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ANN Based Approach to Simulate Power System with STATCOM

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Abstract:

In Power systems, STATCOM is used for compensating purpose. Various Pulse Width Modulation (PWM) techniques are used to control the harmonic content of voltage source inverters. Distribution systems have to supply unbalanced nonlinear loads which transfer oscillations to the DC-side of the converter in the operating conditions. The additional harmonics are modulated through the STATCOM at the point of common coupling (PCC) which requires more attention when switching angles are calculated offline using the optimal PWM technique. This paper presents the artificial neural network model for defining the switching criterion of the Voltage Source Converter(VSC) for the STATCOM. So that it reduces the total harmonic distortion (THD) of the injected line current at the PCC. This model considers the dc capacitor effect, effects of other possible varying parameters such as voltage unbalance as well as network harmonics. A reference is developed for offline prediction and then implemented with Artificial Neural Network (ANN).

I.INTRODUCTION

The Static Synchronous Compensator (STATCOM) has the capability of generating and/or absorbing reactive power at a faster rate [1]. STATCOM can control the line voltage at the point of common connection to the electric power network [2,3]. Power stage of STATCOM can be formed either by voltage or current source converters [4,5]. The voltage source converter (VSC) produces 3-phase output voltages, each nearly in phase with, and coupled to the corresponding AC grid voltage through a relatively small reactance[6]. A minimum energy storage element is placed into the DC-link; it is a capacitor bank in VSC case. In such applications, the VSC have some additional capabilities, such as harmonic filtering, and load balancing in addition to reactive power compensation. These features of STATCOM leads to the generation of harmonic components superimposed on fundamental voltage component at the AC side of VSC, by the turning on and off the IGBT switches at frequencies much higher than the supply frequency [7].

The method of selective harmonic elimination was used as an efficient means for obtaining harmonic reduced waveform from VSC with the introduction of no characteristic harmonics [8]. The switching angles required for the implementation of VSC are usually pre calculated on the basis of fixed dc bus voltage to eliminate a certain number of undesirable harmonics & maintain the desired fundamental component of voltage [9]. Variable modulating function based PWM and correcting optimized PWM switching patterns were proposed in [10,11] but this requires a precise knowledge of the magnitude and phase of dc ripple component, which is usually not known. For minimizing harmonic distortion of multilevel VSC the polarities & the number of levels were required to determine different modulation index [12]. A switching pattern was developed to cancel low order harmonics. The commutation amngles were set to minimum but were varied with voltage amplitude and hence again the harmonics were modulated [13]. The effect of modulation index on the variation of targeted & non targeted harmonics with different STATCOM reactive loading, different ac strengths & different capacitance values was studied in [14]. It was shown that there was increase in level of harmonics while operating under step changes of load & unbalanced ac

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voltages on each phase. A fixed modulation index reference to minimize voltage & current harmonics of a STATCOM wad proposed [15], which showed lower harmonic contents. The scheme of modulation index controlling & the operating modulation indexes range was presented for minimizing harmonic distortion due to switching of VSC [16]. All this was done for balancing dc-link voltage in eight H-bridge inverter unit. The harmonic output at PCC was not discussed. Iman et al. [17] proposed a strategy for voltage balancing of distinct dc buses in cascaded H- bridge rectifier. The method used was to ensure that the dc bus capacitor voltage converges to the reference value, even when the loads attached to them extracts different power. To reduce the current & voltage harmonics both stepped & PWM methods were used.

Thus it can been seen that conventional methods can give good control capability over a wide range of operating conditions. They need a mathematical model of the system to be controlled, which in most cases cannot be obtained easily.

In this paper, a VSC based STATCOM has been designed using ANN in which voltage regulation is achieved , and the input voltage harmonics are minimized by selective harmonic elimination technique (SHEM).

The paper is organized in five section. The first section introduces the role of VSC for STATCOM applications. The second section deals with the inside view of the STATCOM followed by the introduction of SHEM. The design of the neuro controller is presented in section three. In the fourth section the validation of the identified neural network based VSC is presented. The concluding remarks are drawn in the last section

II. CONVENTIONAL STATCOM MODEL

A decoupled conventional control scheme is suggested for the STATCOM which is shown in Fig. 1. It consists of two PI controllers, namely, PIv and PIDC, for regulating the line voltage at the point of common coupling (PCC) and the dc link voltage inside the device. The deviations in the line voltage ΔV and the dc link voltage ΔVdc are passed through these two decoupled PI controllers in order to determine the inverter modulation index ma and the phase shift α, respectively.

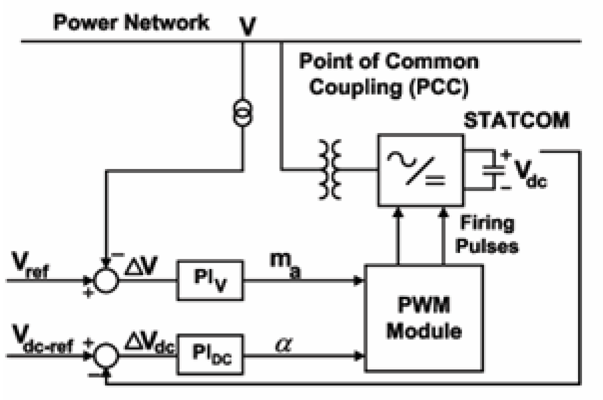

Fig. 1 STATCOM decoupled control scheme

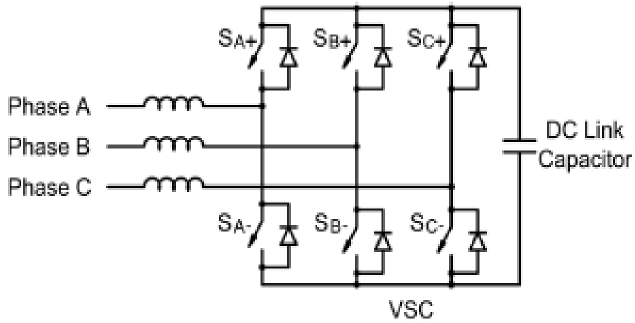

Fig. 2 A general 2 level 3 leg VSC

A general 2 level 3 leg VSC is shown in Fig. 2. The switching pattern of the IGBT switches are defined on the basis of the modulation index (m) and the pahse shift α. The two patterns are then given to the VSC circuit via PWM module which produces switching pattern of IGBTs to produce a corresponding or desired 3 phase voltage waveform for STATCOM application. The voltage regulation can be achieved by one of the following techniques:

(i)varying modulation index m, while keeping DC link voltage Vd constant

(ii)varying Vd, while keeping m constant

(iii)varying both m and Vd

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The highly mathematical PWM method has two base terms modulation index and modulation ratio. Modulation index (MI) determines the output voltage fundamental component. While the modulation ratio (MR) determines the incident (location) of harmonic in the spectra.

SELECTIVE HARMONIC ELIMNATION METHOD

A simplified Single phase Y- equivalent model of STATCOM is given in Fig. 3

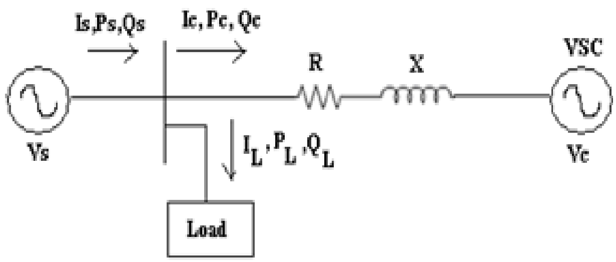

Fig. 3 Single Line Diagram of STATCOM

where

VS : RMS line to neutral AC grid voltage

VC : RMS line to neutral STATCOM fundamental voltage

Is : RMS source fundamental current

IL : RMS load fundamental current

IC : RMS STATCOM fundamental Curent

QS : Source reactive power

QL : Load reactive power

QC : STATCOM reactive power

R :Y- equivalent of total loss resistance including coupling transformer losses, input filter losses and converter losses

X :Y-equivalent of total reactance including source reactance, leakage reactance of coupling transformer, and input filter reactance.

Harmonic content of STATCOM line current IC in Fig.1 should comply with IEEE Std. 519-1992[18]. this can be achieved by applying a proper PWM technique such as SHEM. In this research work, since fixed dc link voltage and variable modulation index (m) has been chosen, harmonic content of line current and load voltage will be minimized by SHEM technique. At the expense of coupled active and reactive power control, and relatively slower transient response, it is advantageous to apply SHEM to VSC topology given in Fig. 2. Since SHEM allows optimized PWM pattern, its implementation is much easy.

In SHEM, switching frequency of power semiconductor, fs is directly related to the number of harmonics to be eliminated, N[16_19], as given below

$$f_s = (2N+1)f_1 \qquad (1)$$

Where f1 is the grid frequency and hence the fundamental frequency.

Modulation index (m) can be defined as in (2) for SPWM or SHEM

$$V_s = m\, V_{dc}/2 \qquad (2)$$

Where Vdc is the mean dc link voltage and Vs is the peak value of the fundamental component of line to neutral STATCOM voltage.

ic waveforms are found by Vc waveform arising from SHEM, by simulating this circuit in MATLAB. This is because in application where STATCOM, is going to be utilized as VAr compensator, or terminal voltage regulator, point of common coupling (PCC) should be taken as common connection of STATCOM. Therefore, THD values of STATCOM line current ans individual magnitude of harmonic components at PCC are of the designer’s direct interest, and should comply with the IEEE std. 519-1992.

NEURO CONTROLLER

Neuro-controllers may originate from various sources. Neural networks may be trained to mimic the control action of existing VSC controllers, thereby distributing the inverter functionality over several neurons. Neuro-controllers are also developed utilizing evolutionary reinforcement learning techniques [19]. Neural networks are beneficial to an adaptive scheme, such as generalization and graceful degradation. Neural network controllers are collections of neurons, with each neuron specifying the weights from the input

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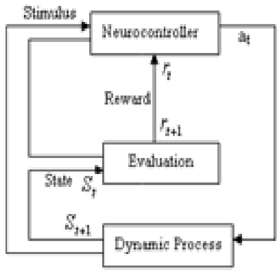
layer (process states) to output layer (control actions). Neuro-controller parameters are the neural network weights.

Block Representation of Neuro-Controller

ANC maintains a population of possible neuro-controller solutions that serve as reinforcement learning evaluations, similar to EVOP experiments [20]. The neuro-controller is evaluated individually over a number of sensor sample periods while interacting with a dynamic process as in Fig. 4.

Initially, the process may be at an arbitrary operating point (state, st). The neuro-controller observes the current process operating point at sample, t, and selects a control action, at. The control action changes the operating point to st+1. A reward, rt, is assigned based on the economic value of this new operating point. The objective is to maximize the total reward over a series of control actions, while maintaining a specified control response.



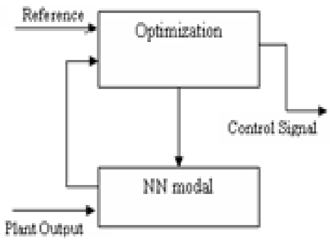


Fig. 4 Proposed Adaptive Neuro Controller

Fig. 5 The Adaptive Neuro Controller

An optimization algorithm adapts the neural network weights based the reward feedback from each evaluations. The above controller can also be represented as shown in Fig. 5 while maintaining the above explained generality. The neural network model and the simulation block of above said ANC is shown in Fig. 6 and Fig. 7 respectively.

The shown network can be trained for a given set of plant parameter data-base. The training will result in optimum set of weights and bias, for a predefined number of neurons, selected for achieving the selected/ or the defined performance and the control criterion.

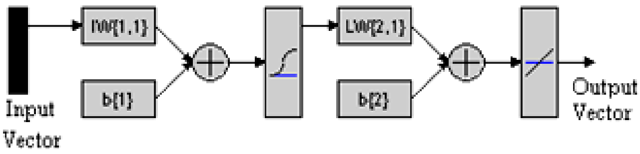


Fig.6 ANC Network Representation

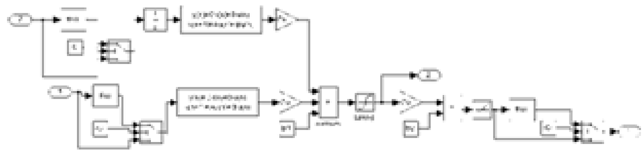


Fig.7 Simulation Block of ANC

VALIDATION & RESULT DISCUSSION

The switching test circuitry used is shown in Fig.2. The analysis is comparative in nature as the other circuitry is nearly the same except that the firing pulses for the VSC are now generated by the adaptive neuro controller which forms the part of the feedback circuit which has its reference from the conventional VSC circuitry (ref. fig.2) and the 3 phase voltage output is fed back to the ANN controller and then the neuro controller generates the firing pulses for the VSC (ref. fig 5).

The comparison is done between the current & voltage outputs at the load and at the PCC. The simulation are carried in MatLab and the waveforms obtained are shown below

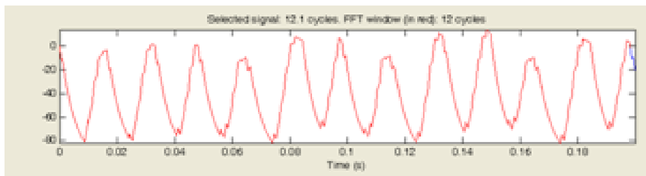


Fig. 8.RMS fundamental load current

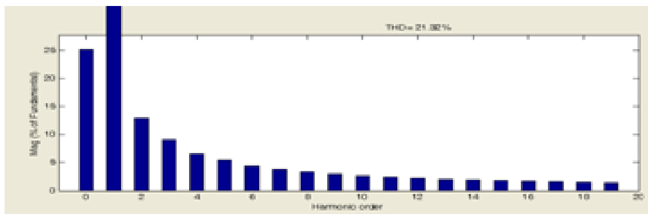


Fig. 9.RMS load current harmonics as a percentage of fundamental components for IL.

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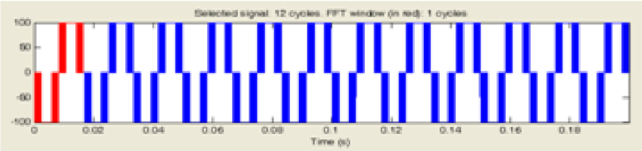

Fig.10.RMS line to neutral STATCOM fundamental voltage

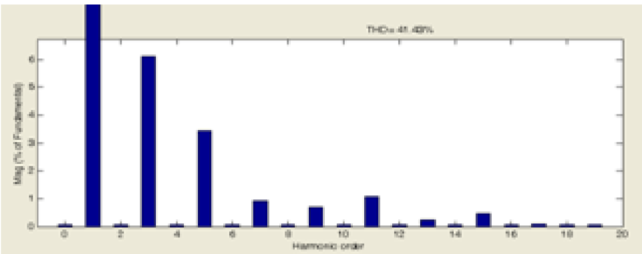

Fig.11RMS VSC voltage harmonics as a percentage of fundamental component of VC

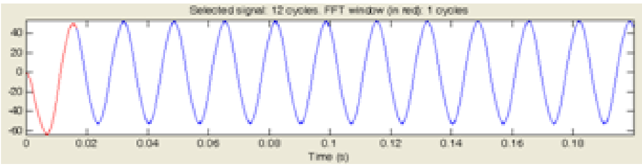

Fig. 12.RMS fundamental load current of ANN based VSC.

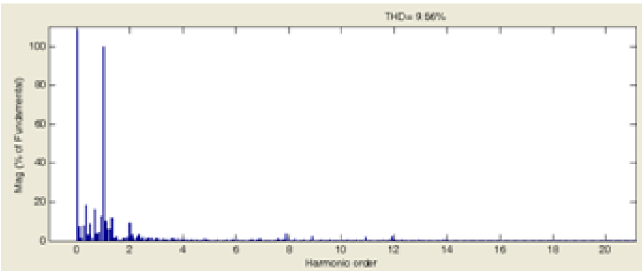

Fig. 13.RMS load current harmonics as a percentage of fundamental components for IL of ANN based VSC.

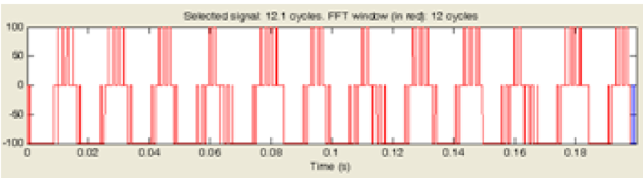

Fig.14.RMS line to neutral STATCOM fundamental voltage of ANN based VSC

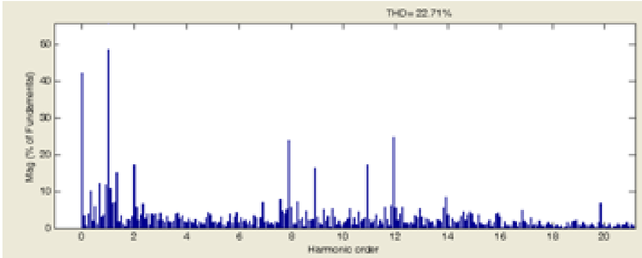

Fig.15RMS VSC voltage harmonics as a percentage of fundamental component of VC of ANN basd VSC

From the simulations carried out it is found that the neural network based VSC performs in a better way. In order to make it clear the results for the odd harmonics current components are given in Table 1

Table 1

Harmonic Distortion in line current of VSC based STATCOM at the Point of Common Coupling

Harmonic Number n	VSC (in %)	ANN Based VSC (in %)	Limits recommended by IEEE Std. 519-1992 (in %)
3	9.09	1.56	7
5	5.41	0.35	7
7	3.83	0.23	7
11	2.44	0.24	3.5
17	1.58	0.08	2.5
19	1.41	0.06	2.5

If individual harmonic magnitude and also there TDD values are compared with the limit values given in IEEE Std. 519-1992,it can be concluded that SHEM technique is very successful in approximating the line current waveform of STATCOM to a pure sine wave. The same can be extended to the voltage waveforms also.

CONCLUSION

This paper gives the presentation of design, implementation, and performance of an ANN based adaptive controller of a VSC based STATCOM. In this, the voltage regulation is done by the optimization of modulation index and VSC harmonics which are eliminated by SHEM technique. The selective harmonic elimination technique is applied to the voltage source converter based static synchronous compensator. This leads to reduction in switching frequency.

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