A Novel Control Method for DSTATCOM Using Artificial Neural Network

YANG Xiao-ping*, ZHONG Yan-ru**, WANG Yan*

*Xi'an University of Technology/Institute of Water Resources and Hydro-electrical Engineering,

**Xi'an University of Technology/Department of Electrical Engineering

Xi'an, China

Abstract—**In this paper, a new control method for Distribution Static Compensator (DSTATCOM) using Artificial Neural Networks (ANN) instead of the conventional direct controller is presented. A feedforward three-layer neural network is adopted to control the output compensating currents. This is accomplished by producing the appropriate switching patterns of the IGBTs. A backpropagation algorithm trains this network. A practical case with PSCAD/EMTDC is presented to check the proposed control performance. The simulation results show a better source current waveforms and a near unity power factor operation is achieved. This technique offers an alternative to the multi-pulse techniques that require complex magnetic circuit arrangements as well as to the conventional PI controller that the parameters are hard to determine.**

Keywords-DSTATCOM, Artificial Neural Network(ANN), Back propagation, PSCAD/EMTDC, Simulation.

I. INTRODUCTION

As a typical flexible AC transmission system (FACTS) device, DSTATCOM is one of the most effective reactive power compensation devices to improve power transfer capability [1]. To obtain the best compensation effects, DSTATCOM must be controlled properly. In recent years most of the papers have suggested many methods for designing DSTATCOM controllers using linear control techniques, in which the system equations are linearized at a specific operating point and based on the linearized model, the PI controllers are tuned in order to have the best possible performance. The drawback of such PI controllers is that their performance degrades as the system operating conditions change. Nonlinear adaptive controllers on the other hand can give good control capabilities over a wide range of operating conditions, but they have a more sophisticated structure and are more difficult to implement compared to linear controllers. In addition, they need a mathematical model of the system to be controlled [2].

Artificial Neural networks (ANN) offer a solution to this problem, they are able to identify and model such nonlinear system. Nowadays, this technique is considered as a new tool to design DSTATCOM control system. The ANN presents two principal characteristics. It's not necessary to establish specific input-output relationships but they are formulated through a learning process or through an adaptive algorithm. Moreover, it can be trained online without requiring large amounts of offline data [3].

In this paper, a novel design of a DSTATCOM control method based on ANN is presented. The ANN block will be used instead of the conventional direct control. The performance of the method is demonstrated via transient simulation using the electromagnetic transients simulation program PSCAD/EMTDC.

II. CONTROL SYSTEM OF DSTATCOM

Fig.1 shows the complete control system with DSTATCOM. The ac source is three-phase sine wave. The load current I_l is the sum of the source current I_S and the compensation current I_n. The objectives are to get a source current without harmonic and reactive components and to get a constant value of the DC voltage. The ac side of the converter is connected to the power supply through a synchronous link reactor *L*, Fig.2, which also performs as a low pass filter. The main losses are reduced to *R*. The simplified main circuit of DSTATCOM is shown in Fig.3.

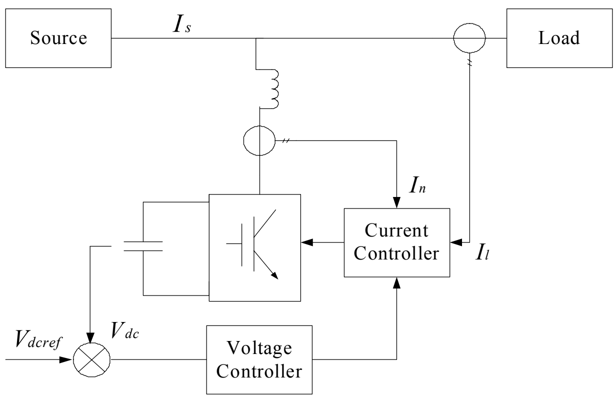

Fig.1 Control system with DSTATCOM

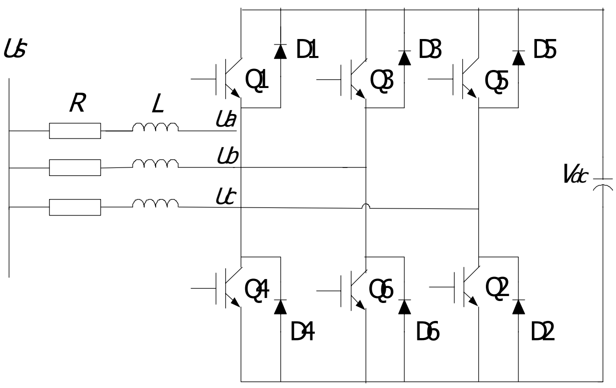

Fig.2 The main circuit

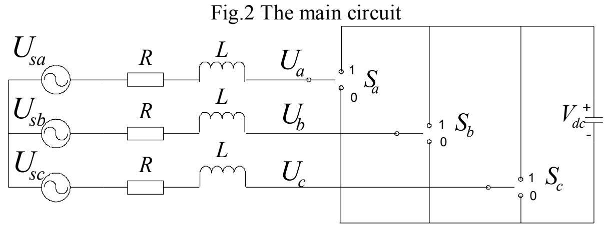

Fig.3 Simplified main of DSTACOM

III. CONVENTINAL CONTROL METHOD OF DSTATCOM

Fig.4 shows the conventional direct control of DSTATCOM. V_{dc} is the DC side voltage, I_{na}, I_{nb}, I_{nc} are the output currents of the inverter, and I_{la}, I_{lb}, I_{lc} are the load currents [4].

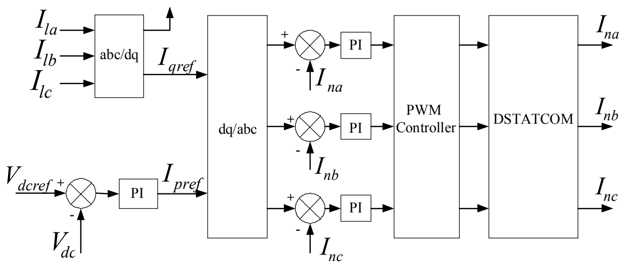

Fig.4 The conventional direct control of DSTATCOM

A. Generation of The Reactive Reference Current

The reactive reference current I_{qref} is generated by the load current, using dq transformations. The relationship between the peak ac input current and the mean -axis values is as follow:

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin\omega t & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\ -\cos\omega t & -\cos(\omega t - \frac{2\pi}{3}) & -\cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \cdot \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin\omega t & -\cos\omega t \\ \sin(\omega t - \frac{2\pi}{3}) & -\cos(\omega t - \frac{2\pi}{3}) \\ \sin(\omega t + \frac{2\pi}{3}) & -\cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \cdot \begin{bmatrix} I_d \\ I_q \end{bmatrix} \quad (2)$$

B. Generation of Tthe Active Reference Current

Although the voltage of the DC side should be maintained at a pre-specified design value, voltage fluctuations cannot be avoided. Voltage control of the DC side is achieved by adjusting a small amount of real power flowing into the DC capacitor. Therefore a DC voltage control loop is included in the DSTATCOM. The error between the actual DC voltage and its reference value is treated in a proportional integral (PI) controller, and the output is the active reference current $I_{pref.}$ The parameters of the PI controller must be chosen carefully to attain the desired stability and dynamics.

C. Generation of Trigger Signals

The DC/AC inverter is a full bridge, three-phase inverter made of six Insulated Gate Bipolar Transistors (IGBTs) controlled by Pulse Width Modulation (PWM) technique. The IGBT is selected as switching component because it is voltage controlled and easy to drive, with relatively low on-state voltage drop. In simulations, the PWM inverter is modeled with related snubber circuits attached to the IGBTs. A current error is observed and fed to the PI control block. The output of the PI controller is the voltage-modulating signal in which its magnitude and phase are controlled. In the PWM technique, the triangular carrier signal is compared with the voltage-modulating signal so as to obtain the firing signals of the IGBTs.

IV. THE PROPOSED ANN CONTROLLER

The disadvantage of direct control method is that harmonics are big. Moreover, the parameters of PI controllers are hard to determine, which influence the performance of the controller.

This paper introduces another option to reduce the ac current harmonics that uses an ANN. The ANN quickly computes the necessary firing instants for providing the necessary reactive power as well as for eliminating only the necessary harmonics, Fig.5.

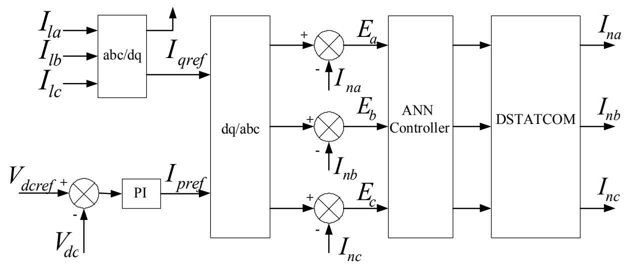

Fig.5 The proposed controller

A. The Architecture of ANN

The ANN controller used is a feed-forward one, comprising three neuron layers, the input layer, the hidden layer and the output layer. The input layer offers connection point to transmit the input signal to the hidden layer. The latter begins the learning process and the output layer continues the learning process and provides outputs. The network topology is shown in Fig.6.The hidden-layer neurons have a tan-sigmoid transfer function, and the output layer neurons have a linear transfer function. The ANN has three inputs that are the three-phase current errors of the DSTATCOM. It also has three outputs that are the three switching functions of the inverter legs.

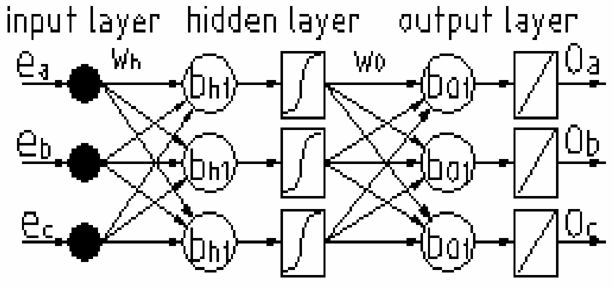

Fig.6 The architecture of ANN

The control objective of the ANN is to provide the wanted proper gating patterns of the PWM inverter, leading to adequate tracking of the DSTATCOM reference phase currents and constant DC voltage. The number of neurons in the hidden layer is specified as the minimum number that produces the permitted training criterion.

On introducing the input vector e_j and $e_j = [e_a, e_b, e_c]^T$, the equations associated with the signals flowing from each layer to the next are

$$I_j = f(W_{hj}^T e_j^T + B_{hj}^T) \tag{3}$$

$$O_j = g(W_{oj}^T I_j^T + B_{oj}^T) \tag{4}$$

where I_j is the hidden layer output vector， O_j is the output vector of the ANN, f is the transfer function of the hidden layer, g is the transfer function of the output layer; W_h is the weight matrix of the hidden layer; W_O is the weight matrix of the output layer; B_h is the bias vector of the hidden-layer neurons; and B_O is the bias vector or the output layer. In this paper, the functions of f and g are as follows:

$$f(x) = \frac{1}{1+e^{-\lambda x}} \tag{5}$$

$$g(x) = \begin{cases} 0 & x < 0 \\ 1 & x \geq 0 \end{cases} \tag{6}$$

Where λ is the up ratio of the function, which is between 0 and 1[5].

B. Training Algorithm

The ANN is trained by changing the weights W_{ij} and the biases B_j . The training criterion is taken as the mean square error of the ANN output with a value of 0.0001and the error function is defined as:

$$E = \frac{1}{2}\sum_{i=1}^{N} e(i) \tag{7}$$

Where N is the number of output neurons and $e(i)$ is the instantaneous error between the actual and estimated values of the output. The training is finished when the value of E is less than 0.0001[6].

Sufficient input-output training samples with different compensation modes are obtained by using the triangular carrier modulation technique**.** The backpropagation (BP) algorithm is used for training. The BP algorithm was developed by Paul Werbos in 1974. It applies a weight correction to the neural network connection weights, which is proportional to the partial derivative of the error function. BP learning algorithm is the most commonly used technique for updating neural network weight parameters [7]. The adjustment to the weights is in the negative direction of the gradient of the error. The neuroidentifier weights are adjusted according to:

$$\Delta W_{ij} = -\eta \frac{\partial E}{\partial W_{ij}} \tag{8}$$

Where η is the learning rate parameter. A large learning rate might lead to oscillations in the convergence trajectory, while a small learning rate provides a smooth trajectory at the cost of slow convergence speed.

V. SIMULATION RESULTS

The detailed DSTATCOM model with a three-phase bridge converter connected into a distribution system is modeled by using PSCAD/EMTDC. The compensator was connected to the network through an inductance. A list of the system parameters considered in the simulation is given in table I. The ANN technique is used for the switching pattern generation. Learning process of ANN is developed in MATLAB 6.5, helped by the toolbox Neural Network.

TABLE I.
SYSTEM PARAMETERS USED IN SIMULATION

Power source	Line voltage = 380V Frequency = 50.0 Hz
DSTATCOM	R=0.074 Ω L=0.7mH C= 1000 μF V_{dc} =760V Capacity = ± 100kvar

Simulation results are presented in Fig. 7-8**,** where V_{as} is the system voltage (phase A), I_{as} is the system current (phase A), and V_{dc} is the DC side capacitor voltage. The DSTATCOM device is put into service at 0.2s. From the waveforms we can see that I_{as} comes in phase with V_{as} quickly after compensation and V_{dc} becomes constant with a short-time transition. As a consequence of the action of the switches, high frequency harmonics arise in the capacitor voltage and system phase currents. A second harmonic is excited in the capacitor voltage and a large third harmonic component is present in the system phase currents. Changing the inductance value or install a filter in the power circuit can reduce the harmonics.

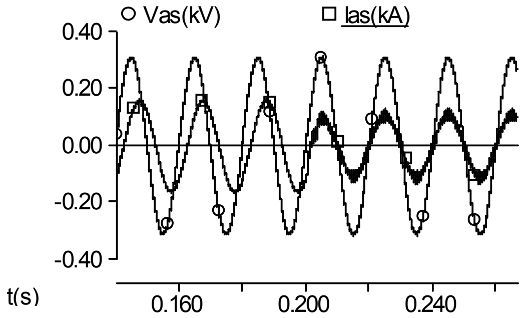

Fig.7 The system voltage and current waveforms of phase A before and after compensation

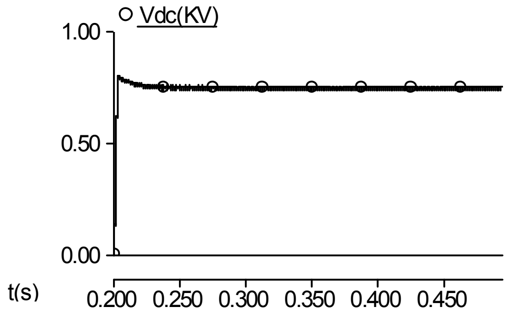

Fig.8 The DC side voltage

VI. CONCLUTIONS

A DSTATCOM based on an artificial neural network has been proposed and analyzed in this paper. Load currents and the DC voltage are sensed, the ANN block calculates the power circuit control signals from the reference compensation currents, and the power circuit injects the compensation current into the power system. The viability of the system has been proved through simulation results. The device has been able to shape the system current into nearly a sinusoidal waveform in phase with the system voltage. The simulation results show that the proposed control strategy is effective.

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