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Manage Formula for Conductance Estimation Utilizing Neural Network Controller for a DSTATCOM

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ABSTRACT

Neural network (NN) based algorithms are used to extract required information after processing of signals by learning or training and activation function. It is used for increasing the processing speed, response, convergence, robustness, accuracy, precision, tracking ability, adaptive ability, steady-state and transient stabilities etc. Due to improved performance, neural network-based control have created much attention in electrical engineering including power quality. An algorithm based on load conductance estimation using NN is implemented on a three phase DSTATCOM for mitigation of power quality problems such as load balancing, reactive power compensation, harmonics elimination and neutral current compensation in a four wire distribution system. Main objectives of neural network application in DSTATCOM (Distribution Static Compensator) are to enhance the efficiency, robustness, tracking capability according to requirements. A control algorithm based on load conductance estimation using the neural network is implemented for DSTATCOM in a four wire distribution system.

Key words: Neural Network, DSTATCOM, Conductance, load balancing, power factor correction (PFC), Harmonics, Zero Voltage Regulation (ZVR).

I. Introduction

The objective of an electric utility is to supply consumer with a sinusoidal voltage and constant magnitude and frequency. Almost all industrial, commercial and residential loads draw non sinusoidal currents and demand high amount of reactive power due to nonlinear and lagging power factor loads [1]. System power quality has been adversely affected. Severe problems have been encountered in power system operation, owing to the load current harmonics. Voltage distortion, power losses, solid state device malfunction and communication interference are some examples. Power filtering is one of the technology to solve power quality problems which are created by non linear loads. Due to development of signal processing techniques, an active filter has taken the leads in practical applications. New active filters have multifunction nature such as harmonics suppression, reactive power compensation, load balancing in power factor correction (PFC) and zero voltage regulation (ZVR) modes [1]. This improved compensating device is known as a distribution static compensator (DSTATCOM) [2]. Some standards also provide specification and application of components, protection, and control of power quality improvement devices [3]–[5]. Suppression of harmonics distortion, reactive power compensation at ac mains which is created by various consumers may be achieved by using compensators connected between ac mains and loads [6] [9]. Response and accuracy of the DSTATCOM depend on the control algorithm for generation of reference currents and design of power circuit elements [10]-[11].

Neural networks(NNs) has the compatibility to improve control of power electronic systems. NNs have self-adapting and super-fast computing features that make them well suited to handling nonlinearities, uncertainties and parameter variations that can occur in a controlled plant [12]. It is used for increasing the processing speed, response, convergence, robustness, accuracy, precision, tracking ability, adaptive ability, steady-state and transient stabilities, etc. [13]–[15]. Neural network (NN) based algorithms are used to extract required information after processing of signals by learning or training and activation function [16]–[17]. Neural network based control have created much attention in electrical engineering including power quality problems such as load balancing, reactive power compensation, harmonics elimination and neutral current compensation in a four wire distribution system.

In this paper we use three phase four wire distributed system which is mainly concerned about the neural network controller implemented in a shunt connected compensating device known as DSTATCOM for the extraction of active power and reactive power components of three-phase distorted load currents. Proposed control algorithm is used for PFC and ZVR modes of operation to maintain a balanced and sinusoidal supply current with a self-supporting dc bus of VSC of DSTATCOM, for this purpose Kohonen learning method has been used. Kohonen learning is used to extract the fundamental components of load current in terms of conductance and susceptance. Weighted value of conductance or susceptance from its clustered values which matches the input conductance very closely near to actual value is considered as extracted conductance or susceptance in signal processing for reference supply current estimation[MP]. Principle of this learning is based on training over an extended region of the network centered on the maximally active mode. Only one neuron per clustered is ready as output signal at any condition. The concept behind this network is that the inputs are clustered together to obtain a fired output neuron. It consists of two layers one is input layer and other is competitive layer. Input layer takes available load currents as a reflection in terms of conductances and susceptances. Competitive layer process the input data and compete each other for the success to respond as a winning neuron in term of output from clustered input data [18].

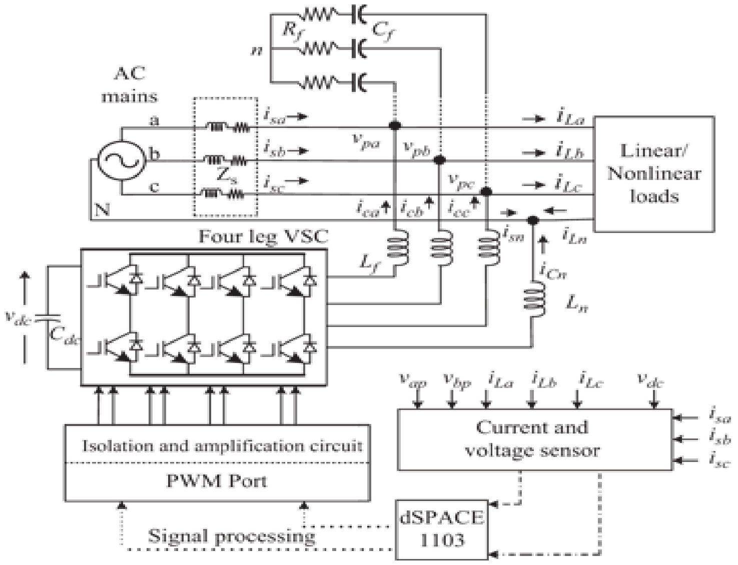


Fig. 1 Schematic diagram of DSTATCOM

II. System Configuration and Control Algorithm

A DSTATCOM is a device which is used in an AC distribution system where, harmonic current mitigation, reactive current compensation and load balancing are necessary. The DSTATCOM is installed at (Point of Common Coupling) PCC with a ripple filter to eliminate high-frequency switching components at PCC The proposed three phase DSTATCOM consists of voltage source converter (VSC), interfacing inductors (Lf), series connected resistance (Rf), capacitance (Cf) as ripple filter and a T connected transformer is used to compensate the neutral currents as shown in Fig.1.

Block diagram of control algorithm for estimation of reference supply currents is shown in Fig. 2. Dc link voltage (vdc), phase PCC voltages (vsa ,vsb ,vsc), load currents(iLa, iLb, iLc) are required for extraction of reference supply currents. Band pass filters are used to filter noise and harmonics.

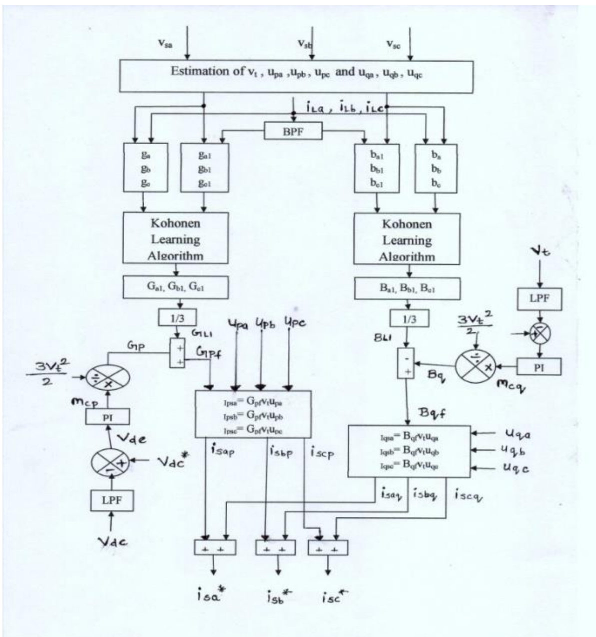


Fig. 2 Block Diagram neural network based conductance based control algorithm

In case of unbalanced in PCC voltages amplitude of three phase voltages are taken by squaring t Dhem and fed into the low pass filters and the amplitude of PCC voltage is given as:

$$v_t = \{(2/3)(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)\}^{0.5} \qquad (1)$$

where $v_{sa} = V_{sa}\sin\omega t$, $v_{sb} = V_{sb}\sin(\omega t-2\pi/3)$ and $v_{sc} = V_{sc}\sin(\omega t-4\pi/3)$

The unit vector in phase of PCC voltages are computed as:

$$u_{pa} = \frac{vsa}{vt} \qquad u_{pb} = \frac{vsb}{vt} \qquad u_{pc} = \frac{vsc}{vt} \qquad (2)$$

where u_{pa} , u_{pb} and u_{pc} are the in-phase unit vectors of PCC voltages.

The power drawn by non linear loads comprises active power which is represented by "p" and reactive power which is represented by "q" and some harmonics. The sensed dc bus voltage of VSC is passed through a low pass filter to filter ripple components. Selected reference dc bus voltage (V_{dc}^*) and filtered dc bus voltage (V_{dc}) of a VSC of DSTATCOM are compared and an error (vde) is processed through the dc bus voltage proportional-integral (PI) regulator. The output of the dc bus voltage PI regulator is considered a loss component of the VSC. The dc bus voltage of the DSTATCOM at r^{th} sampling instant is expressed as:

$$m_{cp}(r)= m_{cp}(r-1) + k_{pp}\{v_{de}(r)- v_{de}(r-1)\} + k_{pi}v_{de} \quad (3)$$

Where $m_{cp}(r)$is active power drawn from ac mains, k_{pp} and k_{pi} are proportional and integral gain constants of the dc bus PI voltage controller. Active power losses of VSC are compensated by using $m_{cp.}$

There are three phade drawn from the ac mains, they are phase "a", phase "b" and phase "c". The power from each phase is given by

$$S_a = p_a + q_a \qquad (4)$$
$$S_b = p_b + q_b \qquad (5)$$
$$S_c = p_c + q_c \qquad (6)$$

The instantaneous value of conductance of phase a,b and c is calculated as:

$$g_a = p_a / v_{ta}^2 \qquad (7)$$
$$g_b = p_b / v_{tb}^2 \qquad (8)$$
$$g_c = p_c / v_{tc}^2 \qquad (9)$$

where v_{ta} , v_{tb} and v_{tc} are the amplitude of individual phase voltages and p_a , p_b and p_c active power of loads.The value of p_a , p_b and p_c is calculated as:

$$p_a = v_t u_{pa} i_{La} \qquad (10)$$
$$p_b = v_t u_{pb} i_{Lb} \qquad (11)$$
$$p_c = v_t u_{pc} i_{Lc} \qquad (12)$$

By using BPF and PCC voltages, instantaneous fundamental conductance is calculated i.e. g_{a1} ,g_{b1} and g_{c1} .At r^{th} sampling instant the updated fundamental active component load conductance is extracted from the Kohonen learning algorithm which is given as :

$$Ga1 = ga1 (r + 1) = ga1 (r) – \tau\{ ga (r) - ga1 (r) \} \qquad (13)$$
$$Gb1 = gb1 (r + 1) = gb1 (r) – \tau\{gb (r) – gb1 (r) \} \qquad (14)$$
$$Gc1 = gc1 (r + 1) = gc1 (r) – \tau\{ gc (r) – gc1 (r) \} \qquad (15)$$

Where "τ" is learning rate and the performance of algorithm depends on this factor. The standard value of learning factor where it gives its best performance is 0.11[18]. Average conductance (GL1) of the three phase load due to active power is calculated as:

$$GL1 = (Ga1 + Gb1 + Gc1) / 3 \qquad (16)$$

The conductance (Gp) of output of dc bus voltage controller mcp is calculated as:

$$Gp = 2 mcp/(3vt2) \qquad (17)$$

The total fundamental active power component of supply is calculated as:

$$G_{pf} = G_p + G_{L1} \qquad (18)$$

In phase components of three phases of reference supply currents are calculated as:

$$isap = Gpf\ vt\ upa \qquad isbp = Gpf\ vt\ upb \qquad iscp = Gpf\ vt\ upc \qquad (19)$$

The quadrature unit vectors i.e. uqa , uqb and uqc are calculated as[19]:

$$uqa = (-upb + upc) / \sqrt{3} \qquad (20)$$
$$u_{qb} = (3u_{pa} + u_{pb} -u_{pc}) / 2\sqrt{3} \qquad (21)$$
$$u_{qc} = (-3u_{pa} + u_{pb} -u_{pc}) / 2\sqrt{3} \qquad (22)$$

The instantaneous value of susceptance of phase a,b and c is calculated as:

$$b_a = q_a / v_{ta}^2 \qquad (23)$$
$$b_b = q_b / v_{tb}^2 \qquad (24)$$
$$b_c = q_c / v_{tc}^2 \qquad (25)$$

where v_{ta}, v_{tb} and v_{tc} are the amplitude of individual phase voltages and q_a, q_b and q_c are reactive power of loads. The value of q_a, q_b and q_c is calculated as:

$$q_a = v_t u_{qa} i_{La} \quad (26)$$
$$q_b = v_t u_{qb} i_{Lb} \quad (27)$$
$$q_c = v_t u_{qc} i_{Lc} \quad (28)$$

By using BPF and PCC voltages, instantaneous fundamental susceptance is calculated i.e. b_{a1}, b_{b1} and b_{c1} .At r^{th} sampling instant the updated fundamental reactive component load susceptance is extracted from the Kohonen learning algorithm which is given as :

$$B_{a1} = b_{a1}(r+1) = b_{a1}(r) - \tau\{ b_a(r) - b_{a1}(r) \} \quad (29)$$
$$B_{b1} = b_{b1}(r+1) = b_{b1}(r) - \tau\{ b_b(r) - b_{b1}(r) \} \quad (30)$$
$$B_{c1} = b_{c1}(r+1) = b_{c1}(r) - \tau\{ b_c(r) - b_{c1}(r) \} \quad (31)$$

Where "τ" is learning rate and the performance of algorithm depends on this factor. The standard value of learning factor where it gives its best performance is 0.11. Average conductance (G_{L1}) of the three phase load due to reactive power is calculated as:

$$B_{L1} = (B_{a1} + B_{b1} + B_{c1}) / 3 \quad (32)$$

Selected reference dc bus voltage (V_{dc}^*) and filtered dc bus voltage (V_{dc}) of a VSC of DSTATCOM are compared and an error (vde) is processed through the dc bus voltage proportional-integral (PI) regulator. The output of the dc bus voltage PI regulator is considered a loss component of the VSC. The dc bus voltage of the DSTATCOM at r^{th} sampling instant is expressed as:

$$m_{cq}(r) = m_{cq}(r-1) + k_{qp}\{v_{de}(r) - v_{de}(r-1)\} + k_{qi} v_{de} \quad (33)$$

Where $m_{cq}(r)$is reactive power drawn from ac mains, k_{qp} and k_{qi} are proportional and integral gain constants of the dc bus PI voltage controller. Reactive power losses of VSC are compensated by using $m_{cq.}$

The susceptance (B_q) of output of dc bus voltage controller m_{cq} is calculated as:

$$B_q = 2\, m_{cq}/(3v_t^2) \quad (34)$$

The total fundamental reactive power component of supply is calculated as:

$$B_{qf} = B_q - B_{L1} \quad (35)$$

Quadrature components of three phases of reference supply currents are calculated as:

$$i_{saq} = B_{qf} v_t u_{qa} \quad i_{sbq} = B_{qf} v_t u_{qb} \quad i_{scq} = B_{qf} v_t u_{qc} \quad (36)$$

The sum of in phase component and quadrature component reference supply currents of three phases give the total reference supply currents i.e. i_{sa}^* ,i_{sb}^* and i_{sc}^*.

$$i_{sa}^* = i_{sap} + i_{saq} \quad i_{sb}^* = i_{sbp} + i_{sbq} \quad i_{sc}^* = i_{scp} + i_{scq} \quad (37)$$

Difference of sensed supply current and reference supply current is used for the extraction of current error. These current error signals are used for generation of appropriate switching pulses for VSC used as DSTATCOM and this type of current control is known as indirect current control.

III. Simulation Results

MATLAB based simulation of DSTATCOM is developed for validation of proposed control algorithm. The proposed control algorithm based on load conductance estimation using neural network is implemented on a TMS320F240 DSP processor (dSPACE1104) for control of DSTATCOM. The dc link voltage of DSTATCOM is maintained at a reference value and test results are recorded at balanced/unbalanced linear and nonlinear loads. Speifications used in simulation are as follows: AC mains: 3-Phase, 110 V (L-L), 50 Hz; Load: (1) Linear: 0.471 kVA, 0.94 pf (DPF) lagging, (2) Nonlinear loads: Three single phase full bridge uncontrolled rectifier with R = 20Ω and L= 150 mH; dc link capacitance: 1650μF ; Reference dc link voltage: 200 V; interfacing inductor (L_f) = mH; Passive ripple filter:R_f = 5Ω , C_f = 10μF ; Learning rate(τ) = 0.11; Sampling time (t_s) = 50μs;Gains of PI controller for dc link voltage: k_{pp} =0.45 , k_{pi} = 0.02; Cut off frequency of low pass filter used in dc link = 15Hz , Cut off frequencies of band pass filter used in load currents =25 Hz to 100 Hz. The performance of the neural network based control algorithm for the three-phase DSTATCOM is simulated for PFC (Power Factor Correction) and ZVR (Zero Voltage Regulation) modes of operation with unbalance in the loads currents. The dc link voltage of DSTATCOM is maintained at a reference value and test results are recorded at balanced/unbalanced linear and nonlinear loadsThe response of proposed control algorithm of DSTATCOM is observed as follows:

A. Performance of Control Algorithm

Fig. 3 shows the various intermediate signals of the control algorithm which include fundamental active power components of load current , reactive power components of load current , average amplitude value of active power component of load currents and reactive currents , output of DC bus PI controller and voltage PI controller , amplitude of active and reactive power component of reference source current, three phase source reference active power and reactive power components of current and three phase reference current respectively. The signals are shown with respect to AC supply mains voltage and load currents. It clearly demonstrates the accurate extraction of control signals even under distorted load currents.

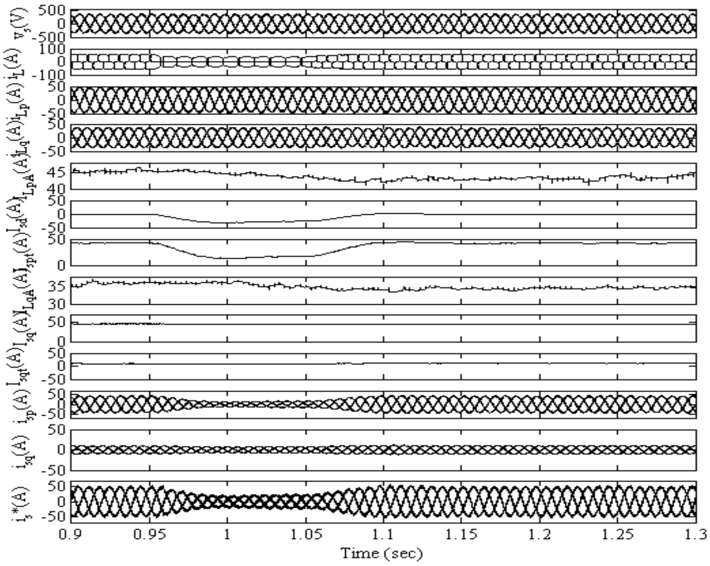


Fig.3 Characteristics of intermediate signals for estimation of supply current

B. Dynamic Performances of DSTATCOM

Under Linear Loads

Fig. 4(a) and (b) show the waveform of supply currents (i_{sa}, i_{sb}, i_{sc}) and load currents (i_{La}, i_{Lb}, i_{Lc}) with PCC line voltage (v_{ab}) under unbalanced linear loads. Unbalanced load is realised by removal of load in phase "a." Changes in supply current (i_{sa}), DSTATCOM current (i_{Ca}) and load current (i_{La}) are shown with dc link voltage in Fig. 4(c) under varying load conditions. It shows the balanced supply currents when load currents are unbalanced. The function of neutral current compensation can be observed from Fig. 4(d) where load neutral current (i_{Ln}) and T connected transformer neutral terminal point (i_{Tn}) current are equal and opposite in phase at the time of load removal.

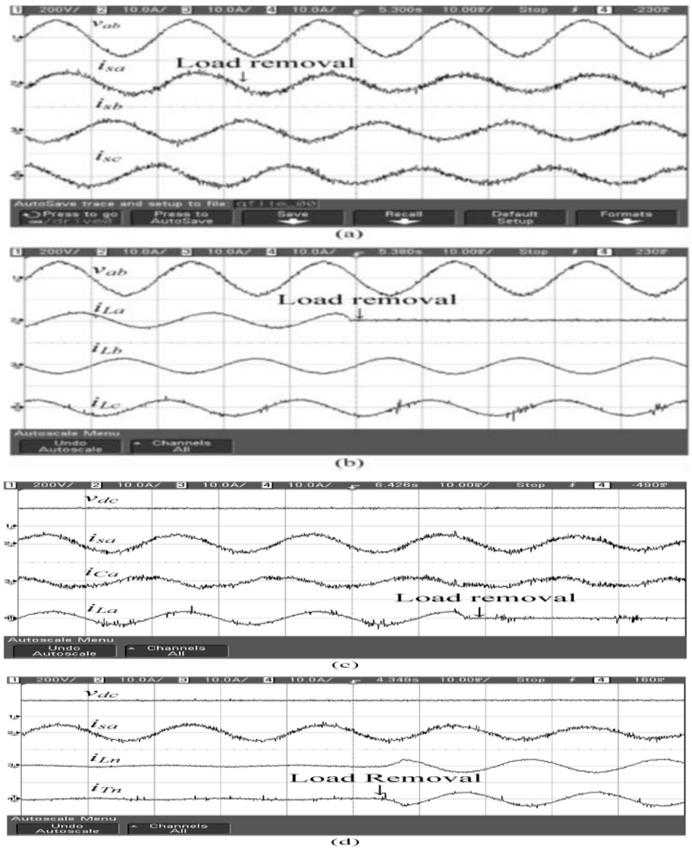
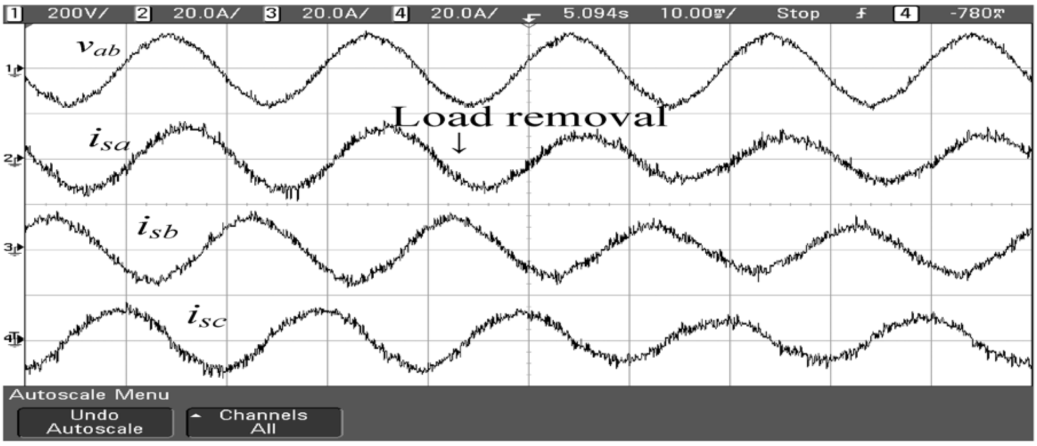


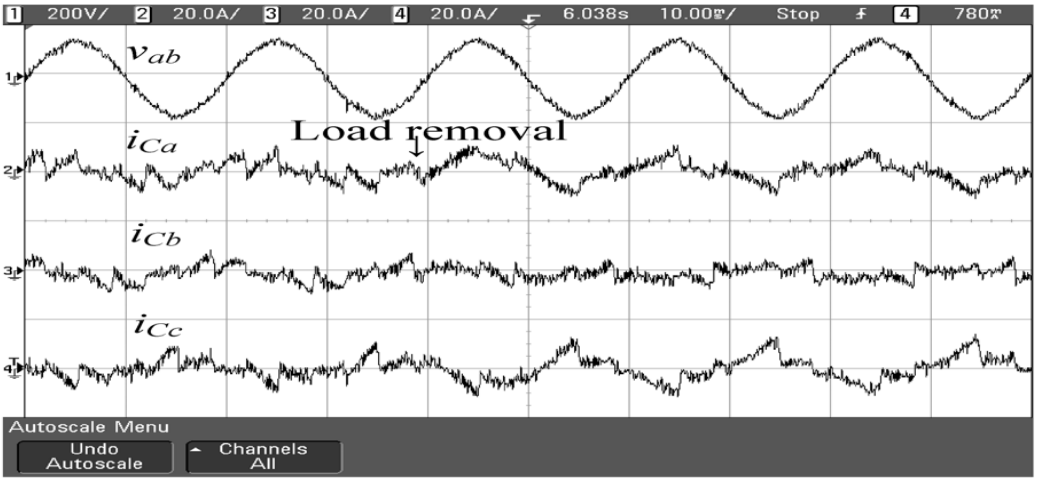
Fig.4 Dynamic performance of DSTATCOM under linear loads.(a)v_{ab},i_{sa},i_{sc} (b)v_{ab} , i_{La} ,i_{Lb} , i_{Lc} (c) V_{dc} ,i_{sa} ,i_{ca} ,i_{La} (d) V_{dc}, i_{sa} , i_{Ln} ,i_{Tn}

C. Dynamic Performances of DSTATCOM under Non Linear Loads

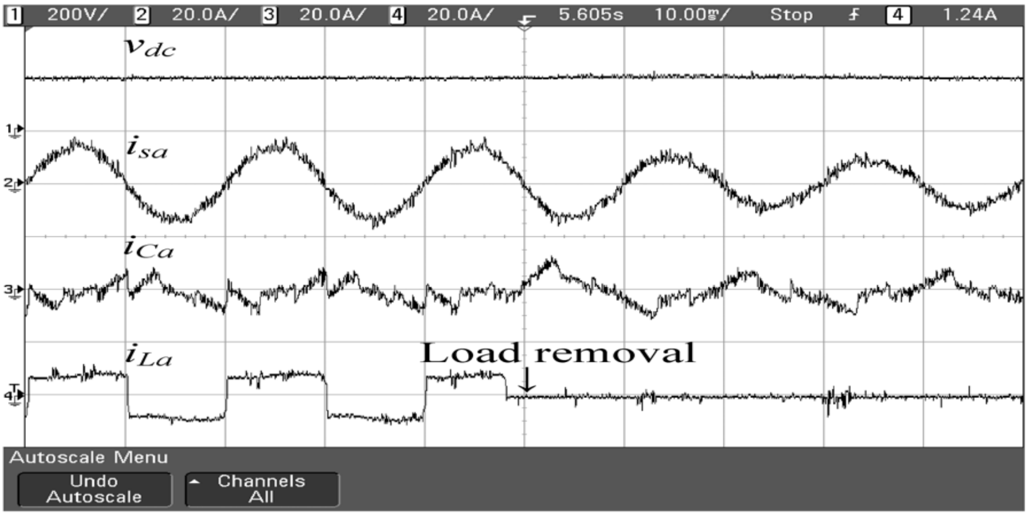
Fig. 5(a) and (b) show the waveforms of supply currents (i_{sa}, $i_{sb,}$ i_{sc}), and DSTATCOM currents (i_{Ca} i_{Cb} i_{Cc}) in dynamic condition with respect to PCC voltage under nonlinear loads. Fig. 5(c) shows the waveform of supply current, compensating current (i_{Ca}) and load current (i_{La}) with dc link voltage under load removal. The function of neutral current compensation is shown in Fig. 5(d) where phase "a" supply current, load neutral current, T connected transformer neutral point current are shown with dc link voltage. Magnitude and nature of load neutral current and T connected transformer neutral point current are equal and opposite in phase. These results demonstrate satisfactory performance of control algorithm of DSTATCOM under dynamic conditions.



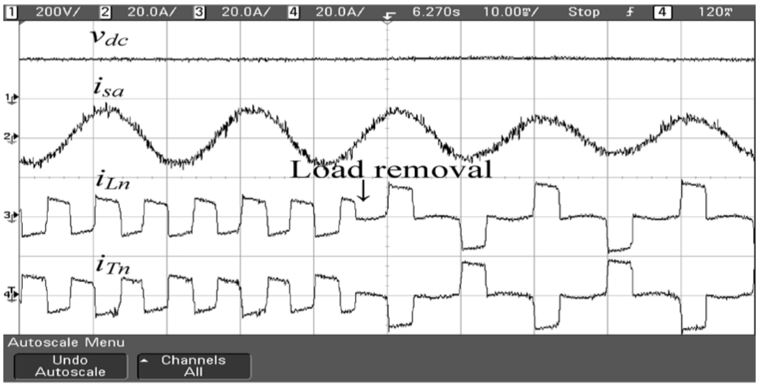
(a)



(b)



(c)



(d)

Fig.5 Fig.4 Dynamic performance of DSTATCOM under non linear loads.(a)v_{ab}, i_{sa}, i_{sc} (b)v_{ab} , i_{La} ,i_{Lb} , i_{Lc} (c) V_{dc} ,i_{sa} ,i_{ca} ,i_{La} (d) V_{dc}, i_{sa} , i_{Ln} ,i_{Tn}

IV. Conclusion

A control algorithm based on load conductance estimation using neural network for control of DSTATCOM has been implemented in a three phase four wire distribution system. The main factors for deciding the performance of DSTATCOM has been observed for detection of power quality problems in real-time and its accuracy. Test results have proved the effectiveness of proposed neural network algorithm for reactive power compensation, harmonics elimination, load balancing, neutral current compensation and increases efficiency under linear/nonlinear loads.

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