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Research paper

Power flow controller based on a new proposed statcom controller

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Abstract

One of the major issues involved in power transmission systems are enhancing the capability of transfer and flexible control of active power through the existing transmission line system. To achieve these goals, power electronics devices for reliable operation and faster control are used and utilized to control the flow of power under the flexible ac transmission systems. STATCOM based on voltage source inverter can compensate a controllable voltage over the identical range of capacitive and inductive independently of the line cur-rent. In this paper, a new proposed scheme of STATCOM using Neuro-Fuzzy logic controller is proposed and trained off-line based on Sugeno type fuzzy logic rules. In addition, dq theory is used to calculate the power system parameters due to its less computation and high accuracy. The simulation results show that the proposed controller is reliable and robust compared with the conventional controllers that are investigated previously.

Keywords: *STATCOM; Neuro-Fuzzy Controller; DQ Theory; Pulse Width Modulation; Power Flow Controller.*

1. Introduction

This Parallel capacitive is widely used for compensation in long transmission lines to keep the total impedance of the transmission line. The parallel capacitive compensation increases the power transfers capacity and enhance the transient stability as well. The dielectric capacitors have been installed in all over the world as efficient and economical way of providing compensation. The new technologies like flexible AC transmission system (FACTS) controllers have made as electric utilities to deal with mentioned issues [1]. FACTS controllers can control the parameters of the network such as line impedance, terminal voltage and load angle to improve both dynamic and the steady state performance of the power system [2]. FACTS devices provide variable parallel compensation that is highly effective in both controlling and enhancing stability and power flow through the lines. The parallel compensator based on static synchronous compensator (STATCOM) can provide the virtual compensation to the impedance of transmission line by injecting the controllable voltage (magnitude and phase angle) in parallel with the transmission system [3]. In recent years, new approaches of artificial intelligence have been proposed to design a FACTS-based controller. These new approaches include particle swarm optimization (PSO) [4], genetic algorithm [5], differential evolution [6], and the algorithm of multiobjectives evolutionary [7]. Since 1988, the methodology of artificial neural networks (ANN) has captured the interest in many applications of power engineering. These applications are include power system stabilizers, economical load dispatching, etc. The results of these applications have shown that ANN controllers have great potential for enhancing power system off-line and online applications [8]. The ANN controller based on fuzzy control, i.e., (Neuro-fuzzy controller) is applied for parallel FACTS device, STATCOM. The purpose of this paper is to design STATCOM based on Neuro-fuzzy controller in order to regulate the power flow and voltage regulation in a transmission line.

2. Statcom model and control

The STATCOM injects almost sinusoidal voltage with variable amplitude. The heart of STATCOM is a voltage source inverter (VSI) that is supplied by a DC source. The fundamental configuration of STATCOM is illustrated in Figure 1. Without external DC link, the injected voltage has two parts: the main part is in quadrature with the line current and emulates an inductive or capacitive reactance in parallel with the transmission line, and a small part of the injected voltage is in phase with the line current to cover the losses of the inverter. When the injected voltage is leading the line current, it will emulate a capacitive reactance in parallel with the line, causing the line current as well as power flow through the line to increase. When the injected voltage is lagging the line current, this will emulate an inductive reactance in parallel with the line, causing the line current as well as power flow through the line to decrease.
A STATCOM connects to the power system through a coupling transformer and uses to insert the ac output voltage of the inverter in parallel with the transmission line. The controller can adjust the magnitude and phase of this inserted compensating voltage rapidly. The transmitted active (P) and reactive (Q) powers become a parametric function of the injected voltage. Therefore the transmittable power can increase or decrease by reversing the polarity of the injected ac voltage. The reversed (180° phase-shifted) voltage adds directly to the reactive voltage drop of the line, if the reactive line impedance was increased. Furthermore, if the injected voltage is made larger than the voltage impressed across the uncompensated line by the sending and receiving end systems ($|V_{comp}| > |V_s - V_r|$) then the power flow can reverse. The stable operation of the system with both positive and negative power flow can also be observed. The STATCOM has an excellent (sub-cycle) response time and the

transition from positive to negative power flow through zero voltage injection is perfectly smooth and continuous [9]. A typical power flow control using STATCOM is shown in Figure 2.

3. Measuring active and reactive power

For measuring active and reactive power, dq theory is used. This theory is based on time-domain and is valid for operating in steady state or transient state, as well as for generic voltage and current power system waveforms. Another important characteristic of this theory is the simplicity of the calculations, which involves algebraic calculation exception to the need of separating the mean and alternated values of the calculated power component [10]. The dq theory performs a transformation known as "park transformation" of a stationary reference system of coordinates a-b-c to d-q rotating coordinates [11].The transform applied to time-domain voltages in the natural frame (i.e. va, vb and vc) is as follows:

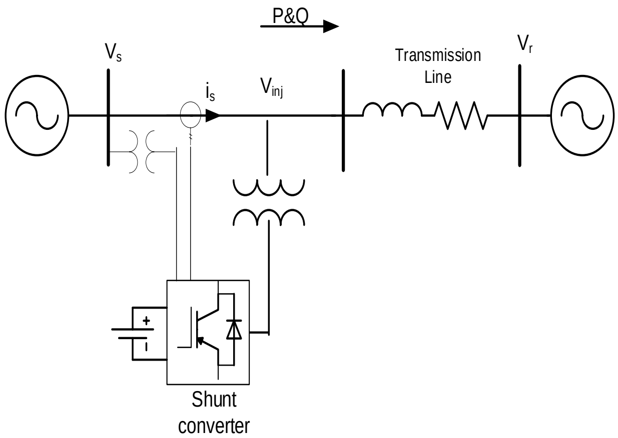

Fig. 1: Fundamental Configuration of STATCOM.

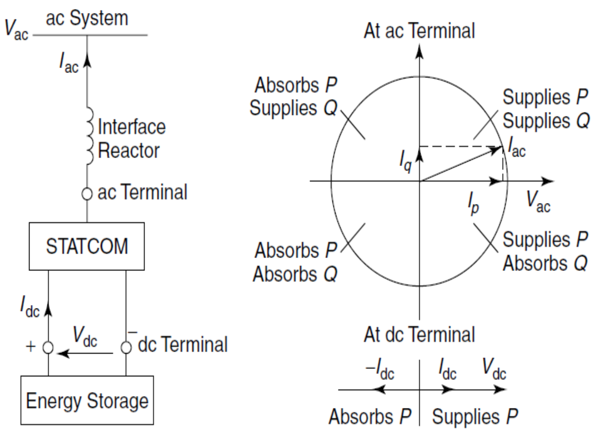

Fig. 2: The Power Exchange between STATCOM and the Ac System.

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(\emptyset) & \cos(\emptyset-\frac{2\pi}{3}) & \cos(\emptyset+\frac{2\pi}{3}) \\ -\sin(\emptyset) & -\sin(\emptyset-\frac{2\pi}{3}) & -\sin(\emptyset+\frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(\emptyset) & \cos(\emptyset-\frac{2\pi}{3}) & \cos(\emptyset+\frac{2\pi}{3}) \\ -\sin(\emptyset) & -\sin(\emptyset-\frac{2\pi}{3}) & -\sin(\emptyset+\frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (2)$$

$$\emptyset = (\omega t + \theta) \quad (3)$$

Where φ is the angle between the rotating and fixed coordinate system at each time and θ represents the phase shift of the voltage. From eq. (1) and (2), the active and reactive power compensated calculated by:

$$p = V_d I_d + V_q I_q \quad (4)$$

$$q = V_d I_q - V_q I_d \quad (5)$$

4. Control scheme of statcom

The block diagram of STATCOM control system is shown in Figure 3. The active (P) and reactive (Q) powers are calculated depending on the line voltages and currents and park transformations. The P and Q work as a feedback for the closed loop control system. The desired active Pref and reactive Qref powers are compared with the P and Q respectively to generate error signals (Erorrp) and (Erorrq) as:

$$Erorr_P = P_{ref} - P \quad (6)$$

$$Erorr_q = Q_{ref} - Q \quad (7)$$

The phase angle of the injected voltage can be adjusted to make the compensation either in capacitive mode or inductive mode by change the sign of the signal.

$$\delta = \emptyset \pm \gamma \quad (8)$$

Where γ can be adjusted in capacitive/inductive mode operations depending on the sign of the $Error_q$ in equation (7).

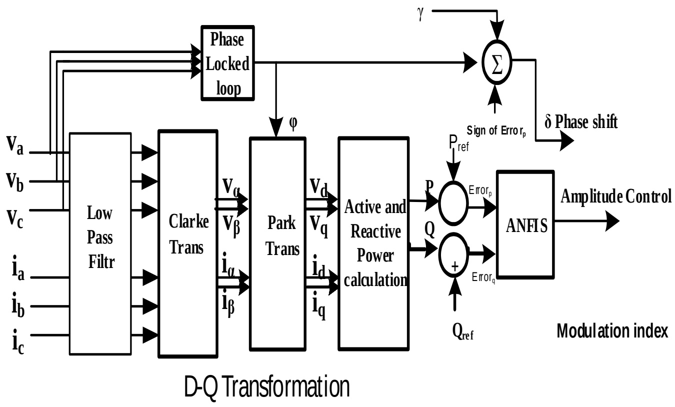

Fig. 3: Block Diagram for Statcom Control System.

5. System control design

Fuzzy systems are suitable for uncertain or approximate reasoning, especially for the system with mathematical model that is difficult to derive. Fuzzy logic controllers play an important role in many practical applications. There are many fuzzy inference mechanisms in fuzzy logic control system and Takagi-Sugeno (TS) is chosen in this study. The artificial neural network (ANN) is used in this study to tune the membership functions of the TS fuzz-like-PI controller. The TS fuzzy controller has a non-linear variable gain controller. It produces wide variations of the controller gain. Arbitrary selection of these parameters may lead to an adequate system response or instability [12]. A better system response may be achieved by using Neuro-Fuzzy system to adapt the fuzzy system parameters and rules by employing ANN learning algorithm. Since it combines the fuzzy qualitative approach with the adaptive learning capabilities of the neural network, such a system can be trained without a great amount of expert knowledge usually required for the standard fuzzy logic [13]. As a result, the rule-base can be reduced. The parameters of the input and output membership functions are to be determined during the training stage. The designed fuzzy system consists of

five layers, each layer has either fixed nodes (no parameters to be tuned) that have parameters to be tuned during training. The output of the five layers which emulate the fuzzy system design steps is given and explained by [14]. The objective of the learning algorithm is to adjust the parameters of the input and output membership functions so that the Neuro-Fuzzy output matching the training data better than other types. A hybrid learning strategy (Gradient Descent-GD and Lease Squares Estimate-LSE) is applied to identify the network parameters. The GD method updates the antecedent membership function parameters. In this work the input universe of discourse is split into 5 trapezoidal membership functions with 50% overlapping. Therefore, for two inputs, 25-control rule consequent linear functions need to be determined as shown in Figure 4. To tune the TS rules using Neuro-Fuzzy, two sets of data are to be generated. The input data is a vector of the Errorp, Errorq and the output (m), which is the modulation index. Figure 5 shows the validation test of Fuzzy logic system.
The output surface of STATCOM-control designed is shown in Figure 6. This procedure is performed using the GUI of Neuro-Fuzzy file included in the MATLAB/FUZZY Logic Toolbox. The proposed controller has small computation time compared to classical fuzzy controller's mamdani type. The selected system consists of single machine infinite bus bar.

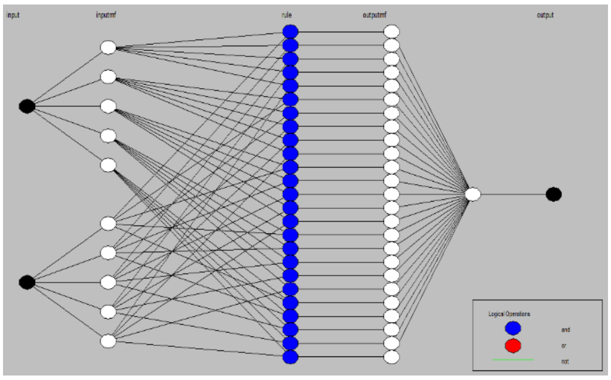

Fig. 4: Fuzzy Control Scheme.

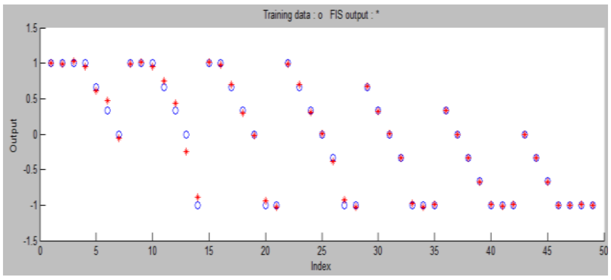

Fig. 5: Fuzzy Logic Validation Tests.

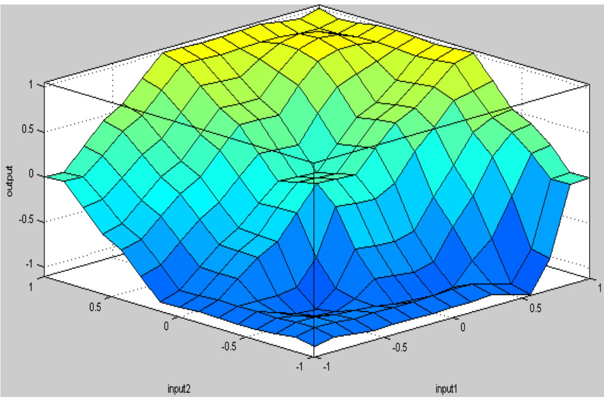

Fig. 6: Control Surface of STATCOM-Based Neuro-Fuzzy Controller.

6. Simulation study

The designed power system with STATCOM controller is modeled using MATLAB/Simulink. The system shown in Figure 7 is simulated to investigate the performance of the proposed intelligent controller under the step change of the load condition. The system consists of two generating machines along with transmission line and load. The compensator is provided with a DC voltage source, which helps in feeding or absorbing the active and reactive power from the system. The characteristic of the storage battery model shown in Figure 8. The results illustrate the capability of the STATCOM to compensate the reactive power flow and then controlled the line current. A conventional PI controller is used for the sake of comparison. In this work, the STATCOM is simulated as controlled voltage source. The response to step changes in the system reference signals is used to test the controller performance. Figure 9 shows the injected compensated voltage with two-step values of injected voltage in capacitive mode (the injected voltage lag the line current). This will change in the line current above the reference values and the active power. Figure 10 shows the system response to a step change in the line current in capacitive mode (forward mode). The reverse direction was done by injection voltage as inductive mode (the injected voltage lead the line current). The results clarify that the designed fuzzy logic controller has a smoother, fast response and less oscillation than the conventional PI controller does. The simulation results illustrated the effectiveness of the Neuro-Fuzzy controller in optimizing the STATCOM performance. In addition, the results prove that the proposed controller can improve the voltage profile and transient stability of the test system more efficient than the conventional PI controller.

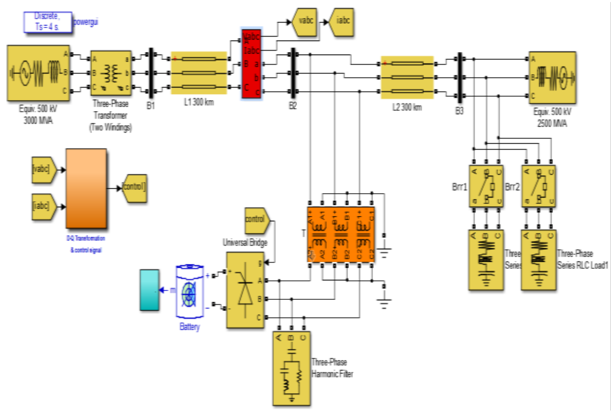

Fig. 7: System Model for Simulation.

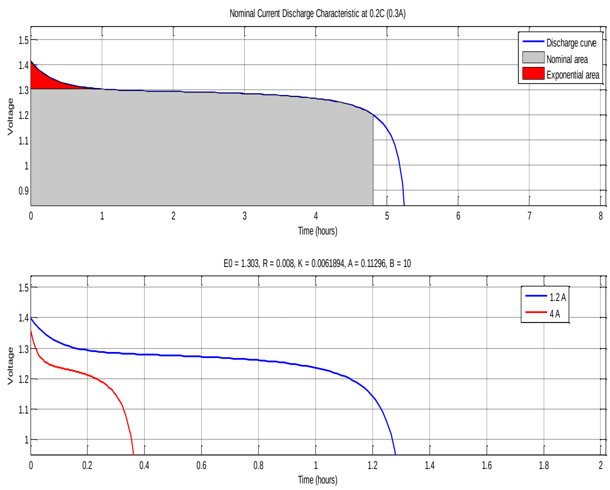

Fig. 8: The Characteristic of the Storage Battery Model.

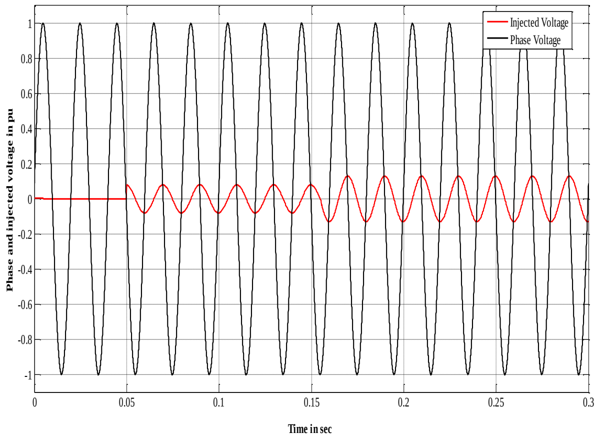

Fig. 9: The Line Voltage versus Injected Compensated Voltage.

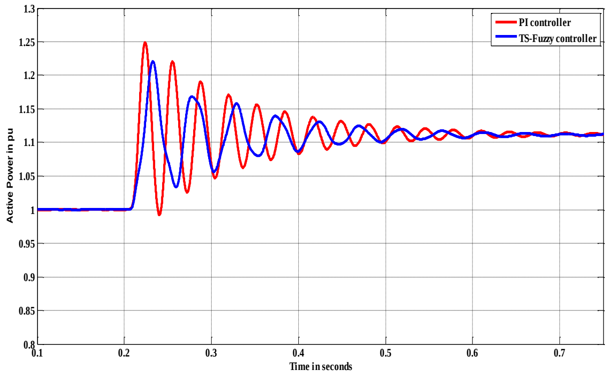

Fig. 10: The Step Change Response for Two Types of Controlle.

7. Conclusion

In this paper, Neuro-Fuzzy controller algorithm is used to control the STATCOM. The tuning algorithm is performed off-line to employ the concept of Neuro-Fuzzy System. The rules defined by training the change of error for real and reactive powers to initiate the tuning process. By using Takagi-Sugeno fuzzy logic system, the small computation time of the controller has obtained and this is the potential of implementation in real time. The proposed controller has been applied successfully to control the reactive power and the line current flow in the transmission system. The simulation results show that the proposed controller can provide an adequate performance for the STATCOM operation.

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