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IJIEMR Transactions, online available on 30th June 2017. Link :

http://www.ijiemr.org/downloads.php?vol=Volume-6&issue=ISSUE-4

Title: Fuzzy Based Combined Lms–Lmf-Based Control Algorithm of Dstatcom For Power Quality Enhancement.

Volume 06, Issue 04, Page No: 1374 – 1383.

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FUZZY BASED COMBINED LMS–LMF-BASED CONTROL ALGORITHM OF DSTATCOM FOR POWER QUALITY ENHANCEMENT

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ABSTRACT:

In this paper Fuzzy based Combined LMS–LMF-Based Control Algorithm of DSTATCOM is presented. Power quality problems are of major concern in the distribution system that leads to decrease in efficiency of the system. The abundant uses of nonlinear loads inject harmonics into the system and decline the quality of power. Least mean square–least mean fourth (LMS–LMF)-based control algorithm is used for distribution static compensator (DSTATCOM) in three-phase distribution system to alleviate the power quality problems caused by solid-state equipments and devices. The proposed control algorithm has advantages of both LMF- and LMS-based control algorithms, which helps in fast and accurate response with a robust design. DSTATCOM is a shunt connected FACTS device. It is a reactive source that can be controlled and it is capable of absorbing or generating reactive power. DSTATCOM consists of coupling transformer, voltage source converter, DC energy storage device and necessary control circuits. In this paper fuzzy logic technique can be used to implement a controller for controlling the output of DSTATCOM. In order to maintain a constant voltage at the dc-bus of a voltage-source converter (VSC) and to obtain a fast dynamic response and for better performance proportional-integral (PI) controller is replaced with fuzzy logic controller is used. .In extension Fuzzy logic controller is used to reduce total harmonic distortion in the system and to attain better performance. The results are shown by using MATLAB/SIMULINK model.

Key Words: *LMS–LMF Control Algorithm, D-STATCOM, Voltage source converter, Fuzzy Logic controller,*

I. INTRODUCTION

Industry, commerce, health care services, banks and other service providers are extremely dependent upon electrical and electronic systems. These systems influence mains quality themselves in many ways, but they react extremely sensitively to any disturbance as well. It is thus the entrepreneurial responsibility of all modern business operations to keep their own electrical systems under control - 24 hours a day under any possible conditions [1]. Action should be taken as soon as the first signs of poor mains quality appear such as overheated transformers and cables, excessive current in neutral conductors without any explicable cause, tripped protective devices, flickering lights, computer failures and data network problems, interference in telephone lines or inexplicably increased energy costs. Causes can be pinpointed and the elimination of faults can be implemented through the use of suitable measuring equipment. Custom power is a strategy, which is intended principally to convene the requirement of industrial and commercial consumers. The concept of the custom power is tools of application of power electronics controller devices into power distribution system to supply a quality of power, demanded by the sensitive users [2]. These power electronics controller devices are also called custom power devices because through these valuable powers is applied to the customers. They have good performance at medium distribution levels and most are

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available as commercial products. For the generation of custom power devices VSI is generally used, due to self-supporting of dc bus voltage with a large dc capacitor.

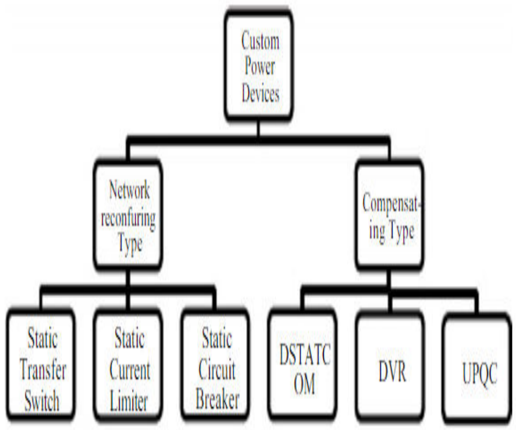

Fig.1. Classification of custom power devices

DSTATCOM is a Voltage source inverter (VSI) based static compensator device (STATCOM, FACTS controller) applied to maintain bus voltage sags at the required level by supplying or receiving of reactive power in the distribution system. It is connected in shunt with distribution feeder with the help of coupling transformer. The single line diag. of DSTATCOM is shown in shown fig. 2.The DSTATCOM consists of a VSI, dc energy storage device, an ac filter and coupling transformer

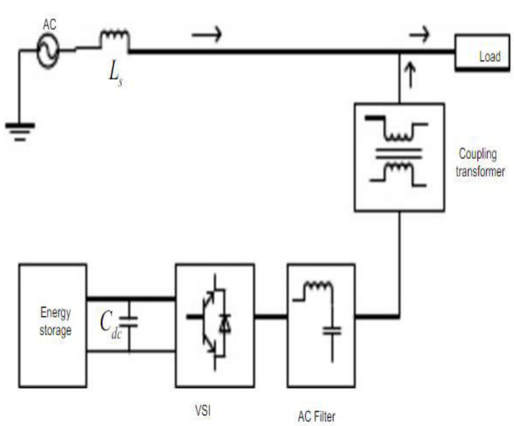

Fig.2. Single line diagram of DSTATCOM

Voltage sags 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 [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. Harmonic currents in distribution system can cause harmonic distortion, low power factor and additional losses as well as heating in the electrical equipment. It also can cause vibration and noise in machines and malfunction of the sensitive equipment. The development of power electronics devices such as Flexible AC Transmission System(FACTS) and customs power devices have introduced and emerging branch of technology providing the power system with versatile new control capabilities.

In power distribution networks, reactive power is the main cause of increasing distribution system losses and various power quality problems. Conventionally, SVCs have been used in conjunction with passive filters at the distribution level for reactive power compensation and mitigation of power quality problems[4]-[6]. Though SVCs are very effective system controllers used to provide reactive power compensation at the transmission level, their limited bandwidth, higher passive element count that increases size and losses, and slower response make them inapt for the modern day distribution requirement. Another compensating system has been proposed by, employing a combination of SVC and active power filter, which can compensate three phase loads in a minimum of two cycles. Thus, a controller which continuously monitors the load voltages and currents to determine the right amount of compensation required by the system and the less response time should be a viable alternative.

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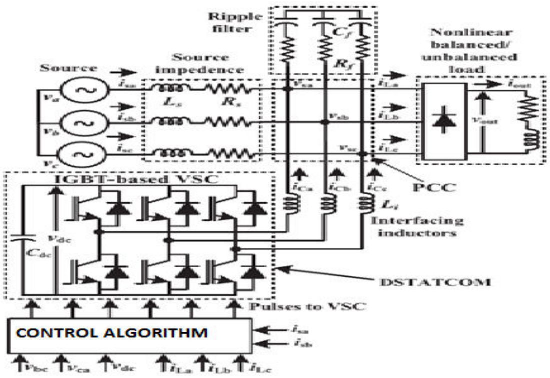

Fig.3. Schematic of the distribution system with DSTATCOM

D-STATCOM has the capacity to overcome theabove mentioned drawbacks by providing precise controland fast response during transient and steady state, withreduced foot print and weight. A D-STATCOM is basicallya converter based distribution flexible AC transmissioncontroller, sharing many similar concepts with that of aSTATCOM used at the transmission level. At thetransmission level, STATCOM handles only fundamentalreactive power and provides voltage support, while a DSTATCOM is employed at the distribution level or at theload end for dynamic compensation. The latter, DSTATCOM, can be one of the viable alternatives to SVC ina distribution network [7]. Additionally, a D-STATCOM canalso behave as a shunt active filter, to eliminate unbalanceor distortions in the source current or the supply voltage.Since a D-STATCOM is such a multifunctional device, themain objective of any control algorithm should be to make itflexible and easy to implement, in addition to exploiting itsmulti functionality to the maximum. The main inconvenience of the steepest-descent (MMS) gradient algorithm consists in the detail that exact measurements of the gradient vector are required at each step in the iteration process. This is not practical and one needs an algorithm for deriving estimates of the gradient vector only from the available data. This is achieved by using the least-mean-square (LMS) error gradient algorithm. Its advantages are the following: it is done straightforward, does not require matrix inversion, and it does not require correlation measurements. The least mean squares (LMS) algorithms adjust the filter coefficients to minimize the cost function. Compared to recursive least squares (RLS) algorithms, the LMS algorithms do not involve any matrix operations. Therefore, the LMS algorithms require fewer computational resources and memory than the RLS algorithms. The implementation of the LMS algorithms also is less complicated than the RLS algorithms. However, the eigenvalue spread of the input correlation matrix, or the correlation matrix of the input signal, might affect the convergence speed of the resulting adaptive filter. In LMS family, the least mean fourth (LMF) algorithm was first developed by Walach and Widrow[8]-[10]. The algorithm applied the fourth-order power optimization criterion instead of the square powerused for LMS. This idea came from the fact that higher-order power filters can mitigate noise interferenceeffectively, especial in low SNR region. However, the computational complexity of LMF isvery high, which is caused by higher-order power optimization in its updating equation. A combined least mean square–least mean fourth (LMS–LMF)-based control algorithm of DSTATCOM is proposed for the power quality improvement in the proposed system. The error of the algorithm is minimized by appropriately selecting either LMS or LMF for the pulse generation, thus the algorithm helps in extracting accurate pulses for the operation of DSTATCOM [11][12]. Depending on the value of error signal obtained in any of the phases either of LMS- or LMF-based control algorithm is used to minimize the error, thereby taking the advantage of both algorithms. The step size is selected on the basis of power rating of the system. The combined LMS–LMF control algorithm has better performance as compared with LMF and

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LMS control algorithm based on steady-state performance and mean-square error. The proposed control algorithm has fast convergence speed when compared with LMS and LMF control algorithms. This control algorithm is designed for harmonics' elimination, ZVR, PFC, and load balancing of nonlinear loads. This algorithm is robust for application, easy to implement, and the response is fast.To fully take the advantages of both LMS and LMF, a combined LMS/F algorithm has beenproposed by Lim and Harris as a method to improve the performance of LMS adaptive filterwithout sacrificing its simplicity and stability. However, the proposed method only considered its updatingequation, and it neglected specific applications in different SNR regions. In this paper, we introducethe combined LMS/F algorithm to ASI by considering the tradeoff between convergence speed andsteady-state performance. The cost function of LMS/F is constructed for adaptive filter updating.

II. PROPOSED SYSTEMCONFIGURATION

The power quality in the distribution system can be improved using the proposed configuration, as shown in Fig 3. This system includes a three-phase nonlinear load that is supplied from a 415-V, 50-Hz, three-phase ac supply with supply resistance (Rs) and supply inductance (Ls), VSC with a dc-bus capacitor (C_{dc}), and ripple filters (R_f and C_f) to eliminate the high switching frequency noise during the operation of VSC. The VSC is linked to the point of common coupling (PCC) through the interfacing inductors (Li) that are tuned such that they reduce the ripples in the compensating currents. A three-phase diode bridge rectifier (DBR) is used as a nonlinear load with an RL branch on the dc side. For the simulation using MATLAB software, the passive elements such as ripple filters (R_f and Lf) and interfacing inductors (Li) are designed considering the specifications of three-phase PCC voltage at 415 V and the load to operate at 20-kW power rating [13].

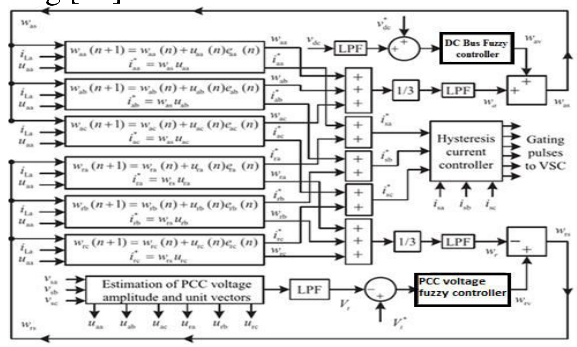

Fig.4. Block diagram of the combined LMS–LMF-based control algorithm

III. CONTROL ALGORITHM

The schematic of the combined LMS–LMF-based control algorithm of DSTATCOM is shown in Fig 4. This combined LMS–LMF-based algorithm is used to derive the required reference supply currents from the observed load currents (iLa, iLb, and iLc), unit templates (uaa, uab, and uac) derived from the sensed supply voltages (vsa, vsb, and vsc), the dc-link voltage across the compensator (vdc), and the magnitude of supply voltages (Vt). The reference supply currents that are generated from the algorithm are correlated with the supply currents sensed from the system and the resulting error difference is used to generate the appropriate pulses for the DSTATCOM by passing these error signals through hysteresis-based current controller. Initially, one derives the active unit template components (uaa, uab, and uac) for the three phases that are in-phase to the supply voltages (vsa, vsb, and vsc) are expressed as

$$u_{aa} = \frac{v_{sa}}{V_t}; \quad u_{ab} = \frac{v_{sb}}{V_t}; \quad u_{ac} = \frac{v_{sc}}{V_t} \qquad (1)$$

whereVt is the amplitude of sensed supply voltages (vsa, vsb, and vsc) or PCC voltage and is expressed as

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

These unit templates are used to synchronize the obtained active weights (waa, wab, and wac) with the phase of supply voltage to obtain the appropriate errors (eaa, eab, and eac).

The active weight component of the phase "a" at sampling instant $(n + 1)^{th}$ is estimated as

$$w_{aa}(n+1) = w_{aa}(n) + u_{aa}(n)e_{aa}(n) \quad (3)$$

Where$e_{aa}(n)$ is the actual active error vector of phase "a" for the proposed combined LMS–LMF-based control algorithm and this error component is expressed as

$$\begin{aligned} e_{aa}(n) &= er_{aa}(n) \text{ if } er_{aa}(n) \geq 1 \\ &= er^3_{aa}(n) \text{ if } er_{aa}(n) < 1 \end{aligned} \quad (4)$$

Where$er_{aa}(n)$ is the error in active load component of phase "a," at sampling instant (n)th and is estimated as

$$er_{aa}(n) = k\{i_{La}(n) - u_{aa}(n)w_{aa}(n)\} \quad (5)$$

The factor used in the formation of these equations is k which is a step size and the suitable value for this application is 0.1. Similarly, the active weight component for phases "b" and "c" are expressed as

$$w_{ab}(n+1) = w_{ab}(n) + u_{ab}(n)e_{ab}(n) \quad (6)$$

$$w_{ac}(n+1) = w_{ac}(n) + u_{ac}(n)e_{ac}(n) \quad (7)$$

By adding (3), (6), and (7), the mean value of the fundamental active weight components is obtained as

$$w_a = (w_{aa} + w_{ab} + w_{ac})/3 \quad (8)$$

The set dc voltage reference value is correlated with sensed dc-link voltage (vdc) of VSC and the error is given to the proportional integral (PI) controller of dc-bus voltage. The output of this controller is taken to be the dc loss weight component and is expressed as

$$\begin{aligned} w_{av}(n+1) = w_{av}(n) + K_{pd}\{v_{dd}(n+1) - v_{dd}(n)\} \\ + K_{id}v_{dd}(n+1) \end{aligned} \quad (9)$$

where $w_{av}(n + 1)$ and vdd(n + 1) are the dc-bus loss component and error between of sensed dc-link voltage of VSC and reference dc value at (n + 1)th sampling time. Kid and Kpd are the integral and proportional gains of the dc-bus voltage controller. By adding the dc loss component to the average fundamental active weight component, one obtains the total active weight component (was) of the supply reference currents as

$$w_{as} = w_a + w_{av} \quad (10)$$

The active in-phase reference supply current components for the three phases are expressed as

$$i^*_{aa} = w_{as}u_{aa}; \quad i^*_{ab} = w_{as}u_{ab}; \quad i^*_{ac} = w_{as}u_{ac} \quad (11)$$

The reactive unit template components (ura, urb, and urc) for the three phases that are quadrature to the supply voltages (vsa, vsb, and vsc) are expressed as

$$u_{ra} = -\frac{u_{ab}}{\sqrt{3}} + \frac{u_{ac}}{\sqrt{3}}; \quad u_{rb} = \frac{\sqrt{3}u_{aa}}{2} + \frac{(u_{ab} - u_{ac})}{2\sqrt{3}}$$
$$u_{rb} = -\frac{\sqrt{3}u_{aa}}{2} + \frac{(u_{ab} - u_{ac})}{2\sqrt{3}}. \quad (12)$$

The reactive weight components for three phases a, b, and c are estimated using the following equations:

$$w_{ra}(n+1) = w_{ra}(n) + u_{ra}(n)e_{ra}(n) \quad (13)$$

$$w_{rb}(n+1) = w_{rb}(n) + u_{rb}(n)e_{rb}(n) \quad (14)$$

$$w_{rc}(n+1) = w_{rc}(n) + u_{rc}(n)e_{rc}(n) \quad (15)$$

By adding (13)–(15), the mean value of the fundamental reactive weight components is obtained as

$$w_r = (w_{ra} + w_{rb} + w_{rc})/3. \quad (16)$$

The average magnitude of the supply voltage is sensed and is correlated with set reference magnitude value and the error difference is given to the ac voltage PI controller. The ac voltage controller output is weighted to be the ac loss weight component and is expressed as

$$\begin{aligned} w_{rv}(n+1) = w_{rv}(n) + K_{pt}\{v_{dt}(n+1) - v_{dt}(n)\} \\ + K_{it}v_{dt}(n+1) \end{aligned} \quad (17)$$

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Where $w_{rv}(n + 1)$ and vdt(n + 1) are the reactive power component and error between sensed ac-link voltage and reference magnitude value at $(n + 1)^{th}$sampling time. Kit and Kpt are the integral and proportional gains of ac voltage controller. By subtracting the average fundamental reactive weight component from the reactive power component, one obtains the total reactive weight component (wrs) of the supply reference currents and it is estimated as

$$w_{rs} = w_{rv} - w_r \quad (18)$$

$$i^*_{ra} = w_{rs}u_{ra}; \quad i^*_{rb} = w_{rs}u_{rb}; \quad i^*_{rc} = w_{rs}u_{rc} \quad (19)$$

Finally, adding the active and reactive reference components of the supply currents of each of the three phases, reference supply currents are expressed as

$$i^*_{sa} = i^*_{aa} + i^*_{ra}; \quad i^*_{sb} = i^*_{ab} + i^*_{rb}; \quad i^*_{sc} = i^*_{ac} + i^*_{rc} \quad (20)$$

These reference supply currents (i^*_{sa},$i^*_{sb}$and i^*_{sc}) and sensed supply currents (i_{sa},i_{sb} and i_{sc}) are given to hysteresis current controller that generates the gating pulses to VSC.

IV FUZZY LOGIC CONTROLLER

Fuzzy control is a methodology to represent and implement a (smart) human's knowledge about how to control a system. A fuzzy controller is shown in Fig 5. The fuzzy controller has several components:

- A rule base that determines on how to perform control
- Fuzzification that transforms the numeric inputs so that the inference mechanisms can understand.
- The inference mechanism uses information about the current inputs and decides the rules that are suitable in the current situation and can form conclusion about system input.
- Defuzzification is opposite of Fuzzification which converts the conclusions reached by inference mechanism into numeric input for the plant.

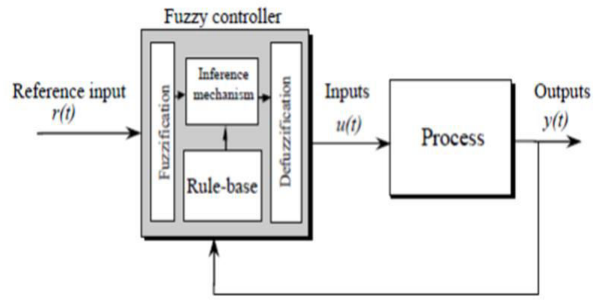

Fig.5. Fuzzy Control System

e / Δe	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

Fig.6.Rules for Fuzzy System

Fuzzy logic is a form of logic that is the extension of boolean logic, which incorporates partial values of truth. Instead of sentences being "completely true" or "completely false," they are assigned a value that represents their degree of truth. In fuzzy systems, values are indicated by a number (called a truth value) in the range from 0 to 1, where 0.0 represents absolute false and 1.0 represents absolute truth. Fuzzification is the generalization of any theory from discrete to continuous. Fuzzy logic is important to artificial intelligence because they allow computers to answer 'to a certain degree' as opposed to in one extreme or the other. In this sense, computers are allowed to think more 'human-like' since almost nothing in our perception is extreme, but is true only to a certain degree. The fuzzy logic controller provides an algorithm, which converts the expert knowledge into an automatic control strategy. Fuzzy logic is capable of handling approximate information in a systematic way and therefore it is suited for controlling nonlinear systems and is used for modeling

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complex systems, where an inexact model exists or systems where ambiguity or vagueness is common. The fuzzy control systems are rule-based systems in which a set of fuzzy rules represent a control decision mechanism for adjusting the effects of certain system stimuli. With an effective rule base, the fuzzy control systems can replace a skilled human operator. The rule base reflects the human expert knowledge, expressed as linguistic variables, while the membership functionsrepresent expert interpretation of those variables.

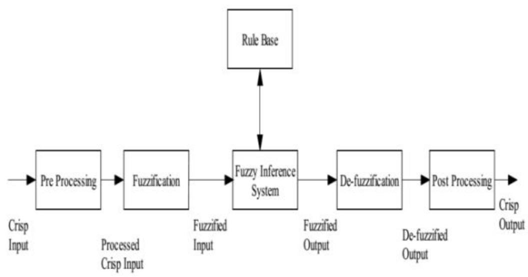


Fig.7.Block diagram of fuzzy control system

Fig7 shows the block diagram of fuzzy control system. The crisp inputs are supplied to the input side Fuzzification unit. The Fuzzification unit converts the crisp input in to fuzzy variable. The fuzzy variables are then passed through the fuzzy rule base. The fuzzy rule base computes the input according to the rules and gives the output. The output is then passed through defuzzification unit where the fuzzy output is converted to crisp output.

VI.MATLAB/SIMULATION RESULTS

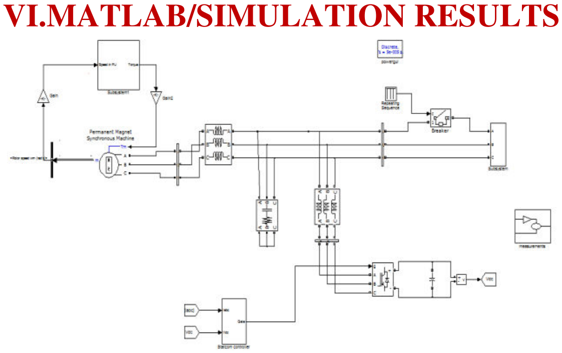


Fig.8.Matlab/Simulink circuit for PI based DSTATCOM

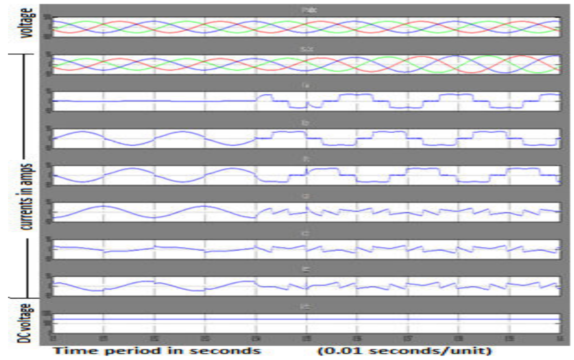


Fig.9. Simulation waveforms of characteristics of intermediate signals using combined LMS–LMF-based control algorithm with PI controller.

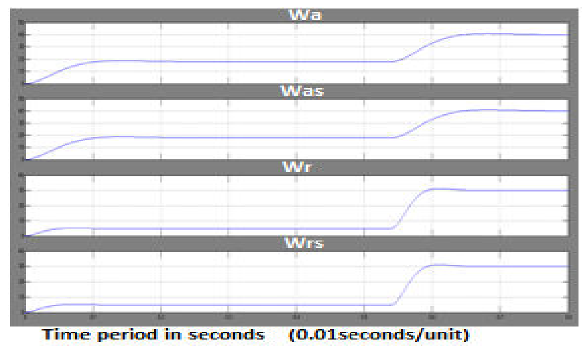
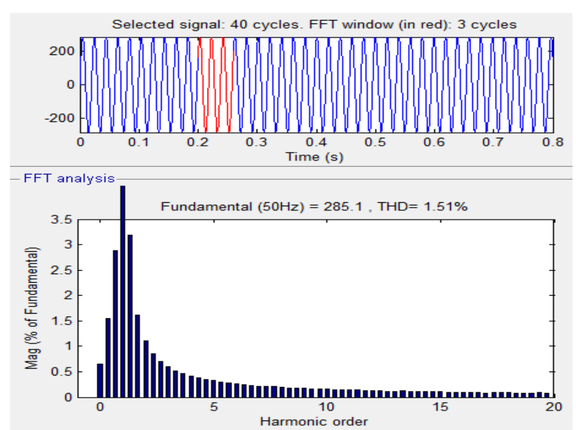


Fig.10.Matlab/Simulation of Average value of the active weight components in-phase to the PCC voltages (wa), total active weight component (was), average value of the reactive weight components in-phase to the PCC voltages (wr), and total reactive weight component (wrs)



(a)

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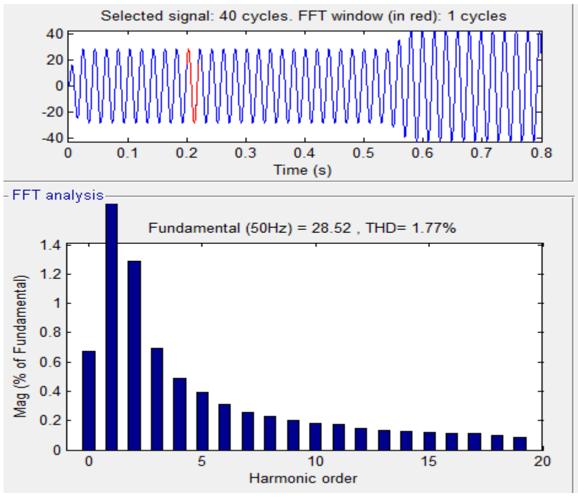
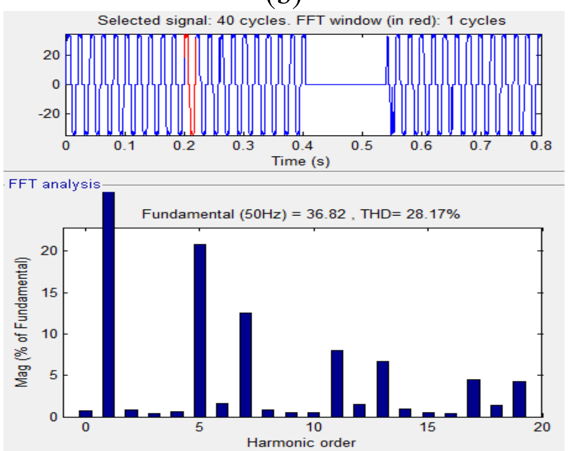


(b)



(c)

Fig.11. Harmonic FFT analysis of (a) phase “a” PCC voltage, (b) phase “a” current of supply, and (c) phase “a” current of load with PI controller

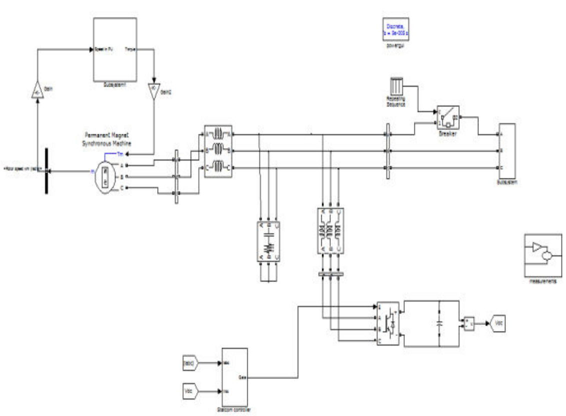


Fig.12. MATLAB/Simulation circuit for Fuzzy based DSTATCOM

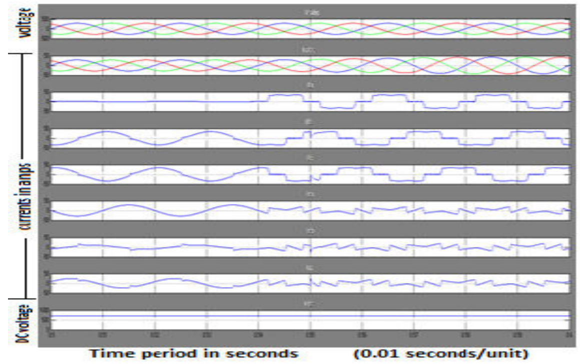


Fig.13. Simulation waveforms of characteristics of intermediate signals using combined LMS– LMF-based control algorithm with fuzzy

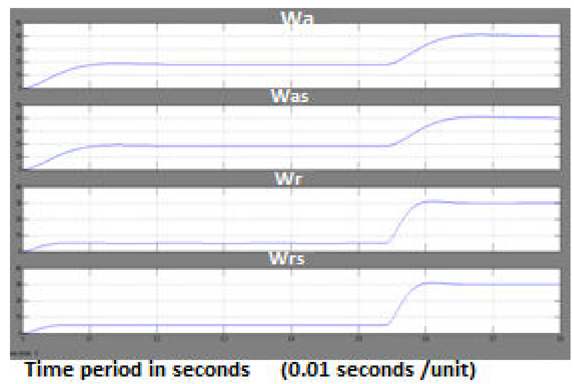
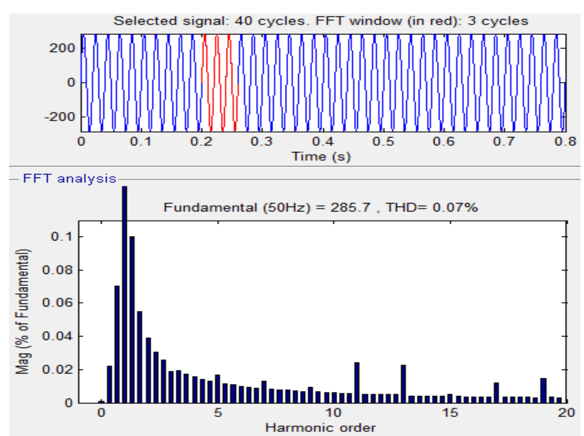
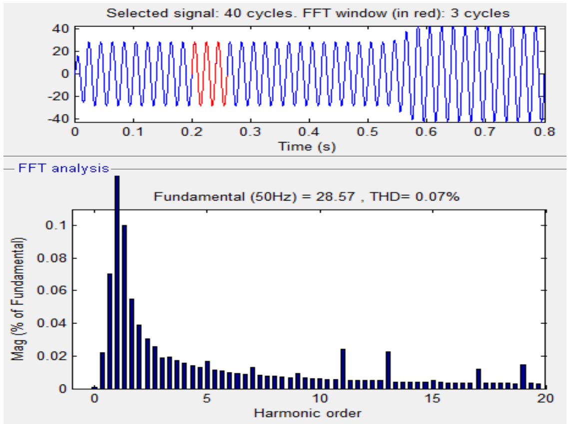


Fig.14.Matlab/Simulation of fuzzy Average value of the active weight components in-phase to the PCC voltages (wa), total active weight component (was), average value of the reactive weight components in-phase to the PCC voltages (wr), and total reactive weight component (wrs)



(a)



(b)

Fig.15. Harmonic FFT analysis of (a) phase "a" PCC voltage, (b) phase "a" current of load with Fuzzy controller

VII. CONCLUSION

The proposed combined LMS–LMF-based control algorithmof DSTATCOM has been implemented and simulated for bothZVR and PFC modes under nonlinear balanced and unbalancedloads. The proposed algorithm has been used for obtaining thereference supply currents from the active and reactive weightcomponents with distortions of the PCC voltages and supplycurrents well below 5%, which is well within the specifiedstandard. The load balancing has also been achieved keepingthe waveforms of PCC voltages and currents as sinusoidal andin-phase. Mainly The proposed system is implemented with fuzzy logic controller and it is compared with the conventional PI controller. It is observed that the power quality of the system is improved andTHD is reduced from 1.77% to 0.07%.

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