ANN-LMS Based Control Algorithm for DSTATCOM

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Abstract— *This paper proposes the real-time implementation of a three-phase distribution static compensator (DSTATCOM) using ANN inference system least-mean-square (ANn-LMS)-based control algorithm for compensation of current-related power quality problems. This algorithm is verified for various functions of DSTATCOM, such as harmonics compensation, power factor correction, load balancing, and voltage regulation. The ANN-LMS-based control algorithm is used for the extraction of fundamental active and reactive power components from non-sinusoidal load currents to estimate reference supply currents. Real-time validation of the proposed control algorithm is performed on a developed laboratory prototype of a shunt compensator. The performance of the proposed control algorithm is also compared with fixed-step LMS and variable-step LMS (VSLMS) to demonstrate its improved performance.*

Index Terms— Back propagation (BP) control algorithm, harmonics, ANN-Artificial Neural networks, load balancing, PQ-power quality, weights**.**

I. Introduction

The quality of available supply power has a direct economic impact on industrial and domestic sectors which affects the growth of any nation [1]. This issue is more serious in electronic based systems. The level of harmonics and reactive power demand are popular parameters that specify the degree of distortion and reactive power demand at a particular bus of the utility [2]. The harmonic resonance is one of the most common problems reported in low- and medium-level distribution systems. It is due to capacitors which are used for power factor correction (PFC) and source impedance [3]. Power converter-based custom power devices (CPDs) are useful for the reduction of power quality problems such as PFC, harmonic compensation, voltage sag/swell compensation, resonance due to distortion, and voltage flicker reduction within specified international standards [4]–[6]. These CPDs include the distribution static compensator (DSTATCOM), dynamic voltage restorer, and unified power quality conditioner in different configurations [7]–[9]. Some of their new topologies are also reported in the literature such as the indirect matrix converter- based active compensator where the dc-link capacitor can be removed [10]. Other new configurations are based on stacked multicell converters where the main features are on the increase in the number of output voltage levels, without transformer operation and natural self-balancing of flying capacitor voltage, etc. [11]. The performance of any custom power device depends very much upon the control algorithm used for the reference current estimation and gating pulse generation scheme. Some of the classical control algorithms are the Fryze power theory, Budeanu theory, p-q theory and SRF theory [12]–[14], Lyapunov-function-based control [15] and nonlinear control technique [16], etc.

Many non-model and training-based alternative control algorithms are reported in the literature with application of soft computing technique such as neural network, fuzzy logic and adaptive neuro-fuzzy, etc. [17]–[20]. Adaptive learning, self-organization, real-time operation, and fault tolerance through redundant information are major advantages of these algorithms. A neural network-based control algorithm such as the Hopfield-type neural network is also used for the estimation of the amplitude and phase angles of the fundamental component both with highly distorted voltage by the assumption of known power frequency [21]. An improved adaptive detecting approach for the extraction of the error signal with variable learning parameters can be chosen for fast response to improve tracking speed and for a low value in a stable period to improve accuracy [22]. Wu et al. [23] have proposed a new control algorithm based on inverse control with a neural network interface which was applied for the instantaneous calculation of switching on–off time in a digital environment. A survey on iterative learning control (ILC) is presented by Ahnetal. [24], and it is classified into different subsections within the wide range of application. The main idea of ILC is to find an input sequence such that the output of the system is as close as possible to a desired output. Control algorithms reported in available texts such as the quantized Kernel least mean square algorithm [25], radial basis function (RBF) networks [26], and feed forward training [27] can also be used for the control of CPDs. An immune RBF neural network integrates the immune algorithm with the RBF neural network. This algorithm has the advantages in the learning speed and accuracy of the astringent signal. Therefore, it can detect the harmonics of the current timely and precisely in the power network [28]. A multilayer perceptron neural network is useful for the identification of nonlinear characteristics of the load. The main advantage of this method is that it requires only waveforms of voltages and currents. A neural network with memory is used to identify the nonlinear load admittance. Once training is achieved, the neural network predicts the true harmonic current of the load when supplied with a clean sine wave. Its application with SRF theory is described by Mazumdar et al. [29], [30]. Feed forward back propagation (BP) artificial neural network (ANN) consists of various layers such as the input layer, hidden layer, and output layer. It is based on feed forward BP with a high ability to deal with complex nonlinear problems [31]. The BP control algorithm is also used to design the pattern based on decision support system. The standard BP model has been used with the full connection of each node in the layers from input to the output layers. Some applications of this algorithm are as to the identification of user faces, industrial processes, data analysis, mapping data, control of power quality improvement devices, etc. [32].

The control of power quality devices by neural network is a latest research area in the field of power engineering. The extraction of harmonic components decides the performance of compensating devices. The BP algorithm which trained the sample can detect the signal of the power quality problem in real time. Its simulation study for harmonic detection is presented in [33]. Many neural network-based algorithms are reported with theoretical analysis in single phase system, but their implementation to DSTATCOM is hardly reported in the available literature.

In this paper, a BP algorithm is implemented in a three phase shunt connected custom power device known as DSTATCOM for the extraction of the weighted value of load active power and reactive power current components in nonlinear loads. The proposed control algorithm is used for harmonic suppression and load balancing in PFC and zero voltage regulation (ZVR) modes with dc voltage regulation of DSTATCOM. In this BP algorithm, the training of weights has three stages. It includes the feed forward of the input signal training, calculation and BP of the error signals, and upgrading of training weights. It may have one or more than one layer. Continuity, differentiability, and non-decreasing monotony are the main characteristics of this algorithm. It is based on a mathematical formula and does not need special features of function in the learning process. It also has smooth variation on weight correction due to batch updating features on weights. In the training process, it is slow due to more number of learning steps, but after the training of weights, this algorithm produces very fast trained output response. In this application, the proposed control algorithm on a DSTATCOM is implemented for the compensation of nonlinear loads.

II. System Configuration And Control Algorithm

A voltage source converter (VSC)-based DSTATCOM is connected to a three phase ac mains feeding three phase linear/nonlinear loads with internal grid impedance which is shown in Fig. 1. The performance of DSTATCOM depends upon the accuracy of harmonic current detection. For reducing ripple in compensating currents, the tuned values of interfacing inductors (L_f) are connected at the ac output of the VSC. A three phase series combination of capacitor (Cf) and a resistor (Rf) represents the shunt passive ripple filter which is connected at a point of common coupling (PCC) for reducing the high frequency switching noise of the VSC. The DSTATCOM currents (i_{Cabc}) are injected as required compensating currents to cancel the reactive power components and harmonics of the load currents so that loading due to reactive power component/ harmonics is reduced on the distribution system.

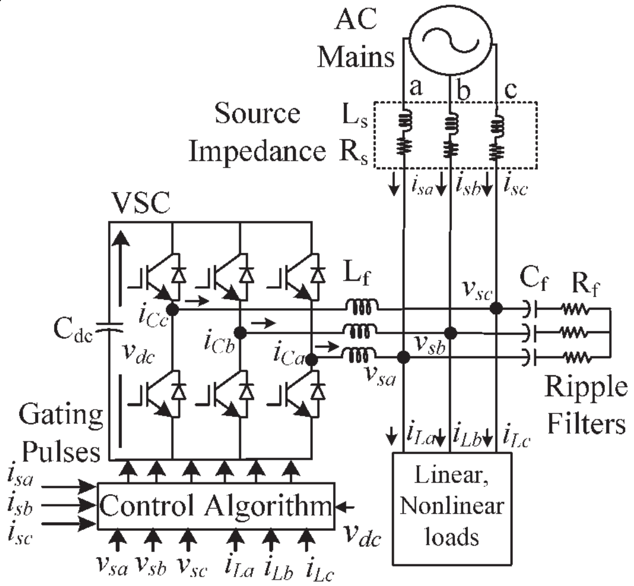


Fig. 1. Schematic diagram of VSC-based DSTATCOM.

Fig. 2 shows the block diagram of the BP training algorithm for the estimation of reference source currents through the weighted value of load active power and reactive power current components. In this algorithm, the phase PCC voltages (v_{sa}, v_{sb}, and v_{sc}), source currents (i_{sa}, i_{sb}, and i_{sc}), load currents (i_{La}, i_{Lb}, and i_{Lc}) and dc bus voltage (v_{dc}) are required for the extraction of reference source currents ($i_{sa}*$, $i_{sb}*$, and $i_{sc}*$). There are two primary modes for the operation of this algorithm: The first one is a feed forward, and the second is the BP of error or supervised learning.

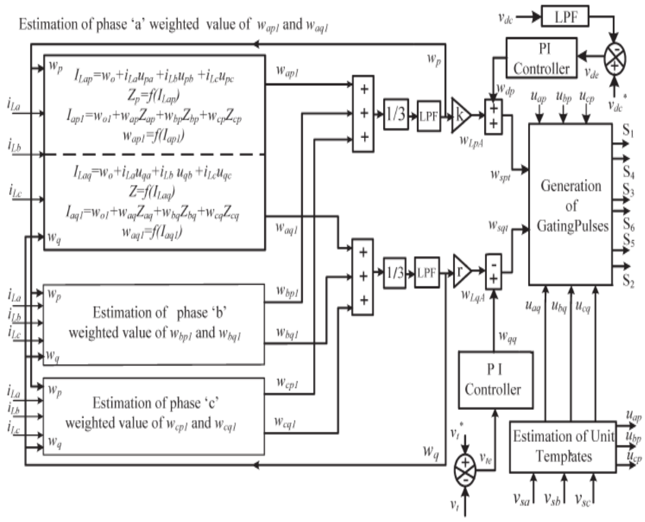


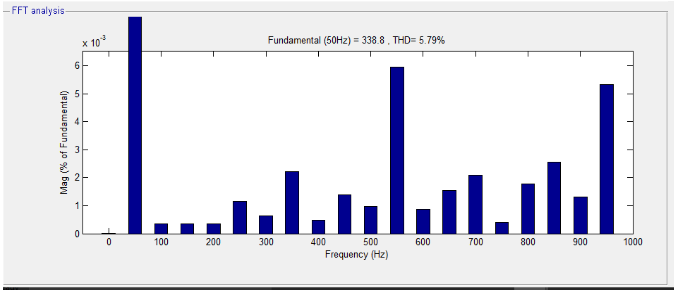
Fig. 2. Estimation of reference currents using BP control algorithm.

III. Simulation Results and Discussions

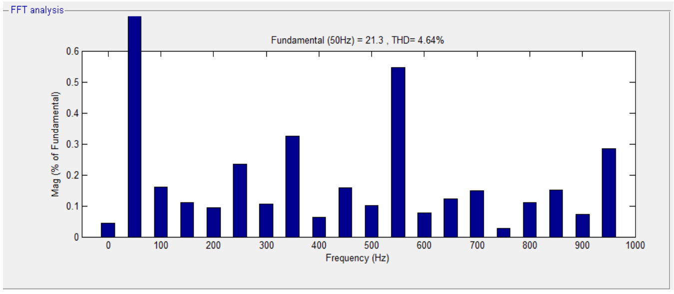
MATLAB with SIMULINK and Sim Power System tool- boxes is used for the development of the simulation model of a DSTATCOM and its control algorithm. The performance of the BP algorithm in the time domain for the three phase DSTATCOM is simulated for PFC and ZVR modes of operation under nonlinear loads. The performance of the control algorithm is observed under nonlinear loads.

A. Performance of DSTATCOM in PFC Mode:

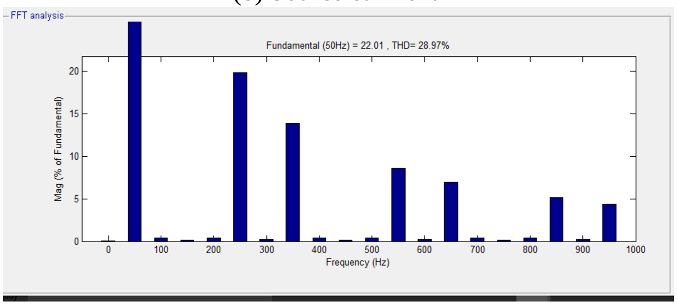
The dynamic performance of a VSC-based DSTATCOM is studied for PFC mode at nonlinear loads. The performance indices are the phase voltages at PCC (v_s), balanced source currents (i_s), load currents (i_{La}, i_{Lb}, and i_{Lc}), compensator currents (i_{Ca}, i_{Cb}, and i_{Cc}), and dc bus voltage (vdc) which are shown in Fig. 4. The waveforms of the phase "a" voltage at PCC (v_{sa}), source current (i_{sa}), and load current (i_{La}) are shown in Fig. 3(a)–(c), respectively. The total harmonic distortion (THD) of the phase "a" at PCC voltage, source current, and load cur- rent are found to be 5.79%, 4.64%, and 28.97%, respectively. It is observed that the DSTATCOM is able to perform the functions of load balancing and harmonic elimination with high precision.



(a) PCC voltage



(b) Source curr1ent



(c) Load current

Fig. 3. Waveforms and harmonic spectra of phase "a" in PFC mode.

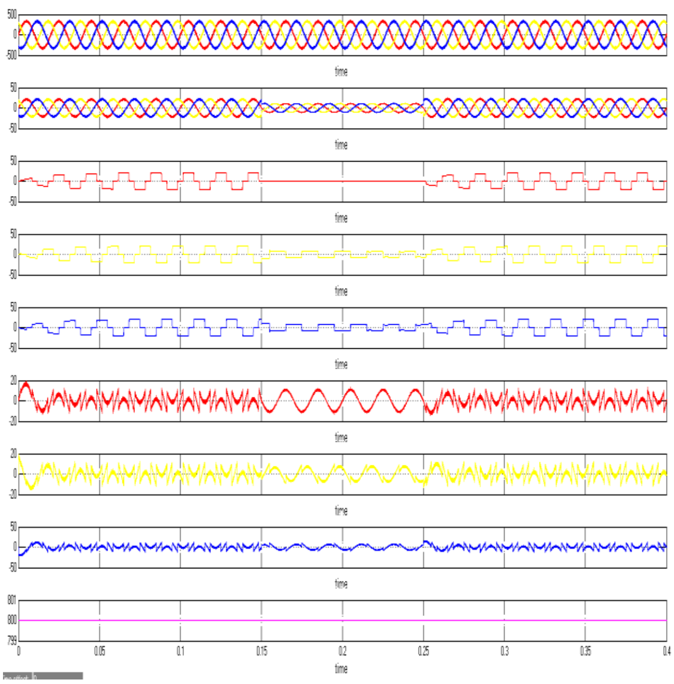
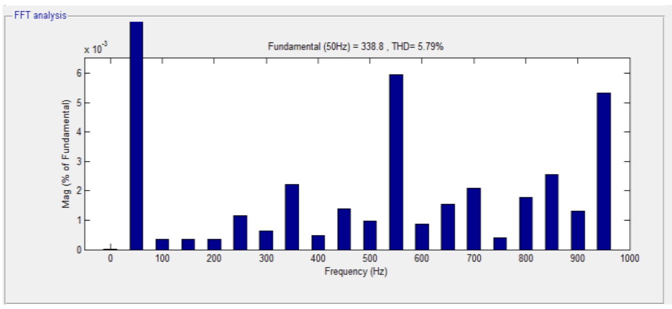


Fig.4: Dynamic performance of DSTATCOM under varying nonlinear loads in PFC mode

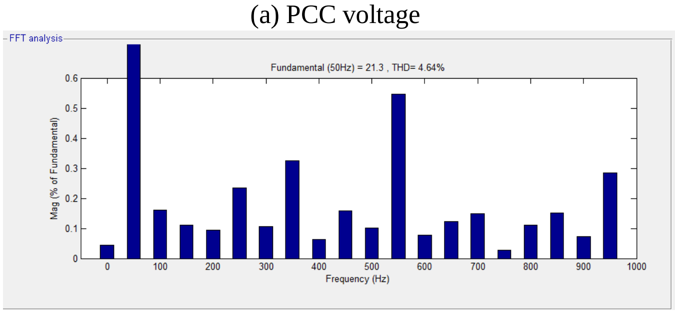
B. Performance of DSTATCOM in ZVR Mode:

In ZVR mode, the amplitude of the PCC voltage is regulated to the reference amplitude by injecting extra leading reactive power components. The dynamic performance of DSTATCOM in terms of PCC phase voltages (v_s), balanced source currents (i_s), load currents (i_{La}, i_{Lb}, and i_{Lc}), compensator currents (i_{Ca}, i_{Cb}, and i_{Cc}), amplitude of voltages at PCC (v_t), and dc bus voltage (v_{dc}) waveforms is shown in Fig. 6.

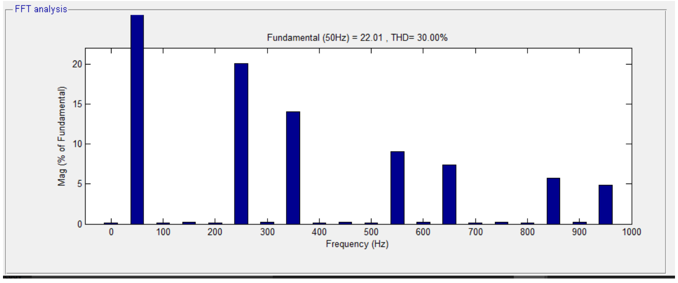
The harmonic spectra of the phase "a" voltage at PCC (v_{sa}), source current (i_{sa}), and load current (i_{La}) are shown in Fig. 5(a)–(c). The THDs of the phase "a" at PCC voltage, source current, load current are observed to be 5.79%, 4.64%, and 30.00%, respectively. Three phase PCC voltages are regulated up to the rated value. The amplitude of the three phase voltages is regulated from 335.2 to 338.9 V under nonlinear loads. It may be seen that the harmonic distortions of the source current and PCC voltage are within the IEEE-519 standard limit of 5%. The PCC voltage is also regulated at different operating conditions of load.



(a) PCC voltage



(b) Source current



(c) Load current

Fig. 5. Waveforms and harmonic spectra of phase "a" in ZVR mode.

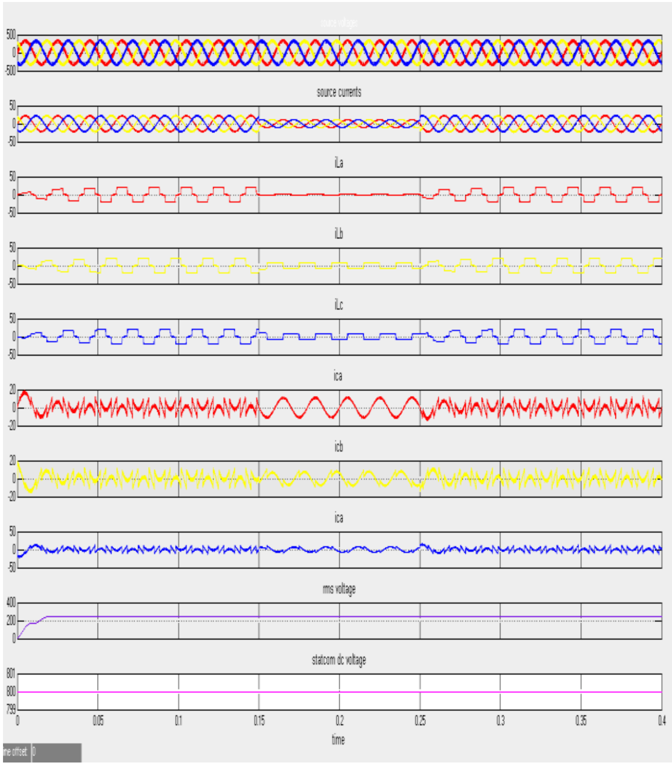


Fig. 6. Dynamic performance of DSTATCOM under varying nonlinear loads
in ZVR mode.

IV. Conclusion

The ANN-LMS-based control algorithm has been verified for the control of three-phase shunt compensator. This algorithm has been used to extract reference supply currents from non-sinusoidal load currents. The performance of DSTATCOM using ANFIS-LMS-based control has been found to be satisfactory for PFC and voltage regulation modes under varying load conditions. The power quality problems such as harmonics, reactive power, and load unbalancing have been mitigated using DSTATCOM. The THD in supply current has been reduced to 2.57% when there is THD of 26.66% in load current. The proposed algorithm has advantages over other two in terms of fast convergence, less static error, and fast learning of step size parameter.

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