Control of DSTATCOM using Fuzzy Logic Controller

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Abstract **- Effort for improvement of power quality in distribution systems has been gradually increased. Traditionally, fixed, mechanical switched reactor/capacitor banks and Static Var Compensator have been used for improving the power quality issue in distribution systems. In recent years, applications of inverter based power quality conditioner have been growing for reactive power compensation in distribution systems, since their response is faster than that of the conventional compensators. Distribution STATCOM (DSTATCOM) is an inverter based power quality conditioner device used to improve the power quality issues in distribution systems. This paper describes the control and the simulation of a two level distribution static synchronous compensator (DSTATCOM), with the aim of improving the quality of electric network; we were also required to develop and implement a method of control by a fuzzy logic controller. Switching pulses for the two-level inverter are generated by Space Vector Modulation (SVM). Simulation results are provided to illustrate the performance of our controller. Validation of models and control algorithms is carried out through simulations in SimPowerSystems of MATLAB/Simulink.**

Index Terms - DSTATCOM; Fuzzy logic controller; Space Vector Modulation (SVM).

I. Introduction

The FACTS (Flexible AC Transmission Systems) technology [1] is a new research area in power engineering. It introduces the modem power electronic technology into traditional ac power systems and significantly enhances power system controllability and transfer limit. In this paper, the static synchronous compensator (DSTATCOM) [2-3] and fuzzy logic control will be used to improve power system dynamic behavior after a system disturbance; DSTATCOM is based on a voltage-source inverter. The inverter under proper control can manage the capacitor, i. e. the dc voltage source, to be charged (or discharged) to the required voltage level. In this way, or by SVM controller, the amplitude of the output voltage of the inverter can be controlled for the purpose of reactive power generation or absorption. The control strategy is very important to the operation of DSTATCOM in order to yield desired steady state performance and improve the integrated system dynamic behavior.

Now a day there has been growing interest in applying fuzzy theory [4] to controller design in many engineering fields. The fuzzy controller has very attractive features over conventional controllers. It is easy to be implemented in a large scale nonlinear dynamic system and not so sensitive to the system models, parameters and operation conditions. In particular human knowledge can be included in control rules with ease. Therefore investigation of fuzzy theory application in power system control grows rapidly [5].

In this paper, fuzzy logic controller is proposed for the control of DSTATCOM, with the aim of improving the quality of electric power, and corrects the power factor. Power circuit of DSTATCOM is constructed by two-level NPC inverter. Gate pulses for this inverter are generated with space vector modulation (SVM) technique. The aim of the paper is shows to implement DSTATCOM with control strategies in the MATLAB, simulink using Simpower systems tool box and to verify the results through various case studies applying different loads and study them in detail.

II. Distribution Static Compensator (DSTATCOM)

A DSTATCOM (Distribution Static Compensator), which is schematically depicted in Fig.1, consists of a DC capacitor, a Voltage Source Converter (VSC), and coupling inductance. It converts the DC into three-phase AC and is connected to the distribution line through leakage inductance of a coupling transformer. Fig.1 shows the basic structure of a DSTATCOM, if the output voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the DSTATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages. By controlling the magnitude of VSC output voltage, reactive power is compensated and the voltage is regulated at the point of common coupling (PCC).

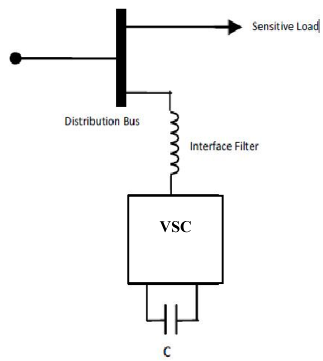


Fig. 1. Basic structure of DSTATCOM

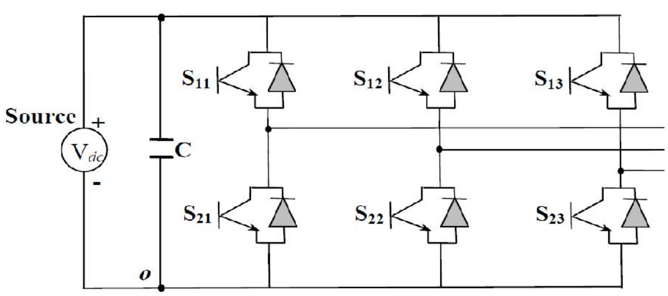


Fig. 2. Structure of the two-level inverter.

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation and compensation of reactive power.
2. Correction of power factor.
3. Elimination of current harmonics.

III. Two Level Inverter description

The two-level three phase inverter circuit shown in Fig. 2 consists of three similar legs, one for every ac-phase. There are two IGBTs per leg which are always in an opposite switching position (state "1" for upper switch on and state "0" for the lower switch on.) Under these conditions for every leg, there are 2^3=8 possible switching states: PPP, PPN, PNN, PNP, NNN, NNP, NPP et NPN. They are identified by indicating the states of the three legs of the inverter (state P or state N). Table 1 shows the switching states of each phase of the inverter.

TABLE I
States of Three Level Inverter

STATE	Leg1		Leg2		Leg3		Output voltages		
	F_{11}	F_{12}	F_{21}	F_{22}	F_{31}	F_{32}	v_1	v_2	v_3
P	1	0	1	0	1	0	v_{dc}	v_{dc}	v_{dc}
N	0	1	0	1	0	1	0	0	0

IV. Space Vector Modulation (SVM) For Two Level Inverter

In this paper, switching pulses for the inverter of DSTATCOM are generated by Space Vector Modulation (SVM) technique. SVM method is an advanced computation intensive PWM technique and the literature says that it is the best among all PWM techniques for digital implementation in variable frequency drive application [6].

The SVM strategy proposed in this paper, it consists of the generation of a specific sequence of states of the inverter. The reference voltage vector is defined as:

$$V^* = v_a^* e^{j0} + v_b^* e^{-j2\pi/3} + v_c^* e^{j2\pi/3} = v_d^* + j\, v_q^* \quad (1)$$

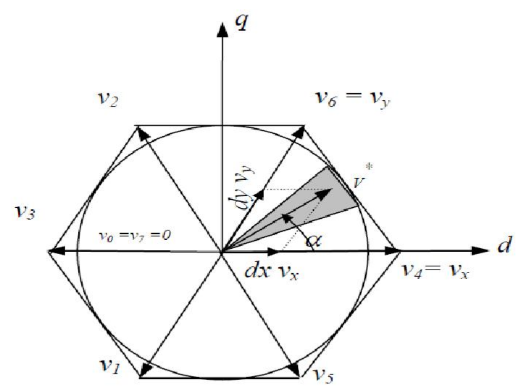


Fig. 3. Space vector diagram of two level inverter.

V^*_d and v^*_q are the components of the vector v^* in the plan d-q. This vector takes eight discrete positions in *dq* plane according to the status of the inverter (PNN, PPN, NPN,NPP, NNP, PNP,PPP et NNN). The positions of the vector v^* in the dq plane are shown in the vector diagram of Fig.3. Vectors v1-v6 divide the d-q plane into six sectors of 60° long. In turn, each sector is divided into N equal switching intervals.

A. Determination of region and sector

From the angle θ, we deduce in what area (*s*) is the vector v^* situ in the *dq* plane. The triangular area is derived as follows:

$$S = \begin{cases} 1 & if \quad 0 \le \theta < \pi/3 \\ 2 & if \quad \pi/3 \le \theta < 2\pi/3 \\ 3 & if \quad 2\pi/3 \le \theta < 3\pi/3 \\ 4 & if \quad 3\pi/3 \le \theta < 4\pi/3 \\ 5 & if \quad 4\pi/3 \le \theta < 5\pi/3 \\ 6 & if \quad 5\pi/3 \le \theta < 2\pi \end{cases} \quad (2)$$

B. Calculating the switching times T_x, T_y, T_z

The switching times T_x, T_y, T_z for any sector are calculated as:

$$T_x = T_s.m.\sin(\pi/3-\alpha)$$
$$T_y = T_s.m.\sin(\alpha)$$
$$T_z = T_s - T_x - T_y$$
(3)

The equation (3) applies to all sectors comprising the vector diagram.

C. Finding the switching states

For generating output voltages v_1, v_2 and v_3 as close as possible to reference voltages v^*_1, v^*_2 and v^*_3, during each sampling period T_s, the state X is applied during a time T_x, the state Y during a time T_y and the state Z for the remainder of the period T_z.

Switching sequence can be arranged according to certain optimal objective, for example, minimum switching loss or minimum total harmonic distortion (THD) [7]. In this paper, in order to achieve low THD and to reduce harmonics of the output Voltage, the following sequence applies during each sampling period:

Z2XYZ1/Z1YXZ2 if s=1,3 or 5
Z2YXZ1/Z1XYZ2 if s=2,4 or 6

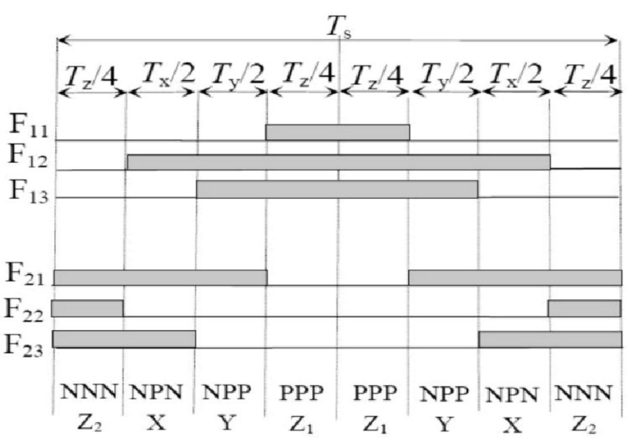


Fig. 4. Switching signals of Sector 3

V. DSTATCOM CONTROL

A DSTATCOM is schematically depicted in Fig. 5. The VSC converts the voltage across the capacitor into a set of three-phase voltages. These voltages are in phase with the AC system and coupled with AC distribution system through the reactance of the coupling transformer. The DSTATCOM generates reactive power when system voltage is lower than its output voltage, and it said to be in capacitive mode. The DSTATCOM absorbs reactive power when system voltage is greater than its output voltage, and is said to be in the inductive mode. Insufficient reactive power in the system affects the bus voltage, which affect the sensitive loads connected to the bus.

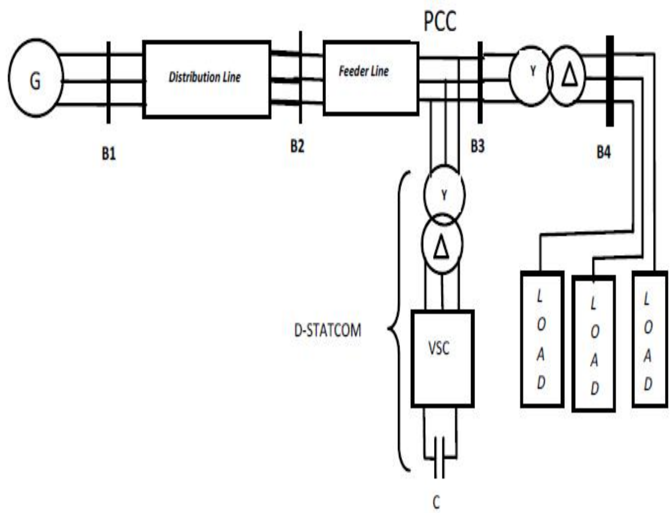


Fig. 5. Schematic of a DSTATCOM

A. Regulator

In the control circuit we can find two regulators,

1. Current regulators.
2. DC voltage regulator.

DC voltage regulator sets direct axis reference current. And current regulator will form the input for SVM. These regulators will be normally PI controller, PID controller or any artificial intelligence control technique like fuzzy controller, neuro-fuzzy etc. DC link voltage is kept constant by controlling the active power flowing to/from the converter. DC link voltage is compared with the DC link voltage reference and DC link voltage error is processed in DC voltage regulator. Therefore DC voltage regulator determines the phase angle of the converter voltage with respect to source voltage.

B. Fuzzy Logic Controller (FLC)

The main disadvantage of conventional PI controller is its inability to react to abrupt changes in the error signal, ε, because it is inefficient during nonlinear variations. Fuzzy logic controller is much efficient in dealing with nonlinearities. The determination of the output control signal is done in an inference engine with a rule base having if-then rules. With the rule base, the value of the output is changed according to the value of the error signal ε, and the rate-of-error $\Delta\varepsilon$. The structure and determination of the rule base is done using trial-and-error methods and is also done through experimentation .

Δe/e	NB	NM	NS	ZR	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZR
NM	NB	NB	NB	NM	NS	ZR	PS
NS	NB	NB	NM	NS	ZR	PS	PM
ZR	NB	NM	NS	ZR	PS	PM	PB
PS	NM	NS	ZR	PS	PM	PB	PB
PM	NS	ZR	PS	PM	PB	PB	PB
PB	ZR	PS	PM	PB	PB	PB	PB

The fuzzy controller of figure (6) is introduced like a system at two entries and an exit. The variables used as entered are the error and the variation of the error:

$$\begin{cases} e_k = Y_{réf} - Y_k \\ \Delta e_k = e_k - e_{k-1} \end{cases} \quad (4)$$

In general one introduces for each variable three, five or seven sets, represented by functions of memberships. In our case we considered the case of seven sets represented by functions of memberships in triangular form. The sizes are standardized in a universe of speech in seven classes (NB, NM, NS, ZR, PS, PM, PB).

NB: Negative big. NM: Negative Medium.
NS: Negative small. ZR: Zero. PS: positive small. PM: Positive medium. PB: Positive big.

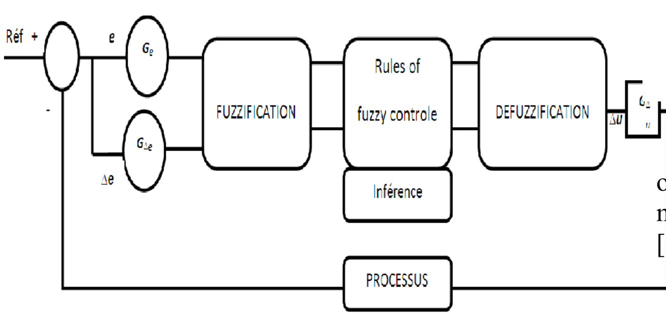


Fig. 6. Structure interns of a regulator by fuzzy logic

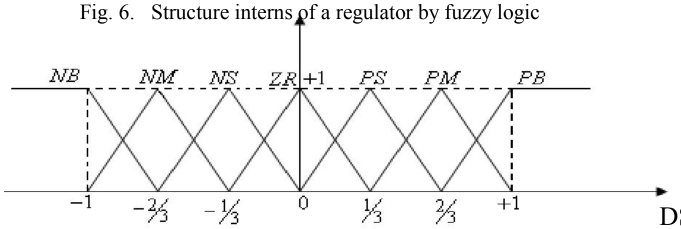


Fig. 7. Distribution of the functions of membership according to the triangular form

The sizes are standardized in a universe of speech in seven classes (NB, NM, NS, ZR, PS, PM, PB). The number of the sets depends on the resolution and the intervention of the desired adjustment. A finer subdivision, i.e. more than seven sets, in general does not make any improvement of the dynamic behavior of the adjustment by fuzzy logic. On the other hand, such a choice would complicate the formulation of the rules of inference and increases the processing time. This subdivision is organized in the shape of a decision table, inspired by the behavior of a response of a system in the linguistic plan of phase. The fuzzy control rule is illustrated in the table II.

TABLE II
Fuzzy controller rule base

- *Law of Order*

The adopted law is a function of the error and its variation ($U = f\ (e,\ \Delta e)$). In the simple cases, this variation of order is obtained by reading of a decision table defined off line. The general form of this law of command is given by:

$$U_{k+1} = U_k + G_{k+1} * \Delta U_{k+1} \quad (5)$$

Where G_{k+1} is the profit associated with the order U_{k+1} generally selected weak to ensure the stability of the system. ΔU_{k+1} Is the exit of the fuzzy regulator which represents the variation of the command *U.*

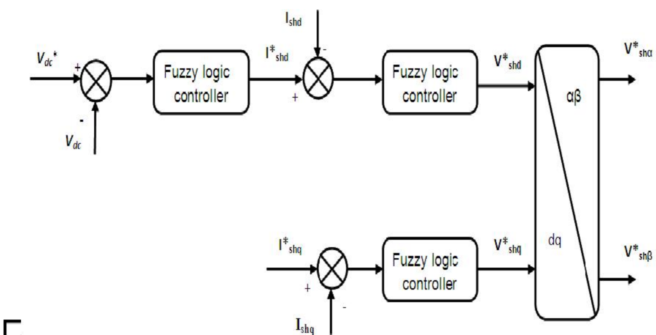


Fig. 8. Control unit of DSTATCOM

The method of the most used defuzzification is that of the determination of the centre of gravity during the method the balanced heights. It is defined as follows: [8]

$$X_R^* = \Delta U = \sum_{i=1}^{m} \frac{\mu_{CEi} X^* Ei}{\mu_{CEi}} \quad (6)$$

VI. Simulation Results

In this study, the model of power system, DSTATCOM and controller are developed in MATLAB/Simulink environment and shown in Figure 9. Fuzzy logic was used for controlling DSTATCOM. The performance of DSTATCOM is studied in a power system. The distribution part of the power system is represented by a Thevenin's equivalent voltage source and short circuit impedance.

Initially the DC bus capacitor is charged and the voltage across the latter is 5 kv. At the beginning of the simulation, the grid supplies the load (L1). The second charge (L2) is connected to the grid at time (t = 0.25s), and at time (t = 0.5s) line is loaded by load (L3), and finally at time (t = 0.75s) both load (L1) and (L2) is Logged Out.

The simulation diagram, shown in Fig. 9, is used to simulate the DSTATCOM operation for different loads. All the relevant outputs are shown in Fig. 10 to Fig. 13. The capacitor voltage is maintained at *5 kV* as shown in Fig. 10. Fig. 11 shows the dynamics of active and reactive current exchanged between the DSTATCOM and network. The significance of the Fig. 12 is the improvement of power factor with DSTATCOM. The reactive power injected by DSTATCOM as shown in Fig. 13.

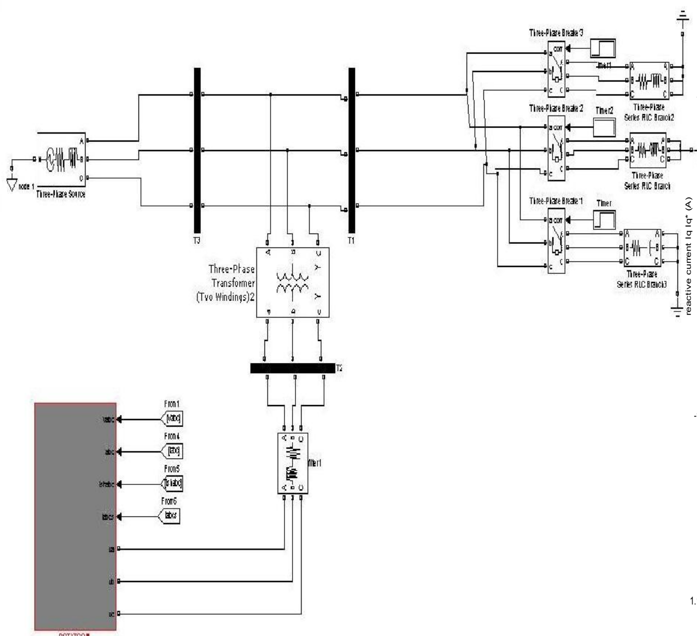


Fig. 9. DSTATCOM simulation in MATLAB

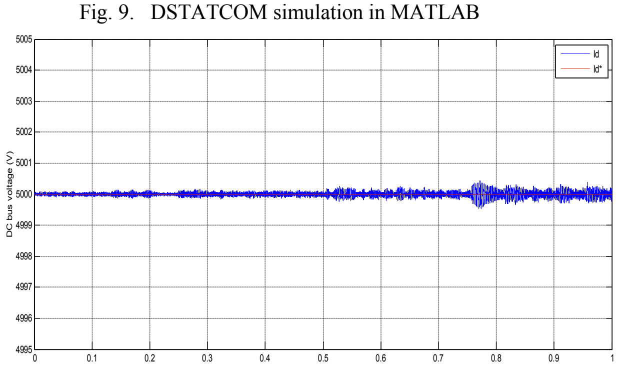
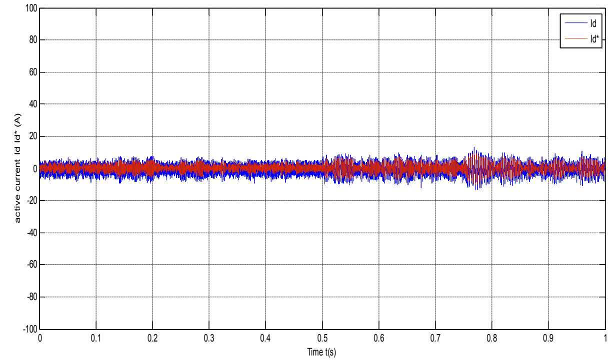
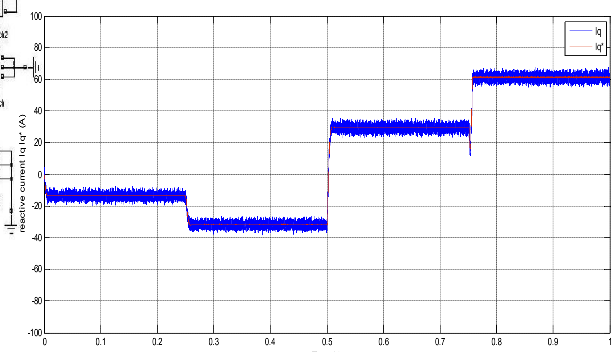


Fig. 10. Variation of DC bus voltage



(a)



(b)

Fig. 11. The injected current by the DSTATCOM (a) active current and (b) reactive current.

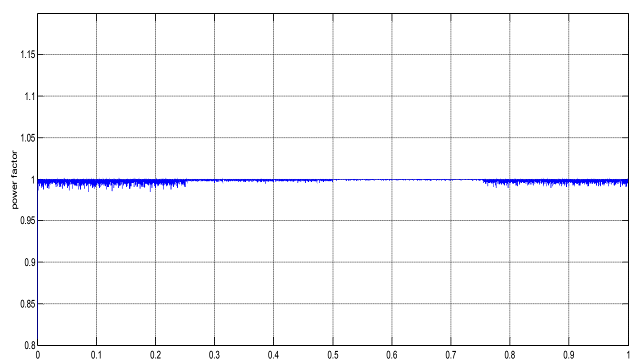


Fig. 12. Power factor

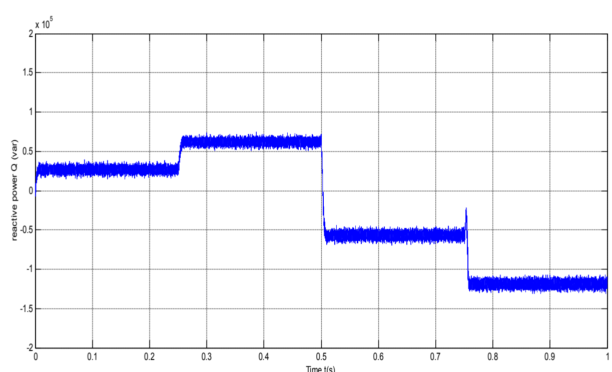


Fig. 13. Reactive power injected by the DSTATCOM

VII. Conclusion

In this paper, theoretical study with simulation of fuzzy logic controllers for a DSTATCOM based two-level inverter in order to improve the power quality is studied. The SVM method is used to generate the switching signals for the two level inverter. The fuzzy controller is different from conventional controller as it attempts to implement the operator's knowledge rather than mathematical equations of plant. The control engineer can design the fuzzy rule base for fuzzy controller and as well as fuzzy rule base for gain updating factor according to their knowledge. The proposed fuzzy based controller is proven to improve the performance of conventional controller. Matlab based simulation results have verified the effectiveness of the design methodology. It significantly enhances the power system stability. It is clear from the simulation results that to add a fuzzy controller for DSTATCOM is potential alternative to conventional controller.

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