AN ADAPTIVE STATCOM BASED STABILIZER FOR DAMPING GENERATOR OSCILLATIONS

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Key words :*STATCOM - adaptive control - self-tuning regulator - power oscillation damping (POD).*

ABSTRACT

An adaptive STATCOM controller utilizing the least squares identification methods and pole placement control strategy is proposed in this paper. The adaptive controller can provide better damping to the action of power oscillation damping under varying operating conditions than conventional fixed parameters STATCOM based stabilizer. Non-Linear simulation of the system following a three-phase fault is performed to express the robustness of the controller.

I. INTRODUCTION

Shunt connected static VAR compensator has been used for many applications such has voltage regulator, increasing transmission capacity and damping power oscillations [1-2]. With appearing high power GTO's based electronic converters have made it possible to generate or absorb reactive power without large capacitors and reactors. [3-4]. One of these converter based FACTS is static compensator (STATCOM). It has two controllers one of them is AC voltage regulator. The action of this controller is voltage regulation of the bus bar that STATCOM is connected. The difference between measured voltage and reference voltage through controller causes to inject or absorb reactive power to or from the system and regulation of the bus bar voltage. The second controller is DC voltage regulator which makes it possible to exchange active power with power system during oscillations. it has been shown that this controller provides the power system with negative damping torque.[6]. For designing the AC and DC controllers of STATCOM the linearized model of the power system in an operating condition proposed, then with the help of phase compensation or damping torque analysis the parameters of controller is adapted [6-7]. However the parameters of the controllers are determined under a particular operating condition and are therefore a compromise between the best values for light and heavy loading conditions. Under certain circumstances a set of gain settings that are suitable for one loading condition may become completely unsatisfactory for another. In order to have best controller gains over a wide range of loading conditions and to achieve better dynamic responses when sever disturbances occur in the system the Parameters of the controller must be adapted on line based on measurement of the input and the output of the system [3]. In this paper an example power system is presented with computation and simulation results to conform that the adaptive controller can damp the oscillations in power system better than fixed parameters STATCOM controller and under different operating conditions .

II. MATHEMATICAL MODEL OF POWER SYSTEM

In this study a single machine connected through a double circuit transmission line to an infinite bus bar power system is considered. The system has a STATCOM in the middle of generator bus bar and infinite bus bar. Fig (1). The synchronous generator is described by third order nonlinear equations [7], [8]. The excitation system is shown in Fig. 2.In this figure E_{fd} is proportional to the field voltage and V_{st} is the stabilizing signal, V_{ref} is the reference voltage and V_{meas} is measured voltage of V_t.

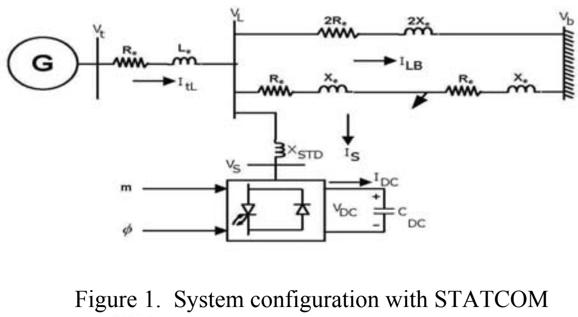

Figure 1. System configuration with STATCOM

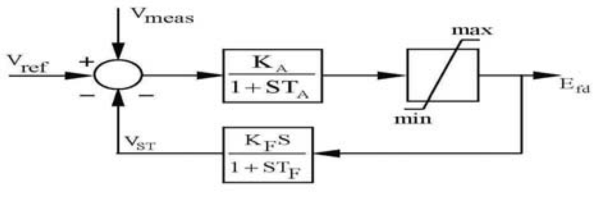

Figure 2. Block diagram of the excitation system

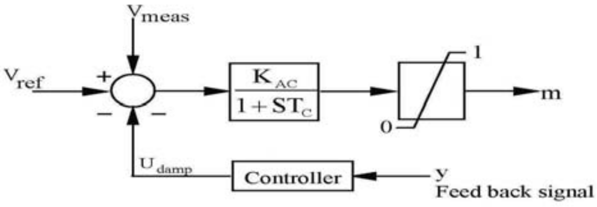

Figure 3-a. STATCOM AC voltage regulator

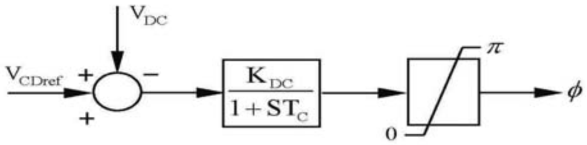

Figure 3-b. STATCOM DC voltage regulator

The STATCOM consists of a step down transformer with a leakage reactance X_{STD} , a three phase GTO and PWM based voltage source converter (VSC) and a dc capacitor. The VSC generates a controllable Ac voltage source $\overline{V}_s = V_s$ Sin (ωt- φ) = k.m.sin (ωt- φ) which m is modulation index and k is the ratio between the Ac and Dc voltage depending on the converter structure. In this paper the value of k is $\sqrt{\frac{3}{8}}$. The difference between amplitudes of V_S and V_L causes reactive power changes and the difference between the angles of voltages changes the active power of the STATCOM. Thus the reactive and active power changes can be controlled by the magnitude V_S and phase angle φ . STATCOM is installed for controlling Ac bus voltage and damping of oscillations. The input signals to the STATCOM are modulation index m and phase angle φ as shown in fig (1). The control system of AC and Dc voltage regulators with U_{damp} as damping signal is shown in fig 3-a, 3-b. [6], [7].In the computer simulation of system dynamic responses under severe disturbance conditions a set of non linear equations describing the behaviour of the generator and STATCOM are required. The equations are given in Appendix A. [6], [2] and [8]. The parameters of AVR, STSTCOM and power system are also given in Appendix B. IF the necessary equations are linearized around the nominal loading condition the complete state space equations of the system without the damping controller can be written in the form of:

$$\dot{X} = AX + BU \qquad y = CX \qquad \textbf{(1)}$$

$$X^T = [\Delta\delta \ \Delta\omega \ \Delta E'_q \Delta V_{DC} \ \Delta E_{fd} \ \Delta m \ \Delta\varphi \ \Delta V_{st}]^T$$

Where: $y = \Delta\omega$ and $u = u_{damp}$

u_{damp} is the damping signal and output of the controller. For damping of oscillations a controller must be designed, which obtains $\Delta\omega$ as y and generates u_{damp} as the input control signal. This block diagram can be shown in fig (4).For designing controller if we choose the transfer function of the controller as

$$H(S) = k\frac{ST_W}{1+ST_W}.\frac{1+T_2S}{1+T_1S}.\frac{1+T_4S}{1+T_3S} \qquad (2)$$

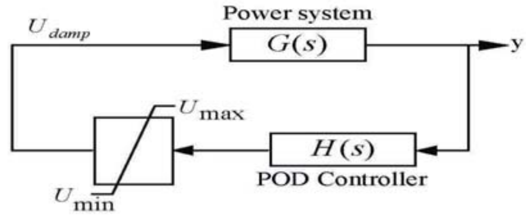

Figure 4. Block diagram of the system with controller.

The equation (1) can be written in the form of:

$X(S) = (SI - A)^{-1} B U(S)$
$U(S) = H(S) Y(S)$ (3)
$X(S) = (SI-A)^{-1} B H(S) CX(S)$
$\det [I-(SI-A)^{-1} B H(S) C] = 0$

For this system with operating condition of the system as P = 1 pu, Q= 0.25 pu and with parameters given in Appendix B the open loop eginvalues are obtained and the local mode that have poor damping are $\lambda_0 = -0.11 \pm j4.26$ if we want to design a controller that moves real part of the eginvalue $\lambda_\circ$ without changing the frequency of oscillation then for damping ratio 0.3 the closed loop poles will be $\lambda_{1,2} = -1.38 \pm j4.79$. With phase compensation method we will obtain T_W = 10, K_S= 10, T_1= 0.9, T_2= 0.1, T_3= 0.9, T_4= 0.2

The control input is injected to Ac voltage regulator for effective damping [6]. IF the loading condition becomes different from the nominal condition the closed loop poles that designed would shift to other places. Under these conditions the dynamic responses is not good as that which was designed. In order to prevent the system egien values from shifting from the specified locations when the system is subjected to load changes or severe disturbances a self-tuning controller whose parameters adjusted on line according to system operating conditions must be employed

III. ADAPTIVE FEEDBACK CONTROLLER DESIGN

In self-tuning control the system to be controlled is represented by an equivalent model and the model parameters are identified in every sampling interval [2, 3]. In this example a third order model of system as equation (4) is assumed.

$y(k)-a_1y(k-1)-a_2y(k-2)-a_3y(k-3)=b_1u(k-1)+b_2u(k-2)+b_3u(k-3)$ (4)

Where y`s are output samples and u`s are input samples, a_1, a_2, a_3, b_1, b_2, b_3 are coefficients of the model which can be estimated by using the recursive least squares (RLS) identification method with variable forgetting factor. Equation (4) can be written in the form of:

$A(q)\, y(k) = B(q)\, u(k)$ (5-a)

$A(q) = 1+a_1q^{-1}+a_2q^{-2}+a_3q^{-3}$, $B(q) = b_1q^{-1}+b_2q^{-2}$ (5-b)

U is control signal and y is measured out put signal and q is shift operator. In pole placement method if the open loop pulse transfer function of the processes be $\frac{B(q)}{A(q)}$ the problem is finding a control low of the form Equation (6) such that the closed loop system has input - output relation given by the desired closed loop pulse transfer function of $H_m(q) = \frac{B_m(q)}{A_m(q)}$ which $A_m(q)$ is the desired characteristic equation. A block diagram of the closed loop system is shown in fig. 5. The input-output relation for the closed loop system is obtained by eliminating u between equation (5) and equation (6)

$R(q)\, u = T(q)\, U_c - S(q)\, y$ (6)

$y = \frac{BT}{AR+BS} U_c$ (7) , $\frac{BT}{AR+BS} = \frac{B_m}{A_m} = H_m$ (8)

U_c is reference input which in this example because the object is damping $\Delta\omega$ and the steady state value of $\Delta\omega$ is zero then U_c is equal to $\Delta\omega_{ref}$ and the value of it is zero. u is damping control input to the system and y is feed back signal $\Delta\omega$. H_m is the desired closed loop pulse transfer function. The block diagram of the power system with adaptive damping controller is shown in fig. 5.

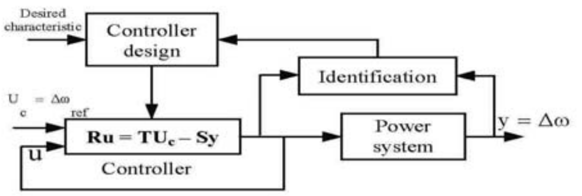

Figure 5. Block diagram of Self Tuning Regulator.

In equation (6) R (q), S (q), T (q) are polynomials of the controller which can be selected as:

$R(q^{-1}) = r_0 + r_1q^{-1} + r_2q^{-2}$
$T(q^{-1}) = t_0 + t_1q^{-1}$ (9)
$S(q^{-1}) = s_0 + s_1q^{-1} + s_2q^{-2}$

With these parameters of the controller the equation (6) can be written as:

$(r_0 + r_1q^{-1} + r_2q^{-2})U(k) = (t_0 + t_1q^{-1})\, U_c(k) - (s_0 + s_1q^{-1} + s_2q^{-2})\, y(k)$

$U(k) = \frac{1}{r_0}\left[t_0 U_c(k) + t_1 U_c(k-1) - s_0 y(k) - s_1 y(k-1) - s_2 y(k-2) \right]$ (10)

Equation (10) shows that the control signal in time t can be obtained from y (k), y (k-1), y (k-2) and $U_c(k)$, $U_c(k-1)$. For obtaining parameters of controller first the desired closed loop pulse transfer function $H_m(q) = \frac{B_m(q)}{A_m(q)}$ and desired characteristic equation with closed loop poles is selected then the parameters of controller r_0 , r_1, r_2, t_0 , t_1 , s_0 , s_1, s_2 are calculated by solving the following Diophantine equation:

$A(q^{-1})\, R(q^{-1}) + B(q^{-1})\, S(q^{-1}) = A_m(q^{-1})$ (11)

$B(q^{-1})\, T(q^{-1}) + F(q^{-1})\, P(q^{-1}) = A_m(q^{-1})$ (12)

In equation (12) $F(q^{-1})$ depends on reference input and for step reference input $F(q^{-1}) = 1 - q^{-1}$, $P(q^{-1})$ is any appropriate polynomial. For obtaining control signal in every sampling time the parameters of the power system ($A(q^{-1})$, $B(q^{-1})$) must be estimated with the recursive least squares method then with the identified parameters for accessing the desired damping ratio and other control characteristics the control signal is computed from solving equations (11), (12) and is injected to the system .

IV. RESULTS AND DISCUSSION

In order to illustrate the effectiveness of the adaptive controller under different operating conditions a nonlinear simulation with all non-linearity is performed. Dynamic responses of the generator to a 4 cycle three phase fault which occurs at the mid point of the transmission lines are shown in fig 6-a with no damping controller and fig 6-b with fixed parameters and fig 6-c with self tuning regulator for p=1 pu, Q = 0.25 pu loading condition. In adaptive controller the damping ratio is like that of fig 6-b and it can be observed from these figures that adaptive controller can provide better damping characteristic than fixed parameters controller. in fig (9) loading condition of generator is changed to P = 1.2 pu, Q = 0.25 pu this figure shows that the dynamic performance of the self tuning controller is less sensitive to the changes in generator loading than the fixed parameters controller. In fig (7) out put of control signal and the parameters of the system are also shown. In fig (8) it can be seen that the parameters of the power system are identified during the fault and the control input is computed for accessing the desired characteristics of the system.

V. CONCLUSION

The present paper introduces an application for adaptive control theory to design a power system STATCOM based stabilizer for damping power system oscillations. A self-tuning controller is more effective than the fixed gain controller when the operating condition is changed. The controller receives output of the system ($\Delta\omega$) and generates control out put signal (U_{damp}) to the STAT COM to set desired damping.

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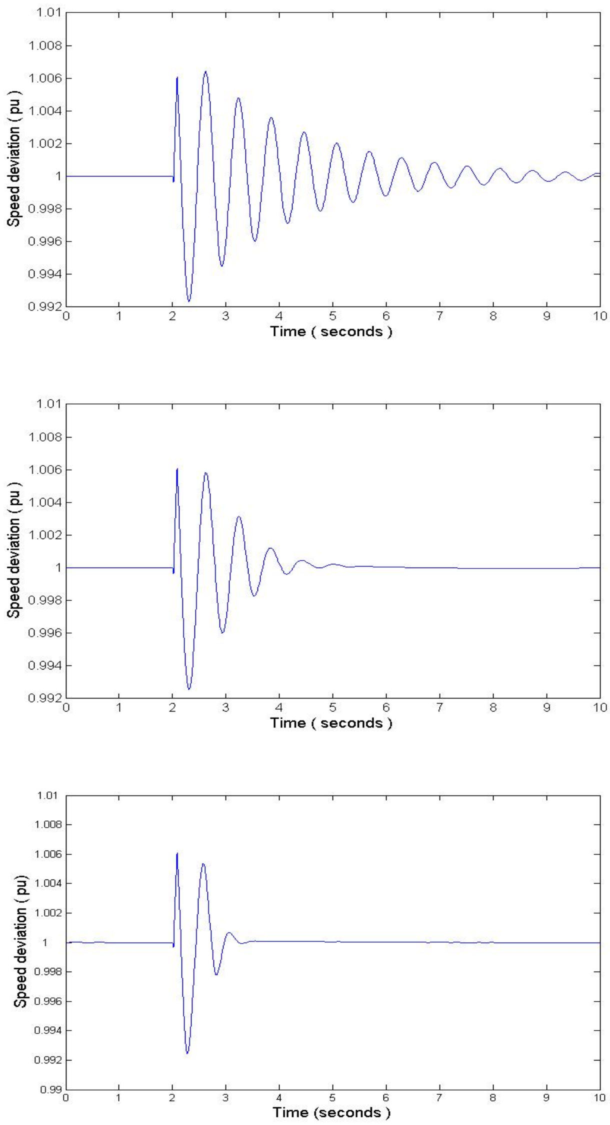

Fig. 6 Angular speed variations of generator for loading condition p = 1 pu (a) Without controller (b) Fixed parameters controller (c) Adaptive controller

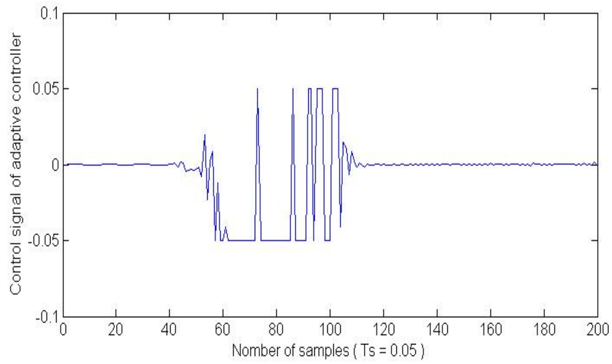

Fig. 7 control signal of the adaptive power oscillation-damping controller P=1 pu

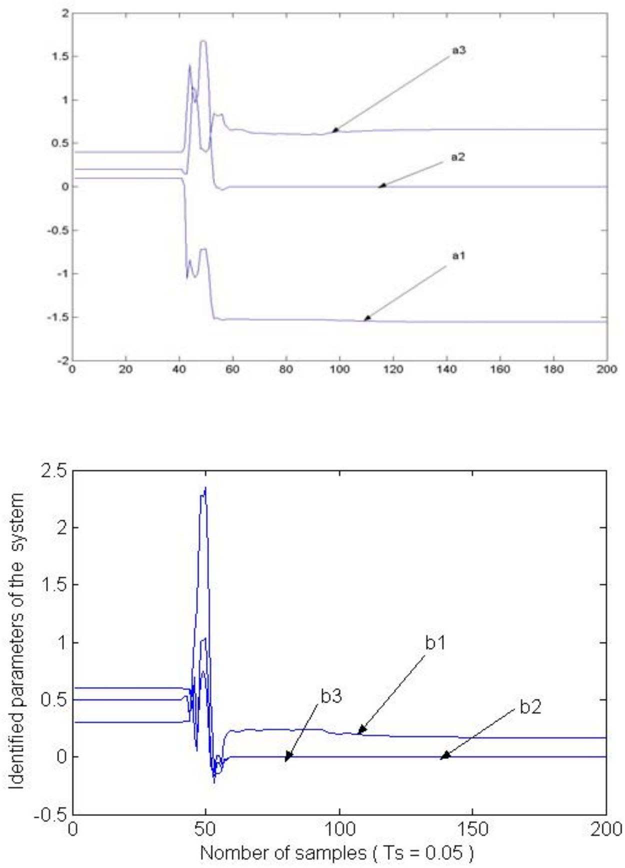

Fig. 8 - Identified parameters of the power system p=1 pu

$$G(z) = \frac{b_1 z^{-1} + b_2 z^{-2} + b_3 z^{-3}}{1 + a_1 z^{-1} + a_2 z^{-2} + a_3 z^{-3}}$$

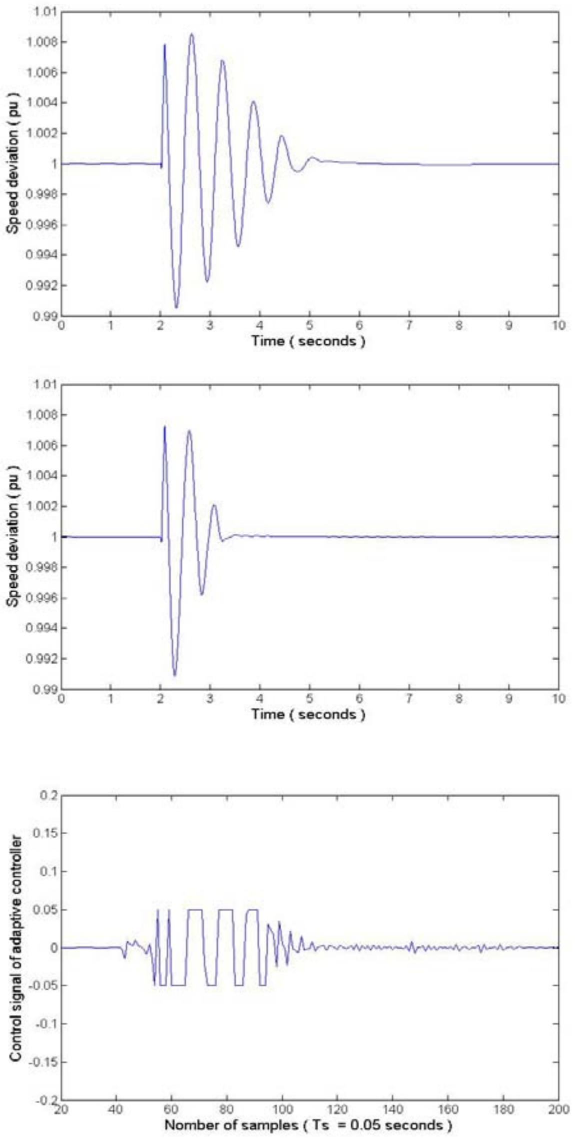

Fig. 9 Angular speed variations of generator for loading condition $p = 1.2$ pu a) Fixed parameters controller (b) Adaptive controller **(c)** control signal of the adaptive power oscillation damping controller

Appendix A

The necessary equations for accessing linearized model of the power system of fig. (1) Installed with the STATCOM are:

$$\overline{V}_s = m.k.V_{DC} < \varphi$$

$$\overline{I}_{tl} = \overline{I}_S + \overline{I}_{LB}$$

$$E_q = E'_q + (x_d - x'_d)I_{tld}$$

$$\Delta\omega^o = \frac{1}{2H}(\Delta P_m - \Delta p_e - D\Delta\omega)$$

$$P_e = E'_q I_{tlq} + (x_q - x'_d)I_{tld}I_{tlq} \qquad \text{(A1)}$$

$$E'_q = (-E_q + E_{fd})/T'_{d0}$$

$$\overset{o}{E}_{fd} = -\frac{1}{TA}E_{fd} - k_A V_{st} + k_A(V_{ref} - V_t)$$

$$T_f \overset{o}{V}_{st} = -V_{st} + k_f \overset{o}{E}_{fd} \qquad \text{(A2)}$$

$$V_t = \sqrt{(E'_q - X'_d I_{tld})^2 + (X_q I_{tlq})^2}$$

by linearizing Equations (A1) we can obtion

$$\Delta\delta^o = \omega_b \Delta\omega$$

$$\Delta \overset{o}{E'_q} = (-\Delta E_q + \Delta E_{fd})/T'_{do}$$

$$\Delta \overset{o}{E}_{fd} = -\frac{1}{T_A}\Delta E_{fd} - k_A \Delta V_{st} - k_A \Delta V_t$$

$$\Delta P_E = k_1\Delta\delta + k_2\Delta E'_q + k_{PDC}\Delta V_{DC} + k_{pm}\Delta m + k_{p\varphi}\Delta\varphi$$

$$\Delta E_q = k_4\Delta\delta + k_3\Delta E'_q + k_{qDC}\Delta V_{DC} + k_{qm}\Delta m + k_{q\varphi}\Delta\varphi$$

$$\Delta P_t = k_5\Delta\delta + k_6\Delta E'_q + k_{VDL}\Delta V_{DC} + k_{vm}\Delta m + k_{v\varphi}\Delta\varphi$$

$$\Delta \overset{o}{V}_{st} = \frac{k_F}{T_F}\Delta E_{fd} + \frac{1}{T_F}\Delta V_{st} \qquad \text{(A3)}$$

$$\Delta \overset{o}{m} = \frac{-k_{AC}B_1}{T_C}\Delta\delta - \frac{k_{AC}B_2}{T_C}\Delta E'_q \frac{k_{AC}B_{DC}}{T_C}\Delta V_{DC}$$

$$-\frac{k_{AC}B_3}{T_C}\Delta m - \frac{k_{AC}B_4}{T_C}\Delta\varphi + \frac{k_{AC}}{T_C}U_{damp}$$

$$\Delta \overset{o}{V}_{DC} = k_7\Delta\delta + k_8\Delta E'_q + k_9\Delta V_{DC} + k_{dm}\Delta m + k_{d\varphi}\Delta\varphi$$

$$\Delta V_L = B_1\Delta\delta + B_2\Delta E'_q + B_{DC}\Delta V_{DC} + B_3\Delta m + B_4\Delta\varphi$$

Equations (A3) give the complete state space model of the system as equation (1) with state variables:

$$x^T = [\Delta\delta \;\; \Delta\omega \; \Delta E'_q \;\; \Delta V_{DC} \;\; \Delta E_{fd} \;\; \Delta m \;\; \Delta\varphi \;\; \Delta V_{st}]$$

Appendix B

Parameters of the example system in PU:

$R_e = 0.02, L_e = 0.4, T_A = 0.05, k_A = 400$ $T_F = 1\text{sec}$

$k_F = 0.025$, $X_{std} = 0.08$, $T_C = 0.05$

$C_{DC} = 1$, $V_{DCO} = 1$, $V_{to} = 1$, $V_{Bo} = 1$, $V_{DCO} = 1$

$V_{Lo} = 1$, $K_{AC} = 10, K_{DC} = 1$