International Journal of Control, Energy and Electrical Engineering (CEEE)
Vol.8 pp.12-17

Modeling, Analysis and Simulation of a D-STATCOM for Reactive Power Compensation in Electric Distribution Power System

F.Z.Messaoud[#1], H.Tédjini[#2], O. Boughazi[#3], A. Hazzab[*4]
[#]Smart Grids & Renewable Energies (SGRE), University Tahri Mohammed
Bechar, Algeria
[*] Research Laboratory on Command, Analysis & Optimisation of Electro-Energetic Systems.
university Tahri Mohammed ,Bechar,Algeria
[1]fz.messaoud45@gmail.com
[2]tedjini_h@yahoo.fr
[3]othmaneboughazi@yahoo.fr
[4]A_hazzab@yahoo.fr

***Abstract*— The device analyzed in this paper is distribution static compensator (D-STATCOM) due to its capability to improve the power quality issues in distribution systems, in this paper the control of D-STATCOM is realized by proportional integral PI controllers to ensure perfect decoupling between the two active and reactive axes and to keep the DC-link voltage of D-STATCOM constant under linear-load variation. D-STATCOM is developed for the compensating reactive power demanded by unbalanced load. Moreover power factor of the source is improved, validation of models and control algorithms is carried out through simulations in MATLAB/Simulink**

.

Keywords— D-STATCOM; PI controller; DC-link voltage; Reactive power; unbalanced linear load .

I. Introduction

The Electrical Distribution System (EDS) is facing a number of power quality (PQ) issues such as low power factor, voltage fluctuation, voltage sag and voltage instability and many other problems due to non-linear loads, In fact in practical applications most of the loads are non-linear, Various custom power devices (CPD) are addressed in to enhance the quality of power, There are several types of CPDs such as DVR, D-STATCOM, UPQC etc, are used in the distribution system for specific purpose . The D-STATCOM is very attractive and it has a good cost-effective solution to minimize the PQ impact in EDS [1]–[3], The main advantage of D-STATCOM is that it can generates or absorb the reactive power required to distribution system[4],[5]. In this paper a detailed linear modeling of D-STATCOM, a conventional PI controller used to regulate the both voltage and current, direct current for active axe control, quadratic current for reactive axe control and voltage controller is designed for DC-link to reduce variations in case of sudden load changes which leads to high overshoot and undershoot[6] . The purpose is to ensure the decoupling between the direct and quadratic axes current that make it possible to control the reactive current flow between the D-STATCOM and the transmission power system used PI controller to regulate PCC voltage by dynamically absorbing or generating reactive power to the AC grid is fully studied in both capacitive and inductive modes across the reactance of coupling transformer, and improve the power factor in the side of the source, So conventional PI controller also feasible solution to show the better performance in driving D-STATCOM by maintaining the constant DC-link voltage under the change of linear inductive and capacitive loads have been demonstrated by some simulations results.

II. BASIC OPERATION OF D-STATCOM

The D-STATCOM is the SVC version consisting of a high-tech semiconductor-based voltage converter associated with a capacitor as a DC voltage source and the set connected in parallel to the distribution system network as shown in the "Fig.1", The D-STATCOM is connected through a filter circuit to the grid at the point of common coupling (PCC)[7]–[9] . In low power applications, low voltage power electronics technology can be used. Thus, higher switching frequencies and 2-level voltage converters based on conventional IGBTs can be used.

The instantaneous active power is defined by the scalar product between currents and voltages. On the other hand, the reactive power is defined by their vector product. The complex apparent power S_f at the output of D-STATCOM can be expressed by the following expression:

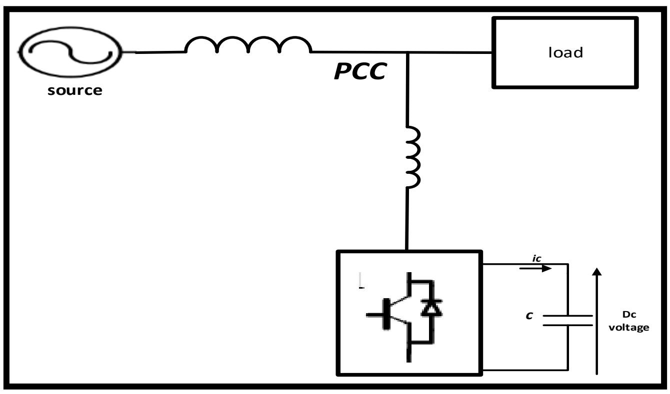

Fig. 1 basic diagram of D-STATCOM

ISSN 2356-5608

$$S_f = P_f + jQ_f \quad (1)$$

The expressions of the powers in the reference of Park are given by:

$$P_f = V_{chd} i_{fd} \quad (2)$$

$$Q_f = -V_{chd} i_{fq} \quad (3)$$

We then notice that the component i_{fq} allows to control the reactive power and the component i_{fd} to control the active power [10]. If the current is late, as shown in the "Fig. 2" the sign of the quadratic component of the current is negative so the result is positive reactive power means the D-STATCOM absorbs reactive power (inductive mode).

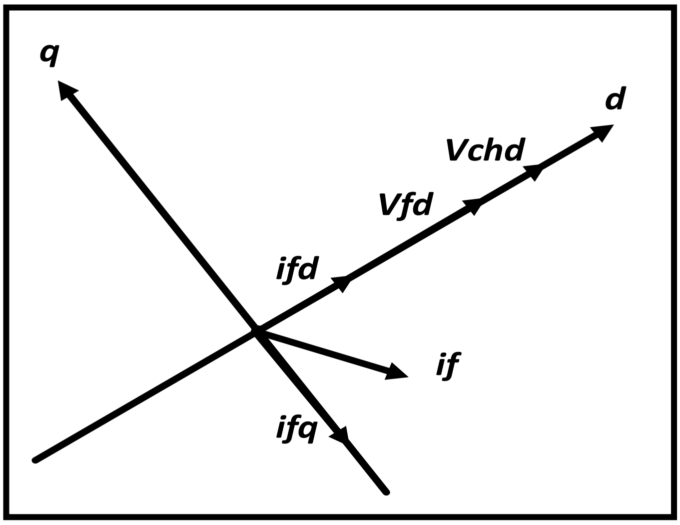

Fig. 2 Operation in inductive mode

When the sign of the quadratic component of the current is positive, the current is in advance, as shown in "Fig. 3", The result is a negative reactive power, which means the D-STATCOM provides reactive power to the network (capacitive mode).

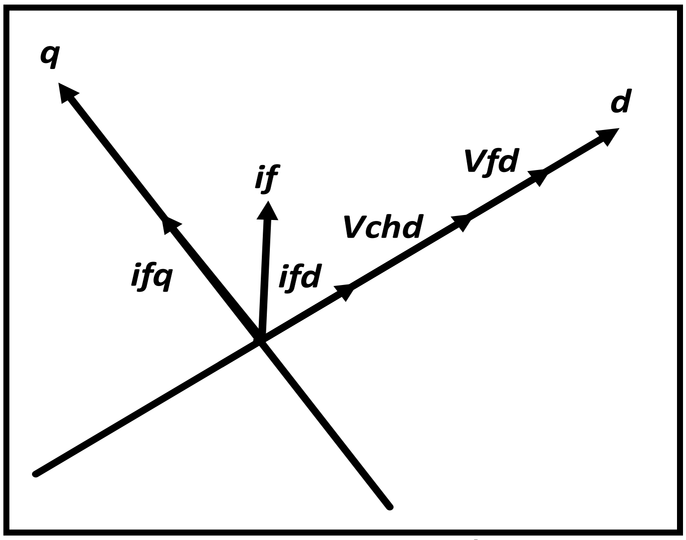

Fig. 3 Operation in capacitive mode

If the magnitude voltage (V_{fd}) of VSC is greater than (V_{chd}) of AC voltage $(V_{chd} < V_{fd})$, therefore D-STATCOM operated in capacitive mode and provides the reactive power to system. And If output voltage (V_{fd}) of VSC is smaller than (V_{chd}) of AC voltage $(V_{chd} > V_{fd})$,therefore D-STATCOM operated in inductive mode and absorbs the reactive power from the system, If the grid voltage V_{chd} and the DSTATCOM voltage V_{fd} are of the same magnitude ($V_{chd} = V_{fd}$), there is no exchange of reactive power between the grid and the D-STATCOM and is operating in the floating state.[11]

III. MODELLING OF D-STATCOM

The three-phase structure of D-STATCOM is given in "Fig. 4" the D-STATCOM is based on the topology of the voltage inverter. In low voltage distribution (BT) networks, two-level DSTATCOMs are usually coupled to the network by an RL filter. The electrical network is represented by three simple voltages (V_{sa}, V_{sb} and V_{sc}) and its internal impedances. The load is a three-phase inductive load coupled in a star.

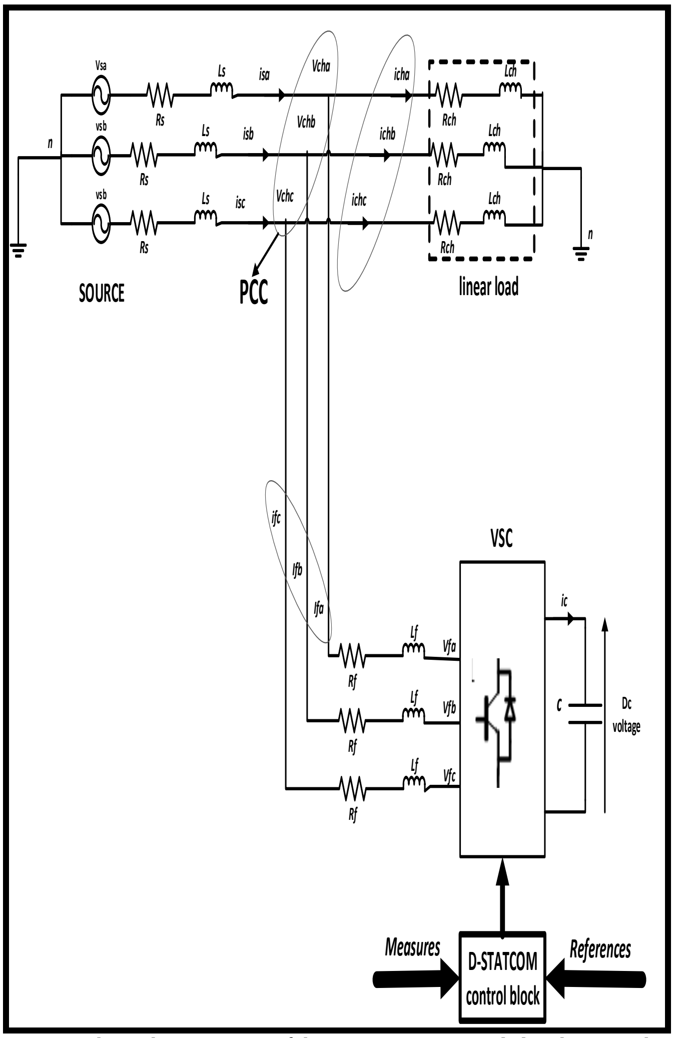

Fig. 4 Three-phase structure of the D-STATCOM coupled to the network

ISSN 2356-5608

International Journal of Control, Energy and Electrical Engineering (CEEE)
Vol.8 pp.12-17

From the "Fig.4", the expressions of the load voltages are defined by:

$$\begin{cases} V_{cha=} - L_f \frac{di_{fa}}{dt} - R_f i_{fa} + V_{fa} \\ V_{chb} = -L_f \frac{di_{fb}}{dt} - R_f i_{fb} + V_{fb} \\ V_{chc} = -L_f \frac{di_{fc}}{dt} - R_f i_{fc} + V_{fc} \end{cases} \quad (4)$$

Which give:

$$\begin{cases} \frac{di_{fa}}{dt} = \frac{1}{L_f}(V_{fa} - V_{cha} - R_f i_{fa}) \\ \frac{di_{fb}}{dt} = \frac{1}{L_f}(V_{fb} - V_{chb} - R_f i_{fb}) \\ \frac{di_{fc}}{dt} = \frac{1}{L_f}(V_{fc} - V_{chc} - R_f i_{fc}) \end{cases} \quad (5)$$

On the other hand, we have:

$$\frac{d{V_{DC}}^2}{dt} = \frac{2 V_{DC} i_c}{c} \quad (6)$$

The equation of the continuous side (6) can be related to the alternative side by the conservation of the active powers:

$$\frac{d{V_{DC}}^2}{dt} = \frac{2(V_{cha} i_{fa} + V_{chb} i_{fb} + V_{chc} i_{fc})}{C} \quad (7)$$

After transformation, the D-STATCOM model in the d-q frame is given by:

$$\begin{cases} \frac{di_{fd}}{dt} = \frac{1}{L_f}(V_{fd} - V_{chd} - R_f i_{fd} + \omega i_{fq}) \\ \frac{di_{fq}}{dt} = \frac{1}{L_f}(V_{fq} - V_{chq} - R_f i_{fq} - \omega i_{fd}) \\ \frac{d{V_{DC}}^2}{dt} = \frac{2\, V_{chd}\, i_{fd}}{C} \end{cases} \quad (8)$$

Equation (8) shows that the DSTATCOM model in the d-q frame shows coupling terms between the d and q axes.

IV. DESIGN OF PI CONTROLLER

In all practical applications, D-STATCOM is mainly used to compensate the reactive power at the PCC where is connected, The control structure of a DSTATCOM consists of a double nested control loop: An external current command generation loop and an internal current control loop "Fig.5". The active and reactive powers exchanged between the D-STATCOM and the network are controlled by the regulation of the direct and quadratic components of the current (i_{fd} , i_{fq}), the Components (V_{fd} , V_{fq}) are the command variables and (V_{chd},V_{chq}),are the disturbance variables so we have:

$$\begin{cases} \frac{di_{fd}}{dt} = \frac{1}{L_f} V_d - \frac{R_f}{L_f} i_{fd} \\ \frac{di_{fq}}{dt} = \frac{1}{L_f} V_q - \frac{R_f}{L_f} i_{fq} \end{cases} \quad (9)$$

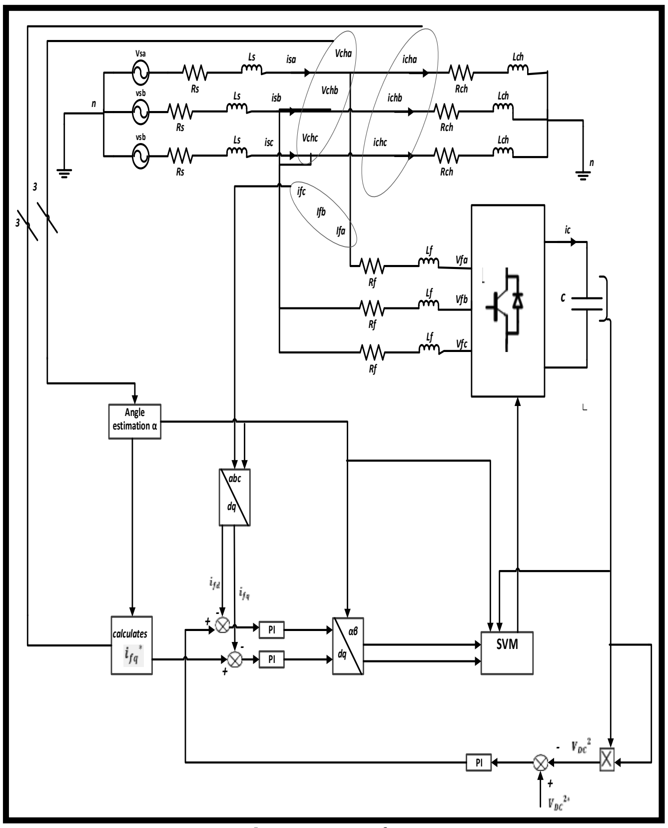

Fig. 5 Control PI structure of a DSTATCOM

A. synthesis of current regulators

The simplified diagram of the current regulation loop is illustrated by the "Fig.6".

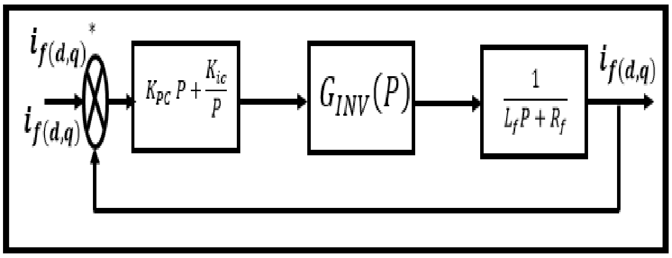

Fig. 6 Current regulation by PI regulators.

The open loop transfer function corresponding to this scheme is:

$$F(P) = K_{PC}\,P + \frac{K_{ic}}{P} \frac{1}{L_f P + R_f}\, G_{INV}(P) \quad (10)$$

the transfer function of the inverter is generally chosen equal to $G_{INV}(P) = 1$ in order to ensure that the value of the output voltage is equal to its reference. The closed loop transfer function will therefore be:

$$H(P) = \frac{K_{PC}\,P + K_{IC}}{L_f P^2 + (R_f + K_{PC})\,P + K_{ic}} \quad (11)$$

Finally we deduce the values of the regulator constants as follows:

ISSN 2356-5608

$$K_{Pc} = 2\zeta_c\omega_{nc}L_f - R_f \quad (12)$$
$$K_{ic} = L_f\omega_{nc}^{\ 2} \quad (13)$$

B. synthesis of the DC voltage regulator

The role of the DC bus voltage regulation loop is to maintain this voltage at a constant reference value, controlling the active power transfer between the PCC and the DC bus, from the system (5),we have the following first order transfer function:

$$\frac{V_{DC}^{2}(P)}{i_{fd}(P)} = \frac{2V_{chd}}{C_P} \quad (14)$$

The following diagram shows the regulation of the DC voltage with a PI corrector:

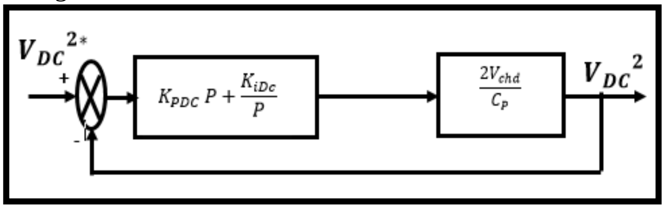

Fig. 7 Voltage regulating DC by a PI regulator

The closed loop transfer function will therefore be:

$$H(P) = \frac{2\,V_{chd}\,(K_{PDC}\,P + K_{iDC})}{C\,P^2 + 2\,V_{chd}\,K_{PDC}P + 2\,V_{chd}\,K_{iDC}} \quad (15)$$

Finally we deduce the values of the regulator constants as follows:

$$K_{PDC} = \frac{C\,\zeta_{DC}\,\omega_{nDC}}{V_{chd}} \quad (16)$$
$$K_{iDC} = \frac{C\ \omega_{nDC}^{\ 2}}{2V_{chd}} \quad (17)$$

The reference of the reactive current $i_{fq}^{\ *}$ can be determined according to the operating mode of the DSTATCOM, either by the regulation of the voltage of the PCC, or by the regulation of the reactive power exchanged between the D-STATCOM and the network.

V. SYSTEM CONFIGURATIONS

The single-line diagram of the distribution network used to validate the operation of D-STATCOM is shown in “Fig.8”

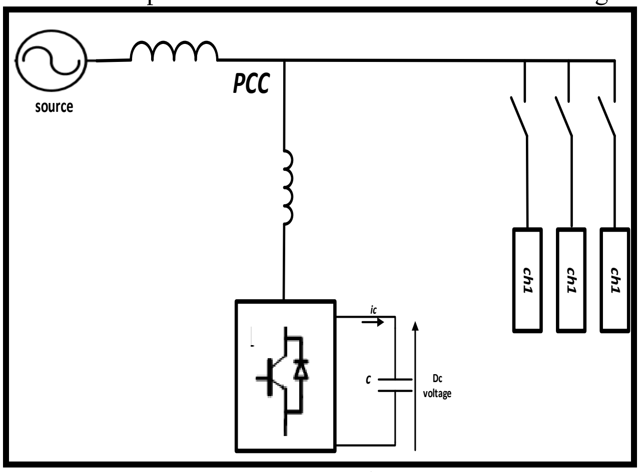

Fig 8. Single-line diagram of the studied network

Such as:
$ch1$ = Inductive load ($Lch1 + Rch1$)
$ch2$ = Inductive load ($Lch2 + Rch2$)
$ch3$ = Capacitive load ($Lch3 + Rch3 + Cch$)

The parameters of the system to be simulated are given by THE TABLE I AND II :

TABLE I

SYSTEM PARAMETERS TO SIMULATE

Parameters	Values	Parameters	Values
V_{Seff}	220 v	$V_{DC}^{\ *}$	800V
L_s	0.001 H	R_{ch1}	50Ω
R_s	0.001Ω	R_{ch2}	50Ω
f_h	5 k Hz	R_{ch3}	15Ω
C_{Ch}	0.18 mH	L_{ch1}	65 mH
L_f	0.01 H	L_{ch2}	110 mH
R_f	0.001Ω	L_{ch3}	13 mH
f_S	50 Hz	C	5 mF

TABLE II

PARAMETERS OF THE PI REGULATORS

Regulators	ω_n	ξ_n
continuous voltage	100	0.707
currents	50 000	1

VI. RESULT AND DISCUSSION

The proposed D-STATCOM model is implemented in MATLAB/SIMULINK software using control algorithm for D-STATCOM with PI controller. The proposed model is verified under linear load condition and is used for power factor correction ,reactive power regulation and DC voltage regulation.

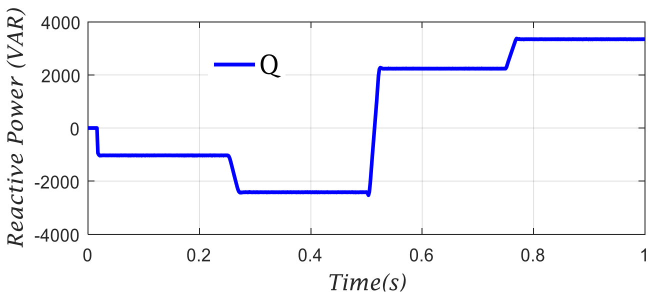

Fig. 9 Reactive Power of the D-STATCOM (injected and absorbed)

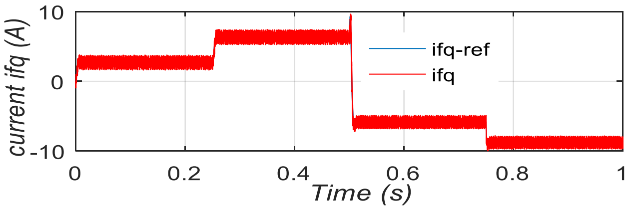

Fig. 10 Reactive current injected by the D-STATCOM into the network and its reference

ISSN 2356-5608

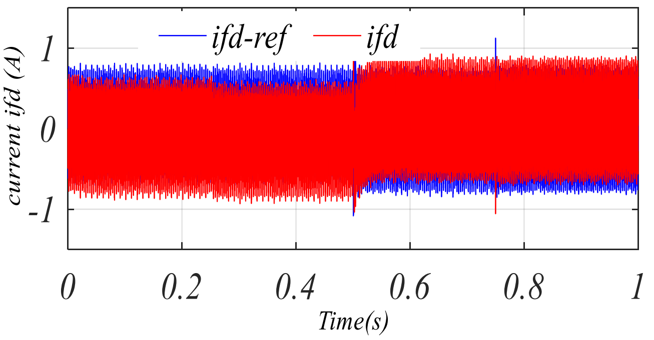

Fig. 11 Active current injected by the D-STATCOM into the network and its reference

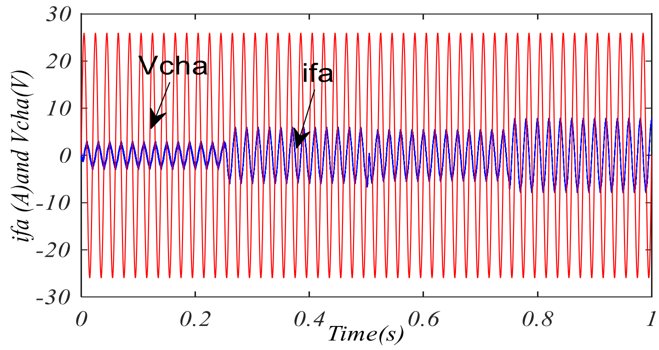

Fig. 12 Current of the first phase injected by the D-STATCOM and charging voltage

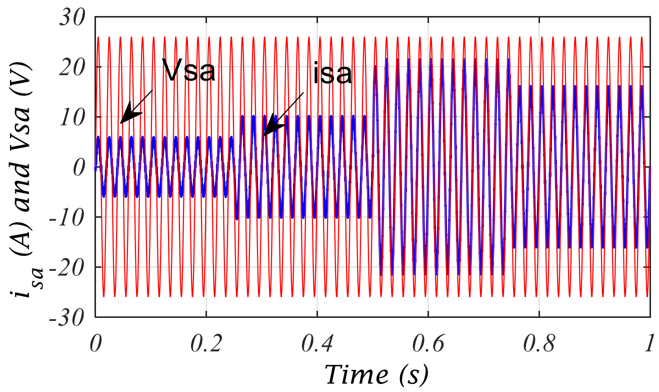

Fig. 13 Current and voltage of the first phase of the network

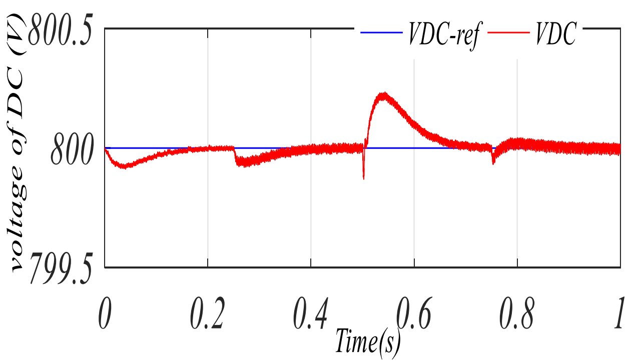

Fig. 14 DC bus voltage of the D-STATCOM and its reference with the PI regulator

Initially the capacitor of the DC bus is charged by a voltage equal to 800V. At the beginning of the simulation, the grid supplies the load ($Ch1$). A second load ($Ch2$) is connected to the network at the instant (t = 0.25 s), and at the instant (t = 0.5 s) we charge the line by the load($Ch3$), and finally (t = 0.75 s) the two loads ($Ch1$) and ($Ch2$) are disconnected. The D-STATCOM injects reactive power to the network from (0.1s to 0.5s) that means the operation of D-STATCOM which is in capacitive mode determines the sign of the reactive current i_{fq} injected by the D-STATCOM to the network. This current is positive "Fig.10", and as the reactive power is the inverse sign "Fig.9" of this current. After the instant (t = 0.5 s) D-STATCOM absorbs reactive power from the network when the inductive loads ($Ch1$ and $Ch2$) are disconnected , so the operation of D-STATCOM is in inductive mode and the reactive current is negative "Fig.9" . The form of this reactive current is shown in "Fig.10".

"Fig.11" shows the shape of the active current exchanged between the D-STATCOM and the network. This current is generally low since it represents only the active power required to maintain the voltage across the capacitor plus the switching losses of the semiconductor components. It is noted that the currents of the D-STATCOM, i_{fd} and i_{fq} follow their reference quantities calculated from the reactive and active powers necessary to compensate the reactive power in the line and to keep the DC voltage constant. These results prove the effectiveness of the regulators used.

In "Fig.12", it is noted that the current is in advance with respect to the voltage of the point of common coupling PCC when the line is charged by the inductive load $Ch2$. It should be noted that at the instant (t = 0.5) the current of the first phase is backward relative to the voltage of the PCC because the D-STATCOM operates in inductive mode. Indeed, the capacitive load delivers a reactive power in the network, a part of this power compensates for the reactive need of the inductive loads ($Ch1$ and $Ch2$) and the remaining part is absorbed by the D-STATCOM. After the instant (t = 0.75) the two charges ($Ch1$ and $Ch2$) are disconnected and all of the reactive power delivered by the charge $Ch3$ is absorbed by the D-STATCOM.

"Fig.13", shows the source-side current and voltage and a unit power factor, such as the current to a sinusoidal form and in phase with the voltage of the source. From the curve of "Fig.14", it seems very clear that the voltage regulator continues to prove its efficiency in maintaining a constant voltage across the global DC bus. The voltage goes through a transient period of less than 0.1s during the variation of the load before it returns to its reference with a zero static error.

VII. CONCLUSION

In this paper, the performance of the D-STATCOM has been analyzed effectively to improve the power quality (PQ) in the distribution network under the change of linear load, the simulation results shows the effectiveness and feasibility of proposed D-STATCOM with conventional PI controller for power factor correction and reactive power regulation, especially for DC voltage regulation.

ISSN 2356-5608

REFERENCES

[1] K.-H. Tan, F.-J. Lin, C.-Y. Tsai, et Y.-R. Chang, “ A Distribution Static Compensator Using a CFNN-AMF Controller for Power Quality Improvement and DC-Link Voltage Regulation ”, *Energies*, vol. 11, nº 8, p. 1996, août 2018.

[2] S. S. SHIRDHONE, “A DSTATCOM Topology with Reduced DC-Link Voltage for Load compensating the using Non-stiff Source ”, vol. 14, nº 2, p. 5.

[3] J. P. Busi et S. Yelavarthi, “A Fuzzy Logic based DSTATCOM for Diesel Generation System for Load Compensation ”, *Indian J. Sci. Technol.*, vol. 8, nº 23, sept. 2015.

[4] C. Sumpavakup et T. Kulw, “ Distribution Voltage Regulation Under Three- Phase Fault by Using D-STATCOM ”, p. 5, 2008.

[5] *D. I. SATYANARAYANA, “ Multilevel D-STATCOM for Linear and nonlinear loads to compensate reactive and active power during operation of distribution systems ”, Appl. Sci., vol. 5, nº 8, p. 8, 2015.*

[6] D. S. Kumar, G. Pawanekar, et K. C. Reddy, “ MMC based D-STATCOM for Different Loading Conditions ”, vol. 02, nº 12, p. 6.

[7] G. Kumar A. et C. A. Babu, “ A Zig-Zag Transformer and Three-leg VSC Based DSTATCOM for a Diesel Generator Based Microgrid ”, *Procedia Technol.*, vol. 21, p. 310-316, janv. 2015.

[8] T. Yuvaraj, K. Ravi, et K. R. Devabalaji, “ DSTATCOM allocation in distribution networks considering load variations using bat algorithm ”, *Ain Shams Eng. J.*, vol. 8, nº 3, p. 391-403, sept. 2017.

[9] S. R. Reddy, P. V. Prasad, et G. N. Srinivas, “ Design of PI and Fuzzy Logic Controllers for Distribution Static Compensator ”, Int. J. Power Electron. Drive Syst. IJPEDS, vol. 9, no 2, p. 465-477, juin 2018.

[10] M. Kullan, R. Muthu, J. B. Mervin, et V. Subramanian, “ Design of DSTATCOM Controller for Compensating Unbalances ”, Circuits Syst., vol. 07, no 09, p. 2362-2372, 2016.

[11] O. P. Mahela et A. G. Shaik, “ A review of distribution static compensator”, Renew. Sustain. Energy Rev., vol. 50, p. 531-546, oct. 2015

ISSN 2356-5608