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DSTATCOM modelling for voltage stability with fuzzy logic PI current controller

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ABSTRACT

In recent years, applications of inverter based power quality conditioners have been growing for reactive power compensation in distribution systems due to their faster response times as compared to the conventional compensators. Distribution Static Synchronous Compensator (D-STATCOM) is an inverter based power quality conditioner device used to improve the power quality issues in distribution systems. Control of D-STATCOM is usually realized by Proportional-Integral (PI) controllers with fixed parameters. However, the overall control performance may be unsatisfactory due to its nonlinear structure. In this paper, Fuzzy-PI controller which has a nonlinear and robust structure is proposed for control of D-STATCOM's direct and quadrature axes currents. The article presents the fuzzy logic control of the D-STATCOM which tries to improve the damping of a power system. Simulation of Fuzzy-PI current controlled D-STATCOM is performed by MATLAB/Simulink software. In simulation study, the dynamic response of D-STATCOM is observed by changing the reference reactive current. A comparison of the simulation results between the proposed technique and the conventional PI controller has been presented.

Introduction

Fixed or switched reactor/capacitor banks and Static VAR Compensators (SVC) have been widely used for reactive power compensation. These types of conventional equipment have some disadvantages such as limited bandwidth, large size, more losses, and slow response times. Today, inverter based power quality conditioners have been proposed for improving power quality in distribution systems because of their fast response, small size and low losses.

Distribution Static Synchronous Compensator (D-STATCOM) is an inverter based power quality conditioner connected in shunt with ac system. It is used for power factor correction, load balancing, voltage regulation and harmonic filtering in distribution systems [2]. D-STATCOM is a power electronic based synchronous voltage source that generates a three-phase voltage from a dc capacitor. By controlling the magnitude of the voltage at D-STATCOM, reactive power exchange between the device and the transmission system can be controlled.

Use of D-STATCOM controller for reactive support of induction generators have also been reported recently. The reactive power is controlled by the ac inductors, dc bus capacitor and solid state commutating devices in the D-STATCOM. In addition to proper control of reactive power exchange, D-STATCOM's can also provide damping support to a power system. In the control system of D-STATCOM, reference values for "*d* and *q*"-axes currents are usually obtained from Proportional-Integral (PI) controllers designed with linear control methods. In the design of PI controllers, linear mathematical model of controlled system is required [1,2,4].

Parameters of these controllers are tuned to obtain the best performance for a particular region of operation and conditions. However the task is difficult and often fails to perform satisfactorily under parameter variation, load disturbance, and nonlinear dynamics of the plant [7].

Most of the control designs are carried out with linearized models. Nonlinear control strategies for D-STATCOM have also been reported recently-STATCOM controls for stabilization have been attempted through complex Lyapunov procedures for simple power system models. Recently, intelligent controllers like Fuzzy Logic Controllers (FLC) and Artificial Neural Network (ANN) as alternative linear and nonlinear control techniques have been used in the control of D-STATCOM. Applications of fuzzy logic and neural network based controls have also been reported [1,8].

The mathematical model of system to be controlled is not needed for these controllers. Moreover, they can provide efficient control over a wide range of system operating conditions, which distinguishes them from conventional linear controllers. Effectiveness of the fuzzy strategies in damping power system oscillations often depends on the choice of inputs to the controller.

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In this paper, Fuzzy-PI controller which is a robust controller is proposed for D-STATCOM's *d* and *q*-axes currents control. Models of power system, D-STATCOM, and controller unit are developed in MATLAB/Simulink environment. Two Fuzzy-PI are used for the control of *d* and *q*-axes currents separately. Inputs of Fuzzy-PI controllers are chosen as error values of *d* and *q*-axes currents and the change in these errors. Steady state error is eliminated by using the external integrator in outputs of Fuzzy-PI controllers. Compared results of simulation with Fuzzy-PI controller and the linear PI with fixed parameters are given for the variations in reference reactive current.

Basic operational principle and mathematical modelling of D-STATCOM

A single machine infinite bus system with a D-STATCOM installed at the mid-point of the transmission line is shown in Fig. 1. The D-STATCOM consists of a step down transformer, a three phase Gate Turn Off (GTO)-based voltage source converter, and a DC capacitor. The D-STATCOM is modelled as a voltage Sourced Converter (VSC) behind a step down transformer. Depending on the magnitude the VSC voltage, the D-STATCOM current can be made to lead or lag the bus voltage. Generally, the D-STATCOM voltage is in phase with the bus voltage. Some active power control may be possible through limited variations in the voltage phase angle. This would necessitate a power source behind the capacitor voltage.

In Fig. 1, R_{DC} and R_{SDT} represent switching losses in inverter and winding resistance of coupling inductance respectively.

D-STATCOM is assumed to be connected at the middle of the line connecting the generator to the network. The network equations excluding the generators and the D-STATCOM are expressed through the relationships,

$$I_{BUS} = Y_{BUS} \times V_{BUS} \tag{1}$$

where

I_{BUS} is the injected current.
V_{BUS} is the node voltages of the Power System.
Y_{BUS} is the Admittance matrix of the Power System.

The D-STATCOM capacitor voltage equation is,

$$\frac{dV_{DC}}{dt} = \frac{I_{DC}}{C_{DC}} = \frac{m}{C_{DC}}(I_{LOd}\,\mathrm{Cos}\psi + I_{LOq}\,\mathrm{Sin}\psi) \tag{2}$$

where

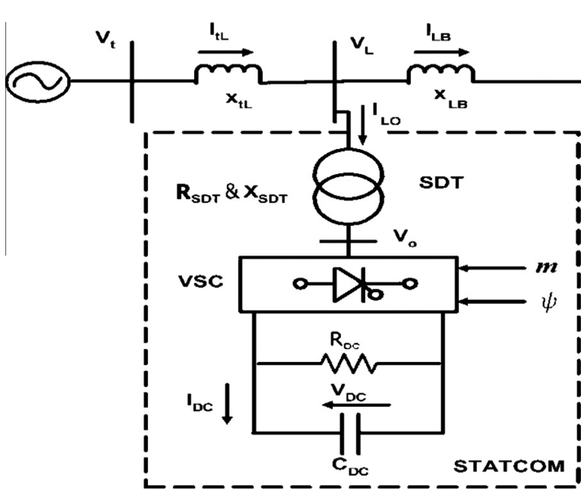

Fig. 1. A single machine system with D-STATCOM [8].

V_{DC} is DC voltage for inverter.
I_{DC} is current of inverter.
I_{LOd} & I_{LOq} are reference values for "*d* and *q*"-axes currents.
C_{DC} is storage capacitor.
m is pulse width modulation index.
ψ is phase angle of the shunt inverter voltage.

Schematic representation of D-STATCOM is shown in Fig. 2. Complete block diagram of D-STATCOM's control algorithm is presented in Fig. 3. D-STATCOM consists of inverter, dc-link capacitance (*C*) supplying the dc voltage for inverter, coupling inductance (L_{SDT}) to exchange reactive power and filter out the current harmonics as well as a control unit to generate Pulse Wave Modulated (PWM) signals for the switches of inverter.

Fuzzy logic control

The Fuzzy Logic Control (FLC) system, shown in Fig. 4, contains four main components – the Knowledge Base (KB), the Fuzzification Interface (FI), the Decision Logic (DL), and the Defuzzification Interface (DI) [9–14]. The KB contains knowledge about all the input and output fuzzy partitions. It includes the term set and the corresponding membership functions defining the input variables to the fuzzy 'Rule-Base' (RB) system and the output or decision variables to the plant.

The crisp stabilizing input signals are converted to fuzzy linguistic variables in the fuzzifier. These are then composed with the fuzzy decision variables. The decision-making logic generates the fuzzified control through various composition rules [15–20]. The fuzzy control is then defuzzified and is used to fire the thyristors in the STATCOM. The following steps are involved in designing the fuzzy STATCOM controller [4,5].

In Fuzzification part, crisp values of input are converted into fuzzy values, so that these values are compatible with the fuzzy set representation in the rule base. The choice of Fuzzification method is dependent on the interference engine. The knowledge base consists of a database of the plant. It provides all the necessary definitions for the Fuzzification process. Rule base is essentially the control method of the system. It is usually obtained from expert knowledge or heuristic as a set of IF-THEN rules. The rules are based on the fuzzy inference. Inference called fuzzy model applies fuzzy reason to rule base to obtain a proper output. Mamadani and Takagi–Sugeno [1] fuzzy systems are the most commonly used fuzzy inference mechanisms. Mamadani is suitable for the systems with slow-changing dynamics while Takagi–Sugeno is suitable for the systems with fast changing dynamics. Results obtained from fuzzy process are converted into crisp values by using any Defuzzification method such as maxima methods and center of area.

Fuzzy-PI controller design for D-STATCOM

Linear PI controller is well established in classical control systems and it is often used as a benchmark against the other types of controllers. This controller is linear, thus unsuitable for strongly nonlinear systems. Fuzzy Logic Controller (FLC) is an alternative to classical PI controllers in such cases. FLC has been widely used in systems with complex structure because it doesn't need mathematical model of controlled system [21–27].

The structure of the Fuzzy-PI controller used in simulation study is shown in Fig. 5. It has two inputs and one output. Inputs of controller are errors of *d* and *q*-axes currents and derivatives of these errors. In addition, an external integrator is used to eliminate the steady state error in the output of FLC.