can be observed that he load voltage is almost sinusoidal, but the load current is having distortions as shown in Fig.5. The voltage of the load is almost constant with 230 volts, whereas the current slowly increased and reached a peak point and then decreased and a steady-state of 40 amps is reached. It can also be observed that, even the DSTATCOM is switched on at 0.15s, there is no change in the load profile. Hence the DSTATCOM operates based on the load voltage and current and also source voltage and current but will improve the source waveforms only. The load current is having harmonics from 5th to all higher order values but with decreasing magnitude. This load current waveform is for both linear RL load and non-linear RLC loads together.

The source voltage and current waveforms are shown in the Fig. 6, here the source voltage profile is sinusoidal with the phase voltage of 230 volts. It can also be observed that till the 0.15s instant, the source current and load current profile are alike as DSTATCOM is not connected to the circuit. When the DSTATCOM is switched ON at 0.15s, with a large surge current, it is connected to the circuit and compensated the source current waveform. To observe clearly the source current profile, the Fig.7 will show the zoom waveform of it. It can be observed clearly that source current and load current are same till 0.15 seconds. There is change in the source current waveform from 0.15 seconds as DSTATCOM is switched into the circuit and will compensate the load current harmonics entering into the source side by absorbing those frequencies which are not fundamental. Only very low magnitudes will reach the source side which can be neglected as shown in Fig.7.

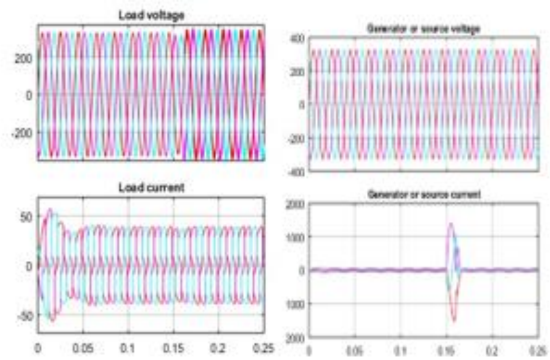


Fig.5 Load voltage and current waveforms
Fig.6 Source voltage and current waveforms

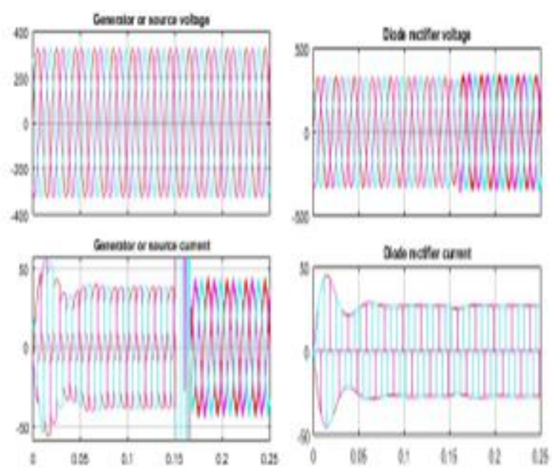


Fig.7 zoom of source voltage and current waveforms
Fig.8 Diode rectifier voltage and current waveforms
The diode bridge uncontrolled rectifier voltage and current profile waveforms are shown in the Fig8. In this due to diode non-linearity and the inductor and capacitor charging behaviors make the starting current to increase slowly and reach its highest value and then settling at a constant value with small oscillations can be observed in the Fig.8. the diode rectifier with inductor element will distract mostly the current waveform and partially the voltage waveform. Due to multiple frequencies with decreasing magnitude with frequency order make the current waveform square shape instead of sinusoidal nature. Since there voltage is having smaller distortions, the DSTACOM is injecting current and is improving the voltage profile can be observed.

The DSTATCOM voltage and current waveforms are shown in Fig.9. The voltage across is 600 volts till 0.15s and this waveform is having mostly third harmonics due to the converter circuit. When it is ON, there is a sudden decrease in it and then started injecting the current and hence due to the rectification and inversion operation, its waveform shape changed. The DSTATCOM current is negligible till 0.15s as the circuit is open circuited, and when the switch is closed, a severe surge current is injected into the supply-load network as load impedance profile is changed. This can be smoothened in operation by limiting the current injection by using rate controllers in the control circuit and also adding resistance at start of the circuit and then diverting when a steady-state is reached.

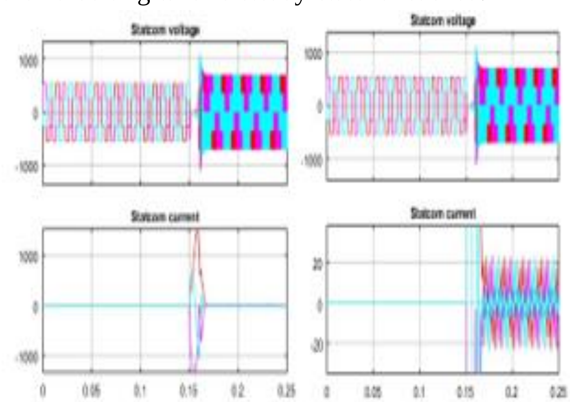


Fig.9DSTATCOM voltage and current waveform
Fig.10 zoom of DSTATCOM voltage and current waveform

It is observed from zoom waveform of DSTATCOM as shown in the Fig.10, till 0.15s, the current is zero amps as switch is open. The injecting current from 0.15s is observed and has lot of harmonics in it is absorbed by the VSC and pure waveform will be injected. The switches in the VSC are bidirectional in current which is faster, reliable and efficient. Hence, the overall current and voltage profile are improved with the proposed DSTATCOM active power-based controller and the topology.

## V.CONCLUSION

A DSTATCOM new topology and control scheme are proposed in this paper to compensate the load current harmonics entering into the source side. The control scheme is named as active current compensation technique as the scheme mostly deals with the computation of working or active current component and this waveform has to be there on the load side to meet the power system standards. If there is any deviation in the waveform amplitude due to the harmonic behavior, those waveforms will be absorbed by the DSATCOM and will be filtered and stored in the capacitor and then pump into the system as compensating current. The fundamental current will be in the hysteresis band and all other harmonics will be lesser or above the band, so will be diverted naturally by the hysteresis controller. So, reference current computation plays a vital role along with the fast acting switches. Hence our converter and topology are simple in design as there is no three phase to two phase transformation. It is quicker in response, reliable, easy to implement and the design of the passive elements and dc link capacitors are very easy with the proposed technique. The disadvantages of this method is little slower in dynamic response, due to which surge current at the switching instant is observed and also like other methods earlier in the literature is source and load current and voltage parameter dependent which is natural.

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