VOLTAGE STABILITY IMPROVEMENT USING VSC BASED D-STATCOM WITH FUZZY CONTROLLER

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Abstract – ***Performance evaluation and Investigation of voltage source converter based Distribution static compensator (D-STATCOM) with FLC in Power distribution System (PDS) for voltage stability enhancement and harmonics elimination. Proposed scheme employed with Cascaded H-bridge inverters having several advantages over conventional swathing devices i.e low harmonic distortion, reduced number of switches there by reduction of switching losses. The Distribution static compensator D-STACTOM is a shunt connected fast switching reliable FACTS device. Which can able to generate and absorb the reactive power based on load requirements in power distribution system. It can also helps for power factor improvement, voltage stability enhancement, stability profile improvement and also eliminate the Total Harmonics Distortion (THD) drawn from a Non-Liner Diode Rectifier Loads (NLDRL). Here D-Q reference frame theory is employed to generate them reference compensating currents for D-STACTOM while Fuzzy controller(FC) is used for capacitor dc voltage regulation. A CHB Inverter is considered for shunt compensation of a 11 kV secondary distribution system. Finally a level shifted PWM (LSPWM) & Phase shifted PWM (PSPWM) technique adopted to analyze the performance of CHB Inverter for the proposed scheme. Final results are obtained through Mat lab/ Simulink software tool box.***

Key Words: VSC, D-STATCOM, LSPWM, PSPWM, *CHB*

I.INTRODUCTION

Modern power system is a complex dynamic inter connecting network, where large number of generating stations and their loads are connected to gather by means long over head power transmission lines and finally in contact with distribution networks. Even though the power Generation is mostly reliable, but quality of power consumers loads is not always so reliable the base reason for this is contingencies which are undesirable. Power distribution system should provide reliable flow of energy at smooth sinusoidal voltage at the required magnitude level and Frequency in order to have high degree of power quality to at all customers hence power quality the degree of voltage quality. In whole of PS network especially distribution system has large number of non-linear loads, which significantly affect the power quality. Apart from non-linear loads, events like capacitor switching, motor starting and abnormal faults could also inflict power quality (P-Q) problems. P-Q problem is defined as any manifested problem in voltage or current or leading to frequent change in frequency variations could result in failure of system or maloperation of consumer equipments. Voltage sags (voltage Dips) and swells are among the most of the P-Q problems in industrial processes have to face with Voltage sags which are more severe and causes more damage of equipment. During the past few decades, power industries have proved that the adverse impacts on the P-Q can be mitigated or avoided by conventional means, that advancement in controlled techniques using fast force commutated power electronics (PE) are even more effective. P-Q compensators can be categorized into two main types. One is shunt connected compensating device can effectively eliminates harmonics. The other is the series connecting device, which has an edge over the shunt type for correcting the distorted system side voltages and voltage sags caused by power transmission System contingencies. The STATCOM which used in distribution systems is called D-STACOM (Distribution-STACOM) and its configuration is also similar to normal STATCOM, with small modifications. It can exchange both active and reactive power in power distribution systems by varying the amplitude and phase angle of the converter voltage with respect to the line terminal voltage. A multilevel inverter is an advanced power electronic device which reduces the Harmonics presented in output voltage. by increasing the number of output voltage levels with small number steps such that high quality output can be made possible. There are several types of multilevel inverters: cascaded H-bridge (CHB), neutral point diode-clamped, flying capacitor types. In particular, among these topologies, CHB inverters are more popular they are being widely used In different applications due to their Modularity and simplicity. Various modulation methods can be applied to CHB inverters. CHB inverters can also Increase the number of output voltage levels easily by increasing the number of H-bridges. This paper presents a D-STATCOM with a proportional fuzzy controller based CHB multilevel inverter for the harmonics mitigation and voltage stability improvement by reactive power compensation of the nonlinear loads. This type of arrangements have been widely used for P-Q applications due to increase in the number of voltage levels, low switching losses, low electromagnetic compatibility for hybrid filters and higher order harmonic lamination.

2. DESIGN OF MULTILEVEL BASED DSTATCOM

A.Basic Principle of D-STATCOM

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the DSTATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

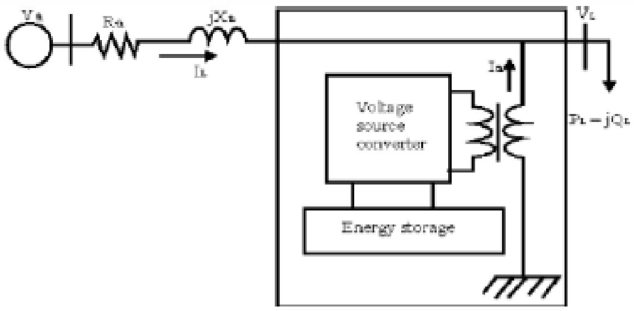


Fig 2.1: Schematic Diagram of a D-STATCOM

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

I. Voltage regulation and compensation of reactive power;
2. Correction of power factor
3. Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter. As shown in Figure-l the shunt injected current Ish corrects the voltage sag by adjusting the voltage drop across the system impedance Zth. The value of Ish can be controlled by adjusting the output voltage of the converter. The shunt injected current Ish can be written as,

$$I_{sh} = I_L - I_S = I_L - (V_{th} - V_L) / Z_{th}$$

$$I_{sh} /\_\eta = I_L /\_- \theta$$

The complex power injection of the D-STATCOM can be expressed as,

Ssh =V L Ish*

It may be mentioned that the effectiveness of the DSTATCOM in correcting voltage sag depends on the value of Zth or fault level of the load bus. When the shunt injected current Ish is kept in quadrature with V L, the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of Ish is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system.

B. Control Reactive Power for Compensation

The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load under system disturbances is connected. The control system only measures the rms voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the fundamental frequency switching methods favored in FACTS applications. Apart from this, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses.

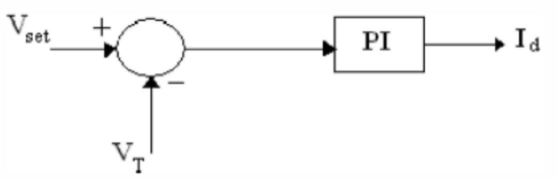


Fig2.2: PI control for reactive power compensation

The controller input is an error signal obtained from the reference voltage and the rms terminal voltage measured. Such error is processed by a PI controller; the output is the angle 0, which is provided to the PWM signal generator. It is important to note that in this case, of indirectly controlled converter, there is active and reactive power exchange with the network simultaneously. The PI controller processes the error signal and generates the required angle to drive the error to zero, i.e. the load rms voltage is brought back to the reference voltage.

C. Control for Harmonics Compensation

The Modified Synchronous Frame method is presented. It is called the instantaneous current component (id-iq) method. This is similar to the Synchrous-Reference Frame theory (SRF) method. The transformation angle is now obtained with the voltages of the ac network. The major difference is that, due to voltage harmonics and imbalance, the speed of the reference frame is no longer constant. It varies instantaneously depending of the waveform of the 3-phase voltage system. In this method the compensating currents are obtained from the instantaneous active and reactive current components of the nonlinear load. In the same way, the mains voltages V (a, b, c) and the available currents ij (a, b, c) in a-b-c components must be calculated as given by formula, where C is Clarke Transformation Matrix.

However, the load current components are derived from a SRF based on the Park transformation, where θ represents the instantaneous voltage vector angle.

$$\begin{bmatrix} I_{l\alpha} \\ I_{l\beta} \end{bmatrix} = [C] \begin{bmatrix} I_{la} \\ I_{lb} \\ I_{lc} \end{bmatrix}$$

$$\begin{bmatrix} I_{ld} \\ I_{lq} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} I_{l\alpha} \\ I_{l\beta} \end{bmatrix}, \theta = \tan^{-1}\frac{V_\beta}{V_\alpha}$$

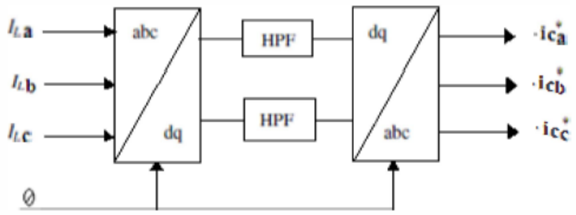


Fig2.3: Block diagram of SRF method

Shows the block diagram SRF method. Under balanced and sinusoidal voltage conditions angle fI is a uniformly increasing function of time. This transformation angle is sensitive to voltage harmonics and un balance; therefore dfI /dt may not be constant over a mains period. With transformation given below the direct voltage component is

$$\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \frac{1}{\sqrt{V_\alpha^2+V_\beta^2}} \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix}$$

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{\sqrt{V_\alpha^2+V_\beta^2}} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix}$$

$$\begin{bmatrix} I_{Comp,a} \\ I_{Comp,b} \\ I_{Comp,c} \end{bmatrix} = [C]^T \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix}$$

D. Cascaded H-Bridge Multilevel Inverter

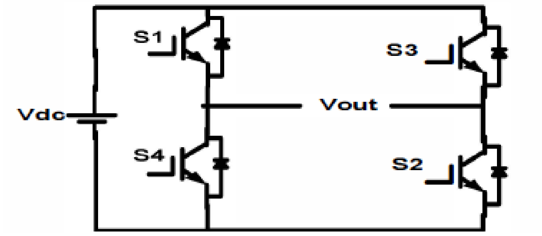


Fig2.4: Circuit of the single cascaded H-Bridge Inverter

The circuit model of a single CHB inverter configuration. By using single H-Bridge we can get 3 voltage levels. The number of output voltage levels of CHB is given by 2n+l and voltage step of each level is given by Vdc/2n, where n is number of H-Bridges connected in cascaded. The switching table is given in Table 9.

Table2.1Switching table for 2-level CHB Inverter

Switches Turn ON	Voltage Level
S1,S2	Vdc
S3,S4	-Vdc
S4,D2	0

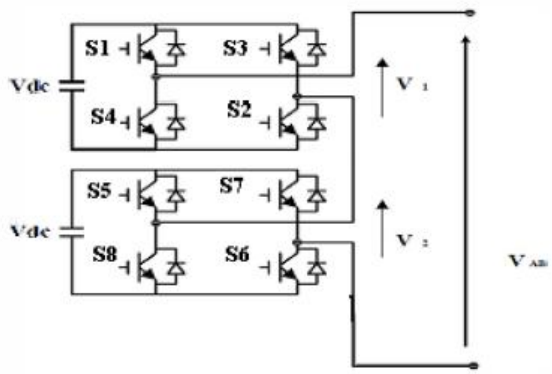


Fig2.5: Block diagram of 5-level CHB inverter model

The switching mechanism for 5-level CHB inverter is shown

Switches Turn On	Voltage Level
S1, S2	Vdc
S1,S2,S5,S6	2Vdc
S4,D2,S8,D6	0
S3,S4	-Vdc
S3,S4,S7,S8	-2Vdc

Table2.2Switching table for 5-level CHB Inverter

A.CONSTRUCTION OF FUZZY CONTROLLER

The internal structure of the control circuit. The control scheme consists of Fuzzy controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a Fuzzy controller, which contributes to zero steady error in tracking the reference current signal.

A fuzzy controller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed either by expert experience or with a knowledge database. Firstly, the input Error 'E' and the change in Error 'ΔE' have been placed with the angular velocity to be used as the input variables of the fuzzy logic controller. Then the output variable of the fuzzy logic controller is presented by the control Current Imax

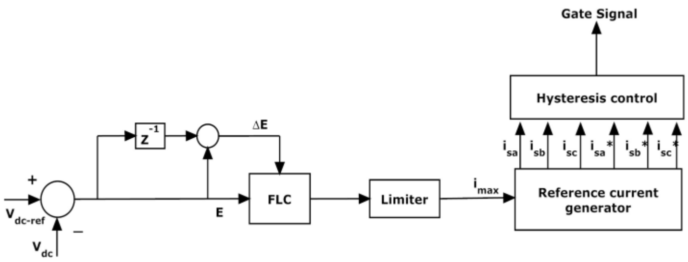


Fig3.2: Conventional fuzzy controller

To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big), as can be seen in Fig.3.14.

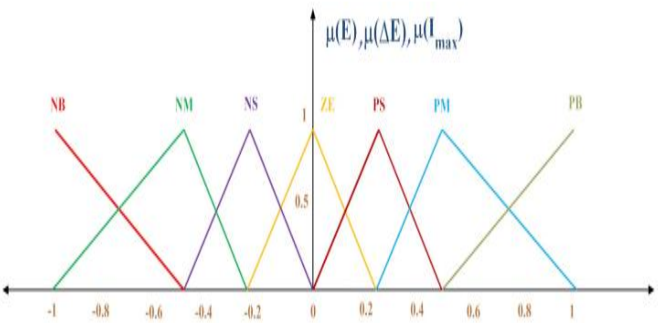


Fig 3.3:Membership functions for Input, Change in input, Output

4. MATLAB/SIMULINK POWER CIRCUIT MODEL OF D-STATCOM

The power circuit model shows as 3-phase ac source, transmission line system, non linear load, D-STATCOM, control circuit, V-I measurements. D-STATCOM is connected across the non linear load, from that we obtained compensating currents, that are used to mitigate the harmonics, and compensation of reactive power.

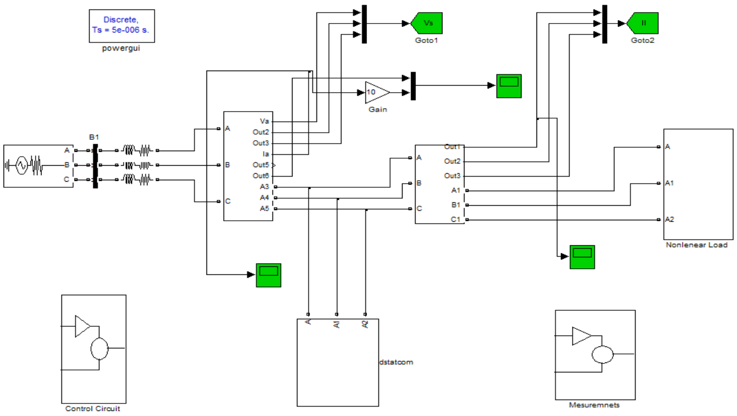


Fig4.1: Matlab/Simulink power circuit model for D-STATCOM

A.Source voltage, current and load current without D-STATCOM

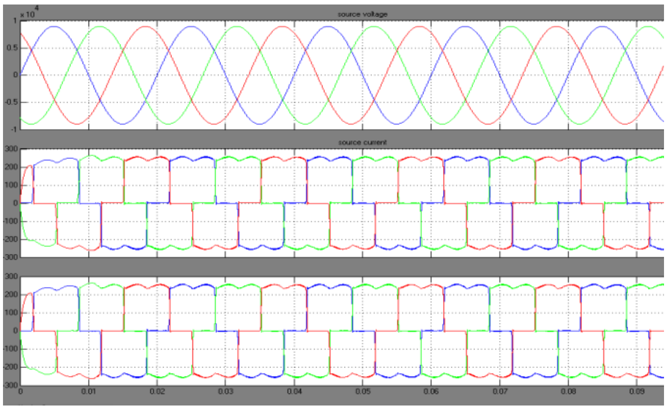


Fig4.2: Source voltage, current and load current without D-STATCOM

The general three phase ac voltage wave form obtained through three phase ac source. Fig shows the three phase source voltages, three phase source currents and load currents respectively without D-STATCOM. It is clear that without D-STATCOM load current and source currents are same.

B.Source voltage, current and load current with D-STATCOM

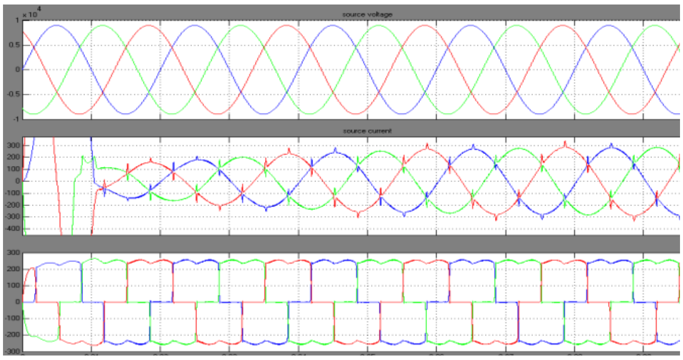


Fig4.3:Source voltage, current and load current with D-STACTOM

The three phase source voltages, three phase source currents and load currents respectively with DSTATCOM. It is clear that with DSTATCOM even though load current is non sinusoidal source currents are sinusoidal

Three phase source current that is given to by the supply, it consists harmonic content in its wave form as shown in

C.Output voltage of Five-level H-bridge inverter

The five levels are 1V, 0.5V, 0V, -0.5V, -1V. These 5 levels are obtained through cascaded H-Bridge 5-level inverter. It gives a single phase voltage, by providing transport delay for each phase in order to get 3-phase ac voltage from 5-Level Cascaded H-Bridge Inverter.

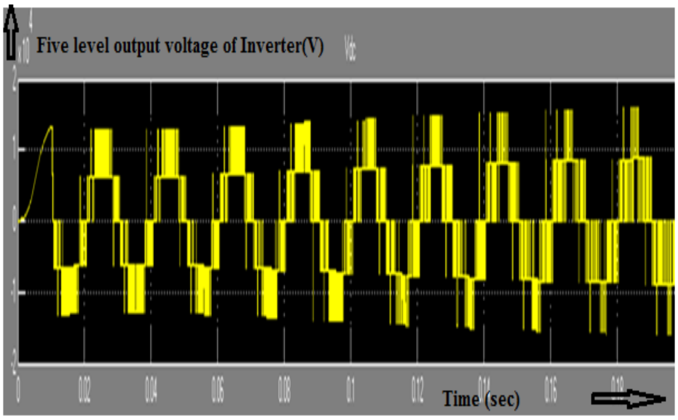


Fig4.4: Output voltage wave form of 5-level H-Bridge Inverter

D.Active power transferred to load with D-statcom

The active power can be improved with compensation of reactive power using DSTATCOM. Numerically average Real Power 4.5*10^6 Watts

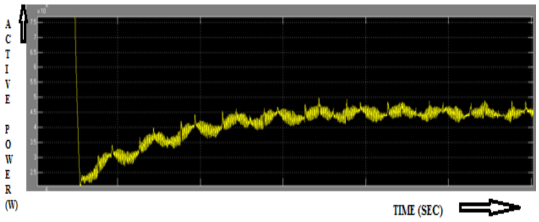


Fig4.5: Active power transferred to load with DSTATCOM

E. Reactive power transferred to load with D-statcom

The average reactive power almost near to 0 VAR, hence the reactive power compensation takes place with D-STATCOM.

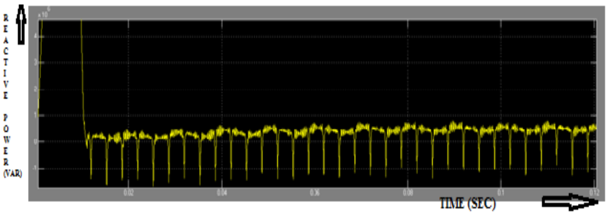


Fig4.6:Reactive power transferred to load with D-STATCOM

F. Harmonic spectrum of phase-a source current with and without D-statcom

Hence the Total Harmonic Distortion (THD) of source current without Dstatcom is 29.93% reduced to 6.19% with D-STATCOM.

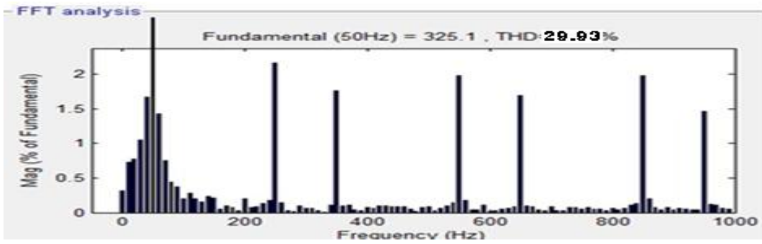


Fig4.7:Harmonic spectrum of phase-a source current with out DSTATCOM

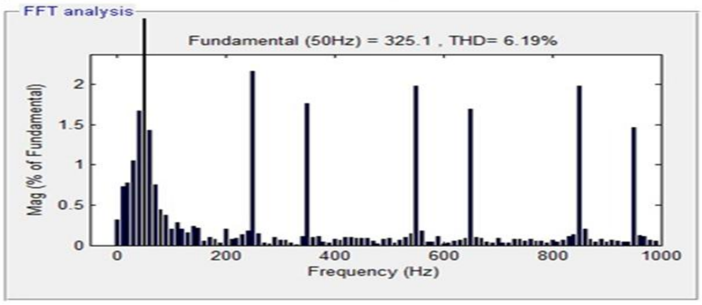


Fig4.8: Harmonic spectrum of phase-a source current with DSTATCOM

G.DSTATCOM WITH FUZZY LOOP CONTROLLER

The Source Voltage, Source Current, and Load Current, of Proposed Cascaded Multilevel Inverter Based DSTATCOM under Inductive load condition with Fuzzy Logic Controller.

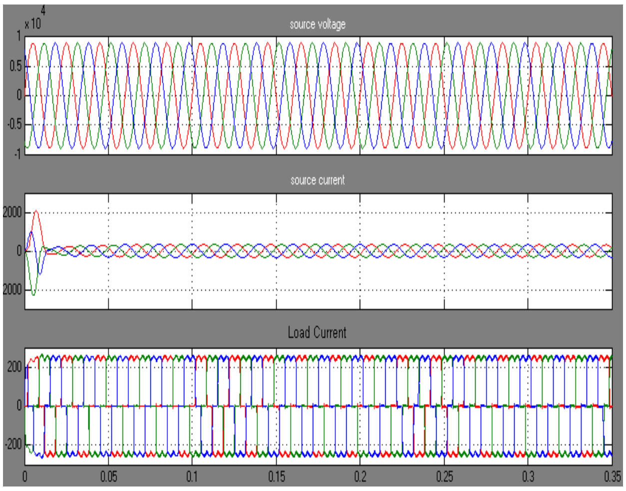
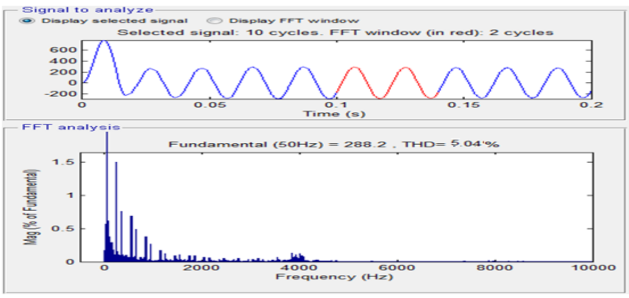


Fig4.9:Source Voltage, Source Current, Load Current with FLC

H.Harmonic spectrum of phase-a source current with FLC



4.10:Harmonic spectrum of phase-a source current with FLC

FFT Analysis of Source Current of Proposed CMLI Based DSTATCOM with Inductive Distorted Load Condition with fuzzy logic controller, here we get the Total harmonic distortion valve is 5.04%

I.PWM for Multilevel Inverter

There are 2 types of PWM techniques for Multilevel Inverter.

1. Phase shifted Carrier PWM
2. Level Shifted Carrier PWM

1. Phase Shifted PWM

The Phase shifted carrier pulse width modulation. Each cell is modulated independently using sinusoidal unipolar pulse width modulation and bipolar pulse width modulation respectively, providing an even power distribution among the cells. A carrier phase shift of 360^0 / m_C (No.of levels) for cascaded inverter is introduced across the cells to Generate the stepped multi level output waveform with lower distortion. If the Number of voltages m=5, the number of carriers required are m_C-1=4 and Phaseshift=360^0

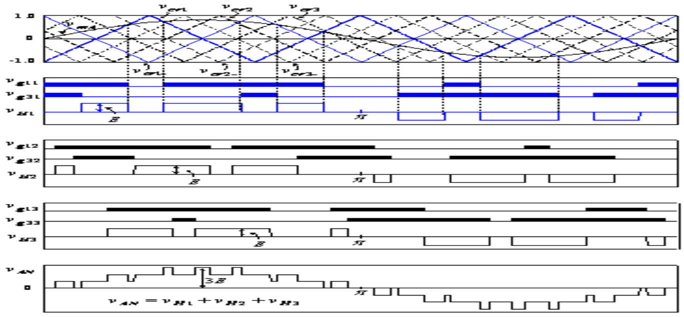


Fig. 4.11 Wave form of Phase Shifted PWM

2. Level shifted PWM

The Level shifted carrier pulse width modulation .Each cell is modulated independently using sinusoidal unipolar width modulation and bipolar pulse width modulation respectively, providing an even power distribution among the cells. A carrier Level shift by 1/m (No.of levels) for cascaded inverter is introduced across the cells to generate the stepped multilevel output waveform with lower distortion.

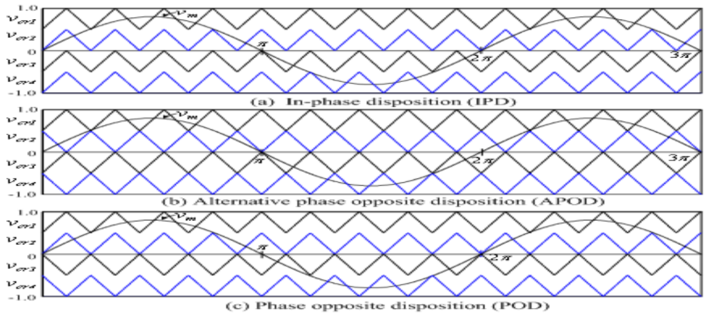


Fig. 4.12 Wave form of Level Shifted PWM

Comparison between the level shifted PWM scheme without, with D-statcom & with Fuzzy Controller

comparisons	Without D-statcom	D-statcom (pi controller)	D-statcom (fuzzy controller)
THD of Source Current	**29.93%**	**6.19%**	**5.04%**

5. CONCLUSION:

D-STATCOM with five levels CHB inverter is investigated. Mathematical model for single H-Bridge inverter is developed which can be extended to multi level H-Bridge. The source voltage, load voltage, source current, load current, power factor simulation results under non-linear loads are investigated for LSCPWM and are tabulated. Finally with the help of Matlab/Simulink based model simulation we conclude that D-statcom fuzzy controller is better than the pi controller techniques and the results are presented. Fuzzy loop controller based D-STATCOM in power distribution system.

5.2 FUTURE SCOPE

Reactive Power Compensation and Harmonics mitigation with fuzzy loop controller based D-STATCOM is the latest technology and is more effective use in future for distribution power systems. It can be further extend Neuro-fuzzy loop controller based D-STATCOM in power distribution system.

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