Hybrid Controller in Immune Feedback Control Algorithm for Distribution Static Compensator

S. Padma Sharon, K. Jithendra Gowd, M. Srinivasarao

Abstract - This paper bestows a biological immune feedback control for DSTATCOM hinge on fuzzy logic techniques. The proposed algorithm relies on adaptive and self-corrective. An immune feedback algorithm proposed for DSTATCOM can balance loads, estimate fundamental grid currents from non-linear load currents, maintain unity power factor, reduce harmonics of the supply currents and can mitigate reactive power. DSTATCOM'S configuration chosen relies on 3-Φ VSC that is appropriately controlled as a shunt compensator to perform on power quality issues. Replacing of ANFIS-PID (hybrid) controller in immune feedback control where, ANFIS is collaboration of fuzzy logic and neural network system, hybrid controller for DSTATCOM can perform better over PI controller. Simulation is directed using MATLAB to prove performance of the system by replacing hybrid controller, enhancement in power quality (PQ) is achieved.

Keywords- immune feedback control; DSTATCOM; power factor correction; power quality; ANFIS-PID controller.

I. INTRODUCTION

Engineers are more worried about quality in power which is a crucial measure for customers. Even in developing countries, consumers are willing to spend extra cost by knowing the significance of fine power quality. Non-linear loads in distribution system like power electronic loads, information technology equipments, electric arc furnaces and so on are simultaneously major causes and victims for the disturbances in voltage waveforms. Harmonics, high reactive power burden, power frequency variations, poor power factor, unbalancing loads [1] are a few P.Q issues related to these loads. IEEE-519 standard defines the principles to delimit harmonics and other power quality allied issues [2].To recompense differing PQ issues in distribution side, an up swing in quality of power are achieved by developing varieties of custom power devices which are power electronic based devices. One of such recent custom power is DSTATCOM which is a shunt connected device [3] used to reduce the current related to power quality problems and it can be controlled in different operating modes.The profound literature evaluation has shown different control methods for shunt compensator [4,5], which are used to approximate the switching pulses for DSTATCOM, initial components of grid reference currents. Adaptive Neuro Fuzzy Inference based control [8],

Normalized least square method (NLMS) [5,6,7] Adaptive synchronous extraction [9] are some of the standard time domain methods for controlling in the past few years. The above conventional methods differ on the status of implementation, tracking, complexity, stability. A biological based immune system control algorithm have been reported by Kawafuku, Sasaki [10]. Identifying and eliminating the strange materials while quickly sustaining itself are the abilities of precocious living system. The living immune system properties like learning capability, optimization problems, memory as well as sophisticated pattern recognition, fast control, stabilization, elimination make it an ideal one. Some of recent applications of proposed algorithm include single phase [11], three phase inverter [12] control where space vector PWM control, dead time elimination have been used. An immune feedback based control algorithm came up on the working basis of human body. It works as an adaptive and self-corrective system [13]. The variations in operating conditions of the system are viewed as homologous with the attack of antigens in immune control.

For controller designing, industrial applications PID controller is the most widely used algorithm. It has all the necessary dynamics like: elimination of oscillations, fast reaction, control signal increasing. For good response in the present scenario, ANFIS controllers are having an essential role. By training the ANFIS structure, the membership functions of the fuzzy variables adjusted which is the main advantage. The steady state value with very less time compared with FLC is observed when ANFIS based controller is trained once. However, design, application of an immune feedback control using hybrid controller in solving problems in quality of power are not proclaimed in before studies.

The proposed algorithm for DSTATCOM is designed to perform in two different modes appropriately. Even when there is noise in the system, ANFIS-PID controller adapts robustness and fast responses.

Simulation results with proposed algorithm by replacing hybrid (ANFIS-PID) controller, can signify the distinctive characteristics and can perform better over PI and enhancement in PQ is achieved.

II. CONTROLLERS STRUCTURES

A. PID Controller

In earlier control strategies, PID (proportional, Integral, derivative) is one and namely, classical control the typical structure is shown in figure 1. PID controller mathematical description is,

$$U(t)=K_p [\, e(t)+1/T_i \int_0^t e(\tau)d\tau +T_d*d.e(t)/dt] \qquad (1)$$

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System stability improvement, decrease in integral time constant T_i, and increase in gain K, which increases the speed response of the controller can be controlled by the derivative mode of PID.
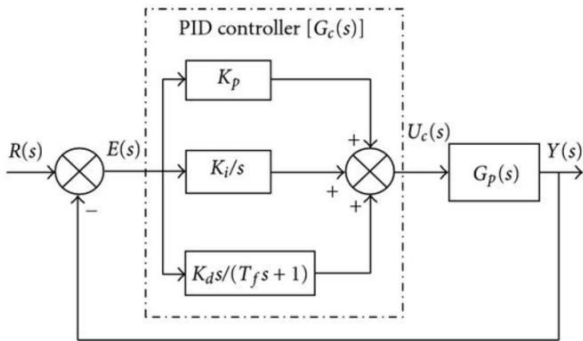

Fig 1.PID controller block diagram

B. ANFIS Controller

ANFIS is a form of Fuzzy Inference system wherein the learning ability of Neural Network's and transparent linguistic representation of Fuzzy logic approaches are together fused so that they can be trained to perform an input/output mapping and its controllers displays advantages specifically suited to time varying and non-linear applications. Its architecture shown in figure 2, consists of 5 layers with two types of nodes: adaptive and fixed, by having IF-THEN rules in its inference system. Zero-steady error improvement and stability by fast response of the system is done by ANFIS controller, which is also highly adaptable for dynamic changes.
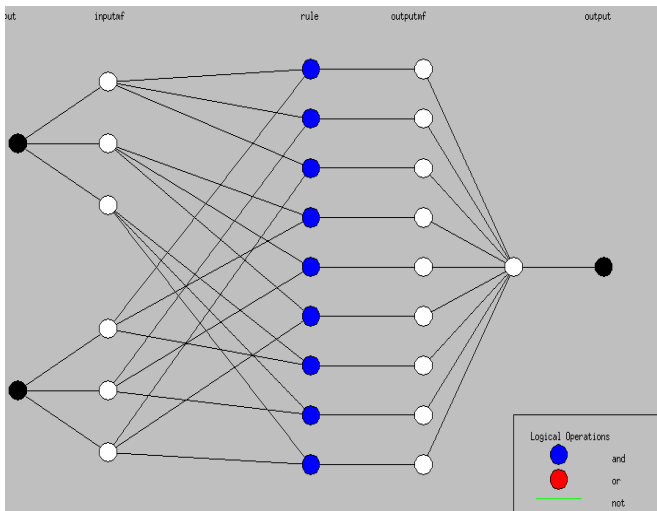

Fig 2 ANFIS controller block diagram

C. HYBRID ANFIS-PID Controller

Combining two controller modes such as ANFIS and PID forms Hybrid ANFIS-PID controller. There are two structures of hybrid controller such as summing and selecting hybrid.

Controller output of summing hybrid is,

$$U_{hybrid} = U_{anfis} + U_{pid} \qquad (2)$$

Controller output of selecting hybrid is,

$$U_{hybrid} = \begin{cases} U_{pid,} & \text{for error} > \Delta \text{ err} \\ U_{anfis,} & \text{for error} <= \Delta \text{ err} \end{cases}$$
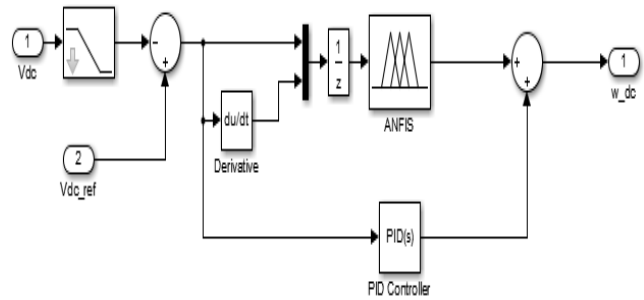

Fig 3.Hybrid ANFIS-PID controller block diagram

In the proposed algorithm block diagram PI controller is replaced with ANFIS-PID controller which is shown in 1,2,3 figures.

III. DSTATCOM MODELLING

DSTATCOM Configuration considered here consists of 3-Φ AC mains with supply impedance $(L_s - R_s)$ feeds an unbalanced linear loads. DSTATCOM designed here is having a DC bus capacitor common to 3-phase Voltage Source Converter. Block diagram of 3-Φ DSTATCOM is shown in figure.4. At Point of common Coupling, series resistive (Rf) and (Cf) elements which are passive filters accustomed to extinguish the shifting sound originated from IGBT's which have components of high frequency. Using hybrid controller the proposed immune feedback algorithm is demonstrated under variety of loads by executing an extent prototype in the laboratory.
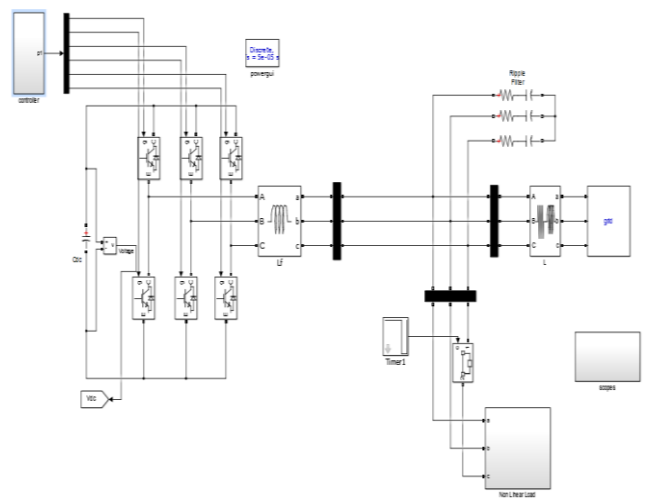

Fig.4 three phase DSTATCOM Configuration

IV. IMMUNE FEEDBACK RESPONSE AND MATHEMATICAL MODELLING

In human body immune feedback system is the important function which have control over

  i.   Immune defence
  ii.   Immune surveillance
  iii.   Immune self-stability

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Antibodies that are resistant to foreign invaders are produced by the immune system. Lymph is composed of 'T' and 'B' cells that are produced and formed in thymus, bone marrow to sense the antigens and stimulate antibodies.

Perfect immune feedback system in body can stabilize itself quickly after responding to antigens. Immune feedback control algorithm is an adaptive and self-corrective system. On the functions of biological immune system of human body this algorithm is framed and its block diagram is shown in fig 5. Values of weights of I_L which correspond to elemental positive sequence value can be extracted using the principle of immune feedback. This mathematical section is categorized into 3 sub sections: Discussion in the next section is using of PWM current controller for Gate pulse generation and reference current estimation.
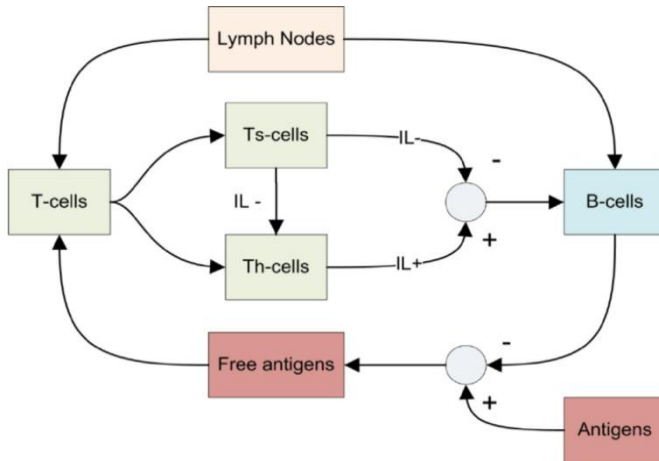

FIG 5 immune system mechanism

TABLE I : Duality between Biological name and Electrical name

BIOLOGICAL NAME	ELECTRICAL NAME
Antigen	Variations in the operating conditions in the system
Antibody	DSTATCOM'S behaviour with immune feedback principle based control method

4.1 Mathematical Approach for estimating weighted values by using algorithm known as Immune feedback control.

Calculation of PCC peak voltages using
(v_{sa}, v_{sb}, v_{sc})
$V_t = ((2/3)*(V^2_{sa} + V^2_{sb} + V^2_{sc}))^{1/2}$ (4)

The quadrature vector and unit in phase vectors are computed using V_t, which calculates the supply current's reactive and active components. In-phase unit vectors of u_{pa}, u_{pb} and u_{pc}, PCC voltages which are used in calculation of reference current's updated active weighted value are calculated as follows,

$v_{sx} = 1/V_t(v_{sx})$ (5)

Where x=a,b, c

The incremental weight at $(n + 1)^{th}$ sampling moment based on immune feedback principle is shown as,

$(n+1)*\Delta w = \alpha\Delta + \delta J(n)[1-\gamma*\{\Delta w(n-1)-\Delta w(n)\}^2]\eta/(\delta w(n))$ (6)

Here, α - is the foreign materials/germ factor, η - used to control the speed response known as learning rate, gama-controls the stabilizing effect known as stabilizing factor and the cost function J(n) has to reduce and showed as

$$J(n) = e(n)^2.0.5$$ (7)

$$e(n) = i_l - i_e$$ (8)

By using weight vector $w^T=[w_x]$ where x = p, q,… and input vector $x(n) =[u_a]$ where a = p,q…the estimated current is computed.
 Here,
 Fundamental reactive and active values of weight from load current are represented as w_q and w_p.
Unit voltage templates of PCC in quadrature and phase are shown as u_q, u_p.

$$i_e = wx^T(n)$$ (9)

$\Delta w(n+1) = w(n+1) - w(n)$ (10)

Replacing $\Delta w(n+1)$ from 5 in 9 at $(n+1)^{th}$ sampling

$(n+1)*w = \alpha\Delta w(n) + \delta J(n)[1-\gamma*\{\Delta w(n)-\Delta w(n-1)\}^2]\eta/(\delta w(n))+w(n)$ (11)

Weighted values of I_L of active power components are
$W_{lpx} = w_{px} + \eta[1-\gamma\{\Delta w_{px} - \Delta w_{\overline{px}}\}^2]e_x u_{px} + \alpha\Delta w_{px}$ (12)

Where , x= a, b, c

For reactive power weighted $(w_{lqa}, w_{lqb}, w_{lqc})$ values of i_L, the update weight given in (10) are modified same as the active power components.
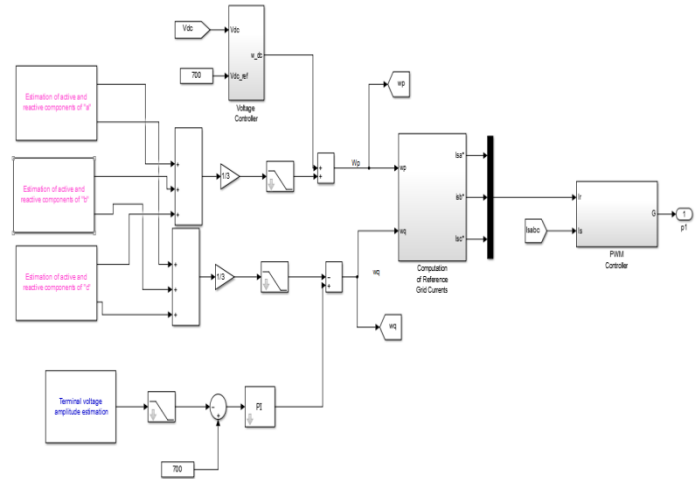

Fig6. Block diagram of experimental setup for DSTATCOM

Estimation of active and reactive reference weighted values is as,

$w_{lp} = (w_{lpa} + w_{lpb} + w_{lpc})/3$

$w_{lq} = \frac{w_{lqa}+w_{lqb}+w_{lqc}}{3}$ (13)

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4.2 Reference grid currents estimation

Passing (v_{de}) to the hybrid controller, to its reference magnitude, the Voltage (V_{dc}) is regulated . Comparing the sensed voltage and the value of reference (V_{dc}^*) at (V_{dc}) voltage error is generated.The component, w_{pdc} is the estimated output value provided by the hybrid controller. By adding w_{lp} and w_{pdc} the weight of (w_p) is weighed as

$$w_p = w_{lp} + w_{pdc} \qquad (14)$$

Using (u_{pa}, u_{pb}, u_{pc}) templates and (w_p) reference ($i_{pa}^*, i_{pb}^*, i_{pc}^*$) indicating 3-Ø components are found which are used for the estimation of total grid currents

$$i_{pa}^* = w_p u_{pa} \ , i_{pb}^* = w_p u_{pb} \ , i_{pc}^* = w_p u_{pc} \qquad (15)$$
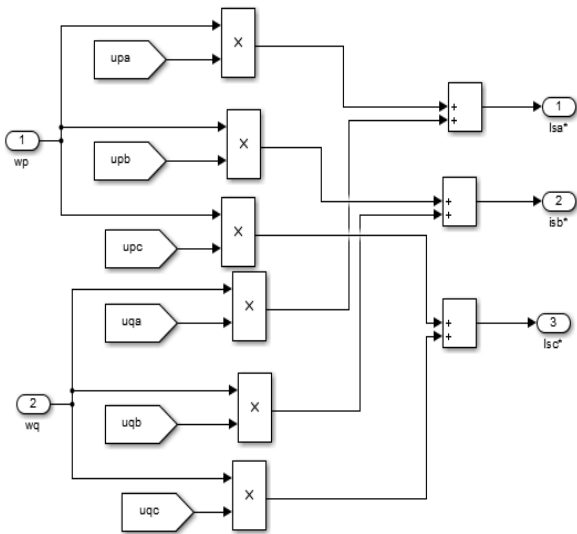

Fig 7. Computation of reference grid currents

On comparing, V_t with V_t^* error is generated. To put reference value of PCC voltage magnitude it is passed through the second hybrid controller.

Weight w_q , is calculated as follows,

$$w_q = w_t - w_{lq} \qquad (16)$$

From (u_{qa}, u_{qb}, u_{qc}) quadrature templates and initial reactive power weight (w_q), the

reactive initial currents are ($i_{qa}^*, i_{qb}^* and \ i_{qc}^*$) computed.

$$i_{qa}^* = w_q u_{qa} \ , i_{qb}^* = w_q u_{qb} \ , i_{qc}^* = w_q u_{qc} \qquad (17)$$

In the next subsection, calculation of grid reference total currents using active and reactive reference grid currents are seen.

4.3 Switching Pulses Generation

$$i_{sx}^* = i_{px}^* + i_{qx}^* \qquad (18)$$

Comparision between the estimated initial currents $i_{sa}^*, i_{sb}^*, i_{sc}^*$ and grid currents i_{sa}, i_{sb}, i_{sc} that are sensed by current sensors is done to produce switching pulses for IGBT'S of Voltage Source Converter, the generated current errors are passed through the PWM controller.

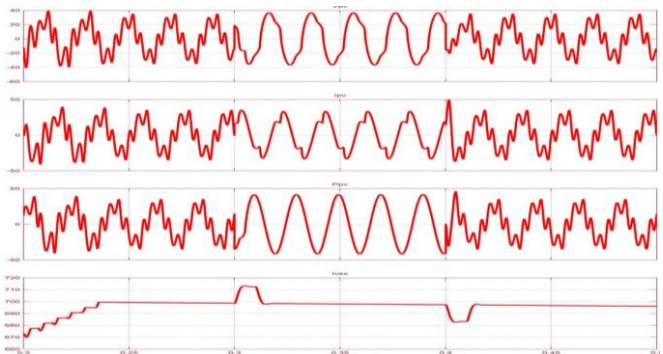## V. DSTATCOM's BEHAVIOUR via IMMUNE FEEDBACK ALGORITHM AND SIMULATION RESULTS

With replacement of hybrid controller in immune feedback control, DSTATCOM's behaviour is justified in dynamic conditions for voltage regulation and correcting power factor. In MATLAB with usage of SIMULINK, (SPS), the proposed system having ANFIS-PID controller is done.

5.1 Dynamic and Steady State behaviour in PFC mode

The results illustrate the voltages of (V_s), (i_s), DC bus voltages (V_{dc}), load currents (i_l) and DSTATCOM currents (i_c) Waveforms. In 8(a) and 8(b) PFC modes shunt compensator behaviour is shown.
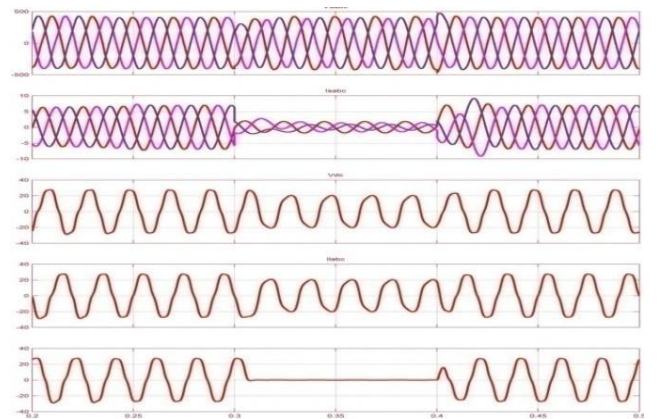

8(a)

8(b)

Figure.8 shows behaviour of shunt compensator by reinstating hybrid controller in Immune feedback algorithm in PFC mode

In figure.8, In steady state the system operates (t=0.3s before), Voltage of DC bus at reference voltage is maintained 700V with ANFIS-PID controller. When phase 'c' load between 0.3s-0.4s is turned off, we'll notice currents of load becomes unequal and unbalanced. Yet, the currents of grid due to DSTATCOM action remained balanced using hybrid, only PID controllers but, in case of only ANFIS controller, the grid currents are unbalanced and unequal. After observation we noticed – between V_{PCC} and I_s relation is in phase with hybrid, PID controller, capability of correcting DSTATCOM's of achieved.In fig.9 After compensation of I_s and I_L the harmonic spectra of PFC mode are illustrated.

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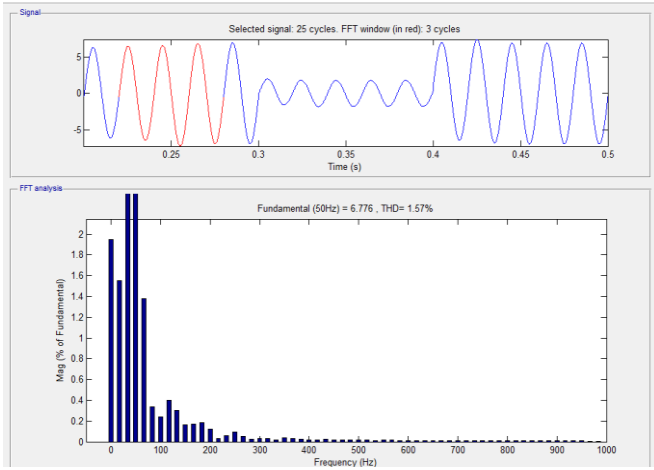
9(a)

It is noticed that the values of supply currents ,load currents are to be 1.57% and 6.88%.From these results it is inferred that the distortions of harmonics of i_{sa},is less than 5% which is IEEE-519 standard imposed limits while load currents harmonics are also highly reduced.
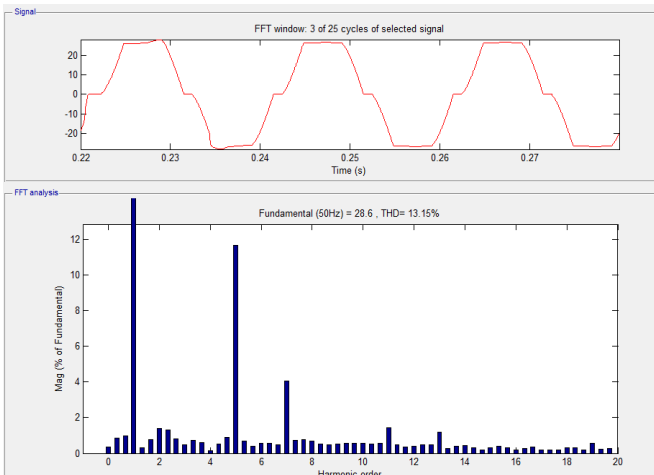

9(b)

Fig. 9 In PFC mode, 'a' phase's (a) i_{sa} **(b)** i_{la} **.harmonic spectra**

5.2 Under varying loads, in VR mode.

Using immune feedback control algorithm with hybrid controller, DSTATCOM behaviour at nonlinear load is tested and observed. The waveforms of 3-Φ voltages at PCC (v_s), currents of compensator (i_c), load currents (i_l) , self sustained DC bus voltage(V_{dc}), grid currents (i_s), at VSC and magnitude (V_t) are represented in figs. 10(a) and 10(b).
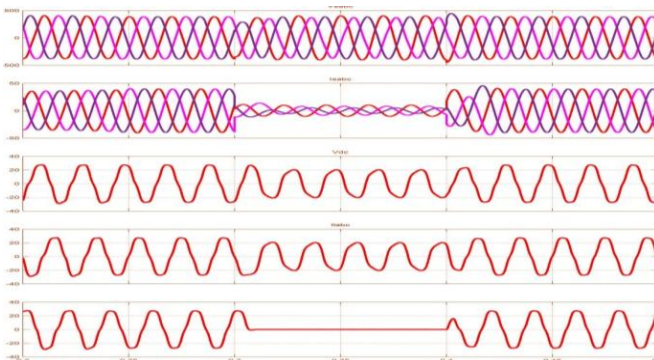

10(a)
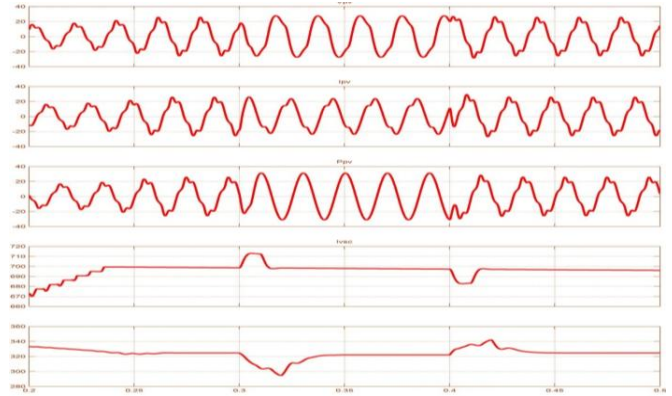
10(b)

In the system a dynamic change at load is created by instantly throwing load off between (t=0.3 – 0.4s) of phase 'c' which creates load unbalancing. Yet perfectly sinusoidal grid currents are observed in this mode with hybrid, pid, anfis due to DSTATCOM operation. Thus the proposed algorithm with hybrid controller replacement extracts weights flexibly under unbalanced and alternate loading conditions along with unbalanced conditions at load. By twice action of hybrid controller ,voltage regulation is achieved.After compensation of I_S and I_L in VR mode harmonic spectra is shown in figure. 11
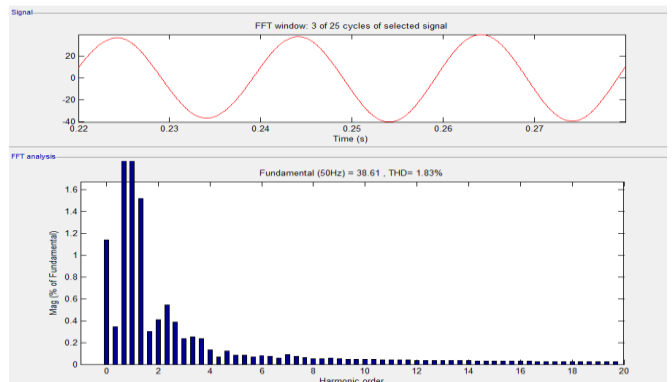

11(a)
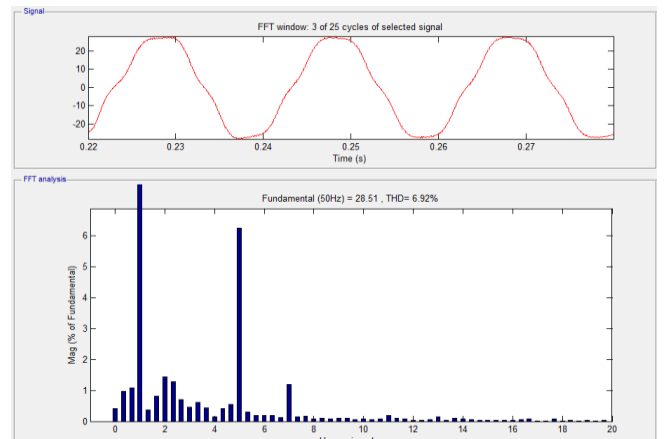
11 (b)

Fig. 11 In Voltage regulation mode,'a' phase's harmonic spectra of (a) i_{sa} **(b)** i_{la}

The limit imposed by standard IEEE-519[2] i.e (<5%) is achieved by i_{sa}.

5.3 Proposed control algorithm performances Comparatively with PI and Hybrid controllers.

Immune feedback control algorithm performances with PI and hybrid(ANFIS-PID) controller in speed of weight convergence, error signals (between load current estimated, sensed current), harmonics compensation in I_{sa}, time T taken for the process with two controllers of the algorithm are in fig. 12 and fig 13. Fig. 12(a) and 12(b)shows the weight convergence which corresponds to load current of phase 'a' and error signal with PI controller.
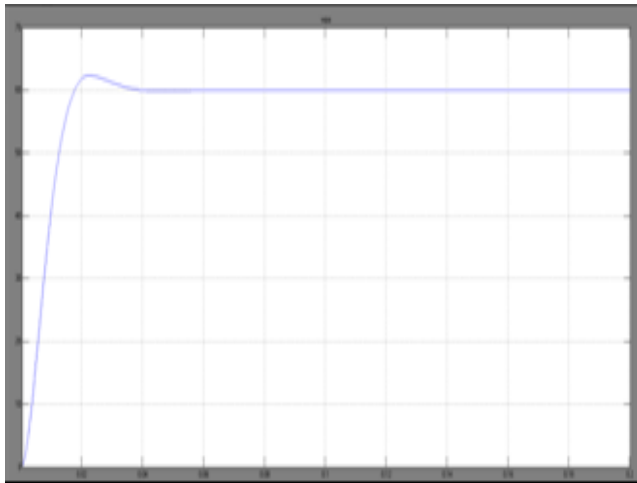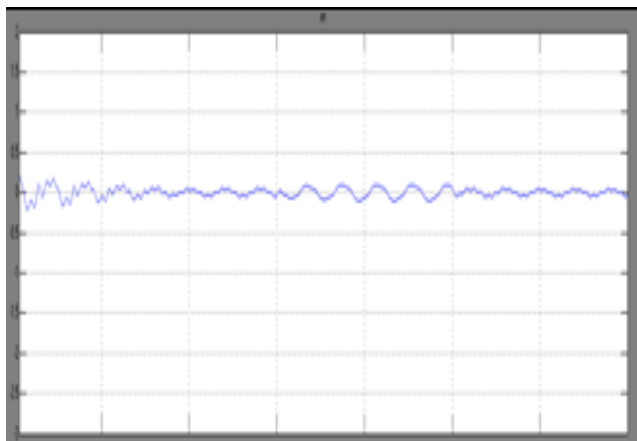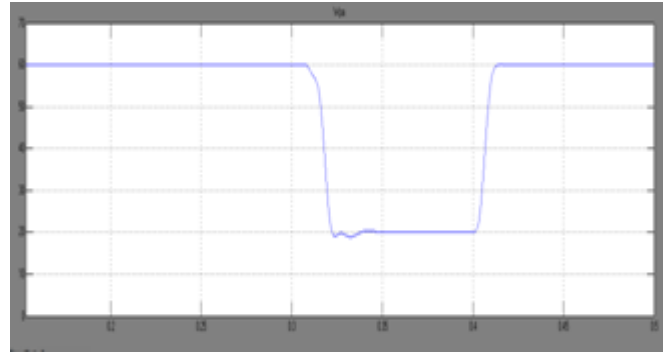

12(a)
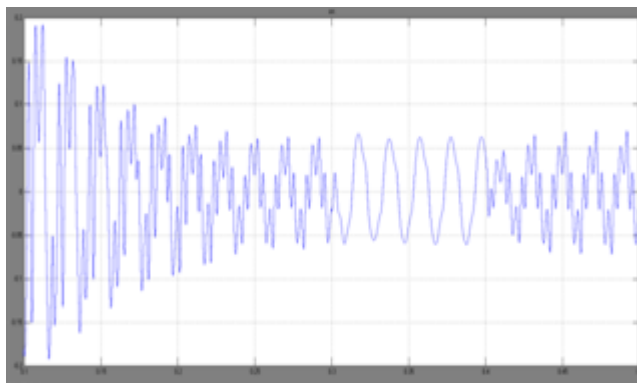
12(b)

Fig.12 (a) weight convergence, fig.(b) Error signal of immune control with PI

13(a)

13(b)

Fig. 13(a) error signal, Fig. 13(b) weight convergence of Immune control with ANFIS- PID controller

In case of Error signal, hybrid ANFIS-PID controller obtained best performance of less than 0.3 s when other controllers showed more static error than hybrid, with more distortions. While in case of weight convergence, compared to individual controllers, hybrid ANFIS-PID controller only has shorter rise-time and increased over-shoot, obtaining steady state at < t=0.03 s.

Table II Comparative Performances Of Immune Feedback With Different Controllers

Features of immune feedback with controllers	ANFIS-PID	PI	PID	ANFIS
THD, Isa	6.776A, 1.5%	30.14A, 2.64%	30.4A, 2.64%	6.776A, 1.577%
THD, Ila	28.52A, 6.8%	28.6A, 13.10%	28.6A 13.15%	28.52A, 6.88%
Is in PFC mode	Balanced	Balanced	Balanced	Unbalanced
Static error	<0.3	Nearly 0.5	Nearly 2 & more distortions	>0.5 & some distortions
Weight convergence	S.S at <t=0.03 s	S.S at t=0.1s	S.S at T=0.06s	S.S at t=0.06s

VI. CONCLUSION

ANFIS-PID controller fo immune feedback principle for the DSTATCOM control has been developed. To enhance power quality at distribution level it is designed and implemented. In terms of fast response, robustness, reducing more tracking error, compensation of harmonics, ANFIS-PID controller has superior performances when compared with PI controller in immune feedback control algorithm. After compensation by validating the simulation results 1.57% of THD is recorded in the grid currents which is lowest among all, there by meeting the harmonic's IEEE-limits and 6.88% of THD is recorded in the load currents. The following highlight outcomes of this work are

- To improve power quality, the immune feedback control with hybrid controller has been suitably planned and executed.
-

- The immune feedback control algorithm that is proposed with hybrid controller impersonates the behavior of quick response to strange materials while it is fleetly sustaining itself, robustness, an original skill to accommodate, pattern recognition, learning, selfhood corrective-ness and identity quite well.
- Even though each of conventional algorithms been successful in diminishing the harmonics (<5%) in grid currents, the premier staging is observed than all by replacing the ANFIS-PID controller in proposed control algorithm.
- A biological algorithm concept and working is used as a tool for designing the live system controllers. The out-standing's of the work are designing, working and proposed control algorithm application with hybrid controller for resolving PQ issues, remuneration of loads.

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