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Grid Integration of Solar PV by Implementing Adaptive Filter in DSTATCOM

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ABSTRACT: This paper presents an implementation of an adaptive filter in a three-phase DSTATCOM (Distribution Static Compensator) used for compensation of linear/non-linear loads in a three phase grid integrated PV system. The proposed filter which is based on adaptive synchronous extraction is used for extraction of fundamental active and reactive power components of load currents in order to estimate the reference supply currents. This adaptive synchronous extraction is implemented on a developed DSTATCOM for reactive power compensation, harmonics elimination, load balancing and voltage regulation under linear and nonlinear loads. The hysteresis current control is used to interface the DSTATCOM to the PCC. The dq based control technique is used in DSTATCOM to limit the harmonics injected by the load and the solar PV. The performance of DSTATCOM and the filter is observed and it seems to be well performed to limit the harmonics. The test system is implemented using MATLAB SIMULINK software.

KEYWORDS: Adaptive filter, DSTATCOM, Harmonics, Load balancing, Sinusoidal tracking algorithm, VSC.

I.INTRODUCTION

Most of nonlinear loads are represented either as harmonic current source (or) a harmonic voltage source and responsible for power quality problems. An improved version of a shunt connected AF used in the distribution system is known as DSTATCOM. The employment of DSTATCOM is used for

i. Compensation of current related power quality problems.
ii. Reactive power compensation.
iii. Harmonic elimination.
iv. Load balancing.

Non-sinusoidal current in distribution system is mainly due to nonlinear characteristics of equipment such as adjustable speed drives. Switch mode power supplies, rectifiers and other such type of loads [1]. Harmonic current source or a harmonic voltage source in practical applications and responsible for creating power quality problems [2]. Mitigation of power quality problems can be achieved by using passive or active filters but due to certain advantages of active filter (AF) with digital control, it is used for improving power quality [3,4]. An improved version of a shunt connected AF used in the distribution system [5,6]. It is used for compensation of current related power quality problem in power factor correction (PFC) mode and zero voltage regulation (ZVR) mode [7,8]. Various international standards such as IEEE and IEC have reported the guidelines of harmonics limit at the point of common coupling (PCC) [9,10]. Effective utilization of converter used as DSTATCOM depends upon the control algorithm for extraction of reference currents and switching scheme [11]. Unit template based control algorithm without sensing load currents method is applied [12]. Signal processing algorithm used for selective harmonics identification based on heterodyning, moving average finite-impluse response filters and PLL using feed forward-based control [13].

These algorithms are based on basic arithmetic operation of mathematical function, transform, tuning of internal constants, clock, integration, flip-flops, comparators and logic circuits etc. The performance of these classical control algorithms depend upon selection and tuning of internal parameters, circuit components and their formulation [12, 13], Design of control algorithm needs only multiplications, integral, gain and subtraction blocks and the structure of this control algorithm is based on basic arithmetic operation due to this reason its implementation is simple and it does not

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require any extra synchronization circuit. Adaptive nature is discussed [14]. Parameter estimation is based on particle swarm optimization where in artificial immune system-based adaptive control [15]. Robust adaptive control implemented using adaptive pole-placement technique [16]. Improved adaptive detection algorithm for selective harmonic detection where convergence of extracted signal depends on selected value of gains [17].

Other adaptive control algorithms used in compensating devices are learning based algorithms [18]. least mean square (LMS) based control algorithm is discussed and applied to adjust the coefficients of the adaptive notch filter where Clarke transformation with low pass filter is used to detect the load current amplitude [19]. The Model reference adaptive control (MRAC) where advantage over conventional proportional integral control are flexibility, adaptive and robustness [20].

In these control algorithms, performance are based on fixed learning rate, transform based conversion and tuning of many internal parameters etc. This filter takes energy from input as the load current and it is not in the same direction of PCC voltage. This adaptive filter is able to handle variation in supply frequency because any variation in supply, frequency equally affects in current and voltage signals [19]. A simulation study of adaptive filter for synchronous extraction based control has been reported for single phase AC system in the literature for power factor correction [21].

It is used for estimation of only harmonics from deformed signal. Moreover, structure is simple, effective with less number of internal constants. Key factor for selection of this control range. Generally, load currents are deformed or have reactive power component due to nature of loads. An adaptive filter is implemented in three phase deformed voltage AC mains for reactive power compensation, harmonics elimination, and balancing with self supporting DC link in power factor correction (PFC) and zero voltage regulation (ZVR) modes of DSTATCOM. This control algorithm is also modified for DSTATCOM operation in ZVR mode.

II. SYSTEM CONFIGURATION

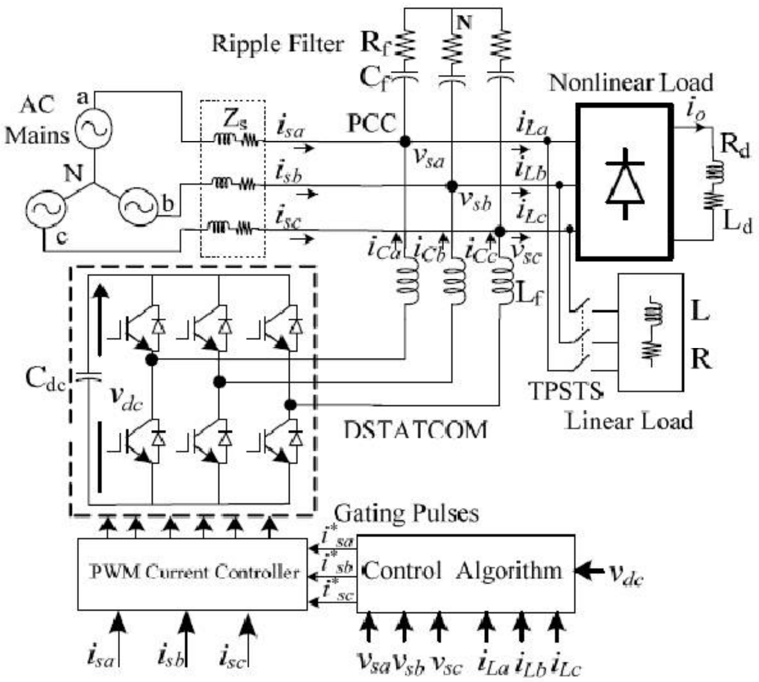

Fig 1: Schematic Diagram of Three Leg DSTATCOM

Fig 1. Shows a schematic diagram of a DSTATCOM connected to a three phase AC mains feeding three phase linear/nonlinear loads. Three phase linear and nonlinear loads are connected through three pole single throw switch (TPSTS) at the PCC as shown in this figure. TPSTS is used of disconnection of linear loads and for single operation another single pole single throw switch is used which is not shown in figure. Three phase diode bridge rectifier with resistive load (Rd) and filter inductance (Ld) is modelled as a nonlinear load for testing purpose. This type of load has

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zero demand of reactive power in ideal condition. A set of three phase resistors (R) with inductors (L) is modelled as a linear load. Ls and Rs are considered as AC mains impedance parameters (Zs). The normal available grid voltage with an extra supply inductance is considered as the distorted voltage of AC mains.

For implementation of control algorithm, sensed variables are PCC voltages (*vsa, vsb, vsc*), supply currents (*isa, isb, isc*), load currents (*iLa, iLb, iLc)* and DC link voltage (*vdc*). Interfacing inductors (Lf) are connected at AC side of the voltage source converter (VSC) for reducing ripple in compensating currents. The series connected capacitor (Cf) and a resistor (Rf) form the passive ripple filter installed at point of common coupling (PCC) in parallel with the load and it is used for filtering the high frequency switching noise of PCC voltages. Design of various components of DSTATCOM is given in Appendix '1' Figure. 1. Schematic diagram of three leg DSTATCOM The compensating currents (*iCa,iCb,iCc)* are injected by the DSTATCOM to suppress the harmonics/reactive power component of load currents so that the supply currents are harmonic free (reduction in harmonics) and the compensation of load reactive power. Maximum rating of the solid state switches is based on the required compensation.

III. CONTROL ALGORITHM

The control algorithm based on adaptive nature for synchronous extraction in time domain for deriving reference supply currents. It is applied under distorted AC mains feeding to linear and nonlinear loads. The basic steps for estimation of different control variables of control algorithm are given below.

A. ESTIMATION OF SIN AND COS COMPONENT OF PCC VOLTAGES:

Sinusoidal tracking algorithm is used for extraction of phase 'a' sin θva and cos θva component of distorted PCC voltages as unit templates in adaptive nature. The block diagram of this algorithm is shown in Fig. 3. Error in the phase 'a' voltage is the difference between *vsa* and *vso* and it is denoted by *Ve*. A1, A2 and A3 are internal constants of the algorithm which are positive real value. These constants decide the behavior of the algorithm in terms of convergence speed and accuracy. Values of these internal parameters A1, A2 and A3 are considered as 4, 2 and 1.5 for this implementation. The proposed algorithm is able to indentify sinusoidal components of input which is close to fundamental frequency after assigning initial condition in its integration block.

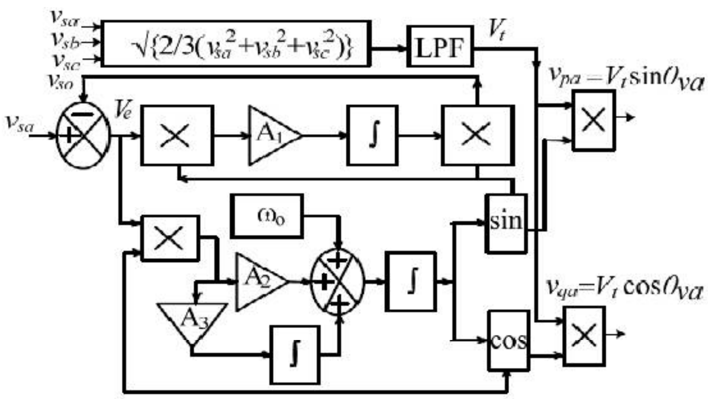

Fig 2: Estimation of phase voltage V_{pa} and V_{qa} components.

It is observed that the variations in sinθva and cosθva component of phase 'a' PCC phase voltage are effectively tracked in less than couple of cycles. The number of tracking cycles are reduced by increasing the value of internal constants up to certain extent. The advantages of this algorithm are low computational time, robust with respect to frequency variation and high estimation accuracy which are necessary in most of practical applications. Similarly, sin θ and cos θ components (sin θvb, cos θvb and sin θvc, cos θvc) of phase 'b' and 'c' voltages are also estimated respectively. *Vpa* and *vqa* are estimated as given below. Amplitude of PCC voltage (Vt) is estimated as follows,

$$V_t = \sqrt{\frac{2}{3}(V_{sa}{}^2 + V_{sb}{}^2 + V_{sb}{}^2} \qquad (1)$$

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Where,

V_t -Amplitude of PCC voltage

$V_{sa}\ V_{sb}\ V_{sc}$ -Phase voltages

In phase component of PCC phase voltages 'a', 'b', 'c' are written as.

$$V_{pa} = V_t \sin\theta_{va} \quad (2)$$
$$V_{pb} = V_t \sin\theta_{vb} \quad (3)$$
$$V_{pc} = V_t \sin\theta_{vc} \quad (4)$$
$$V_{qa} = V_t \cos\theta_{va} \quad (5)$$
$$V_{qb} = V_t \cos\theta_{vb} \quad (6)$$
$$V_{qc} = V_t \cos\theta_{vc} \quad (7)$$

B. ESTIMATION OF AMPLITUDE OF ACTIVE AND REACTIVE POWER COMPONENTS OF LOAD CURRENTS:

Active power, reactive power and harmonics components of load currents are the primary components in distorted and lagging power factor load currents. Active and reactive power components of phase 'a' load current are subtracted from original load current and generated error is multiplied with inphase component of PCC voltage (vpa). This signal is passed through low pass filter (LPF) before integration.

After integration with proper constant, this component is again multiplied with in-phase component of PCC voltage (vpa) in closed loop system. Active power component of phase 'a' load current (iLpa1) is extracted from original load current using above described procedure in adaptive nature. After extraction of active power component of load current, its root mean square value is estimated and converted to peak value using a gain (G). Amplitude of estimated active power component of phase 'a' load current is *iLpa*. Similarly amplitude of active component of phase 'b' and phase 'c' load currents *iLpb*, *iLpc* are estimated.

For extraction of reactive power component of load current, an error signal is multiplied with quadrature component of PCC voltage (*vqa*). After integration of this component again multiply with *vqa* term to extract the reactive power component of phase 'a' load current (*iLqa1*). After extraction of reactive power component of load current, its root mean square value is estimated and converted to peak value using a gain (G). Amplitude of reactive power component of phase 'a' load current is '*iLqa*'. Similarly amplitude of reactive power component of phase 'b' and phase 'c' load currents, *iLqb*, *iLqc* are estimated. Amplitudes of average fundamental active and reactive power components of load currents of three phase loads are estimated using the amplitude sum of individual three phase active and reactive power components of loads divided by three. In terms of mathematical expressions, these are expressed as,

$$I_{LpA=(i_{Lpa}+i_{Lpb}+i_{Lpc})} \quad (8)$$
$$I_{LqA=(i_{Lqa}+i_{Lqb}+i_{Lqc})} \quad (9)$$

Where,

I_{LpA} -Average magnitude of load active current.

I_{LqA} -Average magnitude of load reactive current.

C. AMPLITUDE OF ACTIVE AND REACTIVE POWER COMPONENTS OF REFERENCE SUPPLY CURRENTS:

Reference and sensed DC link voltage of VSC of DSTATCOM are used to calculate voltage error which is fed to a proportional-integral (PI) controller and its output is required for maintaining DC link voltage of the DSTATCOM. The output of DC link PI controller is considered as Iloss. The amplitude of active power component of reference supply current (Ispt) is calculated by an addition of output of DC link PI controller (Iloss) and average magnitude of load active currents (ILPA) as,

$$I_{spt} = I_{loss} + I_{LpA} \quad (10)$$

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Where,

I_{spt} -Amplitude of active power component of reference Supply current.

I_{Loss} -Output of DC-link PI controller.

I_{LpA} -Average magnitude of load active current.

Similarly, a second PI controller is used regulate the PCC terminal voltage. The output of AC bus voltage PI controller is considered Iqr. The amplitude of reactive power component of the reference supply current (Isqt) is calculated by difference of output of the voltage PI controller (Iqr) and average load reactive currents (ILqA) as,

$$I_{sqt} = I_{qr} - I_{LqA} \quad (11)$$

Where,

I_{sqt} -Amplitude of reactive power component of reference supply current.

I_{qr} -Output of AC bus voltage PI controller.

I_{LqA} -Average magnitude of load reactive current.

D. ESTIMATION OF REFERENCE SUPPLY CURRENTS AND GENERATION OF GATING PULSES:

Three phase reference supply currents are computed using an amplitude of three phases (*a*, *b* and *c*) load active power components of currents, reactive power components of currents, sinθ and cos θ components of PCC voltages. Three phase reference supply active and reactive power components of currents are estimated as,

$$i_{sap} = I_{spt} \sin\theta_{va}, i_{sbp} = I_{spt} \sin\theta_{vb},$$
$$i_{scp} = I_{spt} \sin\theta_{vc} \quad (12)$$
$$i_{saq} = I_{sqt} \sin\theta_{va}, i_{sbq} = I_{sqt} \sin\theta_{vb},$$
$$i_{scq} = I_{sqt} \sin\theta_{vc} \quad (13)$$

Where,

$i_{sap}\ i_{sbp}\ i_{scp}$ -Three phase reference Supply current of active Power components.

$i_{saq}\ i_{sbq}\ i_{scq}$ -Three phase reference supply current of reactive power components.

Total three phase reference supply currents are estimated by addition of reference active and reactive power components of currents as,

$$i_{sa}^* = i_{sap} + i_{saq}, i_{sb}^* = i_{sbp} + i_{sbq},$$
$$i_{sc}^* = i_{scp} + i_{scq} \quad (14)$$

Where,

$i_{sa}^*, i_{sb}^*, i_{sc}^*$ -Reference supply currents.

The sensed supply currents (isa, isb, isc) and these reference supply currents (i*sa, i*sb, i*sc) are compared for respective phases and each phase current error is amplified using PI controllers and outputs of PI current controllers are

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fed to PWM controller to generate the gating signals for IGBTs (Insulated Gate Bipolar Transistors) of VSC used as DSTATCOM.

IV. RESULT AND DISCUSSION

Figure shows the test system implemented using MATLAB SIMULINK software. The test system comprises an 3-phase 110V [L-L], 50Hz AC supply. A DSTATCOM is connected by the 2.5MH inductance. Small unbalance and harmonics distortion in PCC voltage are always present in practice. The proposed control algorithm is modified using band pass filter on PCC voltage and low pass filter on the estimated amplitude of PCC voltages.

Case 1: simulation result of supply voltage:

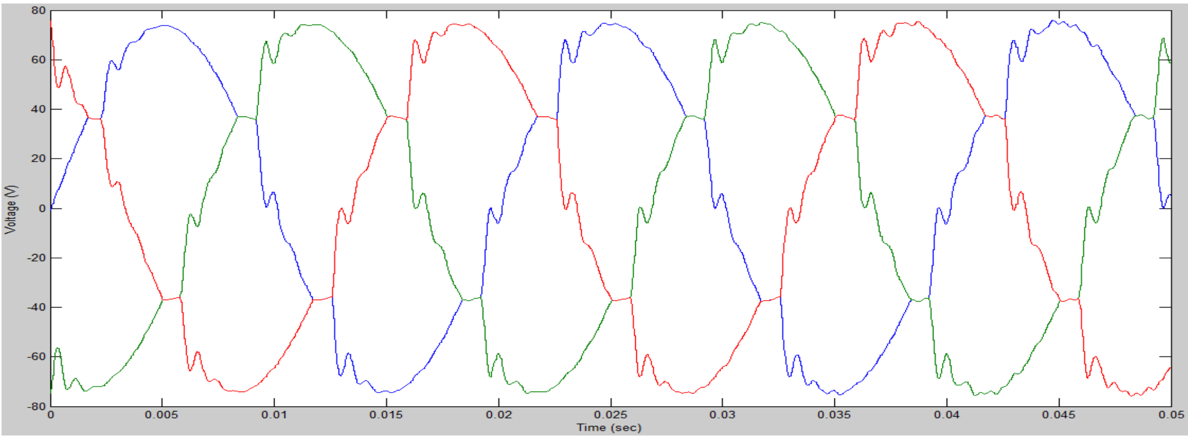

Fig.3 Supply Voltage (V) waveforms without DSTATCOM

Fig.3 shows the supply voltage (V) waveforms without DSTATCOM. When the breaker is kept open the DSTATCOM is not connected to the test of the system. Therefore the supply voltage is 75.9148 V due to absence of compensation by the DSTATCOM. Then breaker is closed and the DSTATCOM is connected to the test of the system with the compensation by the DSTATCOM. The supply voltage is increased from75.9148 to 91.1 V. Fig.4 shows the supply voltage (V) waveforms with DSTATCOM.

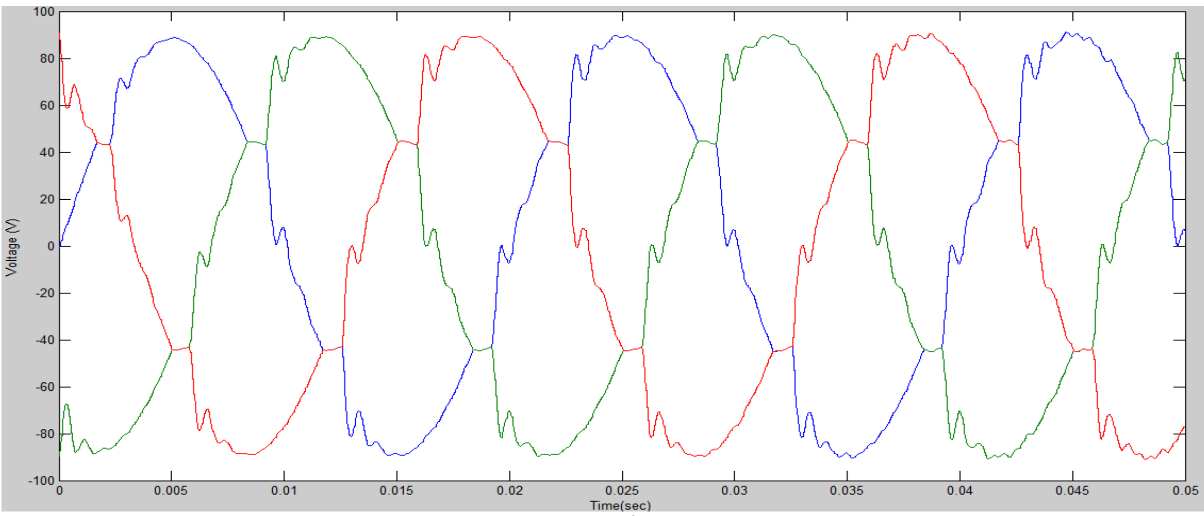

Fig. 4 Supply Voltage (V) waveforms with DSTATCOM

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Case 2: Simulation Result of Supply Current

Fig.5 shows the supply current (A) waveforms without DSTATCOM. It can be seen that the supply current has high amount of harmonic distortion due to the absence of compensation by DSATSCOM.

The total harmonic content is measured from the THD analysis tool. Fig.6 shows the THD measurement without DSTSTCOM and the THD is found to be 8.39%.

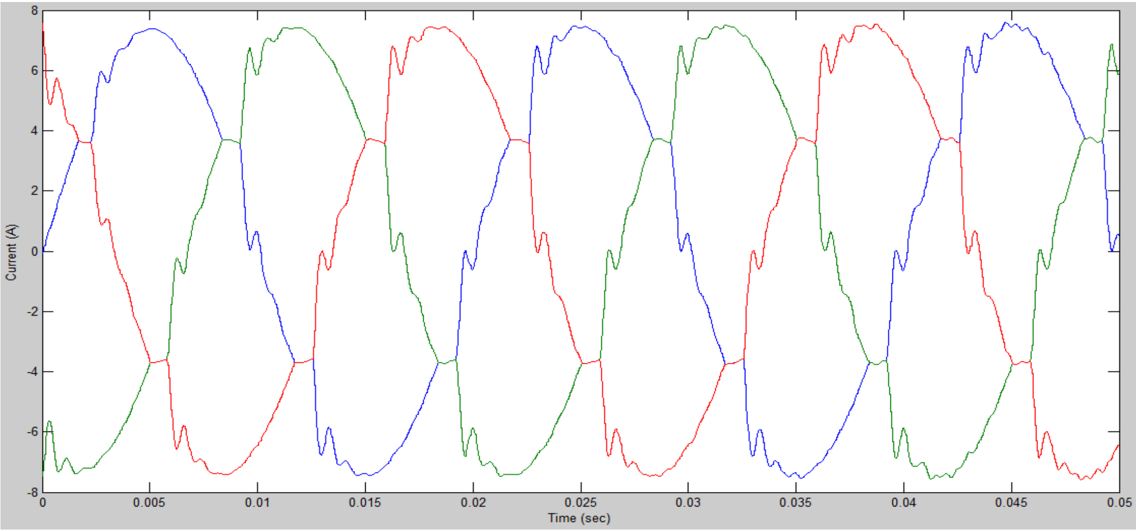

Fig.5 Supply current (A) waveforms without DSTATCOM

Then, the breaker is closed and the DSTATCOM is connected to the test system. Fig.7 shows the supply current (A) waveforms with the compensation by the DSTATCOM the harmonics are elimination in the supply current and the waveform is closed to sinusoidal. Fig.8 shows the THD measurement with DSTATCOM and the THD is found to be 0.83%.

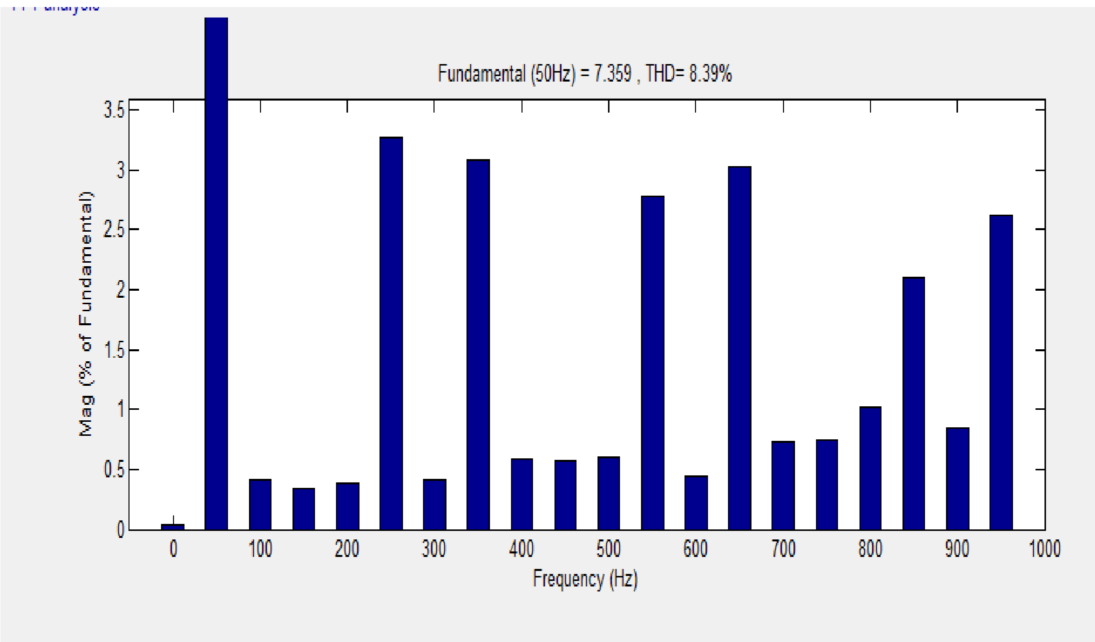

Fig.6 THD Measurement without DSTATCOM

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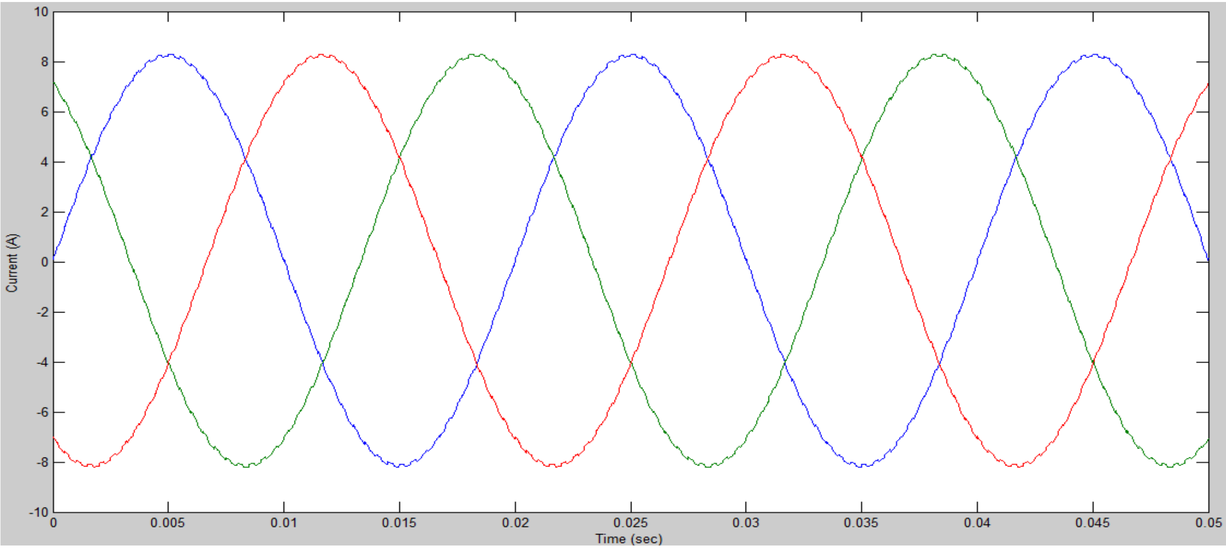

Fig.7 Supply current(A) waveforms with DSTATCOM

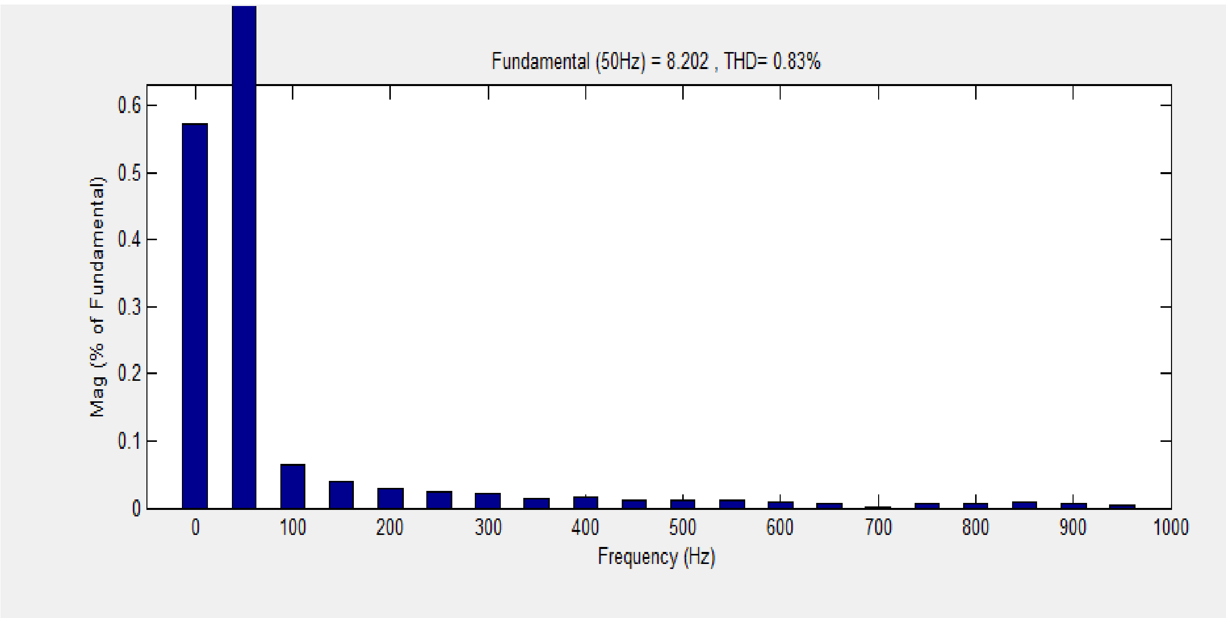

Fig.8 THD Measurement with DSTATCOM

V.CONCLUSION

A DSTATCOM has been implemented for a three-phase grid integrated PV system. An adaptive filter has been used for control DSTATCOM and its performance has been observed satisfactory with non-sinusoidal and distorted voltage of AC mains under load variation. The performance of DSTATCOM with its adaptive filter has been demonstrated for harmonics elimination, reactive power compensation and load balancing. The DC link voltage of the DSTATCOM has also been regulated to desired value under time varying load conditions.

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REFERENCES

1. Ewald F.Fuchs and Mohammad A. S. Mausom, 2007 “Power Quality in Power Systems and Electrical Machines,” Elsevier Academic Press.
2. Hirofumi Akagi, Edson Hirokazu Watanabe and Mauricio Aredes, 2007 “Instantaneous Power Theory and Applications to Power Conditioning,”. John Wiley and sons.
3. Ali Emadi, Abdolhosien Nasiri and Stoyan B. Bekiarov, 2005 “Uninterruptible Power Supplies and Active Filters,” CRC Press.
4. J. Jacobs, D. Detjen, C.U. Karipidis and R.W. De Doncker, 2004 “Rapid prototyping tools for power electronics systems: demonstration with shunt active power filters,” IEEE Transactions on Power Electronics.., vol.19, No.2, pp. 500-507.
5. Arindam Ghosh and Gerard Ledwich, 2009 “Power Quality Enhancement Using Custom Power Devices,” springer Inter.
6. K.R. Padiyar, 2008 “FACTS Controllers in Power Transmission and Distribution,” New Age International.
7. S.B. Karanki, N. Geddada, M.K. Mishra and B.K. kumar, 2012 “A DSTATCOM topology with reduced DC-link voltage rating for load compensation with non-stiff source,” IEEE Trans. On Power Electronics, vol. 27, no. 3, pp. 1201-1211.
8. Bhim singh, P. Jayaprakash and D. P. Kothari, 2008 “A T-connected transformer and three-leg VSC based DSTATCOM for power quality improvement,” IEEE Trans. On Power Electronics, vol. 23, no. 6, pp.2710-2718.
9. IEEE Recommended Practices and requirement for Harmonic Control on electric power system, IEEE std.519,1992.
10. IEEE Guide for Application and Specification of Harmonic Filters, IEEE Std. 1531, 2003.
11. A. M. Massoud , S. J. Finney and B.W. Williams, 2004 “Review of harmonic current extraction techniques for an active power filter,”in Proc. 11th Inter. Conf. On Harmonies and Quality of Power, pp. 154-159.
12. A. Chandra, B. Singh, B.N. Singh and K. Al-Haddad, 2000 “An improved control algorithm of shunt active filter for voltage regulation, harmonic elimination, power-factor correction, and balancing of nonlinear loads” IEEE Trans. Power Electronics, vol. 15, no.3, pp.495-507.
13. F.D. Ferijedo, J. Doval Gandoy, O. Lopez, P. Fernandez Comesana and C. Martinez Penalver, 2009 “A signal-processing adaptive algorithm for selective current harmonic cancellation in active power filters,” IEEE Trans. Industrial Electronics, vol.56,no.8.pp.2829-2840.
14. B. Singh and J.Solanki, 2009 “An implementation of an adaptive control algorithm for a three-phase shunt active filters,” IEEE Trans. On Industrial Electronics, vol. 56, no.8, pp.2811-2820.
15. P. Mitra and G.K. Venayagamoorthy, 2010 “An adaptive control strategy for DSTATCOM applications in an electric ship power system,”IEEE Trans. On Power Electronics, vol.25,no. 1, pp.95-104.
16. R.L. de Araujo Ribeiro, C.C. de Azevedo and R.M. de souse, 2012 “A robust adaptive control strategy of active power filters for power-factors correction, harmonic compensation, and balancing of nonlinear loads,”IEEE Trans. Power Electronics, vol27, no.2,pp.718-730.
17. Qian Lewei, D.A. Cartes and Li. Hui, 2008 “An improved adaptive detection method for power quality improvement,” IEEE Trans. On Industry Application, vol. 44,no. 2,pp.525-533.
18. Yu Zhang and Yupeng Tang, 2009 “Active power filter based on adaptive detecting approach of harmonic currents,” Journal of Electromagnetic Analysis and Applications, vol. 1,pp. 240-244.
19. R.R. Pereira, C.H. da Silva, L.E.B. da Silva, G. Lambert-Torres and J.O.P. Pinto, “New strategies for application of adaptive filters in active power filters,” IEEE Trans. On Industry Application, vol.47, no.3, pp.1136-1141.
20. Kuo-Kai Shyu, Ming-Ji Yang, Yen-Mo Chen, and Yi Fei Lin, 2008 “Model reference adaptive control design for a shunt active-filter system,” IEEE Trans. On Industrial Electronics, vol. 55, no.1,pp.97-106,
21. Houshang Karimi, Masoud Karimi Ghartemani, M. Reza Iravani and Alireza R. Bakhshai, 2003 “An adaptive filter for synchronous extraction of harmonics and distortions,” IEEE Trans. On power Delivery, vol. 18, no.4, pp.1350-1356.
22. Bhim Singh,*E*, Sabha Raj Arya,Ambrish Chandra, Kamal Al-Haddad,2014“Implementation of Adaptive Filter in Distribution Static Compensator” IEEE Trans on Idustry Application.