Insertion study of an artificial intelligence device (STATCOM), to use it in a renewable energy system.

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Abstract **– This paper treats the insertion effect study, the modelling and command of an artificial intelligence FACTS device "Flexible Alternating Current Transmission Systems" the "STATCOM" 'STATic COMpensator' to use it in a renewable energy system, the simulation of the test power grid and the STATCOM were carried out in interface SIMULINK/MATLAB for both cases where, STATCOM was connected into the system and not, with simulation interval [0-2sec]. The aim of STATCOM is to optimize the reactive power and to regulate the voltage at the bus where it is connected. And then the network of the renewable energy system becomes a smart grid. Some results of simulation are presented in this paper, which shows the effectiveness of compensator "STATCOM" used at the reception bus.**

Keywords – FACTS, STATCOM, PI Regulator, Smart Grid

I. INTRODUCTION

In recent years power quality issues have become more and more important both in practice and in research.

Owing to increased sensitivity of applied receivers and process controls, many customers may experience severe technical and economical consequences of poor power quality. Disturbances such as voltage fluctuations, flicker, harmonics or imbalance can prevent appliances from operating properly and make some industrial processes shut down. [6]

When good power quality is necessary for technical and economical reasons, some kind of disturbance compensation is needed and that is why applications of power quality equipment have been increasing. [6]

The most recent approach for solid-state power compensators is based on self-commutated converters using components with a current blocking capability. A STATCOM can provide fast capacitive and inductive compensation and is able to control its output current independently of the AC system voltage (in contrast to the SVC, which can supply only diminishing output current with decreasing system voltage). This feature of the compensator makes it highly effective in improving the transient stability. Therefore, STATCOM systems with GTO thyristors have been initially used for improving flexibility and reliability of energy transmission in FACTS (flexible AC transmission system) applications [1]-[2].The newest applications of STATCOMs concern power quality improvement at distribution network level. Some examples given in the literature are the reduction of flicker, voltage control and balancing single phase load [3]-[4].

The objective of this work is to propose an appropriate solution to optimize the reactive power and to control the voltage in the network of renewable energy system through the incorporation of the intelligent system “STATCOM”.

II. OPERATING PRINCIPLE OF STATCOM

The STATCOM is a shunt device. It should therefore be able to regulate the voltage of a bus to which it is connected [6] and to compensate the reactive power. We can consider the STATCOM as a static synchronous generator which generates a three-phase alternative voltage synchronous with the voltage of the power grid starting from a source of continuous voltage. The amplitude of voltage of STATCOM can be controlled in order to adjust the quantity of reactive energy to exchange with the power grid. In general the voltage of STATCOM V_{sh} is injected in phase with V_r voltage of line and in this case there is no active power exchange with the power grid ($P_{sh}=0$) but only the reactive power which will be injected (or absorbed) by STATCOM. [5]

If the voltage of STATCOM V_{sh} is in phase with bus terminal voltage V_r and V_{sh} is greater than V_r, STATCOM provides reactive power to system. If V_{sh} is smaller than V_r, STATCOM absorbs reactive power from power system. V_r and V_{sh} have the same phase, but actually they have a little phase difference to component the loss of transformer winding and inverter switching, so absorbs some real power from system.

III. MODELLING & COMMAND OF STATCOM

A. Modelling Of STATCOM

The three-phase structure of STATCOM is given by Fig. 1.

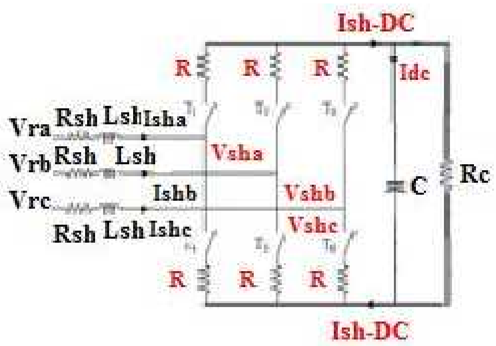

Fig. 1 Simplified diagram of STATCOM.

The DC circuit will not be included in this model.

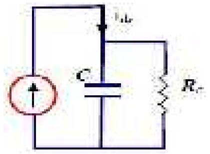

Fig.2. Equivalent diagram of DC circuit of STATCOM.

For each phase, in the matrix form we have:

$$\begin{bmatrix}V_{r-a}\\V_{r-b}\\V_{r-c}\end{bmatrix}-\begin{bmatrix}V_{sh-a}\\V_{sh-b}\\V_{sh-c}\end{bmatrix}=R_{sh}\begin{bmatrix}I_{sh-a}\\I_{sh-b}\\I_{sh-c}\end{bmatrix}+L_{sh}\frac{d}{dt}\begin{bmatrix}I_{sh-a}\\I_{sh-b}\\I_{sh-c}\end{bmatrix} \quad (1)$$

We use Park transformation; we obtain:

$$\frac{d}{dt}\begin{bmatrix}I_{sh\_d}\\I_{sh\_q}\end{bmatrix}=\frac{1}{L_{sh}}\begin{bmatrix}V_{rd}-V_{sh\_d}\\V_{rq}-V_{sh\_q}\end{bmatrix}+\begin{bmatrix}\frac{-R_{sh}}{L_{sh}} & \omega\\ -\omega & \frac{-R_{sh}}{L_{sh}}\end{bmatrix}\begin{bmatrix}I_{sh\_d}\\I_{sh\_q}\end{bmatrix} \quad (2)$$

The power circulating between the condenser and the inverter of voltage is:

$$P_{sh}=U_{dc}I_{dc}=\frac{3}{2}\left(V_{sh_d}I_{sh_d}+V_{sh_q}I_{sh_q}\right) \quad (3)$$

B. *Command Of STATCOM*

To command the device it is necessary to determine the references. We will use the “uncoupled Watt-Var” Method:

$$\begin{bmatrix}I_{shd}^*\\I_{shq}^*\end{bmatrix}=\frac{2}{3(V_d^2+V_q^2)}\begin{bmatrix}-V_{rd} & V_{rq}\\V_{rq} & V_{rd}\end{bmatrix}\begin{bmatrix}P_{sh}^*\\Q_{sh}^*\end{bmatrix} \quad (4)$$

From equation (2), we pose:

$$X_1=\frac{V_{rd}-V_{shd}}{L_{sh}} \quad \& \quad X_2=\frac{V_{rq}-V_{shq}}{L_{sh}}$$

By application of Laplace transformation, we obtain:

$$\left(s+\frac{R_{sh}}{L_{sh}}\right)I_{sh_d}=\omega I_{sh\_q}+X_1=\bar{X}_1 \quad (5)$$

$$\left(s+\frac{R_{sh}}{L_{sh}}\right)I_{sh_q}=-\omega I_{sh\_d}+X_2=\bar{X}_2 \quad (6)$$

$$I_{sh_d}=\bar{X}_1*\frac{1}{\left(s+\frac{R_{sh}}{L_{sh}}\right)} \quad (7)$$

$$I_{sh_q}=\bar{X}_2*\frac{1}{\left(s+\frac{R_{sh}}{L_{sh}}\right)} \quad (8)$$

To eliminate the coupling in the transfers of currents I_{sh_d} & I_{sh_q} we use the PI regulator with pole compensation, we can control the output currents of STATCOM and make them follow their references I_{shd}^* & I_{shq}^* as represents it the diagram block of Fig. 3.

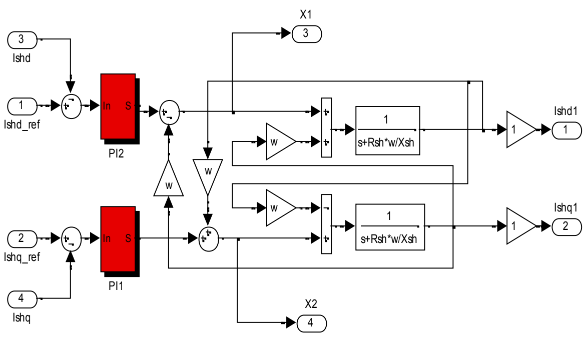

Fig. 3 Diagram block of "uncoupled Watt Var" method of STATCOM.

We can also write another way the two components *X1* and *X2* as follows:

$$\begin{cases}X_1=\left(K_p+\frac{K_i}{s}\right)\left(I_{shd}^*-I_{sh_d}\right)-\omega I_{sh\_q}\\X_2=\left(K_p+\frac{K_i}{s}\right)\left(I_{shq}^*-I_{sh_q}\right)+\omega I_{sh\_d}\end{cases} \quad (9)$$

The transfer function of this regulation in open loop:

$$TFOL=G(s)=\left(K_p+\frac{K_i}{s}\right)\left(\frac{1}{\left(s+\frac{R_{sh}}{L_{sh}}\right)}\right)=K_p\left(\frac{s+\frac{K_i}{K_p}}{s}\right)\left(\frac{1}{\left(s+\frac{R_{sh}}{L_{sh}}\right)}\right) \quad (10)$$

Then we determine the PI controller gains:

$$K_i=K_p*\frac{R_{sh}}{L_{sh}} \quad (11)$$

$$K_p=\frac{3}{T_{BO}}=\frac{3}{\frac{L_{sh}^{pu}}{R_{sh}^{pu}}}=\frac{3R_{sh}^{pu}}{L_{sh}^{pu}}=\frac{3R_{sh}^{pu}\omega}{X_{sh}^{pu}} \quad (12)$$

We can globalize the control by the uncoupled watt var method by using Fig. 4:

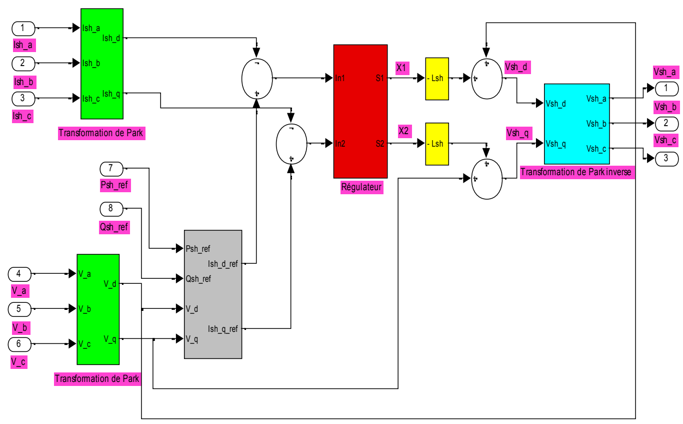

Fig. 4 Total diagram of control by the "uncoupled watt-var" method.

The active power provided in the alternative part (Psh) is equal to the active power absorbed in the continuous part (Pdc) by the condenser:

$$P_{dc}=P_{sh}=\frac{1}{2}C\frac{dU_{dc}^2}{dt}\Rightarrow\frac{dU_{dc}^2}{dt}=\frac{2P_{sh}}{C} \quad (13)$$

Laplace transformation of this equation gives us:

$$\frac{U_{dc}^2}{P_{sh}}=\frac{2}{s*C} \quad (14)$$

To obtain the Psh signal we choose the regulator (PI) since it is often preferable:

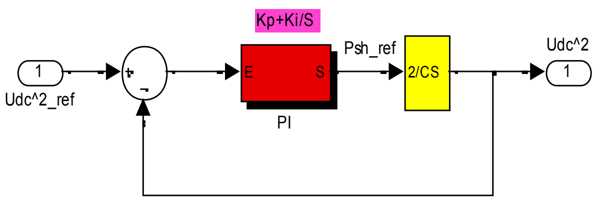

Fig. 5 diagram of continuous voltage regulation

We chose the MLI command because STATCOM commands in strong powers and needs to fixed frequency for commutations.

IV. STATCOM Simulation In The Real Test Network Of Renewable Energy System

The real test network (T-line, 400 KV) of renewable energy system (Biomass .P.S) (France) of our study can be described by:

- Generator of 1000MVA, output voltage of 15.7KV.
- Step-up transformer of 1000MVA, 15.7/400KV.
- A test network length of 200Km. Line is of “CURLEW” type & is modeled in (π) for each 100 km.
- Line feeds a variable load in time, in bus reception “R”.

The equivalent model of the network in per units is presented in Fig. 6:

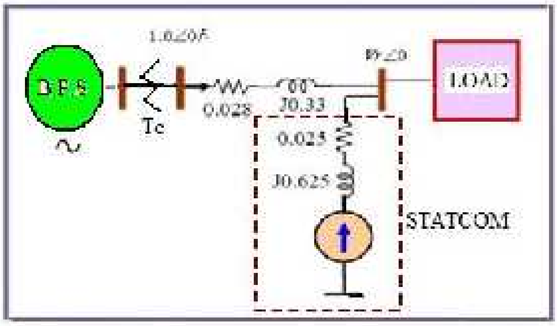

Fig. 6 Equivalent power system model & STATCOM.

Generator B.P.S (Biomass Power Station) represents 4 generators in parallel, its parameters are:

TABLE I
CHARACTERISTIC OF GENERATOR

Sn (MVA)	1000	Xd´ (pu)	0,32
Vn (KV)	15,7	Xq´ (pu)	0,32
Xd (pu)	1,896	Xd´´ (pu)	0,213
Xq (pu)	1,896	Xq´´ (pu)	0,213
X2 (pu)	0,26	Td´ (s)	1,083
X0 (pu)	0,0914	Tq´ (s)	1,1
ra´ (pu)	0,00242	Td´´ (s)	0,135
J (Kg-m2)	10^7	Tq´´ (s)	0,135

At the outlet of each generator, there are 4 transformers put in parallel. The characteristics of these transformers are:

TABLE II
CHARACTERISTIC OF TRANSFORMER TE

Apparent power (MVA)	1000
report/ratio of transformation (KV)	15,7/400
Flight inductance (Xcc)	12,8%
Iron losses (Pmag)	0,1% Sn
losses at the nominal current (Pcu)	0,6% Sn

The general characteristics of the transformer (Tsh) are:

TABLE III
CHARACTERISTIC OF TRANSFORMER TSH

Apparent power (MVA)	160
report/ratio of transformation (KV)	20/400
Flight inductance (Xcc)	10%
Iron losses (Pmag)	0,1% Sn
losses at the nominal current (Pcu)	0,4% Sn

First it is noted that the generation bus voltage (Vs=1). Our system operate initially (t=0s) at (P1=1pu, Q1=0.32pu) in a balance state. This load will be varied arbitrarily in time like it shows table (IV):

TABLE IV
REFERENCES OF ACTIVE & REACTIVE POWERS

TIME(S)	0 0,5	0,5 1	1 1,5	1,5 2
P(pu)	1	1,3	1,4	1,4
Q(pu)	0,32	0,12	0,42	0,43

V. Simulation Results

Initially, coefficients of regulators will be calculated as follows:

$$K_p = \frac{3R_{sh}^{pu}}{L_{sh}^{pu}} = \frac{3R_{sh}^{pu}\omega}{X_{sh}^{pu}} = \frac{3\times 0.025\times 2\pi\times 50}{0.625} = 37.699 \quad (15)$$

$$K_i = K_p * \frac{R_{sh}^{pu}\omega}{X_{sh}^{pu}} = 37.699\times\frac{0.025\times 2\pi\times 50}{0.625} = 473.741 \quad (16)$$

A. Without STATCOM

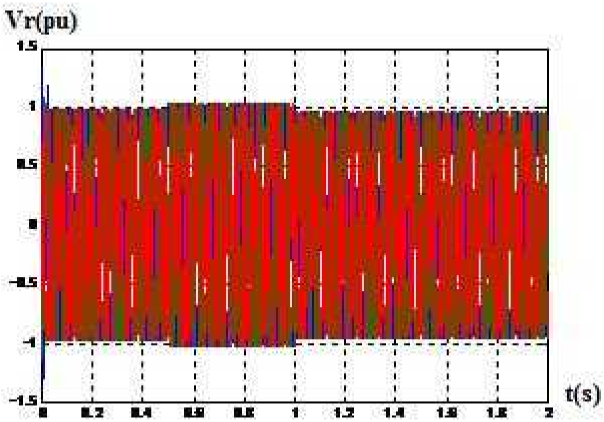

Fig. 7 Voltage at reception bus not compensated.

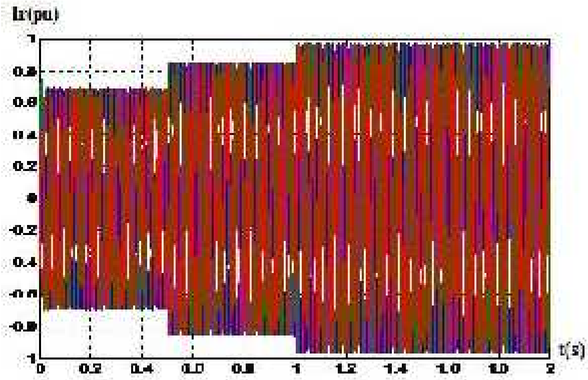

Fig. 8 Current of the not compensated line.

Fig. 7, watch different variations caused on voltage at reception bus, whose interval [0-0.5s] we have a small voltage drop caused by inductive load (P1=1pu, Q1=0.32pu), then we have a rise in voltage because of load (P2=1.3pu, Q2=0.12pu). At time (t=1s) we notice an appreciable voltage drop due to the load (P3=1.4pu, Q3=0.42pu). In the last interval [1.5-2s] it appears a very small variation in the reactive power (P4=1.4pu, Q4=0.43pu) causes a very small drop in voltage.

B. With STATCOM

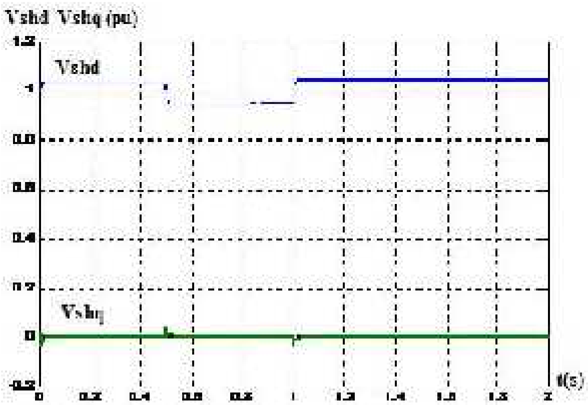

Fig. 9 STATCOM voltage (Vshd & Vshq).

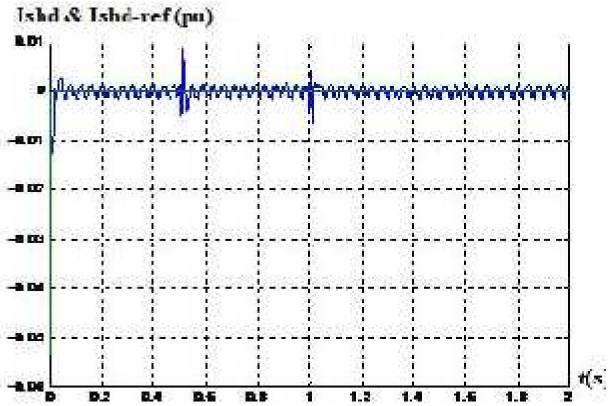

Fig. 10 STATCOM current (Ishd & Ishd_ref).

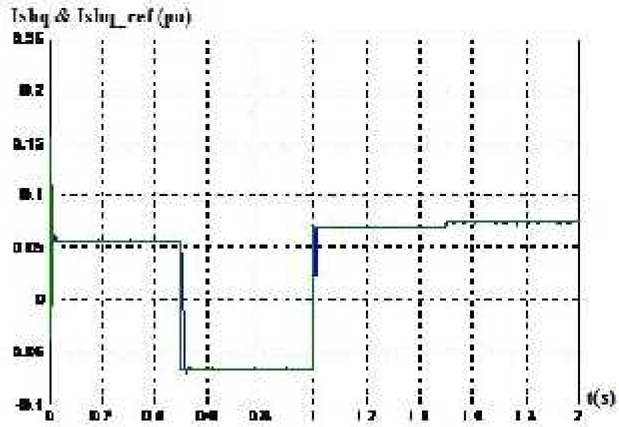

Fig. 11 STATCOM current (Ishq & Ishq_ref).

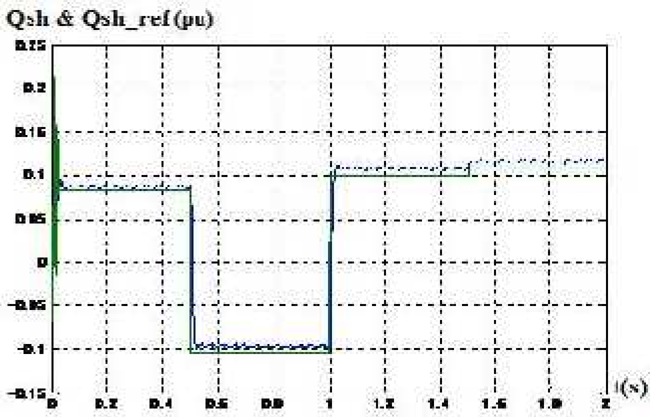

Fig. 12 Reactive power Qsh & Qsh_ref of STATCOM.

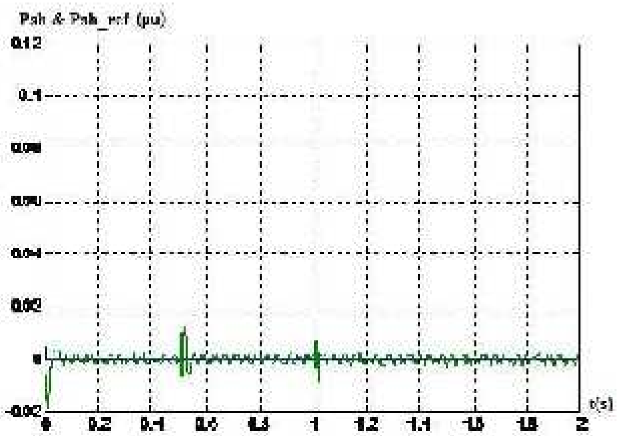

Fig. 13 Active power Psh & Psh_ref of STATCOM.

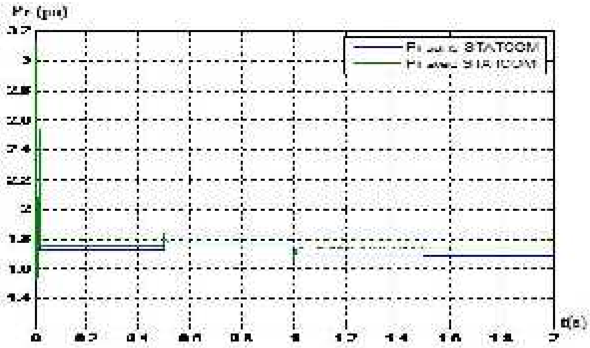

Fig. 14 Active power transported by line without & with STATCOM.

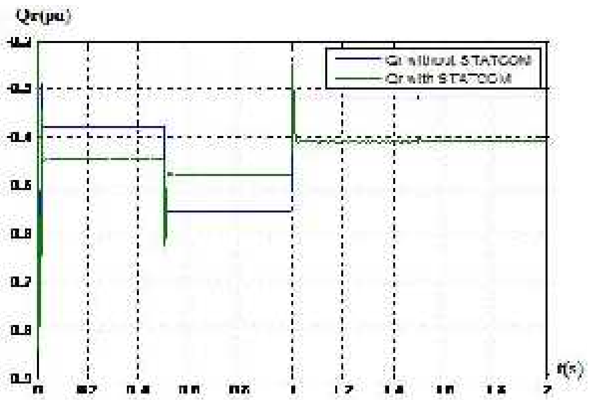

Fig. 15 Reactive power transported by line without & with STATCOM.

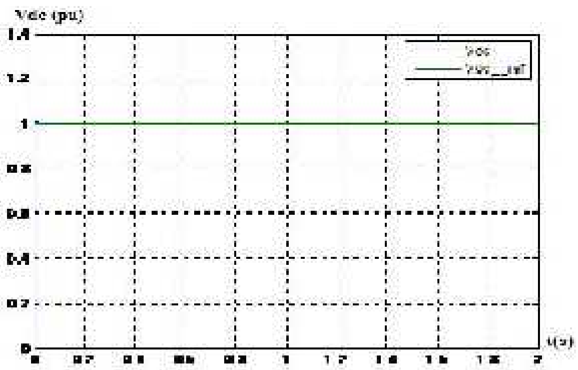

Fig.16. Continuous voltage (VDC) regulated & (VDC_ref).

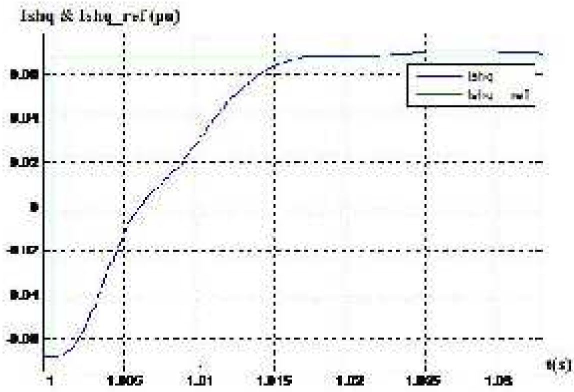

Fig. 17 STATCOM response time.

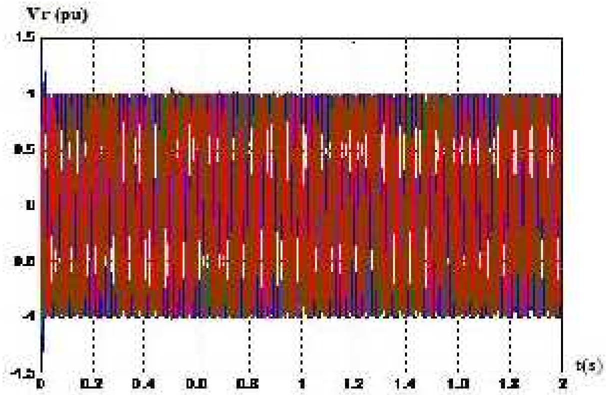

Fig. 18 The reception voltage compensated (Vr).

C. *Interpretation Of Results Obtained*

1) *STATCOM voltage (Vsh)*

Fig. 9, show that the Vshq component is null (Vshq=0), while the Vshd component is varied in time.

when Vshd is in inductive mode and higher than Vr, that determine the positive direction of Ishq injected by STATCOM in power grid (Fig. 11), which indicates that the compensator delivers a reactive power towards the network (Fig. 12); (Intervals: [0s-0.5s], [1s-1.5s], [1.5-2s]). In addition when Vshd is lower than Vr, STATCOM absorbs an Ishq current of negative direction (Fig. 11), which explains the absorption of reactive since the network by STATCOM (Fig. 12); (Interval [0.5-1s]).

2) *STATCOM current (Ish)*

Of Fig. 10 & 11, we note that the currents (Ishd=0) and Ishq follow their reference, what validates the good performance of PI regulators used.

3) *Active & reactive powers of STATCOM (Psh & Qsh)*

Into the interval [0-0.5s], STATCOM injects a minor amount of reactive power Qsh about (0.082 pu) for raising the Vr voltage.

In the interval [0.5-1s], the load causes a rise in voltage at the reception bus Vr and makes that the STATCOM absorbs reactive energy about (0.1 pu) from the power grid to compensate the Vr voltage (Fig. 12).

At the moment (t=1s) STATCOM begins second once to inject the reactive power Qsh at the power grid and at the moment (t=1.5s) a very small waning in the voltage compared to the interval [1-1.5s] causes a very small rise in the reactive power injected, which shows the great sensitivity of STATCOM to the small variations in the power grid.

This behavior of STATCOM owing to the fact that once injects and other absorbs shows the flexibility of our device.

The exchange of active power between the power grid and STATCOM is generally null (Psh=0) (Fig. 13).

4) Powers transported by line (Pr & Qr)

The compensation effect of reactive energy is reflected directly on the transit of active power in the line (Fig. 14 & 15) above; the supply of reactive energy at the point of consumption allows a more important transit of active power in the transport line.

5) Continuous voltage VDC

According to the curve of Fig. 16, it appears very clear that the regulation block of the continuous voltage, proved its effectiveness, with the constant maintenance of the voltage in the terminal of condenser (VDC=1.0 pu).

6) Response time of STATCOM (²):

According to the Fig. 17, STATCOM has a response time shorter, about (τ=0.02s) to compensate the reactive power and to regulate the voltage of power grid as quickly as possible, which gives another characteristic of STATCOM, it is the operating speed.

VI. CONCLUSION

This paper presents the modeling and control study of the artificial intelligence STATCOM device connected in a real test network of renewable energy system (Biomass. P.S), and to test the operating of this device of which the goal is to make the network intelligent in its behavior with the various encountered problems, we used certain values of active and reactive references powers, the results obtained of simulation in SIMULINK/MATLAB interface show that the reactive power is optimized and the voltage of the bus where the STATCOM is connected is regulated. We validated the good performance and good characteristics of STATCOM such as: the great sensitivity to small variations in the power grid, the flexibility and speed of operating, that which enables us to say that the STATCOM built an intelligent grid of renewable energy system.

VII. REFERENCES

For a paper citation:

[1] Mori, S.Matsuno, K.Hasegawa, T.Ohnishi, S.Takeda, M.Seto, M.Murakami and Ishiguro F." Development of a large static var generator using self-commutated inverters for improving power system stability", *IEEE Trans. Power Syst.,1993,*vol. 8, no. 1, pp. 371–377.

[2] Song, Y.H, and Johns,A.T, " Flexible AC transmission systems (FACTS) " *IEEE London 1999*.

[3] Ghosh.A, and Ledwich.G, " Power quality enhancement using custom power devices", Kluwer Academic Publishers, Boston 2002.

[4] K.K. Sen, “STATCOM - STATIC synchronous compensator: The ory, modeling and applications”, *IEEE Trans. Power Delivery*, vol. 2, pp. 1177-1183, Feb. 1999.

For a book citation:

[5] L.Baghli, “modeling and command of the asynchronous machine”, course notes, university Henri Poincaré Nancy-1, 2005.

For a conference citation:

[6] S. Parmar Hiren, K. Vamsi Krishna, Ranjit Roy," Shunt Compensation for Power Quality Improvement using a STATCOM Controller", *Proc. of Int. Conf. on Control, Communication and Power Engineering 2010*.