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# Design and Analysis of Fuzzy and PI Controller based MLI-DSTATCOM with SRF Theory

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***Abstract—*** *In this paper, Fuzzy and PI controller based MLI-DSTATCOM with SRF theory is developed in MATLAB/SIMULINK model. The Power quality is one of the productive concepts in power industry. It deals with Reliability, Quality of Supply and Customer service. The modern distribution systems will effected with power quality problems due to presence of harmonics. This paper discusses the harmonic mitigation by using MLI-DSTATCOM with nonlinear load.*

***Keywords— Multilevel Inverter based Distributed STATCOM(MLI-DSTATCOM),Synchronous Reference Frame(SRF),Power Quality (PQ), Harmonic Mitigation, PI Control, Fuzzy Logic Controller (FLC).***

## I. INTRODUCTION

The insurgency in the computerized world and power electronics considerably affects the electricity network. The energy efficiency and power handling capacity is reduced because of low power factor. Due to the low power factor, the losses are more in electrical machines and appliances, torque pulsations in motor and furthermore creating perilous disturbances to connected devices in electric system [1]-[2]. Several techniques and equipment's are used to mitigate power quality related issues in the distribution system. The passive filter is most commonly used to reduce the harmonics and also improves power factor thereby reduction of losses, but the disadvantage is bulky size, resonance and limited compensation characteristics [3]. Later Custom Powered Devices (CPD) gave enhanced performance over the passive filters and are extremely useful for keeping the present power quality levels [4]-[5]. DSTATCOM connected across load is efficient method to mitigate the harmonics. DSTATCOM also used for reactive power compensation in distribution network [6] - [8]. Any CPDs Performance of is relies upon the gating pulses and the control algorithm to produce estimated reference currents. The most generally used control algorithms are feed forward training [6], SRF theory and instantaneous active and reactive power theory [9] –[12], Lyapunov-function control [13] and the non-linear control technique [14] etc.

The design of MLI-DSTATCOM with nonlinear load is analyzed. Load currents, source currents and source voltages are measured by using fuzzy based control method.

## II. OPERATION OF DSTATCOM

The power quality problems can reduce the power supplied to the customers from its nominal value in the distribution system. The major impacts to distribution system are Voltage sag, harmonics, transient, overvoltage and under voltage. The utility and the users are capable in polluting the supply network because of operating of large loads. There are many solutions in mitigating the power quality problems at a distribution system such as using surge arresters, active power filters, isolation transformer, uninterruptible power supply and static VAR compensator. It proposed a new D-STATCOM control algorithm which enables separate control of positive and negative sequence currents and decoupled control of d- and q axes current components.

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

A DSTATCOM is a controlled reactive source capable of generating and/or absorbing reactive power. The working principles of a DSTATCOM are based on

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the exact equivalence of the conventional rotating synchronous compensator**.**

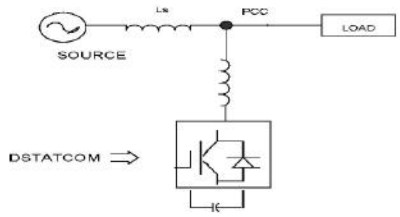


Fig. 1: Single line diagram of a D-STATCOM

The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which is either filter inductance or the leakage inductance of the coupling transformer, as shown in Figure 1. The DC side of the converter is connected to a DC capacitor, which is the main reactive energy storage element and carries the input ripple current of the converter. This capacitor could be either charged by a battery source, or could be pre charged by the converter itself. If the VSC output voltage is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the DSTATCOM is in the capacitive mode of operation and if the output voltage is lesser than the AC terminal voltage, the DSTATCOM will absorb reactive power from the system. The reactive power flow quantity is proportional to the difference of VSC output voltage and AC terminal voltage. It is to be noted that voltage regulation at PCC and power factor correction cannot be obtained simultaneously. The compensation should be such that the supply currents should lead the supply voltages then DSTATCOM used for voltage regulation at the PCC; whereas, the supply current should be in phase with the supply voltages for power factor correction. The control strategies studied in this paper are applied with a view to studying the performance of a DSTATCOM for harmonic mitigation.

## III. SYNCHRONOUS REFERENCE FRAME CONTROL

The DSTATCOM performance depends on the control algorithm used for extraction of reference current components. Many control schemes are utilized for the controlling purpose, and some of these control schemes are instantaneous reactive power (IRP) theory, instantaneous symmetrical components, synchronous reference frame (SRF) theory, current compensation by dc bus regulation, computation based on per phase basis, and neural network techniques scheme. Among these control schemes, IRP and SRF theories are most commonly used. In this thesis, Synchronous reference frame theory is used to generate reference currents, which is shown in fig.4.

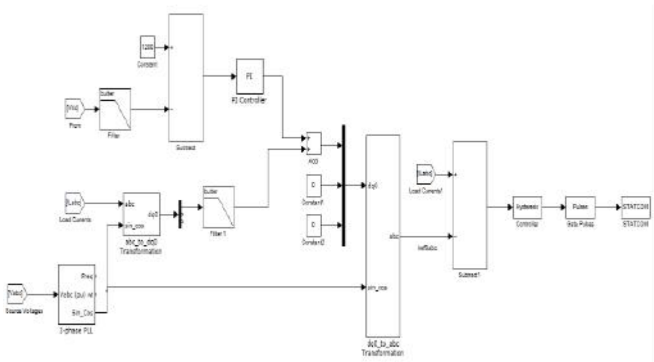

Fig. 4: Simulink model for Reference currents generation using SRF

The Park's transformation i.e a-b-c to d-q transformation is

$$\begin{bmatrix} I_{so} \\ I_{sd} \\ I_{sq} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ \sin(\omega t) & \sin\left(\omega t - \frac{2\pi}{3}\right) & \sin\left(\omega t + \frac{2\pi}{3}\right) \\ \cos(\omega t) & \cos\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} I_{Loa} \\ I_{Lob} \\ I_{Loc} \end{bmatrix} \quad (1)$$

The inverse park's transformation i.e. d-q to a-b-c transformation to get the required three phase reference currents is

$$\begin{bmatrix} I_{refsa} \\ I_{sd} \\ I_{sq} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & \sin(\omega t) & \cos(\omega t) \\ 1/\sqrt{2} & \sin\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t - \frac{2\pi}{3}\right) \\ 1/\sqrt{2} & \sin\left(\omega t + \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} I_{so} \\ I_{sd} \\ I_{sq} \end{bmatrix} \quad (2)$$

Phase locked loop circuit is used to make the reference source current in phase with source voltage.

## IV INTRODUCTION TO FUZZY LOGIC CONTROLLER

The FLC is a robust controller and is suitable for dynamic conditions. Fuzzy logic unlike Boolean or crispy logic, deals with Vagueness and uncertainty. In fuzzy logic the degree of membership in a given set may be anywhere in the range of 0 to 1. Fuzzy logic is a rule

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based operation which can be easily designed for any number of input and outputs. There are two types of Fuzzy Inference Systems (FIS); they are Mamdani type and Sugeno type. These two FIS vary in the way in which the outputs are determined. In Mamdani type to convert the fuzzy output to crisp form, defuzzification methodology is used. In Sugeno type system the output variables are described as linear functions or constants and therefore simplify the computation time required. In this work Mamdani based FIS controller is used as replacement for PI controller. The sequence of steps for Mamdani based FIS controller is

1. Fuzzification of input variables
2. Creating rule base using fuzzy operators (AND or OR)
3. Mapping degree of fuzzy outputs.
4. Aggregation of fuzzy outputs of all rules
5. Defuzzification of aggregated fuzzy output.

The control circuit is shown in fig.5.

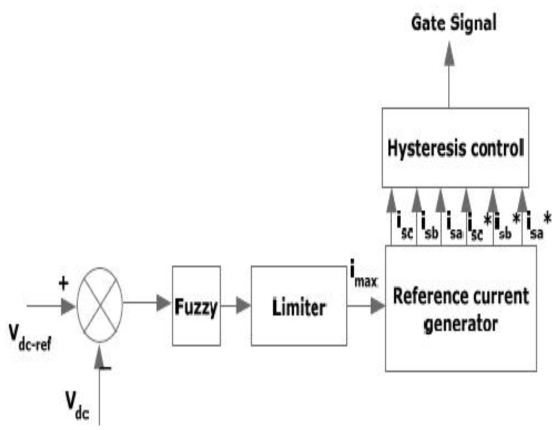


Fig.5: Control circuit of Fuzzy logic controller

The controller uses two input state variables and one output control variable. The difference between the set value and the actual value (error) is termed as the first input variable. The change in error, the difference between the errors in consecutive steps of simulation is assigned as another input variable.

The fuzzy output control variable is the change in the control signal. This control signal acts as the input signal to the DSTATCOM controller. The input and output variables in the proposed controller are represented as a set of seven linguistic variables namely,

NL - Negative Large
NM - Negative Medium
NS - Negative Small
ZE - Zero Error
PS - Positive Small
PM - Positive Medium
PL - Positive Large

In fuzzification, the precise numerical values obtained by measurements are converted to membership values of the various linguistic variables. The degree to which a fuzzy number belongs to a set or not is known as Membership Function (MF). In STATCOM controller, the universe of discourse of the input state variable MF is -0.1 to +0.1 as shown in Figure 6.

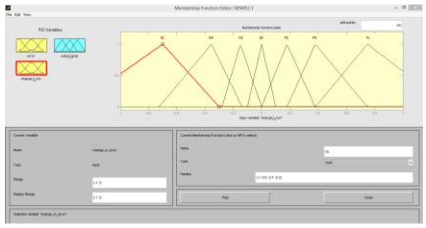

Fig.6: Membership Function for change in Error in DSTATCOM controller

The Mamdani type of fuzzy controller used for the control of DSTATCOM gives better results compared with the PI controller, but it has the drawback of having larger number of fuzzy sets and rules. Moreover, in order to get better performance than the conventional PI controller, all the coefficients have to be optimized. So the complexity of the controller is increased; hence, this demands large computational time. So, it may not be useful for real time applications with small sampling time.

The procedure of converting fuzzy values into crisp values is known as defuzzification. Defuzzification plays a great role in fuzzy logic based control system design, since it converts fuzzy set into numeric value without losing any information. Different defuzzification methods exist to accomplish the task and naturally there exist trade-offs to each method. The selection of right strategy depends on the application and the type of MF used. The performance of FLC depends on the defuzzification process, since the system under control is determined by the defuzzified output. Centroid method is used, because of its computational speed and accuracy in real time control. Figure 4.6 shows the graphical representation of centroid method and an output condition with two significant linguistic values. The output fuzzy variable is converted into a crisp value by centroid method. Since the final output is a combination of recommended actions of many rules, the controller is more robust to accommodate the changes in power system parameters.

## V.MATLAB/SIMULATION RESULTS

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The proposed system is analyzed with nonlinear unbalanced load in MTALAB/SIMULINK model. Here, the MLI-DSTATCOM is connected to the system at 0.1 sec.

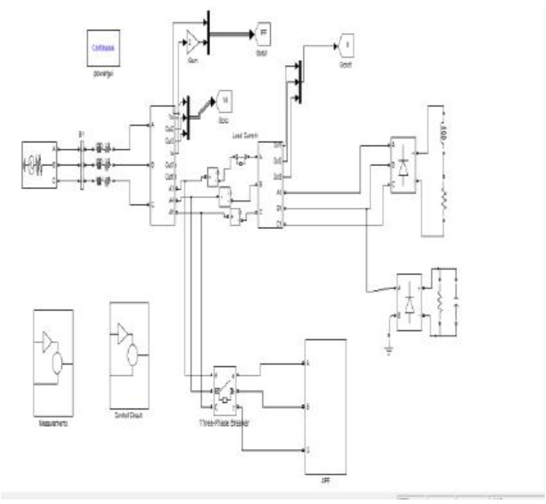


Fig.9: Matlab/simulink circuit of MLI-STATCOM

The simulink model of PI and Fuzzy Controller is shown in fig.10

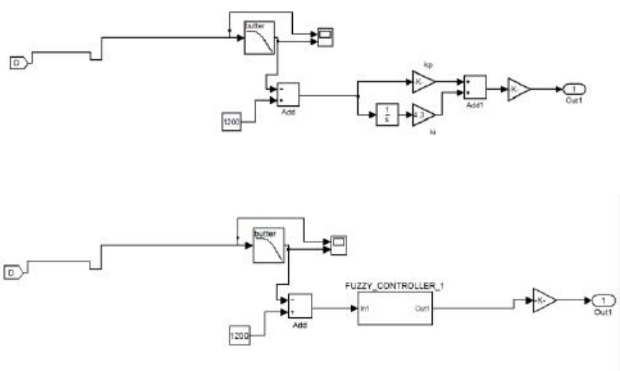
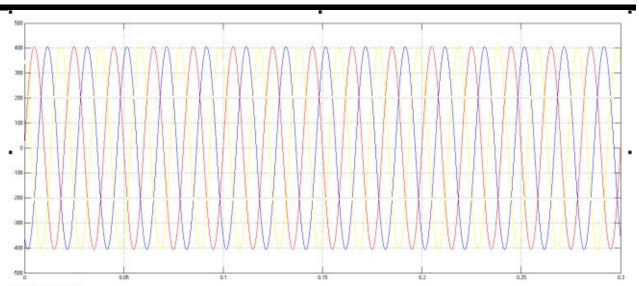


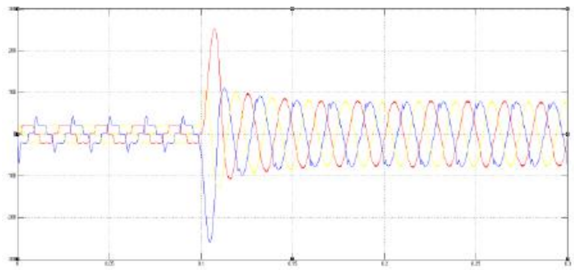

Fig.10: Simulink model of a) PI Controller b) Fuzzy Controller

**With PI Controller:**

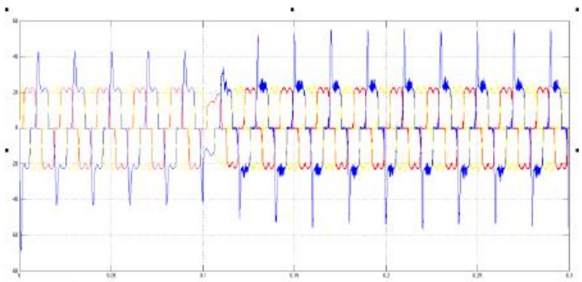
The supply voltages, Supply Currents and load currents are shown in fig.11. The DC link capacitor voltage is shown in fig.12. Source current THD waveform at Non Linear Load with PI controller is shown in fig.13.



(a)



(b)



(c)

Fig.11: Before and after compensation of (a) Source Voltage (b) Load Current (c) Source Current.

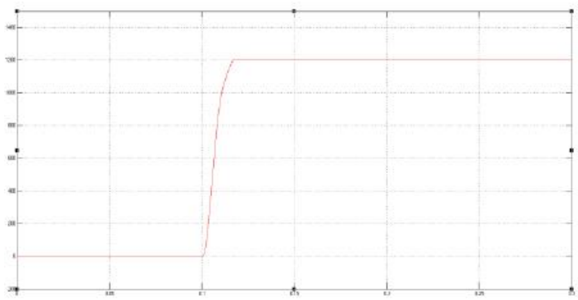


Fig.12: DC Link Capacitor Voltage

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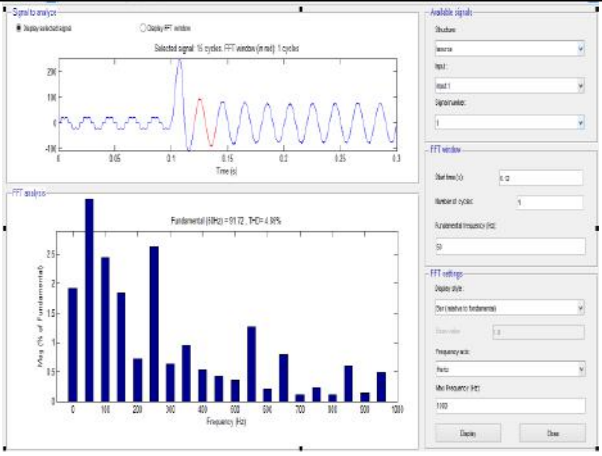
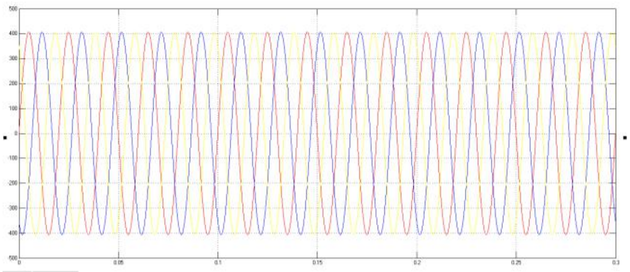


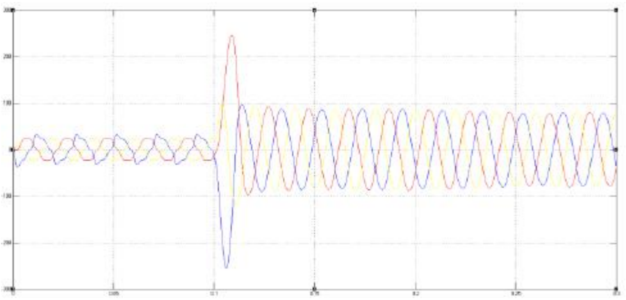
Fig.13: Source current THD waveform at Non Linear Load with PI controller

**With Fuzzy Controller:**

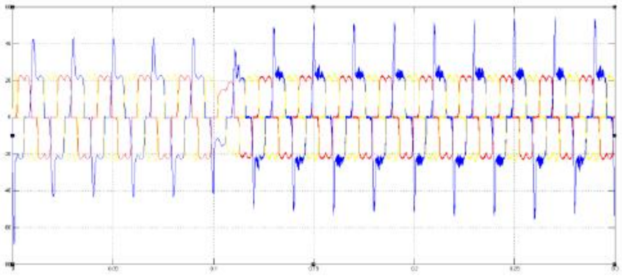
The supply voltages, Supply Currents and load currents are shown in fig.14. The DC link capacitor voltage is shown in fig.15. Source current THD waveform at Non Linear Load with Fuzzy controller is shown in fig.16.



(a)



(b)



(c)

Fig.14: Before and after compensation of (a) Source Voltage (b) Load Current (c) Source Current.

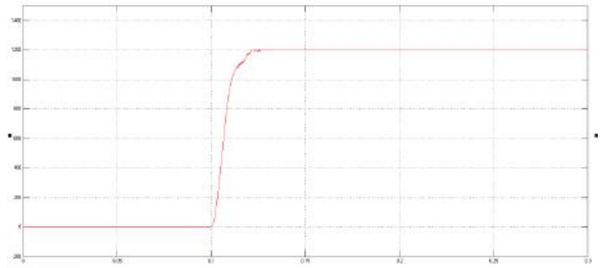


Fig.15: DC Link Capacitor Voltage

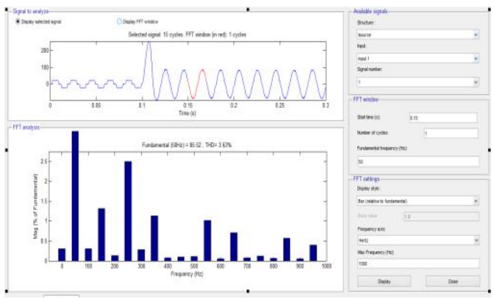


Fig.16: Source current THD waveform at Non Linear Load with Fuzzy controller

The comparison of %THD of supply currents with PI and Fuzzy Controller is tabulated in the Table 2.

Table 2: Comparison of % THD

| MLI DSTATCOM | %THD |
|---|---|
| **With PI Controller** | **4.85** |
| **With Fuzzy Controller** | **3.63** |

## CONCLUSION

The performance of a proposed system is analyzed in matlab/simulink model. It is observed that the proposed system suppress the harmonics more effectively over PI controller. The THD Value of source current is decreased by using Fuzzy Logic Controller when compared with PI Controller. It can be concluded that the proposed system gives superior performance over PI controller.

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