Improvement of stability of a turboalternator using an advanced static VAR compensator

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Abstract - A high performance advanced static VAR compensator (ASVC) which uses a voltage source inverter is presented and analyzed in this paper. The paper shows an analysis based on the modelling of the system in the d-q axis to decouple the two components of currents for ease in control. Principles of operation, control system design and transient operating conditions are also given in this paper. The dynamic behavior of the system is further simulated using MATLAB. The results obtained have led to correct design of a robust current controller which allows instantaneous reactive power control applications.

1. INTRODUCTION

The requirement to design and operate power systems with highest degree of efficiency, security, and reliability have been central focus for the power system designer, ever since the interconnected networks came into existence. To satisfy these requirements, various advances in technology of ac power transmission have taken place in the context of efgfective control of reactive power and its compensation. Static VAR compensator (SVC's) are dynamic reactive power compensation devices. Recent developpements in the solid state VAR compensators have opened a very obtimistic door towards achieving a very efficient control of reactive power. This stems from the fact that the voltage is maintained constant within a specified level, to improve the dynamic stability of the power system and its power factor as well as correcting the phase unbalance.

In this paper, we will study the case when disturbances occur at the studied machine without affecting the behavior of the other machines that is (speed and E.M.F are constants). This means that the voltage and frequency of the network can be considered constants. The turbo-alternator is then connected to a distribution network called 'infinite'.

2. MAIN CIRCUIT CONFIGURATION OF THE ASVC (or CSERA)

The proposed static VAR compensator which uses a PWM DC-to-AC converter of the voltage source type is shown in Fig.1 The main circuit consists of a bridge inverter made up of six power IGBT's with antiparallel diodes which is connected to the three phase supply through a filter reactor, X_s of small value. A dc capacitor is connected to the dc side of the converter.

The main component of the ASVC system is a three phase PWM forced commutated voltage source inverter. The ac terminals of the inverter is connected to the ac mains through a first order low pass filter. Its function is to minimise the damping of current harmonics on utility lines. The dc side of the converter system is connected to a dc capacitor which carries the input ripple current of the inverter and is the main reactive energy storage element. The dc supply provides a constant dc voltage and the real power necessary to cover the losses of the system.

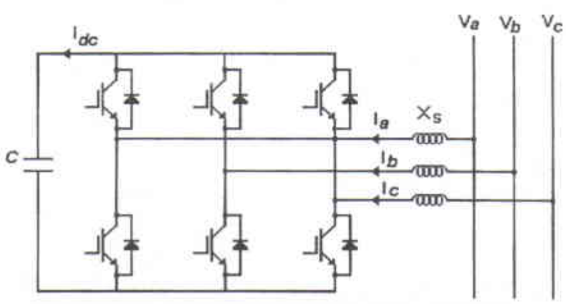

Fig.1 Main circuit configuration of the advanced static VAR compensator

In this representation, the series inductance Ls accounts for the leakage of the transformer and Rs represents the active losses of the inverter and transformer. v_{oa} and v_{sa} are the amplitude of the fundamental of the output voltage of the converter and phase voltage of the supply, respectively

3. MATHEMATICAL MODEL OF THE NETWORK-CSERA

Based on Fig.3 we can establish the following equations :

- Machine side :

$$\begin{cases} V_d = -p\Phi_d - \omega\Phi_q - \Phi_q p\delta' - R_a i_{dA} \\ V_q = -p\Phi_q + \omega\Phi_d + \Phi_d p\delta' - R_a i_{qA} \end{cases} \quad (1)$$

- Network side

$$\begin{cases} V_{rd} = V_d - R.i_{dL} - Lpi_{dL} - L\omega.i_{qL} - L.i_{qL}p\delta' \\ V_{rq} = V_q - R.i_{qL} - Lpi_{qL} + L\omega.i_{dL} + L.i_{dL}p\delta' \end{cases} \quad (2)$$

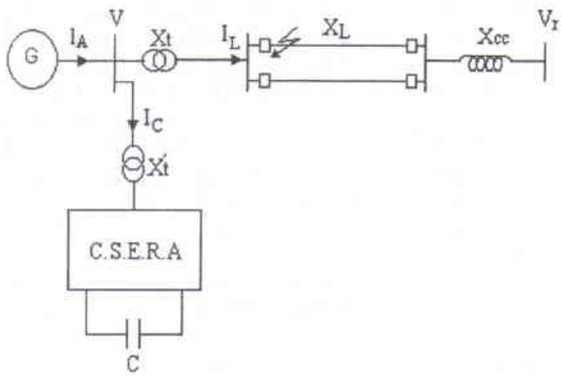

Fig 2 Schematic diagram of the network-ASVC

- CSERA (or ASVC) side :

$$\begin{cases} V_{cd} = V_d - R_s.i_{dC} - L_s pi_{dC} - L_s\omega.i_{qC} \\ V_{cq} = V_q - R_s.i_{qC} - L_s pi_{qC} + L_s\omega.i_{dC} \end{cases} \quad (3)$$

$$\begin{cases} pi_{dc} = \dfrac{1}{L_s}\left[V_d - V_{Cd} - R_s.i_{dC} - L_s\omega.i_{qC}\right] \\ pi_{qc} = \dfrac{1}{L_s}\left[V_q - V_{Cq} - R_s.i_{qC} + L_s\omega.i_{dC}\right] \end{cases} \quad (4)$$

Avec :

$$\begin{aligned} i_{dL} &= i_{dA} - i_{dC} \\ i_{qL} &= i_{qA} - i_{qC} \end{aligned} \quad (5)$$

By putting (5) into (2) we get :

$$\begin{aligned} V_{rd} &= V_d - R(i_{dA} - .i_{dC}) - Lp(i_{dA} - i_{dC}) \\ &\quad - L\omega.(i_{qA} - i_{qC}) - L.(i_{qA} - i_{qC})p\delta' \\ V_{rq} &= V_q - R(.i_{qA} - .i_{qC}) - Lp.i_{qA} + Lp.i_{qC} \\ &\quad - L\omega.(i_{dA} - i_{dC}) - L.(i_{dA} - i_{dC})p\delta' \end{aligned} \quad (6)$$

By developping (6) and replacing by (4) and after a tedious calculation we obtain the complete model of the infinite busbar network with CSERA (or ASVC) :

$$p\,i_{dA} = \left[\begin{array}{l} \sqrt{2}\,v_r \sin\delta' - \left(\xi\left(R_a + \dfrac{B}{\tau'_{do}} + \dfrac{D}{\tau''_{do}}\right) + R\right) i_{dA} \\ + \xi\left(-\omega'\,\Phi_{q2} + \dfrac{\Phi_{d2}}{\tau'_{do}} + \dfrac{\Phi_{d3}}{\tau''_{do}}\right) \\ -\omega'(L + \xi F) i_{qA} - \xi\left(\dfrac{C}{\tau'_{do}} + \dfrac{E}{\tau''_{do}}\right) v_f + \lambda i_{dC} \\ -\dfrac{L}{L_s} v_{Cd} \end{array}\right] / (L + \xi A)$$

(7)

$$p\,i_{qA} = \left[\begin{array}{l} -\sqrt{2}\,v_r \cos\delta' - \left(\xi\left(R_a + \dfrac{G}{\tau''_{qo}}\right) + R\right) i_{qA} \\ + \xi\left(\omega'\,\Phi_{d2} + \omega'\,\Phi_{d3} + \dfrac{\Phi_{q2}}{\tau''_{qo}}\right) \\ + \omega'(L + \xi A) i_{dA} + \lambda i_{qC} - \dfrac{L}{L_s} v_{Cq} \end{array}\right] / (L + \xi F) \quad (8)$$

$$p\Phi_{d2} = \left(B i_d + C v_f - \Phi_{d2}\right) / \tau'_{do} \quad (9)$$

$$p\Phi_{d3} = \left(D i_d + E v_f - \Phi_{d3}\right) / \tau''_{do} \quad (10)$$

$$p\Phi_{q2} = \left(G i_q - \Phi_{q2}\right) / \tau''_{qo} \quad (11)$$

$$p\delta' = \omega' - \omega \quad (12)$$

$$p\omega' = \left(C_m - C_e\right) / J \quad (13)$$

with :

$$\xi = \left(1 + \frac{L}{L_s}\right) \text{ et } \lambda = \left(R - L\frac{R_s}{L_s}\right)$$

The model of the CSERA is established by taking the voltage of the busbar as a reference hence we get :

$$v_{C,dqo} = K\,S\,v_{dc} = m\begin{bmatrix} \sin\alpha \\ \cos\alpha \\ 0 \end{bmatrix} v_{dc} \quad (14)$$

With :

$$S = \begin{bmatrix} s_a \\ s_b \\ s_c \end{bmatrix} = 2/3m\begin{bmatrix} \sin(\omega t + \alpha) \\ \sin(\omega t + \alpha - 2\pi/3) \\ \sin(\omega t + \alpha + 2\pi/3) \end{bmatrix} \quad (15)$$

The current of the DC side capacitor is given by:

In the Park axis :

$$i_{dc} = S^T K^{-1} i_{qdo} = m\left(i_q \sin\alpha + i_d \cos\alpha\right) \quad (17)$$

hence the DC side voltage is given by :

$$v_{dC} = \frac{m}{pC}(i_{qC} \sin\alpha + i_{dC} \cos\alpha) \quad (18)$$

Thus the model of the CSERA is given as :

$$p\, i_{dC} = \left(- R_s i_{dC} - \omega' L_s i_{qC} - m v_{dC} \sin(\alpha_c) + v_d\right)/ L_s \quad (19)$$

$$p\, i_{qC} = \left(- R_s i_{qC} - \omega' L_s i_{dC} - m v_{dC} \cos(\alpha_c) + v_q\right)/ L_s \quad (20)$$

$$p v_{dC} = m\left(i_{dC} \sin(\alpha_c) + i_{qC} \cos(\alpha_c)\right)/ C \quad (21)$$

With : $\alpha_c = \alpha + \delta$, since we have taken the voltage of the busbar as a reference for the CSERA, i.e on the the phasor diagram the voltages of the CSERA are synchronised to those of the busbar considered.

Hence our model will be made up of ten differential equations, seven for the alternator and three for the CSERA.

For the initialisation of the system, we take for the machine the same conditions given in [], and for the CSERA the following initial conditions:

$$v_{dC} = \frac{\sqrt{2}\, v}{m}$$

$$i_{dC} = 0$$

$$i_{qC} = 0$$

4. PROPOSED CONTROL STRATEGY

Fig. 3 shows the main principles of the proposed control of the CSERA,

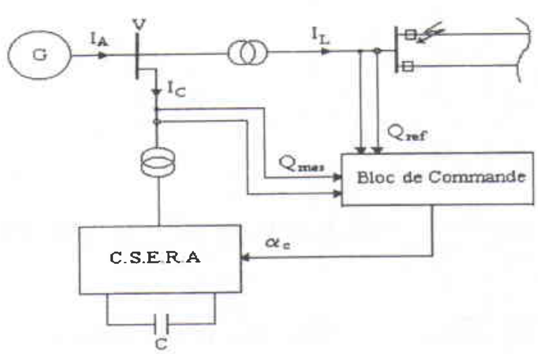

Fig.3 Main circuit of the control strategy

the reactive power demanded is always compensated partly by the capacitive reactive power generated by the a puissance réactive demandée CSERA, this method of compensation help ease the alternator and increase the security boundary for the heating of the rotor circuit.

The details of the control block diagram are given by Fig. 4.

The reactive power demanded being inductive must be compensated by a capacitive reactive power generated by the CSERA.

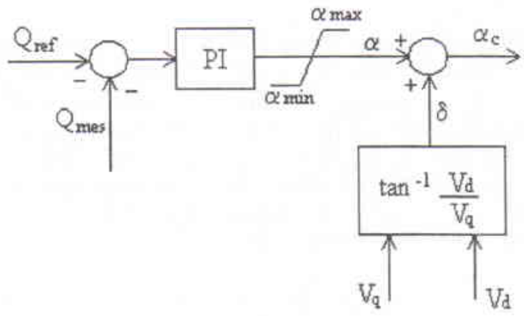

Fig. 4 Details of the control block

This compensation is controlled by a PI regulator which synthesise the control variable α which is added to the angle δ that is necessary for synchronising with the voltages of the busbar considered. This sum being α_c is applied to the CSERA to generate the necessary reactive power, the control variable α being limited by two upper and lower levels will allow to preserve the stability of the compensator.

If we suppose that the refrence is always the voltage of the busbar connected to the CSERA, the transfer fonction relating the reactive power to the control angle α is given by :

$$G(p) = \frac{q(p)}{\alpha(p)} = \frac{\sqrt{2}\, V^2 \left[\frac{p^2}{L_s} + p\frac{R_s}{L_s} + \frac{m^2}{L_s^2 C}\right]}{p^3 + 2p^2\frac{R_s}{L_s} + p\left(\omega^2 + \frac{R_s^2}{L_s^2} + \frac{m^2}{L_s C}\right) + m^2\frac{R_s}{L_s^2 C}}$$

see [] for the demonstration.

As for the PI regulator, it is designed similarly as given in [] with the same constant of time of integration, but the voltage level will change.

Hence by using the root locus method, the parameters of the regulator are given as follows :

$$K_p = 2.3\,10^{-9}$$

$$K_I = 7.7\,10^{-7}$$

5. SIMULATION RESULTS

To analyse the performance of the stability of the turbo-alternator with CSERA, a series of simulation tests have been carried out, by taking the compensator parameters as follows:

AC side : R_s = 1□ , L_s = 5 mH

DC side : C = 500 □F.

The results obtained of the turboalternator and CSERA are compared with those of the turboalternator alone.

Fig. 5 represents the variation of the load angle of the turboalternator group with and without compensation after clearing the fault of *0.08 s*, we notice that the response with the compensation is more damped and the load angle is smaller than that of the turboalternator without compensation.

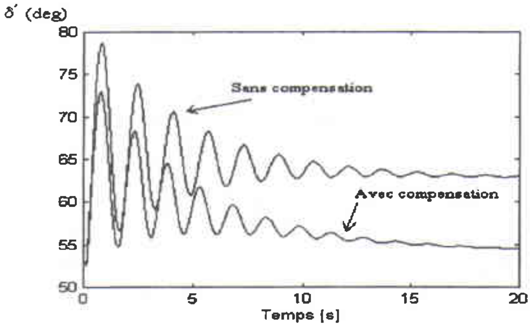

Fig.5 Load angle variation

Fig. 6 represents the variation of the angular speed centered of the turboalternator with and without compensation after clearing the fault of *0.08 s*, we notice that the response (with compensation) is more damped than wihout compensation.

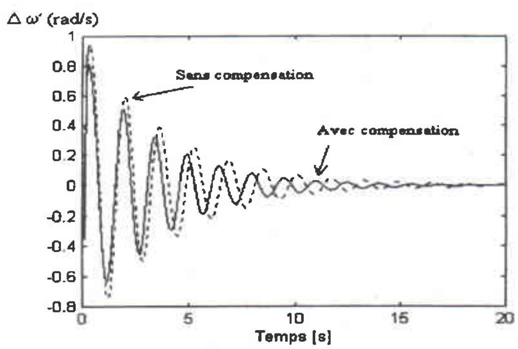

Fig. 6 Variation of the angular speed

Fig. 7 represents the variation of the voltage of the first busbar with and without compensation, the voltage of the system compensated is higher than that without compensation, this is due to the decrease in reactive power in the lines by the CSERA which genrates a capacitive reactive current which annuls a part of the inductive reactive current absorbed by the line.

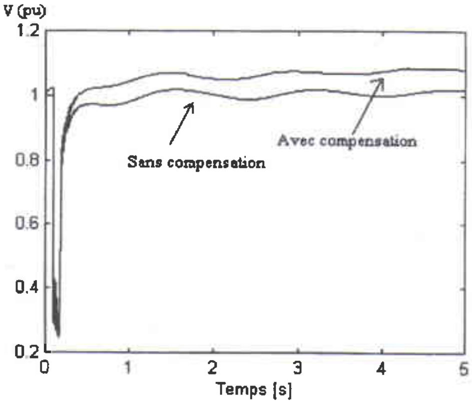

Fig. 7 Variation of the voltage of the first busbar

Fig. 8 shows the variation of the load angle of the turboalternator with and without compensation after the clearing of the fault of *0.3 s* which is the critical time for clearing the fault for the alternator without compensation. We notice that the introduction of the CSERA has allowed to improve this clearing time and to increase the level of stability of the system.

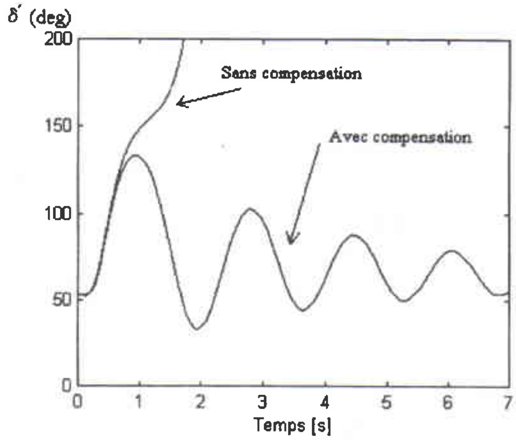

Fig. 8 Variation of the load angle of the turboalternator

Fig. 9 shows the phasor plane of the system without compensation.

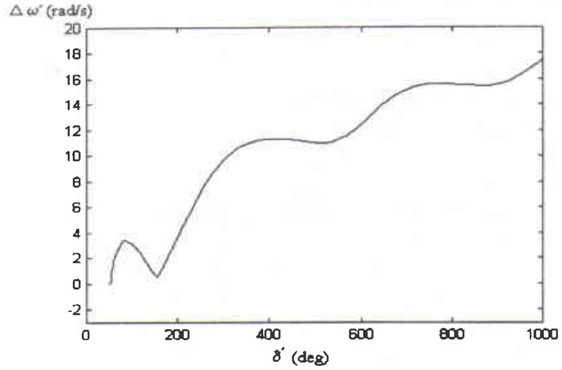

Fig. 9 Phasar plane of the system without compensation

CONCLUSION

In this paper a new approach to improve the stability of a turboalternator using a static VAR compensator has been presented. The proposed system has been analyzed and a fast current controller been implemented for reactive power applications. The mathematical model derived and the transient simulated results obtained are included to confirm the applicability of the proposed control scheme.

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