

FUZZY LOGIC CONTROL OF FIVE LEVEL DSTATCOM

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Abstract: *In this paper, the distribution static synchronous compensator (DSTATCOM) is used for compensation of the reactive power concerned in an electrical distribution network. DSTATCOM is based on a five level Voltage Source Inverter (VSI) and is controlled to compensate reactive power and correcting power factor. Fuzzy logic controller known by its speed and its simplicity of implementation carried out the control of this device. The performance of the DSTATCOM using the proposed control strategy is demonstrated using simulation results in MATLAB/SIMULINK software. Simulation results demonstrate the feasibility of proposed scheme for the control of DSTATCOM.*

Key words: *DSTATCOM, multilevel SVM, reactive power compensation, fuzzy logic controller.*

1. Introduction

More than 60% of the total electrical energy is consumed by electric motors, primarily by induction motors [1]. Due to requirement of reactive power by induction motors, there is an increase in the size of utility and transmission and distribution losses. Furthermore, the custom voltage becomes unstable. Moreover, the operation of transformers and generators are also affected due to unbalancing of currents [2]. Therefore, reactive power compensation of non-linear and/or poor power factor loads and load balancing is an important issue in the modern power distribution system.

Distribution Static synchronous compensator (DSTATCOM) based on voltage source converter

(VSC) technology, which is one of custom power devices, has used to correct power factor, regulate voltage and compensate the reactive power at the Point of Common Coupling (PCC) [3]. The DSTATCOM has good operating performance under unbalanced voltage of distribution networks [4, 5]. The achievements of their work are useful for the future in-depth studies.

The performance of the DSTATCOM is greatly dependent on its control strategy. Several investigations have carried out on the control strategies of DSTATCOM. In [6], the sliding mode control strategy has used to make the controller of DSTATCOM robust. In addition, most of the conventional control schemes of DSTATCOM have several PI controllers. However, parameters adjustment of PI controllers is a complex task for the nonlinear system.

In order to enhance the performance of DSTATCOM controller, computational intelligence (CI) techniques can be used. There are many attempts of using CI techniques in DSTATCOM control. In [7] artificial neural networks (ANNs) are used. The control strategies mentioned above not only are adaptive to the system dynamics, but also can enhance the performance of controller in case of unexpected drastic system disturbances.

To create flexibility and a strategy that takes into account uncertainties, a solely fuzzy logic control scheme is desirable. Unlike most of the conventional and modern controllers, fuzzy logic controllers are capable of tolerating uncertainty and imprecision largely. Hence, they produce good results under

changing operating conditions and uncertainties imprecision in system parameters. Fuzzy control is becoming a powerful control tool in the power industry with application to series-connected FACTS devices, wind–diesel power systems and photovoltaic power systems [8-10].

Fuzzy logic approach is proposed in this paper for designing nonlinear DSTATCOM controller. The proposed controller design is separated into the inner loop and the outer loop controller. In the inner loop, fuzzy logic control is using to calculate the reference voltage necessary for the SVM block. The DC-side voltage is regulated via the outer loop controller cascaded to the inner loop controller. Simulation results are presented to show efficacy of the resulting fuzzy logic controller with regard to reactive power compensation.

2. DSTATCOM description

2.1. System topology

The schematic showing the fundamental building blocks of the power system shown in Fig. 1. The system consists of a three phase star connected ac voltage source (v_s), having line impedance (R_s, L_s) and feeding a variable consumer load. The load in the system can be inductive or capacitive.

DSTATCOM is shunt connected and uses a three phase insulated gate bipolar transistor (IGBT) based five-level voltage source inverter (VSI) bridge circuit. DSTATCOM uses input filter (R_f, L_f) and a DC bus contain four equals capacitors ($C_1=C_2=C_3=C_4=C$) to provide self-supporting DC bus. The changing reactive power requirements of the load are fulfilled by the DSTATCOM.

In this work, DSTATCOM has been used for power factor correction and reactive power compensation.

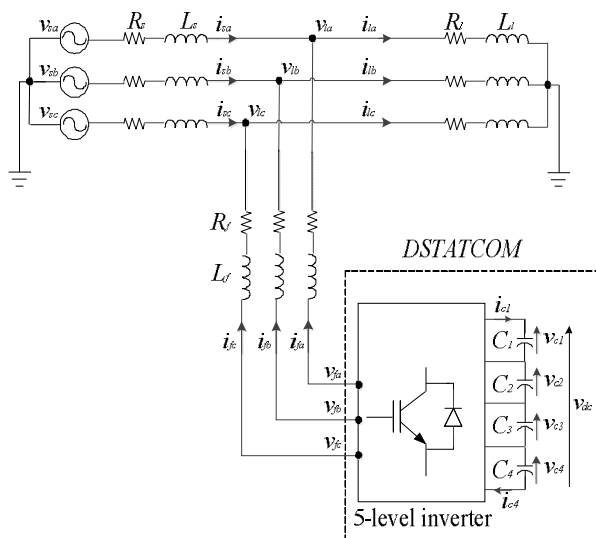


Fig. 1. Three-phase structure of the five-level DSTATCOM coupled with the distribution network.

2.2. Operating principle of DSTATCOM

The reactive power exchanged between DSTATCOM and the distribution network is given by [11]:

$$Q_f = \frac{v_f^2}{X_f} \left(1 - \frac{v_f}{v_l} \right) \quad (1)$$

If the amplitudes of the DSTATCOM output voltage (v_f) and the PCC voltage (v_l) are equal, the reactive component of DSTATCOM current (i_f) is zero and the DSTATCOM does not generate or absorb any reactive power.

When the converter voltage is greater than the PCC voltage, the system considers the DSTATCOM as a capacitive reactance and the DSTATCOM is operating in a capacitive mode. The current flows from the DSTATCOM to the AC system, and the device generates reactive power. In this case, the system draws capacitive current that leads by an angle of 90 degree the PCC voltage.

When the PCC voltage is higher than the converter voltage, the system sees an inductive reactance connected at its terminal. The current flows from the AC system to the DSTATCOM, resulting in the device absorbing reactive power. For an inductive operation, the current lags the AC voltage by an angle of 90 degree.

2.3. Mathematical model

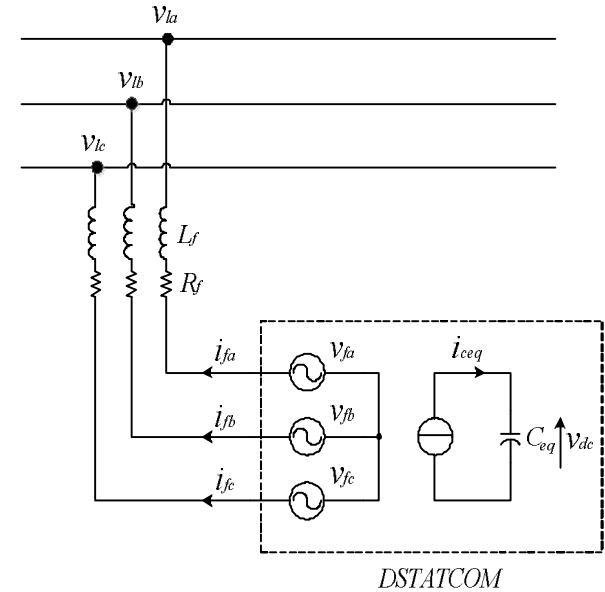


Fig. 2. Simplified equivalent circuit of Fig. 1.

In order to establish a useful mathematical model of DSTATCOM, the following assumptions are considered [12]:

- Distribution networks are considered as three-phase balanced network.
- Equivalent resistances represent all losses within the DSTATCOM, and filters are represented as equivalent inductances.
- The inverter is considered as an ideal sine wave generator and only the fundamental-frequency components is taken into account.

The simplified model represented by Fig.2 can represent the DSTATCOM. The principle of this model consists in representing the DSTATCOM by three sinusoidal voltages sources connected to the PCC by a filter (R_f, L_f). The DC bus is represented by a current source connected to equivalent condenser C_{eq} , where $C_{eq}=C/4$ [11].

It is possible now to model the system dynamics of the diagram in Fig. 2 in the abc frame as follows:

$$\begin{cases} L_f \frac{di_{fa}}{dt} = v_{fa} - R_f i_{fa} + v_{la} \\ L_f \frac{di_{fb}}{dt} = v_{fb} - R_f i_{fb} + v_{lb} \\ L_f \frac{di_{fc}}{dt} = v_{fc} - R_f i_{fc} + v_{lc} \end{cases} \quad (2)$$

For the DC-side circuit, based on the power balance equation in the output and input of DSTATCOM:

$$i_{ceq} = -\frac{1}{v_{dc}} (v_{la} i_{fa} + v_{lb} i_{fb} + v_{lc} i_{fc}) \quad (3)$$

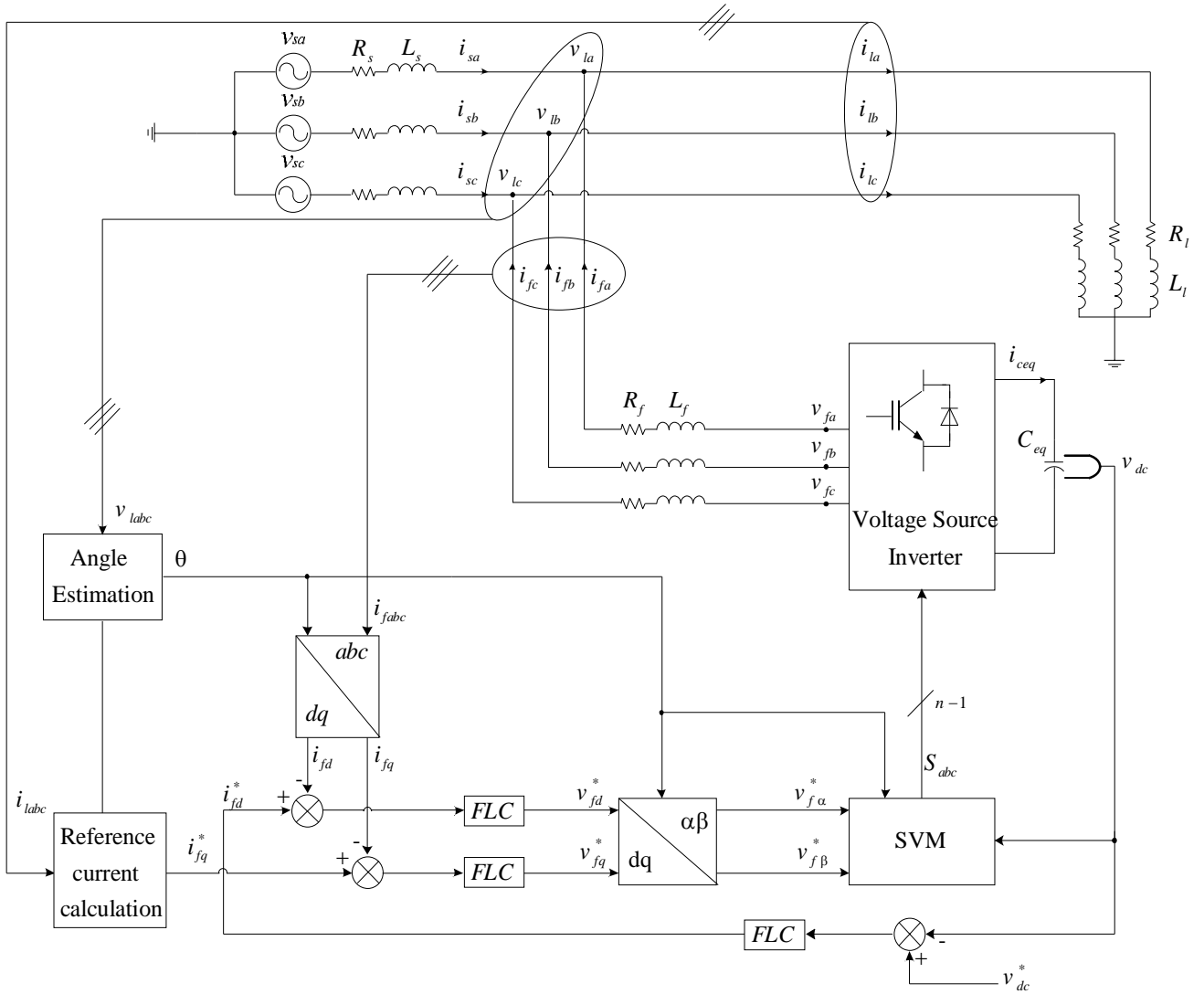


Fig. 3. Fuzzy logic control of DSTATCOM

If the angular velocity of the AC voltage and current vectors is ω and it is considered that the system of reference dq is rotating in the same speed, the d-axis is confused with the PCC voltage vector in order to cancel the component v_{lq} , and then equations (2) and (3) can be transformed into the following dq frame:

$$\begin{cases} v_{fd} = R_f i_{fd} + L_f \frac{di_{fd}}{dt} - L_f \omega i_{fq} + v_{ld} \\ v_{fq} = R_f i_{fq} + L_f \frac{di_{fq}}{dt} + L_f \omega i_{fd} + v_{lq} \\ i_{ceq} = -\frac{1}{v_{dc}} v_{ld} i_{fd} \end{cases} \quad (4)$$

This model is used to synthesize the control of the DSTATCOM.

3. DSTATCOM Control

The control of five-level DSTATCOM is shown in Fig. 3. The inner current control loop calculates the reference voltage necessary for the SVM block. The outer voltage control loop calculates the DC side current reference i_{ceq}^* , then the direct current reference i_{fd}^* is given from (4). Fuzzy Logic Controller (FLC) is considered for both the loops.

The reactive current reference i_{fq}^* can be given according to the operating process of the DSTATCOM, either by regulate the PCC voltage [11], or by regulate the reactive power exchanged between the DSTATCOM and the distribution network [13]. This last method was adopted in this work. The instantaneous detection of the reactive power consumed or delivered by the load makes it possible to order the DSTATCOM so that it delivers or consumes this power, thus allowing to compensate the totality of the reactive power and consequently obtaining a unit power-factor side source. In this case, the reactive current reference i_{fq}^* is only the imaginary component of the current load.

4. Fuzzy logic controller structure

FLC proposed by Mamdani for a simple system has many inputs (two in this work) and only one output, the Fig. 4 represents its internal structure.

Input variables of the fuzzy controller are:

- Control variable error defined by:
$$e(k) = x^*(k) - x(k) \quad (5)$$

- Change in this error (Δe) defined by:
$$\Delta e(k) = e(k) - e(k-1) \quad (6)$$

Output of the fuzzy controller is the change in the output variable (Δu). The new output, adjusted at every sampling period, is defined by the following equation:

$$u(k) = u(k-1) + G_u \Delta u(k) \quad (7)$$

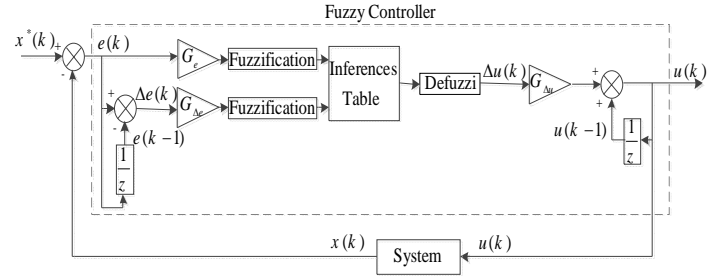


Fig. 4. Structure of fuzzy logic controller used in this work.

Where G_e , G_{De} are input scaling factors and G_u is output scaling factor. These three factors make it possible to act in a total way on the surface of command by widening or reducing the universe of speech of the manipulated variable.

The principal characteristics of the FLC used in this work are the following ones:

- Fuzzification with a universe of speech $[-1, 1]$.
- Implication uses the inference min-max of Mamdani.
- Triangular membership functions were selected for the inputs and output as shown in Fig.5 with seven linguistic variables chosen as positive big (PB), positive medium (PM), positive small (PS), Equal to Zero (EZ), negative small (NS), negative medium (NM), negative big (NB), for both inputs and outputs.

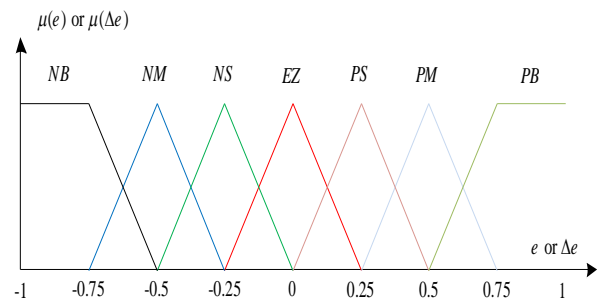


Fig. 5. Triangular membership functions.

D. Fuzzy rules base: A set of decision rules relating the inputs to the output are developed as follows.

R₁: If e is NB and Δe is NB, then Δu should be NB. The remaining forty-eight rules are formed in the same way as shown in the Table. 1.

Table 1. Fuzzy rule table

		E						
		NB	NM	NS	EZ	PS	PM	PB
Δe	NB	NB	NB	NB	NB	NM	NS	EZ
	NM	NB	NM	NM	NM	NS	EZ	PS
	NS	NB	NM	NS	NS	EZ	PS	PS
	EZ	NM	NM	NS	EZ	PS	PM	PM
	PS	NS	NS	EZ	PS	PS	PM	PB
	PM	NS	EZ	PS	PM	PM	PM	PB
	PB	EZ	PS	PM	PB	PB	PB	PB

E. Defuzzification: The FLC output is converted to crisp value by using Centre of Gravity (CG) method. The crisp value of FLC in CG is expressed as:

$$\Delta u = \frac{\sum_{q=1}^7 \mu_{\Delta uq} x_{Gq}}{\sum_{q=1}^7 \mu_{\Delta uq}} \quad (8)$$

Where x_{Gq} is the center of the membership function, $\mu_{\Delta uq}$ is the max of all rules that give the same decision.

4. Simulation results and discussion

Single line diagram of the test system for DSTATCOM is shown in Fig. 6. Such system is composed of a 5.5 kV, 50 Hz generation system that feeds three distribution linear loads, two inductive (L1, L2) and the third (L3) is capacitive.

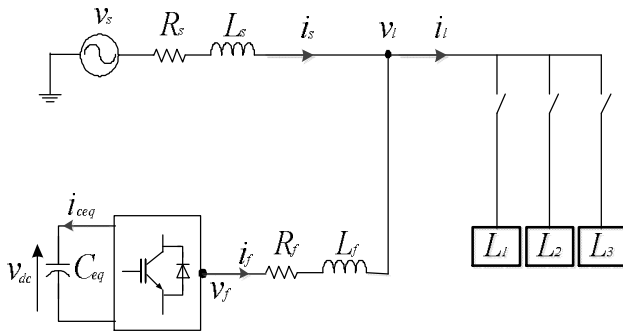


Fig. 6. Single line diagram of studied network.

Initially the condensers of the DC bus are charged and the terminal voltage of each one is 5 kV. At the beginning of simulation, the electrical source feeds the load (L1). A second load (L2) is connected to the distribution network at the moment (t=0.25 s); and at the moment (t=0.5 s), L3 is loaded, and finally at the moment (t=0.75 s) the two loads (L1) and (L2) are disconnected.

Now, the effectiveness of the control system proposed for DSTATCOM will be studied. In order to evaluate the theoretical results, the system shown in Fig. 1, is simulated by using Matlab /Simulink software. These system parameters are listed in Table 2.

Table 2. Simulated system parameters

v_s	5.5 kV
L_s, R_s	0.1 mH, 0.1 mΩ
L_f, R_f	10 mH, 0.1 mΩ
v_{dc}^*, C	20 kV, 5 mF
f_h, f_s	5kHz, 50 Hz
L_{L1}, R_{L1}, C_{L1}	65 mH, 50 Ω, 0 F
L_{L2}, R_{L2}, C_{L2}	110 mH, 50 Ω, 0 F
L_{L3}, R_{L3}, C_{L3}	13 mH, 15 Ω, 0.18 mF

The index “a” refer to the results obtained by the FLC controllers and “b” refer to those obtained by PI controllers.

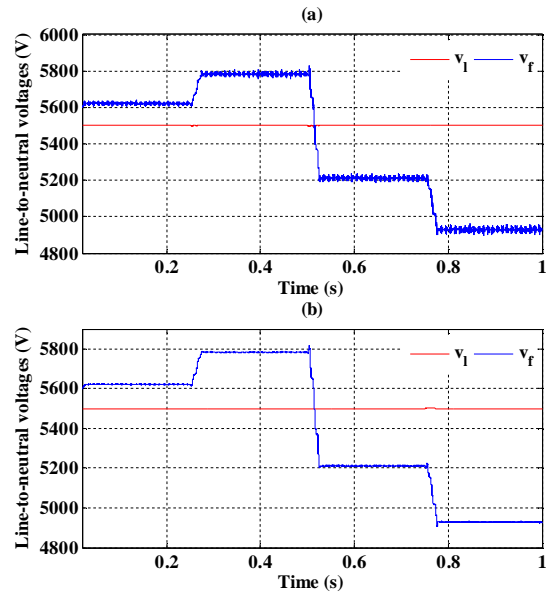


Fig. 7. Line to neutral of PCC voltage and DSTATCOM output voltage.

The PCC voltage and that of DSTATCOM output show both modes of DSTATCOM operation. It is about the inductive mode where v_l voltage is lower than v_f , and the capacitive mode where v_l is higher than v_f .

The shape of the reactive current confirm that this current takes its sign according to the operating mode of the DSTATCOM. Indeed, it is negative during the inductive mode, this means that the DSTATCOM delivers reactive energy towards the network, and it is positive during the capacitive mode; therefore the DSTATCOM absorbs reactive energy from the network.

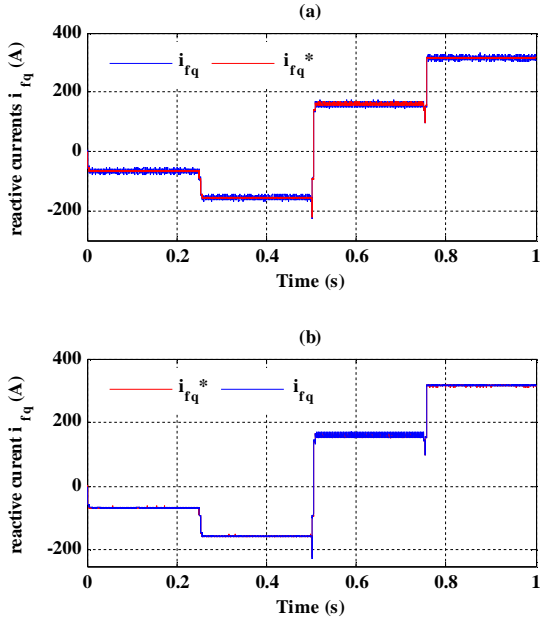


Fig. 8. Reactive current injected by the DSTATCOM into distribution network and its reference.

It can be observed from Figs. 9 and 11 that the FLC controllers are more powerful than PI controllers (less settling time and less overshoot).

Figs. 10 and 11 show that DSTATCOM quickly compensate load reactive current and maintain a constant DC bus voltage across the capacitors. The reactive component of the source current is always null, which shows that the DSTATCOM compensates the totality of reactive energy required by the load and consequently, it ensures unit power-factor operation side source.

Thanks to the stabilization algorithm associated to the five-level, the terminal voltages of the condensers are maintained balanced.

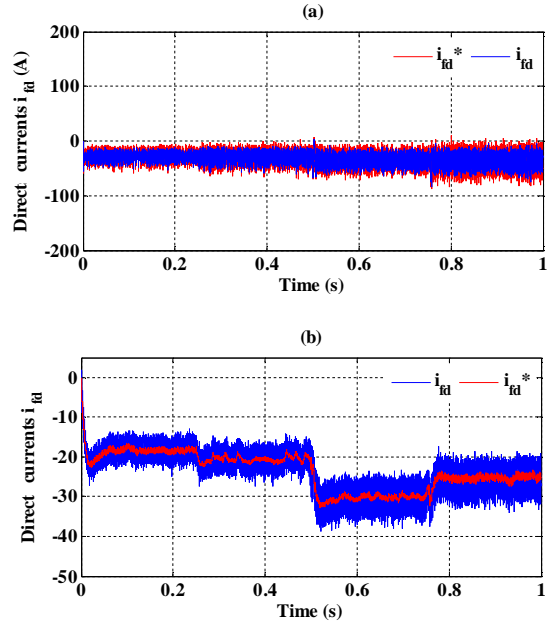


Fig. 9. Direct current injected by the DSTATCOM into distribution network and its reference.

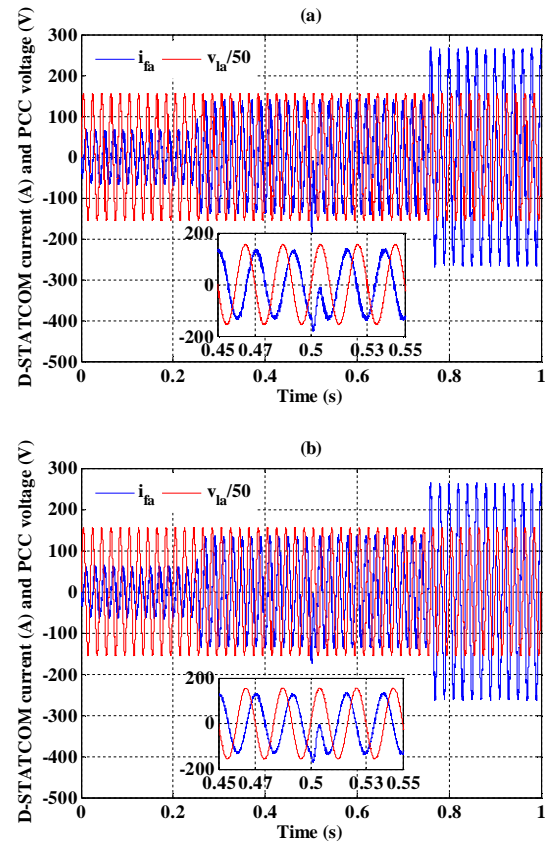


Fig. 10. Line current injected by the DSTATCOM in the network and PCC voltage reduced.

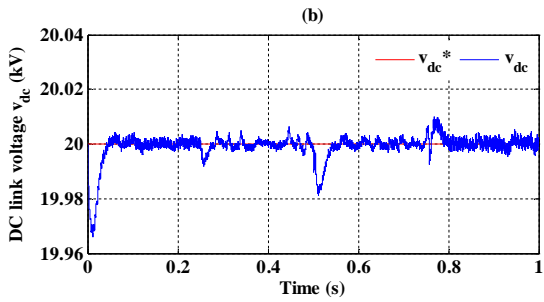
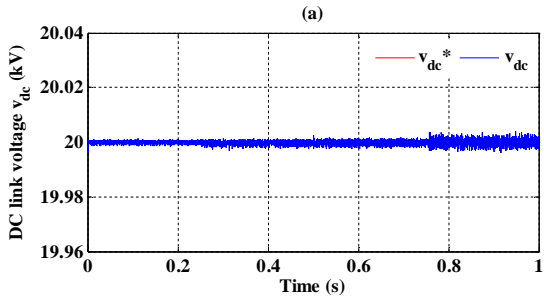


Fig. 11. DC link voltage and its reference.

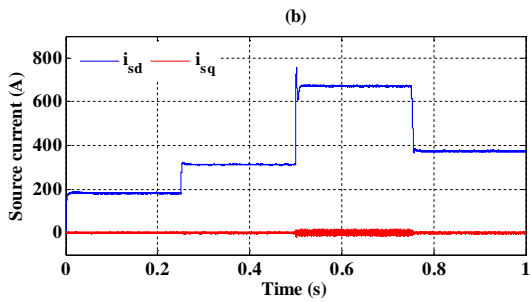
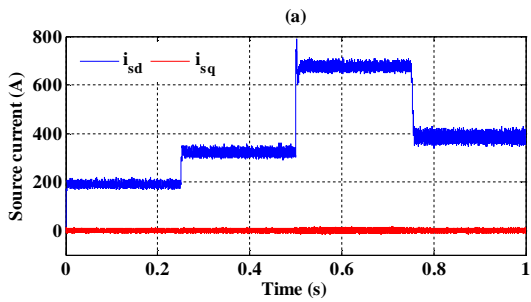


Fig. 12. Direct and reactive components of source current.

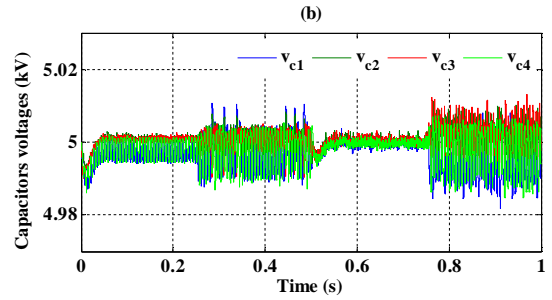
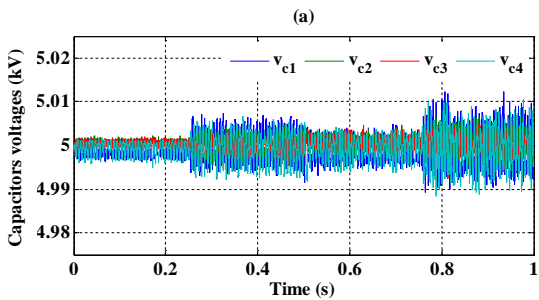


Fig.13. DC link capacitors voltages.

5. Conclusion

In this paper, the behavior of DSTATCOM connected to a distribution network is studied either in inductive mode or in capacitive mode. We have proposed a design procedure of fuzzy logic controller for providing reactive power compensation at the point of connection PCC. The study was beginning by a phase of DSTATCOM description consist those topology and mathematical model followed by the synthesis of their control using fuzzy logic and finally discuss the simulation results.

Simulation results shows that the proposed controller can effectively enhance transient stability of the power system even in the presence of many variation load

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