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DSTATCOM-based Artificial Neural Network Controller for Harmonic Reduction

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Abstract: Harmonic amplification is one of the primary issues in power system networks. The objective of this study is to manage the harmonic event and its significant effects on power quality. A new control approach that uses artificial intelligence (AI) is proposed and applied to a distribution static synchronous compensator (DSTATCOM). DSTATCOM is a FACTS device that can achieve highly effective reactive power compensation to reduce and/or damp the harmonic amplification in power system networks. Simulation results are obtained using the MATLAB/Simulink package.

Keywords: Distribution Static Synchronous Compensator (DSTATCOM), Neural Network, Harmonics, Power Quality

1. Introduction

Currently, power engineers are highly concerned about stability issues due to blackouts. A distribution static synchronous compensator (DSTATCOM) is a flexible alternating-current transmission system (FACTS) device connected via shunt with the system. The static compensator (STATCOM) can electrically mimic the reactor and capacitor by injecting shunt current in quadrature with the line voltage. Nonlinear loads are widely used in power system networks. However, such loads present a serious problem called ‘harmonics’, which is caused by the resonance between L and PF that are installed in consumer capacitors and utilised as power electronic devices. Power system sectors (transmission and distribution) use FACTS devices to reduce harmonic amplification through damping [1, 2].

DSTATCOM is a FACTS device that has been proven valid in power system networks; it works by injecting VAR into power system networks. Amongst the most prominent custom power devices, such as the dynamic voltage restorer and unified power quality conditioner, DSTATCOM can provide cost-effective solutions to compensate for reactive power and unbalanced loading in distribution systems. Addressing the power quality issue is the initial step to ensure that purchasers are satisfied with their electrical power framework. Given the rise of control gadgets and nonlinear loads, control quality issues are expected to increase. FACTS can provide a strategic answer to this issue. Certain inventions with speedy and dependable control over transmission parameters are necessary. This situation motivated us to design an online learning-based controller to improve the performance of the power inverter in terms of total harmonic distortion (THD). Artificial neural network (ANN) techniques and classic backpropagation algorithms have been used to improve the control performance of SAF [3-5]. However, the implemented algorithms lack online adaptation, and their performance under varying load conditions has not been quantified.

The power framework hardware is influenced by deficiencies at any separation on transmission lines [6, 7]. In transmission line systems and appropriation control frame works, deficiencies cause voltage issues and weaken the client equipment [8]. In this study, FACTS gadgets were equipped with improved power framework productivity. These FACTS controllers can be used to empower the related capacity under ordinary and projected conditions. Variations in FACTSs include STATCOM, UPQC, SVC, SSG, TCR, TSC, TSR and SSSC. DSTATCOM was addressed separately in this study. The responsive power at the terminals of STATCOM is subject to the adequacy of the voltage source. This STATCOM in the appropriation framework is called DATACOM (distribution STACOM [7, 9]). In studies mentioned as references [10-12], a similar control approach was incorporated into the frequency control loop of generators to improve the system frequency response and smoothen the variations due to the large-scale wind, photovoltaics (PVs) and/or electric vehicle (EV) integration. However, only a few studies have investigated the challenges encountered in power electronic pulse width modulation (PWM) with the current control through the ADP-based controller [13]. Some studies have [13, 14] proposed and validated the vector control of a grid-connected rectifier/inverter using ANN and backpropagation through the time weight updating rule. This study aimed to prove the capability of DSTATCOM in reducing harmonics in power systems. The method of control used was the neural network (NN) controller, which is an AI method. The simulation results were obtained using the MATLAB-Simulink package.

2. Literature Survey

This paper deals with a shunt active filter which will be installed by an electric utility, putting much emphasis on the control strategy and the best point of installation of the shunt active filter on a feeder in a power distribution system. The objective of the shunt active filter is to damp harmonic propagation, which results from harmonic resonance between many capacitors for power factor improvement and line inductors in the feeder, rather than to minimize voltage distortion throughout the feeder. Harmonic mitigation is a welcome "by-product" of the shunt active filter, which comes from damping of harmonic propagation. This paper concludes that the shunt active filter based on detection of voltage at the point of installation is superior in stability to others, and that the best site selection is not the beginning terminal but the end terminal of the primary line in the feeder. Computer simulation is performed to verify the validity and effectiveness of the shunt active filter by means of an analog circuit simulator, which is characterized by installing it on a feeder of a radial distribution system in a residential area.

P. S. Vazquez. Active power filter control using neural network technologies IEE Proceedings-Electric Power Appl. 54(1): 61-76 [2]. A method for controlling an active power filter using neural networks is presented. Currently, there is an increase of voltage and current harmonics in power systems, caused by nonlinear loads. The active power filters (APFs) are used to compensate the generated harmonics and to correct the load power factor. The proposed control design is a pulse width modulation control (PWM) with two blocks that include neural networks. Adaptive networks estimate the reference compensation currents. On the other hand, a multilayer perceptron feedforward network (trained by a backpropagation algorithm) that works as a hysteresis band comparator is used. Two practical cases with Matlab-Simulink are presented to check the proposed control performance.

In this paper, an efficient and reliable neural active power filter (APF) to estimate and compensate for harmonic distortions from an AC line is proposed. The proposed filter is completely based on Adaline neural networks which are organized in different independent blocks. We introduce a neural method based on Adalines for the online extraction of the voltage components to recover a balanced and equilibrated voltage system, and three different methods for harmonic filtering. These three methods efficiently separate the fundamental harmonic from the distortion harmonics of the measured currents. According to either the Instantaneous Power Theory or to the Fourier series analysis of the currents, each of these methods are based on a specific decomposition. The original decomposition of the currents or of the powers then allows defining the architecture and the inputs of Adaline neural networks. Different learning schemes are then used to control the inverter to inject elaborated reference currents in the power system. Results obtained by simulation and their real-time validation in experiments are presented to compare the compensation methods. By their learning capabilities, artificial neural networks are able to consider time-varying parameters, and thus appreciably improve the performance of traditional compensating methods. The effectiveness of the algorithms is demonstrated in their application to harmonics compensation in power systems.

Lai L L. Intelligent System Applications in Power Engineering: Evolutionary Programming and Neural Networks. 1998 [4]. Cutting-edge research indicates that evolutionary programming is set to emerge as the dominant optimisation technique in the fast-changing power industry. Combining theory and practice, Intelligent System Applications in Power Engineering capitalises on the potential of neural networks and evolutionary computation to resolve real-world power engineering problems such as load forecasting, power system operation and planning optimisation. Unlike existing optimisation methods, these novel computational intelligence techniques provide power utilities with innovative solutions for improved performance.

Features include: Introduction to evolutionary programming and neural networks serving as a foundation for later discussion of the benefits of hybrid systems

- Practical application of evolutionary programming to reactive power planning and dispatch for speedy, cost-effective increases in transmission capacity plus generator parameter estimation

- Examination of economic dispatch, power flow control in FACTS and co-generation scheduling and fault diagnosis for HVDC systems and transformers
- Consideration of power frequency and harmonic evaluation to maximise supply quality
- Employment of distance protection, faulty section estimation and calculation of fault clearing time for transient stability assessment

Graduate students in electric power engineering will value Lai s broad coverage of the applications of evolutionary programming and neural networks in the field. This unique reference will be a boon to engineers, computer application specialists, consultants and utility managers wishing to understand the benefits intelligent systems can bring to the power industry. IEEE Recommended Practice for Evaluating Electric Power System Compatibility With Electronic Process Equipment. IEEE Xplore 1998 [5]. A standard methodology for the technical and financial analysis of voltage sag compatibility between process equipment and electric power systems is recommended. The methodology presented is intended to be used as a planning tool to quantify the voltage sag environment and process sensitivity. It shows how technical and financial alternatives can be evaluated. Performance limits for utility systems, power distribution systems, or electronic process equipment are not included.

3. Proposed System

The below figure1 shows block diagram of the DSTATCOM with ANN controller. The system consists three phase source, load, DSTATCOM and ANN controller the arrangement is shown in below figure. the DSTATCOM consists DC link capacitor (energy storage), Voltage Source Inverter (VSI) and passive filter. The VSI is controlled by SPWM techniques.

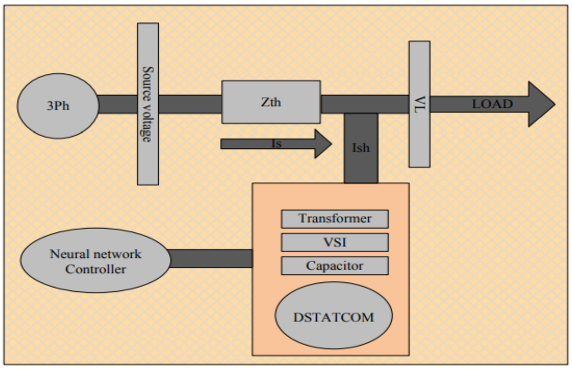

Fig 1 Diagram of the power model with DSTATCOM.

Ish is injected to adjust the voltage drop after voltage sag occurs in the electrical system across Z^{th}. The Ish value can be controlled by the VSC output, as shown in Eqs. (1-3). Eq. (4) expresses the power injected by DSTATCOM to the power system network.

$$I_{sh} = I_L - I_s , \qquad (1)$$

$$IL - Is = IL - \left(\frac{(Vth - VL)}{Zth}\right), \qquad (2)$$

$$Ish\angle\eta = IL\angle - \theta - \frac{Vth}{Zth}(\delta - \beta) + \frac{Vth}{Zth}\angle - \beta \qquad (3)$$

$$S_{sh} = V_L I_{sh}^{*}, \qquad (4)$$

Where,

IL, Is: load and source currents,

Vth, VL: Thevenin and load voltages,

Zth = impedance (R+jx).

At any time, when fluctuation increases due to voltage sags, DSTATCOM corrects the power depending on the Zth value or fault level of the load bus. The voltage after correction is achieved without injecting reactive power into the system when the Ish value is minimized. The viability of DSTATCOM in adjusting the voltage relies on the estimation of Zth. At the point where the shunt infused current Ish is retained in quadrature with VL, the desired voltage remedy can be accomplished without infusing any dynamic power into the framework when the estimation of Ish is limited. As indicated in Fig. (1), DSTATCOM association depends on a current that is equivalent to the IS and IL and a straightforward two-level VSC that is controlled by utilising NN to produce ordinary sinusoidal waveform width adjustment (PWM) [16].

3.1. NN CONTROL ALGORITHM

As shown in Fig. (2), the NN controller employed in this work is an intelligent control system that consists of neuron layers (three of each for input, hidden, and output layers).

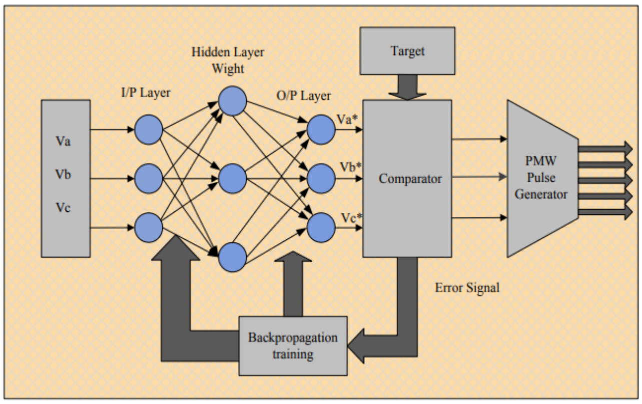

Fig. 2 Single line diagram of the neural network controller

The output passes through a comparator for comparison with a carrier signal and is then applied as a reference variable to PWM.

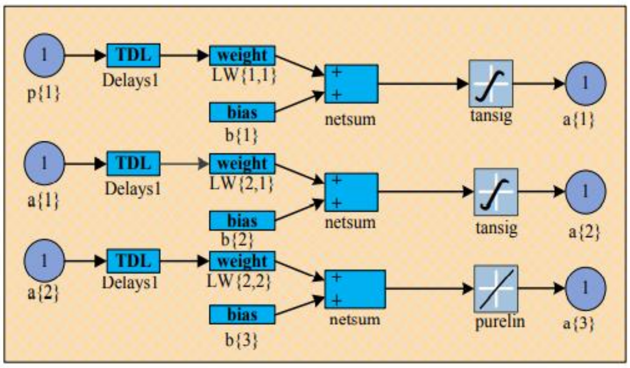

Fig. 3 Neuron in matrix form at each layer

The output will be back to process the filter errors to make the system more accurate. In feedback control design, guaranteeing the tracking performance and the internal stability or boundedness of all variables is crucial. Failure to do so can cause serious problems in the closed-loop system, including instability and unboundedness of signals, which can result in system failure or destruction. In this NN, the weights (Wij) vary with the biases (Bj).

The mean squared error is used to train the NN output with a value of 0.0001, and the error can be determined with Eq. (5).

$$J = \sum_{i=1}^{N} e(i)^2, \qquad (5)$$

where

N = number of o/p neurons,

e (i) = instant error (actual and estimated) values of the output. When the j value is < 0.0001, training is completed. Eqs. (6) and (7) express the summation bias with weighted inputs to obtain the net input.

$$n = w1,1p1 + w1,2p2 + \cdots + w1,RpR \qquad (6)$$

$$n = Wp + b \qquad (7)$$

The matrix is a single neuron, which means it has only one row. The neuron output can be expressed as:

$$a = f(Wp + b). \qquad (8)$$

Overall, using one neuron with numerous inputs is insufficient. At times, more than 10 neurons (called a layer) are required for the parallel operation, as shown in Fig. (3). Fig. (4) presents the neuron connection as layers.

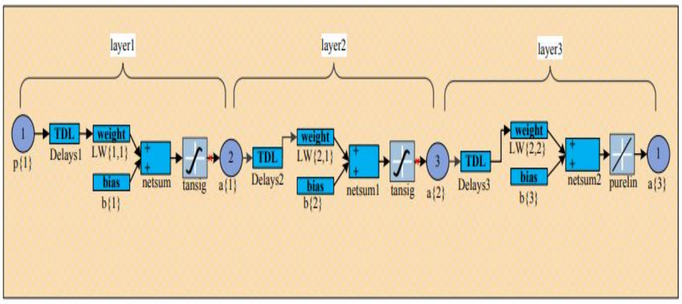

Fig. 4 Three-layer neural network

4. Simulation Results

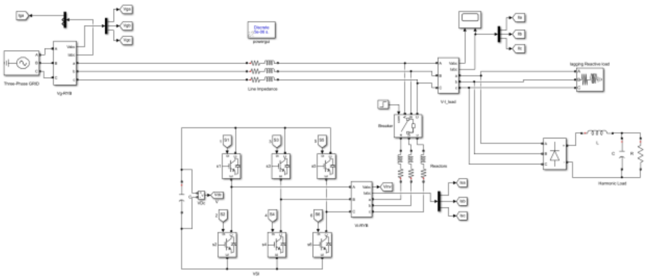

Fig.5 MATLAB/SIMULINK circuit diagram of the proposed system

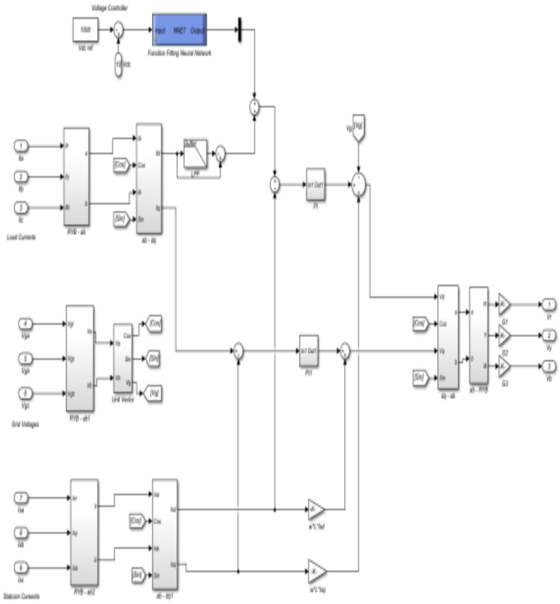

Fig.6 control system

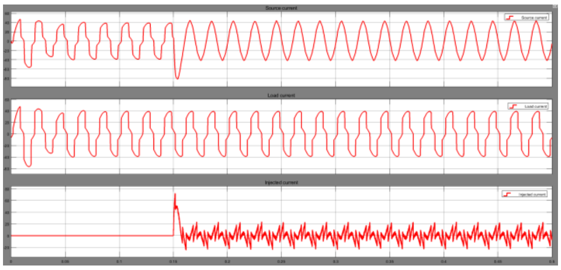

Fig.7 (a)Source current (b) Load current (c)Injected current

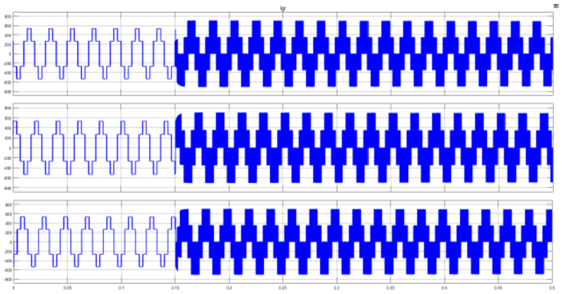

Fig.8 Inverter voltage

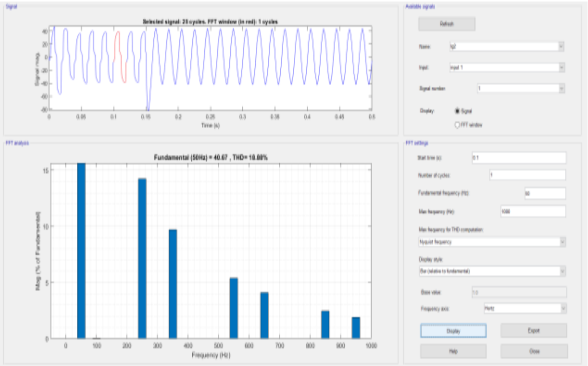

Fig.9 Source current THD% (18.88%) before compensation

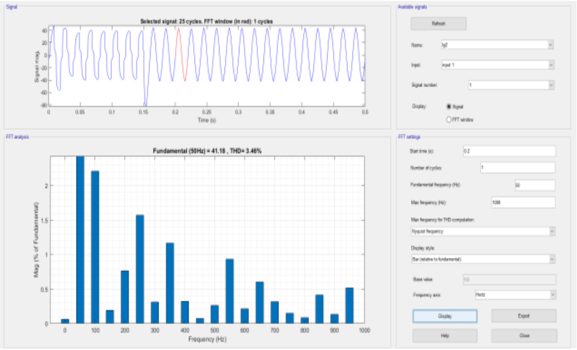

Fig.10 Source current THD% (3.46%) after compensation

6. Conclusion and Future Scope

The harmonics problem is one of the types of power quality problems that a customer may encounter depending on how the voltage waveform is being distorted. In this paper, a discrete-time multilayer neural network-based DSTATCOM controller was proposed. The weights of the network were dynamically updated according to the filtered error of the entire closed-loop system. Distribution static compensator offered conventional series of shunt compensation. A model of distribution control system was constructed for harmonics reduction. The control quality investigation was fabricated and executed in Simulink as a part of the power system network. The investigation included the effects of voltage sag, and controls on related waveforms of field voltage and current were examined. The DSTATCOM examination aims to enhance the power quality in distribution systems with nonlinear loads of sounds removed from the source side. To avoid the power quality problem, a compatible equipment to power system networks was installed.

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