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Simulation of SRF Based DSTATCOM With Grid Connected PV Generation System Using Fuzzy Logic Controller For Reactive Power Management

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ABSTRACT*:* Due to extensive use of automatic and power electronic based devices in an electric distribution system, power quality problems have been substantially increased. Distribution system has poor power quality due to insufficient reactive power during steady and dynamic state. DSTATCOM is promising shunt connected custom power device for mitigating the power quality issues. In this paper investigation of SRF based DSTATCOM with grid connected PV generation system using fuzzy logic controller over PI controller is elaborated for reactive power management and is simulated using simpowersystem block sets of MATLAB. PV generation system is interfaced with the grid through boost converter and two level voltage source converter, SRF based theory is implemented for control of DSTATCOM in UPF mode of operation. The simulation results shows that fuzzy logic control provides better system response and reactive power control over PI controller.

KEYWORDS: PV Generating System, DC-DC Boost converter**,** SRF Theory, DSTATCOM, PI Controller, Fuzzy Logic Controller

I.INTRODUCTION

Due to enormous growth in power demand due to industrial as well as agricultural sectoral loads in the distribution system is resulting in huge reactive power consumption. As a result both real & reactive power required by loads are supplied by the source results in increased power losses in the system & in addition to this voltage regulation of the system becomes poor. At this end a lot of research is taking place to meet the requirements both in the fields of renewable energy sources as well as reactive power compensation & management at the load end [1]. Solar photovoltaic generation is one of the widely used renewable energy source. Various strategies are proposed in the literature for extracting maximum power form solar photovoltaic generation [2]-[6]. On the other hand, most common problems encountered in power distribution system are poor power quality due to the usage of non linear loads operated by power electronics converters, as a result of advancement in technology and also dynamic loads which necessities reactive power, resulting in poor voltage regulation and increased losses in the system which causes the entire power system to operative at higher MVA than as per load requirements. At the outset, reactive power management at load end supports the system for power factor improvement and voltage regulation of the system, which improves the regulation and minimizes the losses in system. All power quality mitigating controllers, which are used in distribution systems, are known as custom power devices. In this paper DSTATCOM is used as the solution for power quality concern & reactive power support at the load end is managed by a promising shunt connected custom power compensating device, DSTATCOM [7]-[8]. It mitigates the current based power quality problems in a distribution system such as reactive power, harmonics and unbalance in neutral current. DSTATCOM consist of VSC, DC link capacitor and interfacing inductor. For operating DSTATCOM various algorithms such as carrier based such as SRF (Synchronous reference frame), PBT (Power balanced theory), IRPT (Instantaneous reactive power theory) and carrier less based algorithms etc., are proposed in the literature. In this paper SRF based algorithm is used for extracting the reference currents [9]. Various modulation techniques are proposed in the literature for generating the pulses for VSC such as hysteresis controller, PWM technique and space vector modulation technique etc., of which sinusoidal pulse width modulation technique is employed .In addition, DSTATCOM uses DC link capacitor and which acts as a source

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for VSC. For maintaining constant and stabilised voltage across capacitor a PI controller is used. To certain extent PI controller works satisfactorily and give better results, but for dynamic and highly non linear loads the stability of the system hampers. In place of PI controller a fuzzy controller is used in this paper and its performance is investigated. Also for operating DC-DC boost converter pulses are generated by PWM technique. In this paper simulation of SRF based DSTATCOM with grid connected PV generation system using fuzzy logic controller for reactive power management over PI controller is investigated. The comparative results are analysed and found that fuzzy logic controller gives better response compared to PI controller over study and dynamic states.

II. SYSTEM CONFIGURATION

Fig.1 shows the schematic diagram of grid interfaced 20kW solar PV power generating system through boost DC-DC converter and two level VSC based DSTATCOM used for implementing/simulating the proposed scheme in MATLAB/simulink environment using simpowersystem block sets.

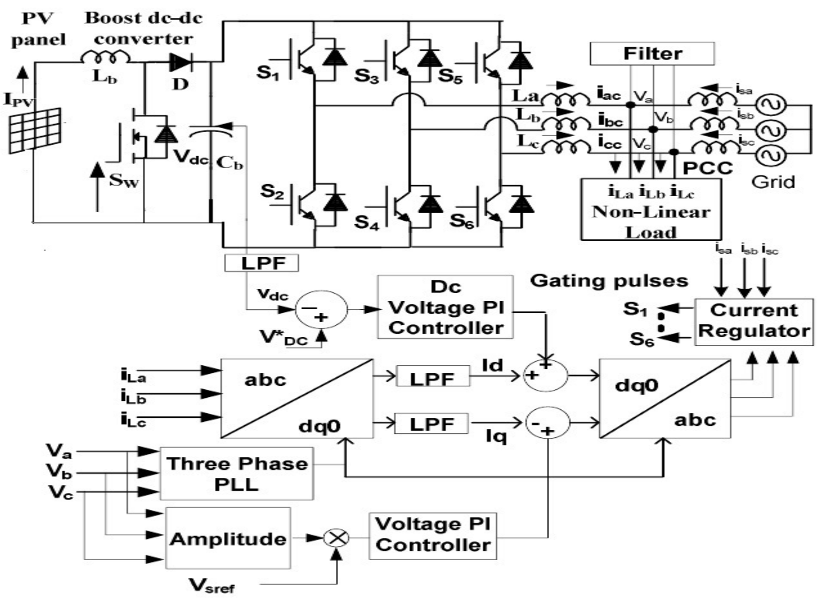

Fig.1 Schematic diagram of grid interfaced solar PV power generating system through boost DC-DC converter and two-level VSC based DSTATCOM

The design and selection criteria involved for development of the entire system components such as solar photovoltaic generation, DC-DC boost converter, interfacing inductors, DC link capacitor and the ripple filter are described below [10]-[11]

A. *Design of the Solar Photovoltaic generation*

The SPV power generating system is designed for a 20kW peak power capacity. According to design considerations 14 modules in series 10 modules in parallel, one solar module consists of 40 cells in series. Each cell has an open circuit voltage (V_{OC}) 0.64 V and short circuit current (I_{SC}) of 3.7A.

B. *Design of DC-DC Boost Converter*

The DC-DC boost converter is shown in Fig.1. The voltage from PV cell is boosted by using DC-DC boost converter to 700V. The design parameters of the DC-DC boost converter are given as.

$$L_b = \frac{V_{pv} * D}{(2 * \Delta i * f_{sw})} \qquad \text{... (1)}$$

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where D is duty cycle (D) = 1-(V_{in}/V_b). This converter boosts the voltage of SPV array from V_{in}= V_{PV} = 360 V to V_{dc}=700 V. The calculated value of D is 0.485 and V_{in} = V_{pv} is output voltage from PV array. Δi_1 is input current ripple and for this converter design, the value of Δi_1 is considered 10% of input current, f_{sw} is switching frequency and the value of f_{swb} = 10 kHz. The value of inductance (L_b) from Eq. (1) is obtained as 1.5 mH.

C. Selection of DC link Capacitor

The output capacitor C_{dc} for this DC-DC boost converter shown in Fig.1 is given as

$$C_{dc} = \frac{I_{ob}*D}{(\Delta v*f_{sw})} \quad ...(2)$$

where I_{ob}= (P_{ob}/V_b) is the output current. P_{ob} is the output power of the DC-DC boost converter and ΔV is peak ripple in output voltage. V_b is output voltage, the value of this ΔV is taken 3% of V_b and value of output current (I_{ob}) is calculated as 31.25 A. The value of output capacitor (C_{dc}) from (2) is calculated as 700µF.

D. Selection of DC reference voltage

The minimum dc bus voltage of VSC should be greater than twice the peak of phase voltage of the system as,

$$V_{dc} = \frac{2\sqrt{2}*V_{LL}}{\sqrt{3}} \quad ...(3)$$

The dc bus voltage is calculated as V_{LL} is the ac line output voltage of VSC. Thus, V_{dc} is obtained from Eq. (2) as 677.69 V for V_{LL} of 415 V and it is selected as 700 V.

E. Selection of interfacing Inductor

The design of AC inductance (L_f) of VSC is given as,

$$L_f = \frac{\sqrt{3}*m*V_{dc}}{(12*h*f_s*\Delta i)} \quad ...(4)$$

where ΔI is current ripple and its value is 5%, f_s switching frequency and its value is 10 kHz, (V_{dc}) dc bus voltage and its value of V_{dc} is 700V, m is the modulation index and its value is 0.9, h is the overload factor and its value is given as 1.2. The calculated of L_f is 4.97 mH. A round-off value of L_f of 5 mH is selected.

III.CONTROL ALGORITHM

Fig .2 shows the schematic diagram for implementation of SRF algorithm used for extracting the reference signals for generating the pulses to operating two-level VSC of DSTATCOM in UPF mode of operation [12]. Solar PV generating system is designed and developed in simulation for supplying about 20Kw real power to the load in addition with grid power. Solar PV generating system is connected to grid through DC-DC boost converter and operated by generating pulses through carrier based PWM process also two level –VSC is operated by carrier based PWM technique. A three phase linear load / variable load is connected to the source for validation of algorithm in Matlab environment by using simpower system block sets for both real and reactive power management in two modes of control strategies i.e., PI controller and fuzzy logic controller.

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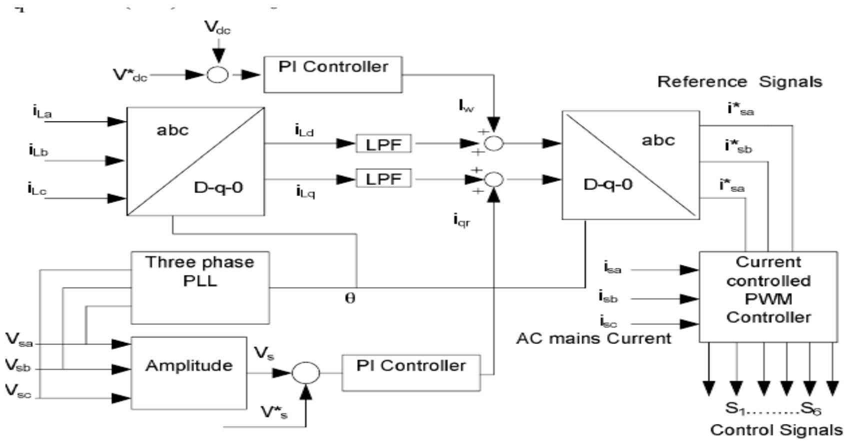

Fig.2 Schematic diagram of SRF based control algorithm for extracting reference source currents

The control approach used for estimation of reference currents for the control of VSC in a synchronous reference frame theory (SRFT) is described below. The SRF theory is based on the transformation of the load currents in synchronously rotating d-q frame. This control system is shown in Fig. 2 load currents (i_{La}, i_{Lb}, i_{Lc}), PCC voltages (V_{sa}, V_{sb}, V_{sc}) and DC bus voltage (V_{DC}) of VSC are sensed as feedback signals. Load currents in the three phases are converted to dq0 frame using following transformations,

$$\begin{bmatrix} iLd \\ iLq \\ iLo \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & -\sin\theta & \frac{1}{2} \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & \frac{1}{2} \\ \cos\left(\theta + \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) & \frac{1}{2} \end{bmatrix} \begin{bmatrix} iLa \\ iLb \\ iLc \end{bmatrix} \quad \text{... (5)}$$

A three phase PLL (phase locked loop) is used to synchronize these signals with the PCC voltage. These d-q current components are then passed through a LPF to extract the DC component of i_{Ld} &i_{Lq}. The d-axis and q-axis currents consist of fundamental and harmonic components as

$$i_{Ld} = i_{dDC} + i_{dAC} \quad \text{... (6)}$$
$$i_{Lq} = i_{qDC} + i_{qAC} \quad \text{... (7)}$$

A SRF controller extracts DC quantities by LPF and hence the non-DC quantities are separated from reference signals.

Control of Proposed System for Unity Power Factor

The control strategy for reactive power compensation for UPF mode of operation considers that the supply must deliver the dc component of direct-axis component of load current (i_{dDC}) along with the active power component for maintaining the dc bus meeting the losses (i_{loss}). The dc link voltage of the VSC is maintained at a predetermined voltage level using a PI controller. This facilitates active power transfer from the PV array and determination of VSC losses. The PI controller generates a compensating current signal as,

$$i_{loss} = i_{loss}(n-1) + K_{pd}\{v_{dc}(n) - v_{dc}(n-1)\} + K_{id} v_{dc}(n) \quad \text{... (8)}$$

where $v_{dc}(n) = v^*_{DC}(n) - v_{DC}(n)$ is the error between the reference (v^*_{DC}) and sensed (v_{DC}) DC voltage at the nth sampling instant and K_{pd}, K_{id} are the proportional and integral gain constant of the DC bus voltage PI controller

Therefore, the reference direct-axis supply current is

$$i^*_d = i_{dDC} + i_{loss} \quad \text{... (9)}$$

The active power component of reference AC mains currents must be in phase of PCC voltages. It is obtained by

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reverse Park's transformation as

$$\begin{bmatrix} i^*sa \\ i^*sb \\ i^*sc \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) & 1 \\ \cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} i^*d \\ i^*q \\ i^*o \end{bmatrix} \quad ... (10)$$

Current-Controlled Pulse width Modulation (PWM) Generator

In a current controller, the sensed and reference source currents are compared and a proportional controller is used for amplifying current error in each phase before comparing with a triangular carrier signal to generate the gating signals for six IGBT switches of VSC of DSTATCOM.

V. FUZZY CONGIC CONTROLLER

A fuzzy logic controller (FLC) consists of four elements, which are a fuzzification interface, a rule base, an inference mechanism, and a defuzzification interface. A FLC is designed for voltage regulation of DC bus. The design of the FLC for DC voltage regulator is described in detail [13]. The design of the fuzzy controllers for the AC and current regulators follows similar procedure. FLC designed for DC voltage regulator has two inputs and one output. The error e(t) (e = V_{dcref} −V_{dc}) and the rate of change of error e^*(t) the inputs and the output of the FLC is ΔI_d. In fact, ΔI_d is integrated to produce I_{dcref}. Fig.3 shows schematic diagram for implementation of FLC for DC voltage regulation across DC link capacitor where GE, GCE, and GCU are the scaling factors for the inputs and output respectively given in appendix. The linguistic variables for error e(t), the rate of change of error e^*(t) and the controller output ΔI_d will take on the following linguistic values: NL = Negative Large; NM = Negative Medium; NS = Negative Small; ZO = Zero; PS = Positive Small; PM= Positive Medium; PL = Positive Large.

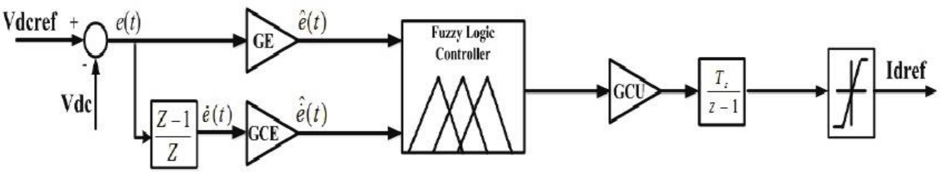

Fig.3 Schematic diagram for implementation of FLC

The above linguistic quantification has been used in this paper to specify a set of rules or a rule-base. The rules are formulated from practical experience. For the FLC with two inputs and seven linguistic values for each input, there are 72 = 49 possible rules with all combination for the inputs [14]-[15]. The tabular representation of the FLC rule base (with 49 rules) of the fuzzy control based DC voltage regulator is shown in Table 1:

TABLE 1: 7 × 7 FLC RULE - BASE IN TABULAR FORM

Error/Change In error	NL	NM	NS	ZO	PS	PM	PL
NL	ZO	PS	PM	PL	PL	PL	PL
NM	NS	ZO	PS	PM	PL	PL	PL
NS	NM	NS	ZO	PS	PM	PL	PL
ZO	NL	NM	NS	ZO	PS	PM	PL
PS	NL	NL	NM	NS	ZO	PS	PM
PM	NL	NL	NL	NM	NS	ZO	PS
PL	NL	NL	NL	NL	NM	NS	ZO

The membership functions to be employed for the inputs/output are of the triangular type. The membership functions for the inputs and the output of the fuzzy controller for the DC voltage regulator are shown in following Fig.4, Fig.5 and Fig.6 respectively

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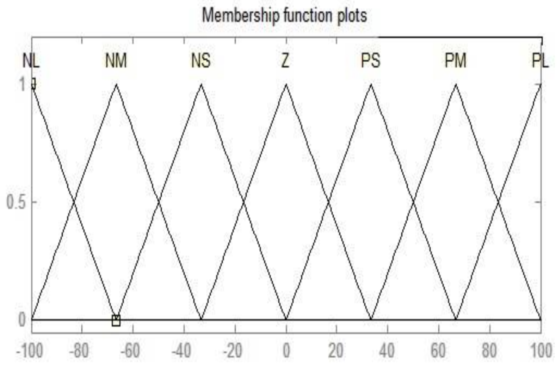

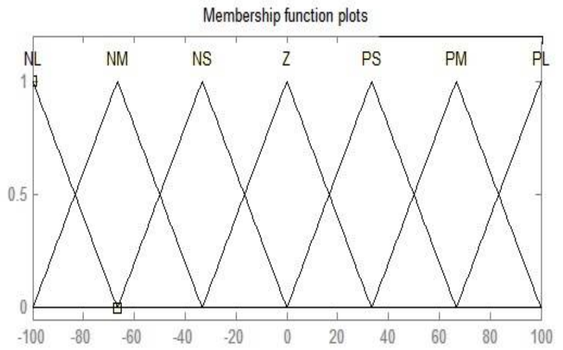

Fig. 4 Membership functions considered for scaling input error e (t)
Fig. 5 Membership functions considered for scaling the rate of change of error ê (t)

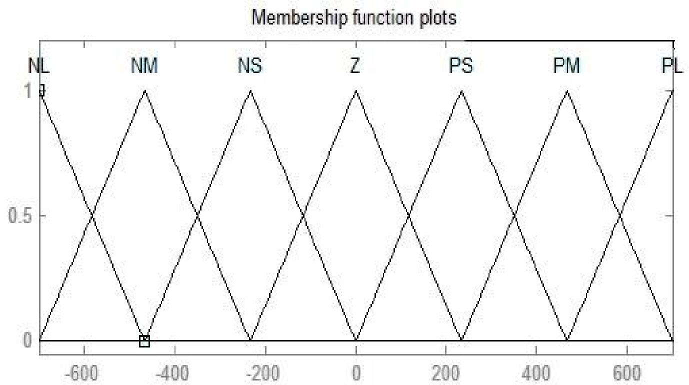

Fig. 6 Membership functions considered for scaling the output.

VI. RESULTS

In this section results pertaining to simulation of SRF Based DSTATCOM with grid connected PV generation system using fuzzy logic controller for reactive power management is investigated for the following cases i) with PI controller, ii) with fuzzy logic controller. From Fig. 7 it is observed that source phase voltage and current are out of phase in the absence of DSTATCOM and it can also be observed that source phase voltage and current are in phase with PI & even with fuzzy controlled DSTATCOM. Fig. 8 shows that the reactive power supplied from the source with DSTATCOM using fuzzy logic controller in comparison with PI Controller found to be very less as observed & as it is noticed from TABLE 2. It is also observed from the Fig. 8 that with fuzzy controlled DSTATCOM, the current supplied from the source is 32.3Amperes in comparison with PI which is about 35.7 Amperes and found to be less and also stability of system in terms of DC voltage regulation across DC link capacitor is improved. From the Fig. 9 it is observed that Total Harmonic distortion of source current with fuzzy logic controller based DSTATCOM is 0.98%. The effectiveness of the algorithm even for the variable loads with & without fuzzy controlled DSTATCOM are shown in Fig.10

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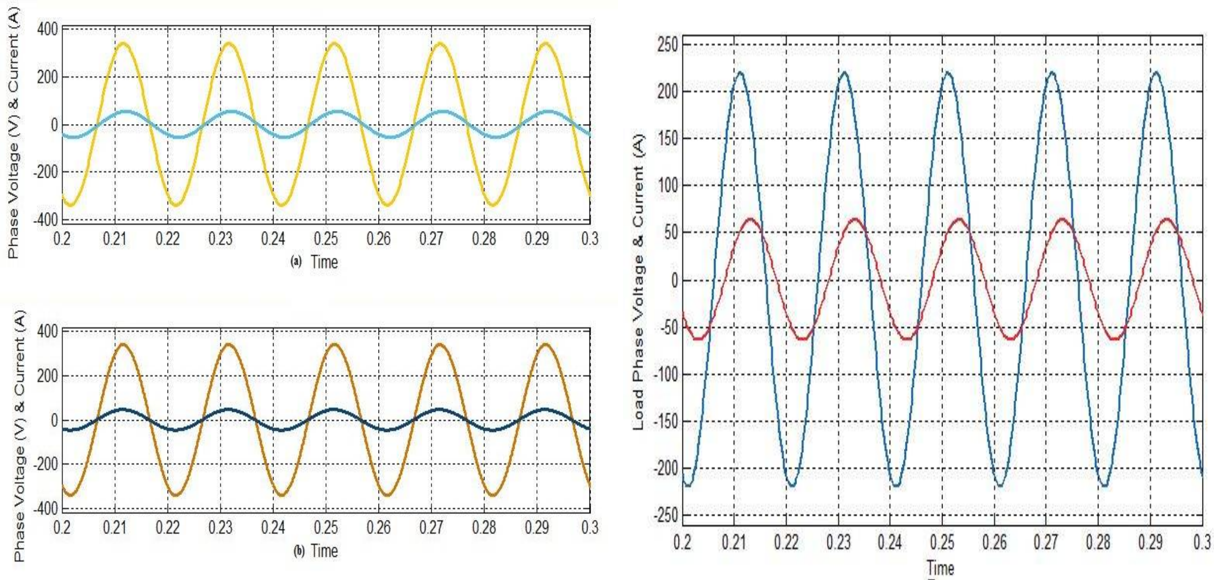

Fig.7 (a) & (b) Source Phase Voltage & Current Relation with fuzzy& PI Controlled DSTATCOM
Fig.7(c) Load Phase Voltage and Current Relation without DSTATCOM

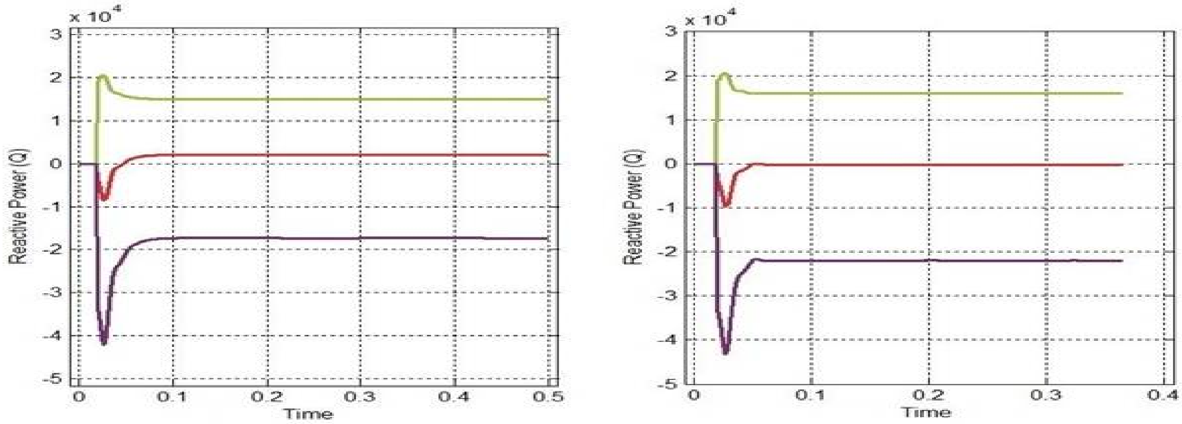

Fig. 8 (a) Reactive power flow in the system with DSTATCOM using PI controller
Fig.8 (b) Reactive power flow in the system with DSTATCOM using fuzzy logic controller

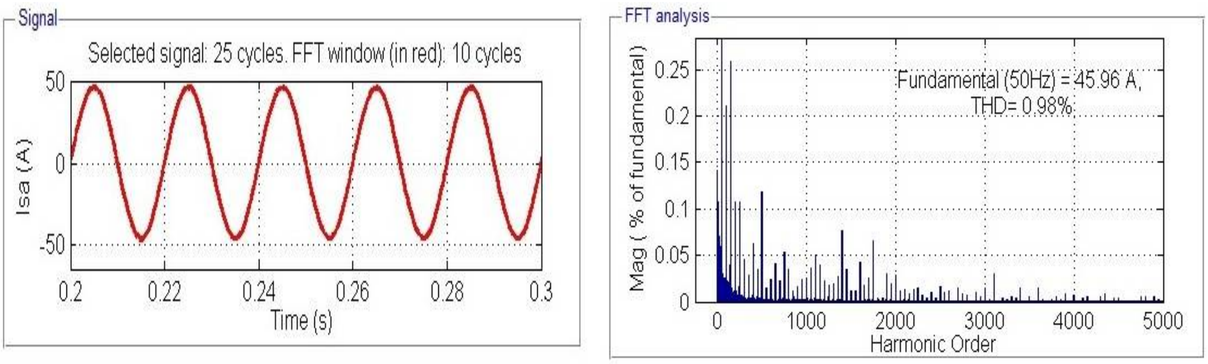

Fig. 9 Waveform and Harmonic Analysis of source line current with Fuzzy Logic Controller

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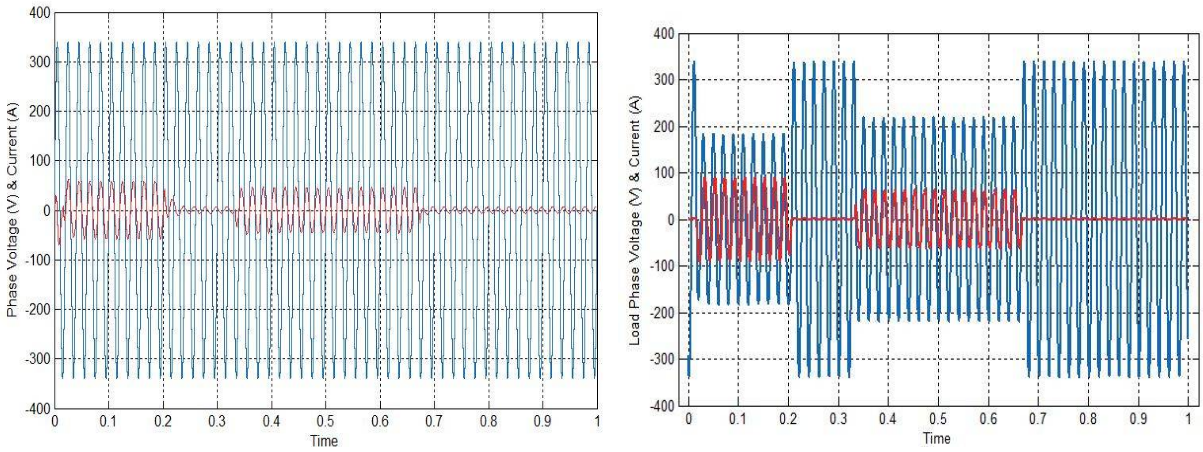

Fig. 10 (a) Source Phase Voltage and Current Relation of Dynamic loads with Fuzzy controlled DSTATCOM
Fig.10 (b) Load Phase Voltage and Current Relation of Dynamic loads without DSTATCOM

TABLE 2: Active and reactive power comparisions of SRF based DSTATCOM with grid connected PV generation system using PI & fuzzy logic controller for reactive power management

DSTATCOM control strategies	Active & Reactive power required by the Load	Active & Reactive power supplied by Source	Active & Reactive power supplied by the Inverter
PI tuned SRF based DSTATCOM With PV generation System	19907.82 KW & 14930.52 KVAR	25069.2 KW & 2022 KVAR	-2192.271 KW & -1737.186 KVAR
FLC tuned SRF based DSTATCOM With PV generation System	21307.67 KW & 15980.20 KVAR	23404.75 KW & 0 KVAR	-4272.5837 KW & -15980.20 KVAR

VII. SUMMARY AND CONCLUSIONS

In this section results pertaining to simulation using MATLAB/simulink of SRF based DSTATCOM with grid connected PV generation system for reactive power management are investigated for the following cases i) with PI controller, ii) with Fuzzy Logic Controller. From the results it is clear that the performance of this algorithm for UPF mode of operation of DSTATCOM with fuzzy controllers is found to be more satisfactory in respective of improvement in Total Harmonic Distortion of source current and reactive power supplied from the grid has been decreased in comparison with PI controlled DSTATCOM. Solar PV generating system at distributed end supplies the required real power to the load, which relays on output voltage of VSC and also supplies losses occurring in VSC. The performance of algorithm for dynamic loads found to be satisfactorily in lieu of system stability.

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APPENDIX

Simulation Data

REFERENCES

Grid voltage & grid frequency	230V and 50Hz respectively
PV Open circuit voltage (V_{OC})	0.64 V
PV Short circuit current (I_{sc})	3.4
One module of PV in series	40
Total Number of modules in series & Parallel	14 &10
Source Impendence	Rs=2Ω, Ls = 1mH
Interfacing Inductor	5mH
Ripple Filter	5Ω, 10mH
DC-Link capacitor	700μF
Duty Cycle of Boost converter	0.4857
FLC Scaling Factors for the DC Voltage Regulator	GE =0.00319; GCE =1.7778; GCU =0.53559
K_p & K_i	1.5 &2.4
Load	40KW, 30KVAR

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