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A NOVEL STATIC FUZZY COMPENSATION SCHEME FOR GRID CONNECTED WIND ENERGY SYSTEM FOR POWER QUALITY IMPROVEMENT

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ABSTRACT

With the widespread use of harmonic generating devices, the control of harmonic currents to maintain a high level of power quality is becoming increasingly important. Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end use equipments. One of the major problems dealt here is the harmonics reactive power compensation and power factor. The performance of the wind turbine and thereby power quality are determined on the basis of measurements and the norms followed according to the guideline specified in International Electro-technical Commission standard, IEC-61400. The paper study demonstrates the power quality problem due to installation of wind turbine with the grid. In this proposed scheme STATIC COMPENSATOR (STATCOM) is connected at a point of common coupling with a battery energy storage system (BESS) to mitigate the power quality issues. The battery energy storage is integrated to sustain the real power source under fluctuating wind power. The STATCOM control scheme for the grid connected wind energy generation system for power quality improvement is simulated using MATLAB/SIMULINK in power system block set. Finally the proposed shceme is applied for both PI Controller & Intelligence Controllers.

Keywords: International electro-technical commission (IEC), power quality, wind generating system (WGS), D-Statcom (Distributed Static Synchronous Compensator), Intelligence Controllers.

INTRODUCTION

In the deregulated power market, adherence to Power Quality (PQ) standards has emerged as a figure-of-merit for the competing power distribution utilities. Among the various P Q problems, voltage disturbances- both steady-state and transient - have been identified to have the maximum probability of occurrence. It has been reported [l]that, High Intensity Discharge (HID)lamps used for industrial illumination get extinguished at voltage dips of 20%. Also, critical industrial equipment like Programmable Logic Controllers (PLCs) and Adjustable Speed Drives (ASDs) are adversely affected by voltage dips of about 10%. Solution approaches to the voltage disturbance problem, using active devices, can involve either (i) a series injection of voltage, or (ii) a shunt injection of reactive current. The Static Var Compensator (SVC) and the STATCOM are the available shunt compensation devices. Harmonic disturbances and their study has been a topic of research and today we can find a whole array of devices used to mitigate such problems. The ever growing use of power electronic based systems has aggravated the harmonics problem. These devices themselves require clean and good power quality but inject undesirable harmonics into the supply system as well as the neighboring loads. Literature review [1-6] indicates the problems, effects and solutions for harmonics in power systems. Different type of low voltage loads can also introduce harmonics in the power network and adversely affect on the overall performance and operation of the power system. In this paper, use of custom power device for harmonic reduction is studied.

The most common power quality problems today are voltage sags, harmonic distortion and low power factor. Voltage sags is a short time (10 ms to 1 minute) event during which a reduction in r.m.s voltage magnitude occurs [1]. It is often set only by two parameters, depth/magnitude and duration. The voltage sags magnitude is ranged from 10% to 90% of nominal voltage and with duration from half a cycle to 1 min. Voltage sags or dip is caused by a fault in the utility system, a fault within the customer's facility or a large increase of the load current, like starting a motor or transformer energizing [2,3].Voltage sags are one of the most occurring power quality problems. For an industry voltage sags occur more often and cause severe problems and economical losses. Utilities often focus on disturbances from end-user equipment as the main power quality problems [5]

Voltage dips are one of the most occurring power quality problems. Off course, for an industry an outage is worse, than a voltage dip, but voltage dips occur more often and cause severe problems and economical losses. Utilities often focus on disturbances from end-user equipment as the main power quality problems. This is correct for many disturbances, flicker, harmonics, etc., but voltage dips mainly have their origin in the higher voltage levels. Faults due to lightning, is one of the most common causes to voltage dips on overhead lines. If the economical losses due to voltage dips are significant, mitigation actions can be profitable for the customer and even in some cases for the utility. Since there is no standard solution which will work for every site, each mitigation action must be carefully planned and evaluated.

There are different ways to enhance power quality problems in transmission and distribution systems. Among these, the D-STATCOM is one of the most effective devices. A new PWM-based control scheme has been implemented to control the electronic valves in the DSTATCOM. The D-STATCOM has additional capability to sustain reactive current at low voltage, and can be developed as a voltage and frequency support by replacing capacitors with batteries as energy storage. [6]. A possible solution to overcome the above mentioned drawback is to use the STATCOM as a power interface between the renewable energy sources and the AC bus of the microgrids as shown in Fig. 1. The STATCOM has proved to be an important alternative to compensate current and voltage disturbances in power distribution systems. Different STATCOM topologies have been presented in the technical literature [7], but most of them are not adapted for microgrids applications.

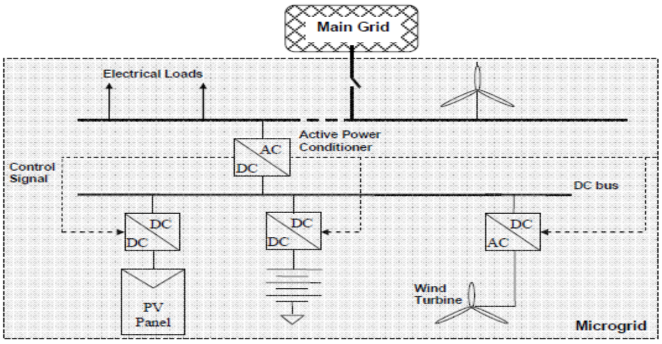

Fig.1. STACOM for Micro grid Application

Conventionally, PI, PD and PID controller are most popular controllers and widely used in most power electronic appliances however recently there are many researchers reported successfully adopted Fuzzy Logic Controller (FLC) to become one of intelligent controllers to their appliances [3]. With respect to their successful methodology implementation, this kind of methodology implemented in this paper is using fuzzy logic controller with feed back by introduction of voltage respectively. The introduction of change in voltage in the circuit will be fed to fuzzy controller to give appropriate measure on steady state signal. The fuzzy logic controller serves as intelligent controller for this propose.

Distribution Static Compensator (DSTATCOM)

A. Principle of DSTATCOM

Generally, four-wire APCs have been conceived using fourleg converters [5]. This topology has proved better controllability [6] than the classical three-leg four-wire converter but the latter is preferred because of its lower number of power semiconductor devices. In this paper, it is shown that using an adequate control strategy, even with a simple three-leg four-wire system, it is possible to mitigate disturbances like voltage unbalance. The topology of the investigated APC and its interconnection with the microgrid is presented in Fig. 2.

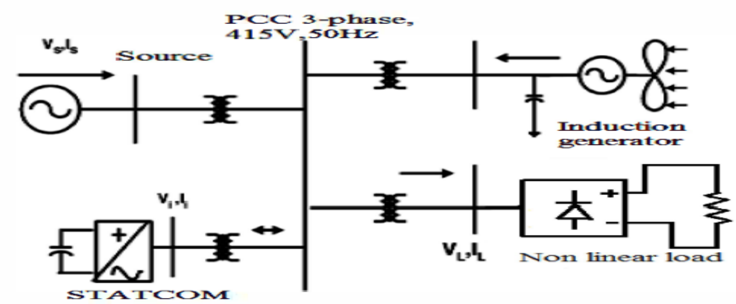

Fig.2. Schematic diagram of grid connected wind energy system

It consists of a three-leg voltage source inverter. In this type of applications, the VSI operates as a current controlled voltage source. In order to provide the constant voltage, capacitors are used to maintain DC-link voltage This topology allows the current to flow in both directions through the switches and the capacitors, causing voltage deviation between the DC capacitors. The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

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

B. Voltage Source Converter (VSC)

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC used to either completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. It also converts the DC voltage across storage devices into a set of three phase AC output voltages [8, 9]. In addition, APC is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages, APC is said to be in capacitive mode. So, it will compensate the reactive power through AC system and regulates missing voltages. These voltages are in phase and coupled with the AC system through the reactance of coupling transformers. Suitable adjustment of the phase and magnitude of the APC output voltages allows effectives control of active and reactive power exchanges between APC and AC system. In addition, the converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage [10].

C. Controller for STATCOM

The three-phase reference source currents are computed using three-phase AC voltages (*v*ta, *v*tb and *v*tc) and DC bus voltage (*V*dc) of STATCOM. These reference supply currents consist of two components, one in-phase (*I*spdr) and another in quadrature (*I*spqr) with the supply voltages. The basic equations of control algorithm of STATCOM are as follows.

D. Reference Current Generation for STATCOM

Reference current for the ST ATCOM is generated based on instantaneous reactive power theory. A STATCOM injects the compensation current which is a sum of reactive component current of IG, non-linear load and harmonic component current of non-linear load. PQ theory gives a generalized definition of instantaneous reactive power, which is valid for sinusoidal or non sinusoidal, balanced or unbalanced, three-phase power systems with or without zero sequence currents and/or voltages.

In the three phase power system, instantaneous Voltages, v_a, v_b, v_c in volts and instantaneous currents, i_a, i_b, i_c in amps of a three phase system are expressed as instantaneous space vectors ' v' and 'i' given by(l)

$$v = \begin{pmatrix} v_a \\ v_b \\ v_c \end{pmatrix} \quad i = \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

p' is the instantaneous active power of a three-phase circuit in Watts, given by (2)

$$P = v.\, i \qquad \ldots\ldots\ldots\ldots\ldots\ldots . (2)$$

Instantaneous active power of a three-phase circuit ' p' is the scalar product of instantaneous voltage and current. It is the product of the sum of three phase voltages and current, given by (3)

$$P = v_a i_a + v_b\, i_b + v_c i_c \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Instantaneous active power consists of average component and oscillatory component as given by (4)

$$P = P_{dc} + P_{ac} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

'Pdc' is the average component of instantaneous active power in watts and 'Pac' is the oscillatory component of instantaneous active power in watts. ' q' is the instantaneous reactive power of a three-phase circuit in V AR, given by(5)

$$q = IIv \text{ x } ill \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Instantaneous reactive power of a three-phase circuit ' q' is the vector product of instantaneous voltage and current, given by (6)

$$q = \begin{pmatrix} q_a \\ q_b \\ q_c \end{pmatrix} = \begin{pmatrix} \begin{vmatrix} V_b & V_c \\ i_b & i_c \end{vmatrix} \\ \begin{vmatrix} V_c & V_a \\ i_c & i_a \end{vmatrix} \\ \begin{vmatrix} V_a & V_b \\ i_a & i_b \end{vmatrix} \end{pmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Total current is the sum of instantaneous active, reactive and harmonic component of current given by (7)

$$i = i_p + i_q + i_h \qquad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

'ip', 'iq' and 'ih' are of instantaneous active, reactive and harmonic component of current respectively. 'ip'is the instantaneous active component current in amps given by (8)

$$i - P_{dc} .V \qquad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

p va2+vb2+vc2

Since it is a non linear load reactive component and harmonic component current are used as a reference current

for ST ATCOM. The reference current for the three phases as given by (9), (10), (11).

$$i_{af}' = i_{ap}' - i_{as}' = i_{aq} + i_{ah} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$i_{bf}' = i_{bp}' - i_{bs}' = i_{bq} + i_{bh} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

$$i_{ef}' = i_{ep}^{*} - i_{es}' = i_{eq} + i_{eh} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

'i_{af}'' , 'i_{bf}'' and 'i_{ef}'' are the STATCOM reference current of three phases respectively.' i_{ap}*', 'i_{bp}*' and 'i_{ep}'' are fundamental active component current of three phases respectively. Similarly 'i_{as}''' 'i_{bs}'' and 'i_{es}'' are the STATCOM source current of three phases respectively. 'i_{aq}', 'i_{bq}' and 'i_{eq} , are the sum of instantaneous reactive component current of induction generator and load of three phases respectively. 'i_{aq}', 'i_{bq}' and 'i_{eq}' are the instantaneous harmonic component current load of three phases respectively.

Introduction to Fuzzy Logic Controller

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and Sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to dc-to-dc converter system. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of converter. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of converters. The basic scheme of a fuzzy logic controller consists of four principal components such as: a fuzzy fication interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10].

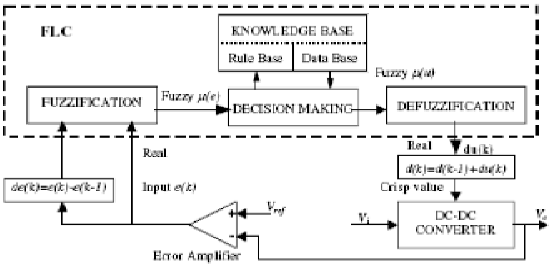

Fig.3. Block diagram of the Fuzzy Logic Controller (FLC) for proposed converter

Fuzzy Logic Membership Functions:

Fuzzy controllers do not require an exact mathematical model. Instead, they are designed based on general knowledge of the plant. Fuzzy controllers are designed to adapt to varying operating points. Fuzzy Logic Controller is designed to control the change in voltage of the converter using Mamdani style fuzzy inference system. Two input variables, error (e) and change of error (de) are used in this fuzzy logic system. The single output variable (u) is steady state signal of the converter, nothing but error free response is directly fed to the system.

Fuzzy Logic Rules

The objective of this dissertation is to control the output voltage of the boost converter. The error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided into seven groups; NL: Negative Large, NM: Negative Medium, NS: Negative Small, ZO: Zero Area, PS: Positive small, PM: Positive Medium and PL: Positive Large and its parameter [10]. These fuzzy control rules for error and change of error can be referred that is shown as below:

MATAB/SIMULINK MODELING OF STATCOM

Here the simulation is carried out in two cases

1. Implementation of proposed converter using conventional PI controller.

2. Implementation of proposed converter using fuzzy logic controller.

Case 1: Implementation of proposed converter using conventional PI controller.

The power circuit as well as control system are modelled using Power System Blockset and Simulink. The grid source is represented by three-phase AC source. Three-phase AC loads are connected at the load end. STATCOM is connected in shunt and it consists of PWM voltage source inverter circuit and a DC capacitor connected at its DC bus. An IGBT-based PWM inverter is implemented using Universal bridge block from Power Electronics subset of PSB. Snubber circuits are connected in parallel with each IGBT for protection. Simulation of STATCOM system is carried out for linear and non-linear loads. The linear load on the system is modelled using the block three-phase parallel R-L load connected in delta configuration. The non-linear load on the system is modelled using R and R-C circuits connected at output of the diode rectifier. Provision is made to connect loads in parallel so that the effect of sudden load addition and removal is studied. The feeder connected from the three-phase source to load is modelled using appropriate values of resistive and inductive components.

Fig. 4 shows the control algorithm of STATCOM with two PI controllers. One PI controller regulates the DC link voltage while the second PI controller regulates the terminal voltage at PCC. The in-phase components of STATCOM reference currents are responsible for power factor correction of load and the quadrature components of supply reference currents are to regulate the AC system voltage at PCC.

Fig. 4 Control Circuit

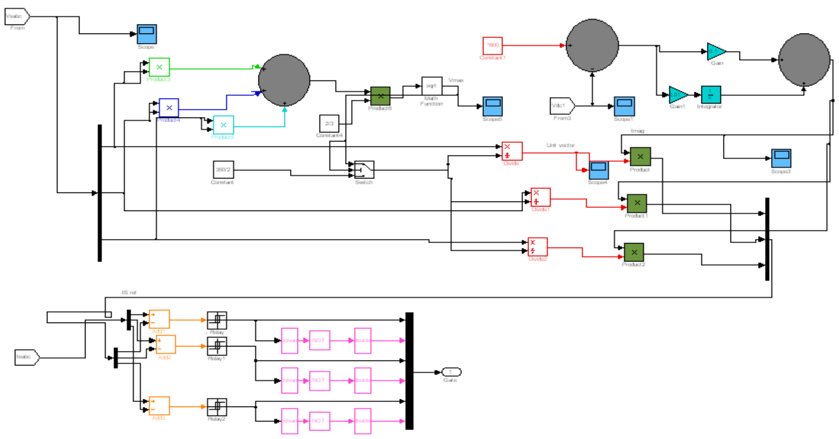

Fig. 4. Control Circuit

The output of PI controller over the DC bus voltage (*I*spdr) is considered as the amplitude of the in-phase component of supply reference currents and the output of PI controller over AC terminal voltage (*I*spqr) is considered as the amplitude of the quadrature component of supply reference currents. The instantaneous reference currents (*i*sar, *i*sbr and *i*scr) are obtained by adding the in-phase supply reference currents (*i*sadr, *i*sbdr and *i*scdr) and quadrature supply reference currents (*i*saqr, *i*sbqr and *i*scqr). Once the reference supply currents are generated, a carrierless hysteresis PWM controller is employed over the sensed supply currents (*i*sa, *i*sb and *i*sc) and instantaneous reference currents (*i*sar, *i*sbr and *i*scr) to generate gating pulses to the IGBTs of STATCOM. The controller controls the STATCOM currents to maintain supply currents in a band around the desired reference current values. The hysteresis controller generates appropriate switching pulses for six IGBTs of the VSI working as STATCOM.

Performance of STATCOM connected to a weak supply system is shown in Fig.5 for power factor correction and load balancing. This figure shows variation of performance variables such as supply voltages (*v*sa, *v*sb and *v*sc), terminal voltages at PCC (*v*ta, *v*tb and *v*tc), supply currents (*i*sa, *i*sb and *i*sc), load currents (*i*la, *i*lb and *i*lc), DSTATCOM currents (*i*ca, *i*cb and *i*cc) and DC link voltage (*V*dc).

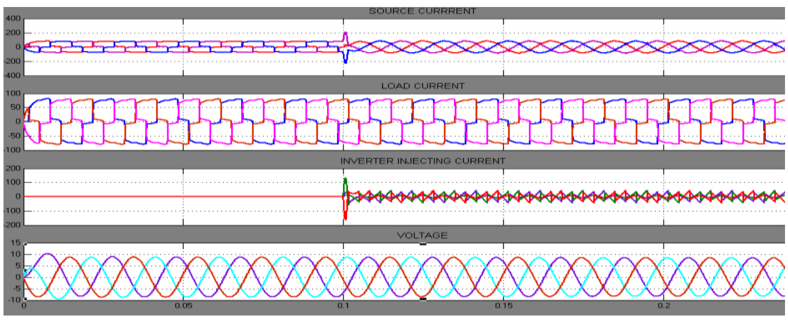

Fig.5. Simulation results for Statcom with PI Controller

(a) Source current. (b) Load current. (c) Inverter injected current. (d) Wind generator (induction generator) current.

Fig. 5 shows the source current, load current and compensator current and induction generator currents plots respectively. Here compensator is turned on at 0.1 seconds.

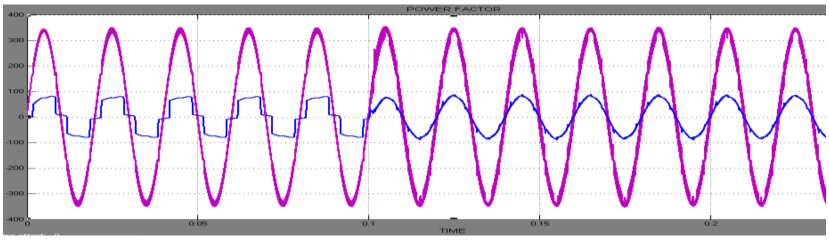

Fig.6. Simulation results power factor for Non linear Load

Fig. 6 shows the power factor it is clear, after compensation power factor is unity.

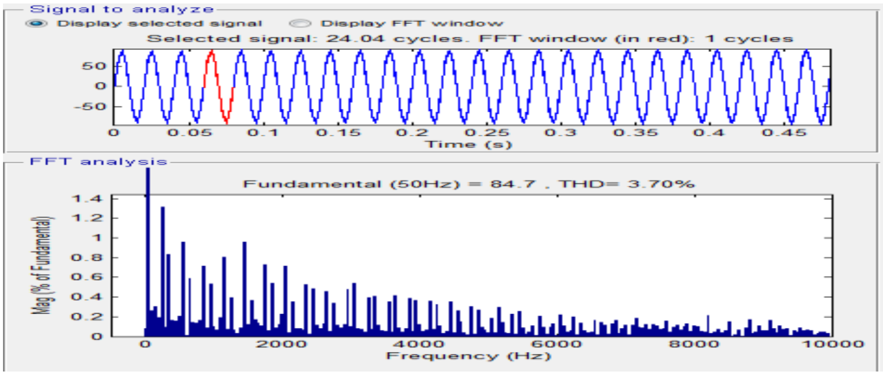

Fig.7 THD Analysis for Phase a Source Current, we get 3.70%, with pi controller based STATCOM.

Case 2: Implementation of proposed converter using conventional Fuzzy controller

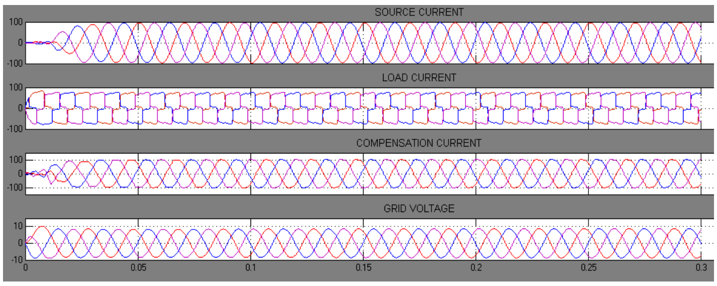

Fig.8. Simulation results for Statcom with PI Controller

(a) Source current. (b) Load current. (c) Inverter injected current. (d) Wind generator (induction generator) current.

Fig. 8 shows the source current, load current and compensator current and grid voltage plots respectively. Here compensator is turned on at 0.1 seconds.

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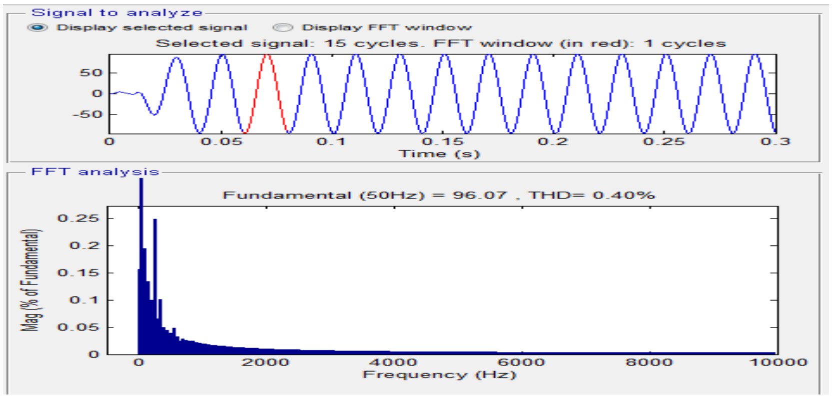

Fig.9. THD Analysis for Phase a Source Current, we get 0.40%, with Fuzzy Controller based STATCOM.

As above Fig. 7, 9 shows the THD Analysis of Phase A source current with PI & Fuzzy Controllers, both of the controller performance we get better THD in Fuzzy Controller.

CONCLUSION

STATCOM system is an efficient mean for mitigation of PQ disturbances introduced to the grid by DERs. STATCOM with Fuzzy compensator is a flexible device which can operate in current control mode for compensating voltage variation, unbalance and reactive power and in voltage control mode as a voltage stabilizer. The latter feature enables its application for compensation of dips coming from the supplying network. The simulation results show that the performance of STATCOM system has been found to be satisfactory for improving the power quality at the consumer premises. The control algorithm of STATCOM has an inherent property to provide a self-supporting DC bus of STATCOM. It has been found that the STATCOM system reduces THD in the supply currents for non-linear loads. THD values also well within IEEE Standard limits..

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