PERFORMANCE ANALYSIS OF A SUPERCONDUCTING GENERATOR USING DAMPING AND SYNCHRONIZING TORQUES

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ABSTRACT:

In this paper the performance of a superconducting generator (SCG) is analysed using damping and synchronizing torques. A numerical algorithm has been applied to obtain these torque components using a time response analysis of the SCG unit with a different suggested controllers. Speed governor , phase advance and proportional integral controllers have been considered and the damping contribution by each of them are shown .

1- INTRODUCTION:

Damping and synchronizing torques has been the subject of many investigations . However , only these torque components are introduced in the analysis of controlled machines [1-3]. An algorithm has been developed to calculate damping and synchronizing components from the system time response and employed to study the effect of the system parameters and loading [4] . The approach of using the damping and synchronizing torque concept in the analysis of the performance of controlled machines is very interesting , as it could provide a quantitative assessment of positive damping contribution from different control signals .

Recently , the superconducting generators are expected to replace conventional synchronous machines in modern turbogenerators , this due to their capability to supply greater base load with higher efficiency . Also , the new machine has a smaller size and weight and lower per-unit reactances compared with the conventional generators . Traditionally , the performance of controlled superconducting generators are analysed either from calculating the open and closed loop eigenvalues or from observing the time response of the system [5-9] .

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In this paper the concept of damping and synchronizing torques is used to provide a quantitative assessment of the performance of the controlled superconducting unit from its time response . Initially , the two torque components are defined and calculated for a system operating without controllers . Then , various controllers have been considered and the performance of the controlled system is analysed

2- THE SYSTEM MODEL

The system under study is shown in fig.(1) . It consists of a superconducting generating unit connected to an infinite network with a step-up transformer and a double circuit transmission line . The generator is driven by a steam turbine with fast acting electro-hydraulic governor .

The general d-q axes non-linear equations of the superconducting generator are given based on Park's representation as [10]:

$$p\psi_f = \omega_o (V_f - i_f R_f) \tag{1}$$

$$p\psi_d = \omega_o (V_d + i_d (R_a + R_e) + \psi_q) + \omega \psi_q \tag{2}$$

$$p\psi_q = \omega_o (V_q + i_q (R_a + R_e) - \psi_d) - \omega \psi_d \tag{3}$$

$$p\psi_{D1} = -\omega_o i_{D1} R_{D1} \tag{4}$$

$$p\psi_{Q1} = -\omega_o i_{Q1} R_{Q1} \tag{5}$$

$$p\psi_{D2} = -\omega_o i_{D2} R_{D2} \tag{6}$$

$$p\psi_{Q2} = -\omega_o i_{Q2} R_{Q2} \tag{7}$$

$$p\delta = \omega \tag{8}$$

$$p\omega = \frac{\omega_o}{2H}(T_m - T_e) \tag{9}$$

Where:

$$T_e = \psi_d i_q - \psi_q i_d \tag{10}$$

Where ,

$$\begin{bmatrix} \Psi_d \\ \Psi_{D1} \\ \Psi_{D2} \\ \Psi_f \end{bmatrix} = \begin{bmatrix} -(X_d + X_e) & X_{dD1} & X_{dD2} & X_{df} \\ -X_{dD1} & X_{D1} & X_{D1D2} & X_{fD1} \\ -X_{dD2} & X_{D1D2} & X_{D2} & X_{fD2} \\ -X_{df} & X_{fD1} & X_{fD2} & X_f \end{bmatrix} \begin{bmatrix} i_d \\ i_{D1} \\ i_{D2} \\ i_f \end{bmatrix} \tag{11}$$

$$\begin{bmatrix}\psi_q\\ \psi_{Q1}\\ \psi_{Q2}\end{bmatrix}=\begin{bmatrix}-(X_q+X_e) & X_{qQ1} & X_{qQ2}\\ -X_{qQ1} & X_{Q1} & X_{Q1Q2}\\ -X_{qQ2} & X_{Q1Q2} & X_{Q2}\end{bmatrix}\begin{bmatrix}i_q\\ i_{Q1}\\ i_{Q2}\end{bmatrix} \tag{12}$$

The transmission system is included in the model, replacing Ra by (R_a+R_e) and X_d and X_q by (X_d+X_e) and (X_q+X_e) respectively.

A three-stage reheat turbine model with electro-hydraulic governors is considered according to the IEEE recommendations as:

$$pY_{HP}=(G_M P_o - Y_{HP})/T_{HP} \tag{13}$$

$$pY_{RH}=(Y_{HP}-Y_{RH})/T_{RH} \tag{14}$$

$$pY_{IP}=(G_I Y_{RH}-Y_{IP})/T_{IP} \tag{15}$$

$$pY_{LP}=(Y_{IP}-Y_{LP})/T_{LP} \tag{16}$$

$$T_m = F_{HP}Y_{HP}+F_{IP}Y_{IP}+F_{LP}Y_{LP} \tag{17}$$

The electro-hydraulic governor equations are:

$$pG_M=(U_{GM}-G_M)/T_{GM} \tag{18}$$

$$p\,G_I=(U_{GI}-G_I)/T_{GI} \tag{19}$$

Where the position and rate limits are,

$0 \le G_M, G_I \le 1.0$ and $-6.7 \le p\,G_M, p\,G_I \le 6.7$ p.u/sec

3- CONTROL SYSTEMS

The superconducting generator has almost zero field winding resistance, which mean very long field circuit time constant. Therefore, the field control was not considered. Fig.(2) shows the schematic diagram of the control system

Different control systems have been considered such as conventional speed governor system (4% droop), a phase advance network with a transfer function of [8,10]:

$$\text{Gph.a}(s) = \mathbf{G}\,\frac{1+T_1 S}{1+T_2 S} \tag{20}$$

where T_1 and T_2 are the time constants of the network and G is the gain. These parameters were adjusted to obtain the best performance (T_1=0.5 ,T_2=0.01 and G=0.1) . Also, a proportional integral controller which previously designed in Ref.[9] is considered with transfer function of the form :

$$G_{PI}(S) = \frac{s}{1+sT_w}[K_p + \frac{K_I}{s}] \tag{21}$$

where K_p , K_I and T_w are proportional , integral gains and washout time constant respectively .

4- DAMPING AND SYNCHRONIZING TORQUE

Damping and synchronizing torques may be defined as follows [4] : at any given frequency of oscillation there will exist a breaking electrical torque on the rotor of the same frequency and is proportional to the amplitude of oscillation . This torque can be broken into two components, one in time phase with the rotor angle called " synchronizing torque " and the other is in time phase with the rotor speed called " damping torque " .

$$\Delta T_e = \Delta T_s + \Delta T_D \tag{22}$$

4-1 Damping And Synchronizing Coefficients :

Following any small disturbance the change in electrical torque can be written as [4] :

$$\Delta T_e = K_D \Delta\omega + K_S \Delta\delta \tag{23}$$

where, K_D and Ks are damping and synchronizing torque coefficients respectively . These coefficients must be positive for the stable operation [11]. The error between the electrical torque deviation and that obtained by summing both torque components from equation (23) can be defined in the time domain as:

$$E(t) = \Delta T_e(t) - (K_S \Delta\delta(t) + K_D \Delta\omega(t)) \tag{24}$$

The summation of errors squared over the oscillation period (t) can be obtained and using the least-square technique to minimize the squared errors , leads to the following algorithm :

$$\sum^{N} \Delta T_e(t).\Delta\delta(t) = K_S \sum^{N} [\Delta\delta(t)]^2 + K_D \sum^{N} \Delta\omega(t).\Delta\delta(t) \tag{25}$$

$$\sum^{N} \Delta T_e(t).\Delta\omega(t) = K_D \sum^{N} [\Delta\omega(t)]^2 + K_S \sum^{N} \Delta\omega(t).\Delta\delta(t) \tag{26}$$

Where, t=NT [N : No of iterations and T the sampling period]
Solving the above two equations the damping coefficients can be calculated.

5- *PERFORMANCE ANALYSIS*

5-1 Open Loop Analysis

The system is initially operated with no controller and subjected to 10% step-change in the governor actuating input . Fig. (3) shows the electrical torque, the torque components and coefficients for a lag and lead power factors .

Effect of operating conditions

It is of interest to know the variation of the damping and synchronizing coefficients as the operating conditions change . For the single machine infinite bus system , the two possibilities are the variation of system loading and the variation of tie-line impedance . Fig. (4) demonstrates the variation in the torque coefficients over a wide range of loading conditions . It can be seen that damping and synchronizing coefficients are always positive . As the power factor becomes increasingly lag the synchronizing torque becomes greater while the damping torque is decreased quite minimal . Generally , the system is operated well for lagging power factor for heavy and light loads . Also , Fig. (5) illustrates how the torque coefficients change as the tie-line impedance change. It is shown that both damping and synchronizing coefficients decrease with the increase in tie-line reactance . While , the tie-line resistance has a little effect .

Effect of machine parameters

The shielding requirements of the field winding and its supportive structure are provided by a double screen shield system . In this section we will consider the effect of the two screens resistances on torque components . Fig. (6-a) demonstrates the variation in the synchronizing and damping coefficients as the screens resistances varied . It is apparent that the screens resistances contributes both positive damping and synchronizing torques . Also , it can be seen that while the maximum damping is obtained at the nominal value of the outer screen resistance , this damping coefficient is increased as the inner screen resistance increased till certain point and if the resistance increased further the damping will decrease . To emphasize this point the system response to a step-change of the governor actuating input at two different values of R_{KD2} are shown in Fig. (6-b) . These results confirms the above concluded remark in Fig. (6-a) indicating that the inner screen resistance must be increased to the optimum value to add positive damping .

5-2 Controlled System

Many types of controllers are employed hence , the system becomes controlled system . Here , we repeat some tests to show the effect of a two different control schemes on the damping and synchronizing coefficients .

Figures (7) and (8) shows the system response to a 10% step change in the governor actuating input when controlled by the two considered control schemes. A higher damping coefficient (K_D) indicate well-damped oscillations following the disturbance. Moreover, higher values of the synchronizing torque coefficient (K_S) means fast pulling back into synchronism [11]. However, fig. (9) shows the effect of system loading on K_S and K_D for both control schemes. It is illustrated for both control schemes that the variation of the synchronizing torque coefficient is the same as that in the open loop case, while the damping torque coefficient is increased. As the reactive power reduced the damping coefficient becomes greater, then for negative reactive power (lead power factor) it decreases, eventually becoming negative. However, it can be noticed that the addition of proportional plus integral controller to the conventional speed governor provides a significant positive damping compared with that obtained using the phase advance network.

In general, the higher the real loading on the machine, the worse the damping torque is. Where as, synchronizing is poorest under lead power factor.

6- CONCLUSION

A numerical algorithm has been applied to compute damping and synchronizing torques in superconducting generators. The technique gives a quantitative assessment of damping so that the effects of all electrical parameters can be predicted.

The specific results obtained shows an accurate variation of synchronizing and damping torques with machine loading, tie-line impedance and screens resistances. Also, we can optimize some parameters to provide maximum damping.

Finally, the technique enables us to compare between different control schemes according to their positive damping additions.

Appendix

* SCG parameters

2000 MVA, 1700 MW, 3000 rpm
$X_d = X_q = 0.0453$ p.u. , $X_f = 0.541$ p.u.
$X_{KD1} = X_{KQ1} = 0.2567$ p.u. , $X_{FKD2} = 0.3398$ p.u.
$X_{af} = X_{fKD1} = X_{ad1} = X_{ad2} = X_{KD1\,KD2} = 0.237$ p.u.
$X_{aq1} = X_{aq2} = X_{KQ1\,KQ2} = 0.237$ p.u.
$R_{KD1} = R_{KQ1} = 0.01008$ p.u.
$R_a = 0.003$, RKD2 = RKQ2 = 0.00134 ,
H = 3 KWS/KVA

* Transmission System Parameters

$X_T = 0.15$ p.u. , $R_T = 0.003$ p.u.
$X_L = 0.05$ p.u. , $R_L = 0.005$ p.u.

* Parameters of Governor and Turbine

$T_{HP} = 0.1$ sec. , $F_{HP} = 0.26$, $T_{IP} = 0.3$ Sec.,

$F_{IP} = 0.42$
$T_{LP} = 0.3$ sec. , $F_{LP} = 0.32$, $T_{RH} = 10$ sec.

$T_{GM} = T_{GI} = 0.1$ sec. , $P_0 = 1.2$ p.u.

Nomenclature

H	*inertia constant* (kWs/kVA)
I	current (p.u.)
P	*differential operator*
R	resistance (p.u.)
T	torque
V	voltage (p.u.)
X	reactance (p.u.)

Greek letters

δ	rotor angle
ψ	flux linkage (p.u.)
ω	angular speed (rad/s)

Subscripts

a	armature
d,q	d and q components of stator winding
e,m	electrical, mechanical
f	field
o	steady state
fKD_1,fKQ_1	d and q mutual components between outer screen and field winding SCG
fKD_2,fKQ_2	d and q mutual components between inner screen and field winding SCG
KD_1,KQ_1	d and q components of outer screen
KD_2,KQ_2	d and q components of inner screen

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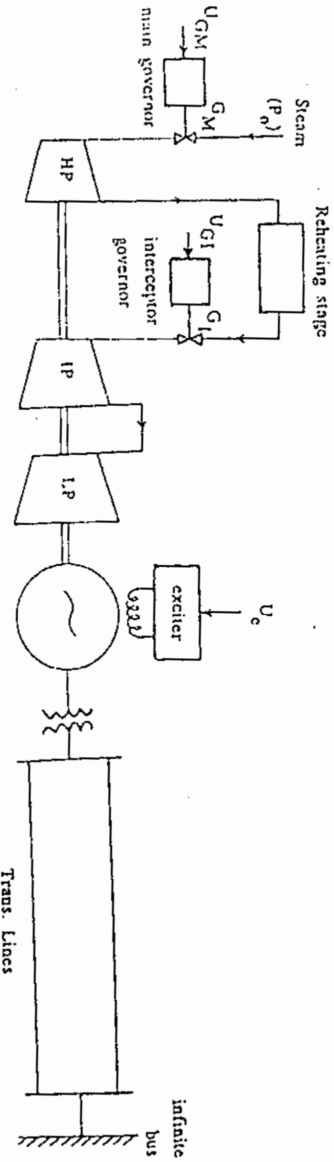


Fig.(1) Schematic diagram of a superconducting turbogenerator system.

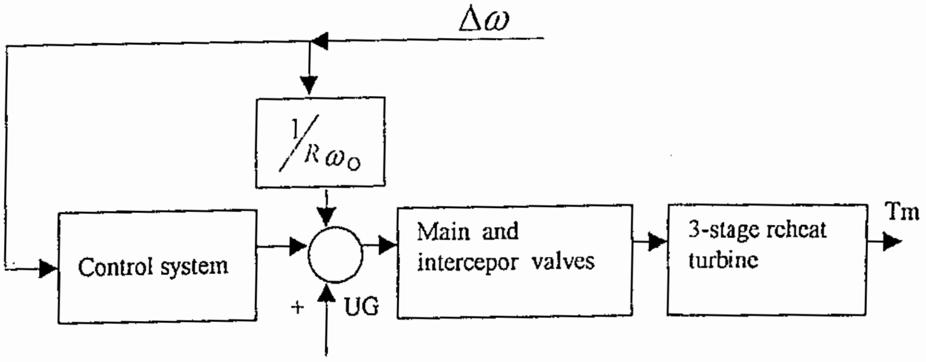
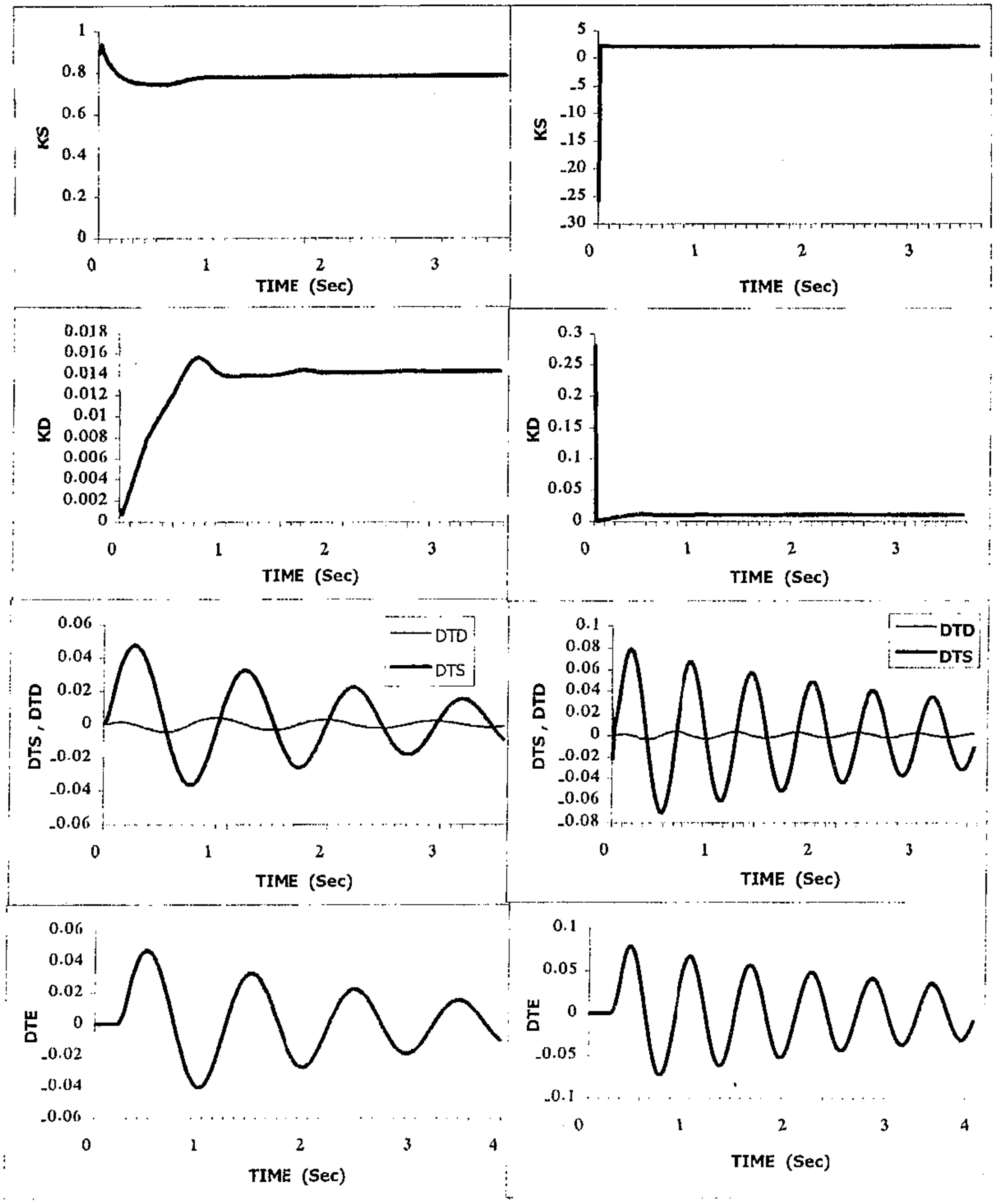


Fig. (2) Schematic diagram of the control system.



(a) Lead P.F **(b) Lag P.F**

Fig.(3) SCG response to 10% step change in the reference input (UGR) for 100 ms

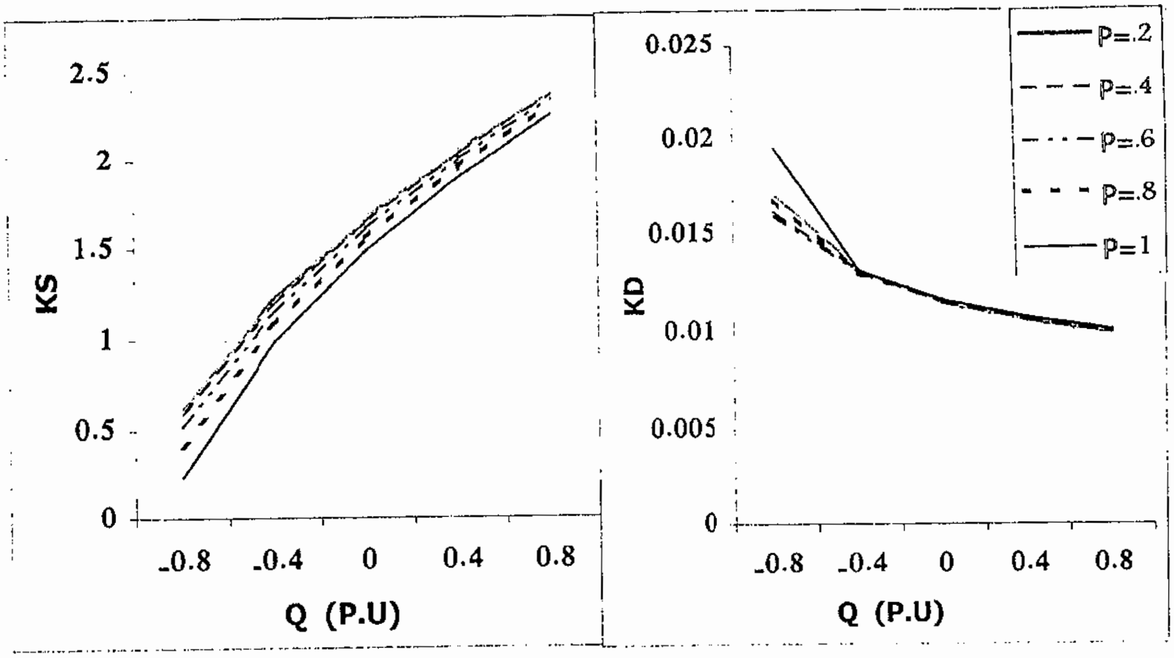


Fig.(4) Effect of system loading on Ks and KD

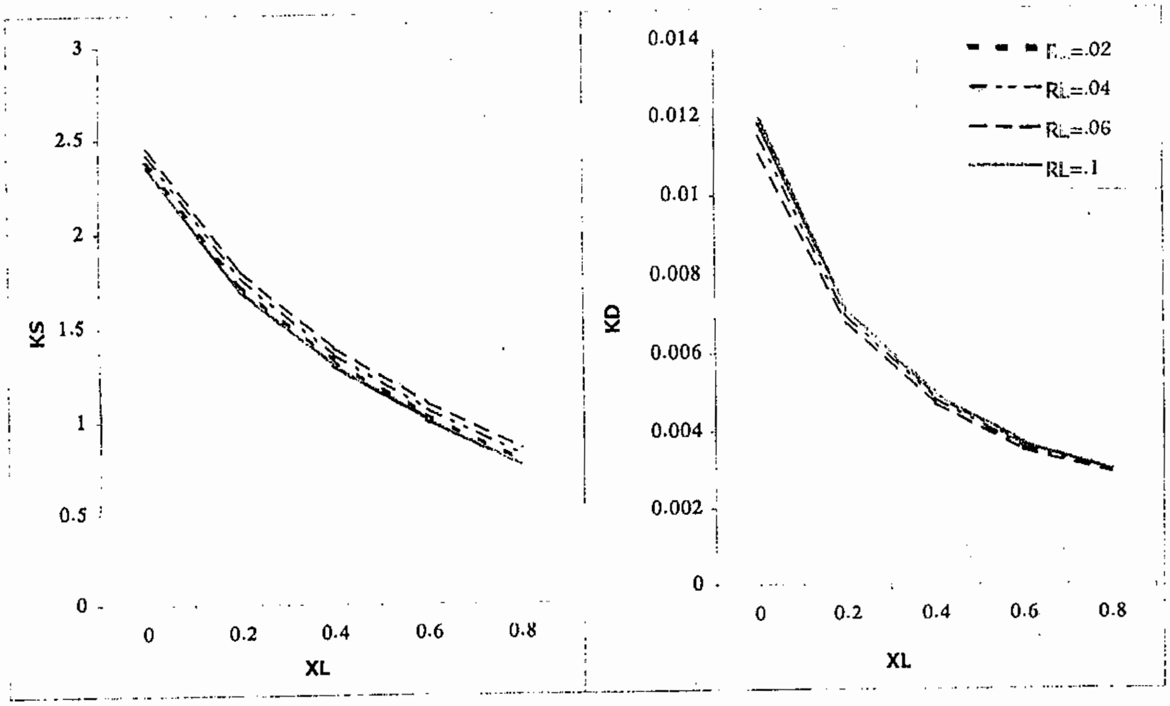


Fig.(5) Effect of Tie line on Ks and KD

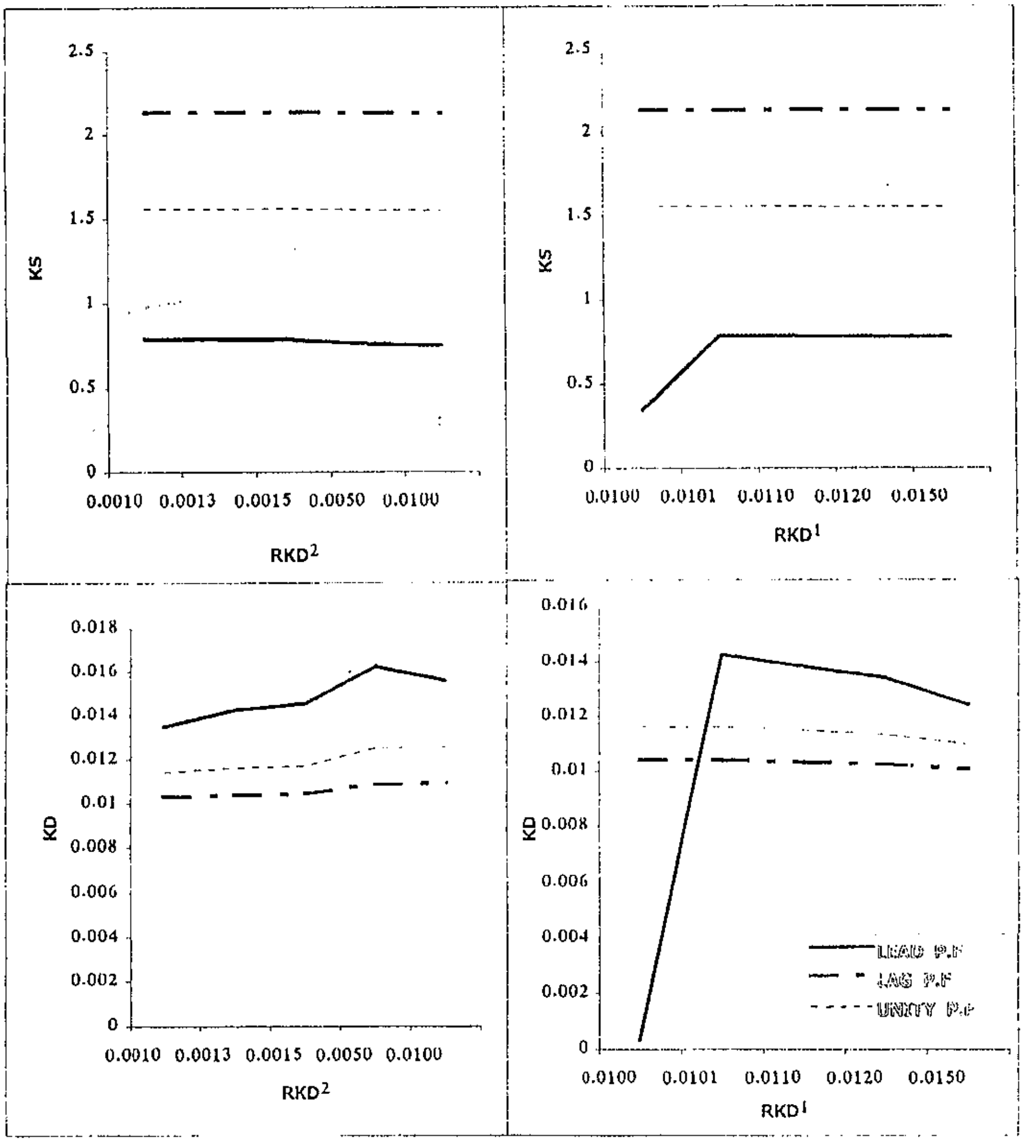


Fig.(6) Effect of damper winding resistance on Ks and KD

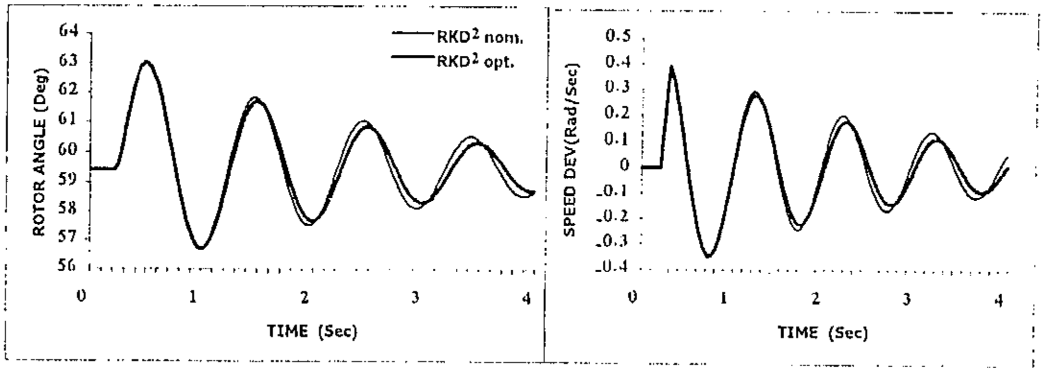
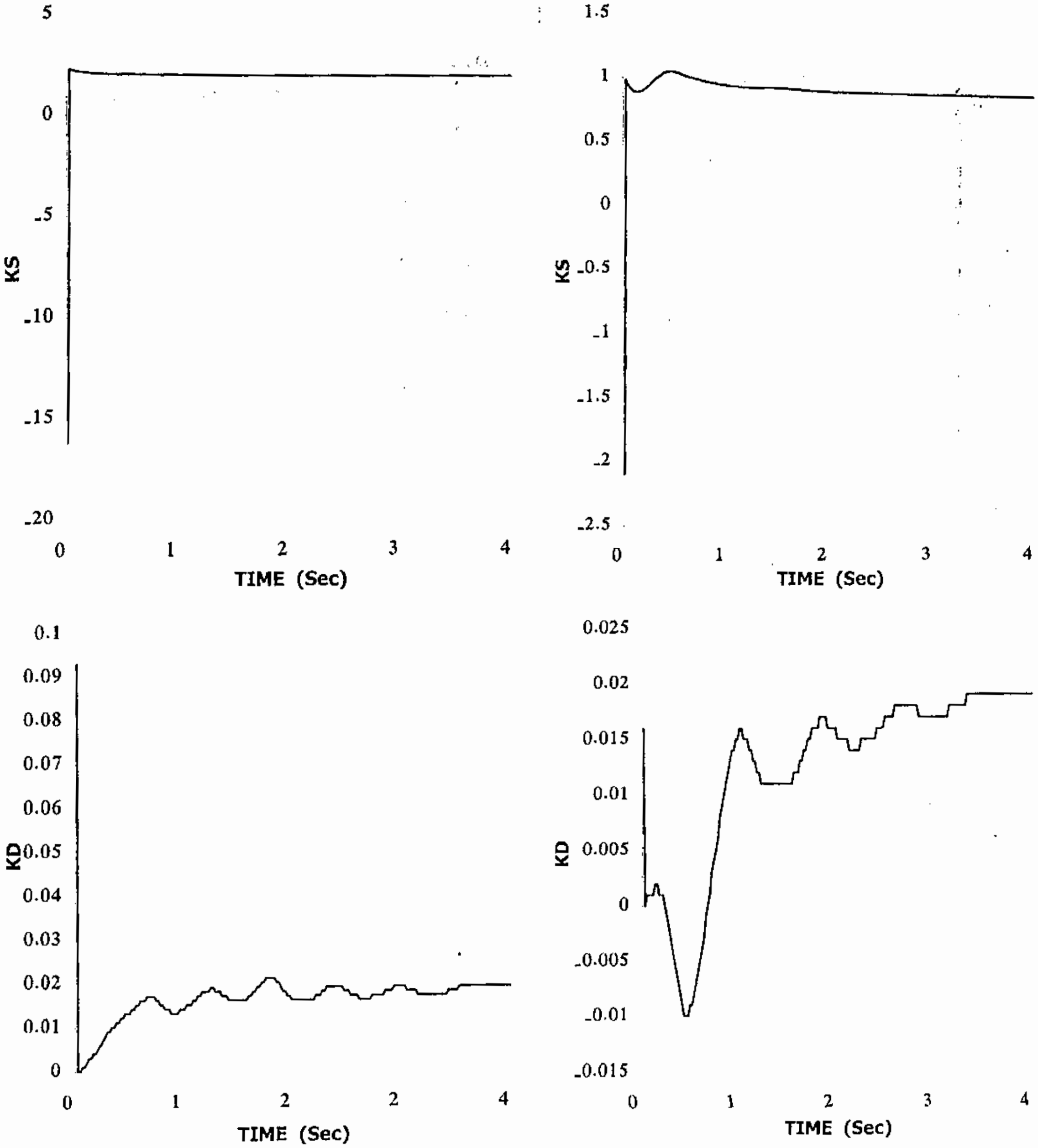


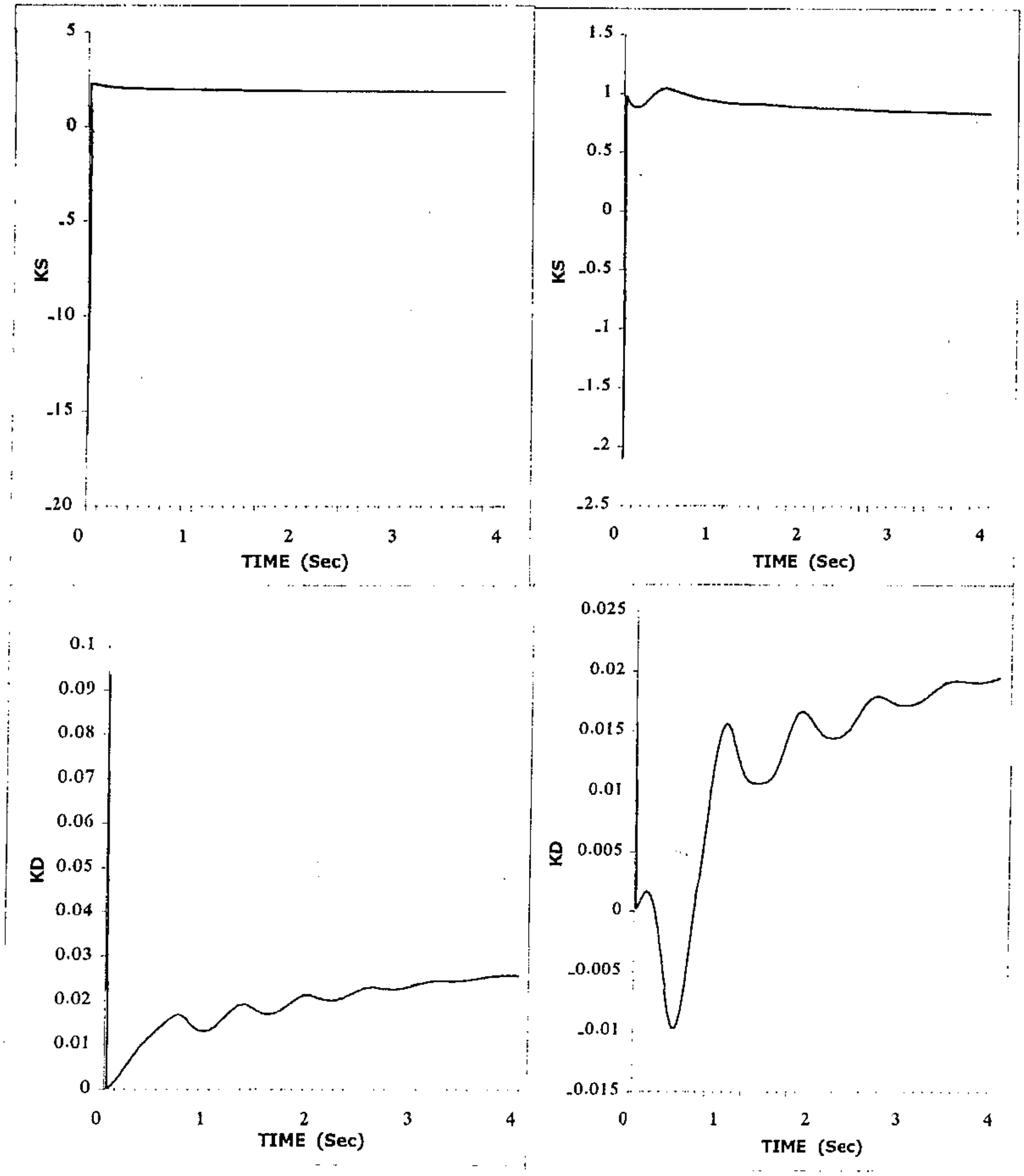
Fig.(6-b) Response to a 10% step change in the mechanical input Pt = 0.8 , lead p.f



(a) Lag P.F

(b) Lead P.F

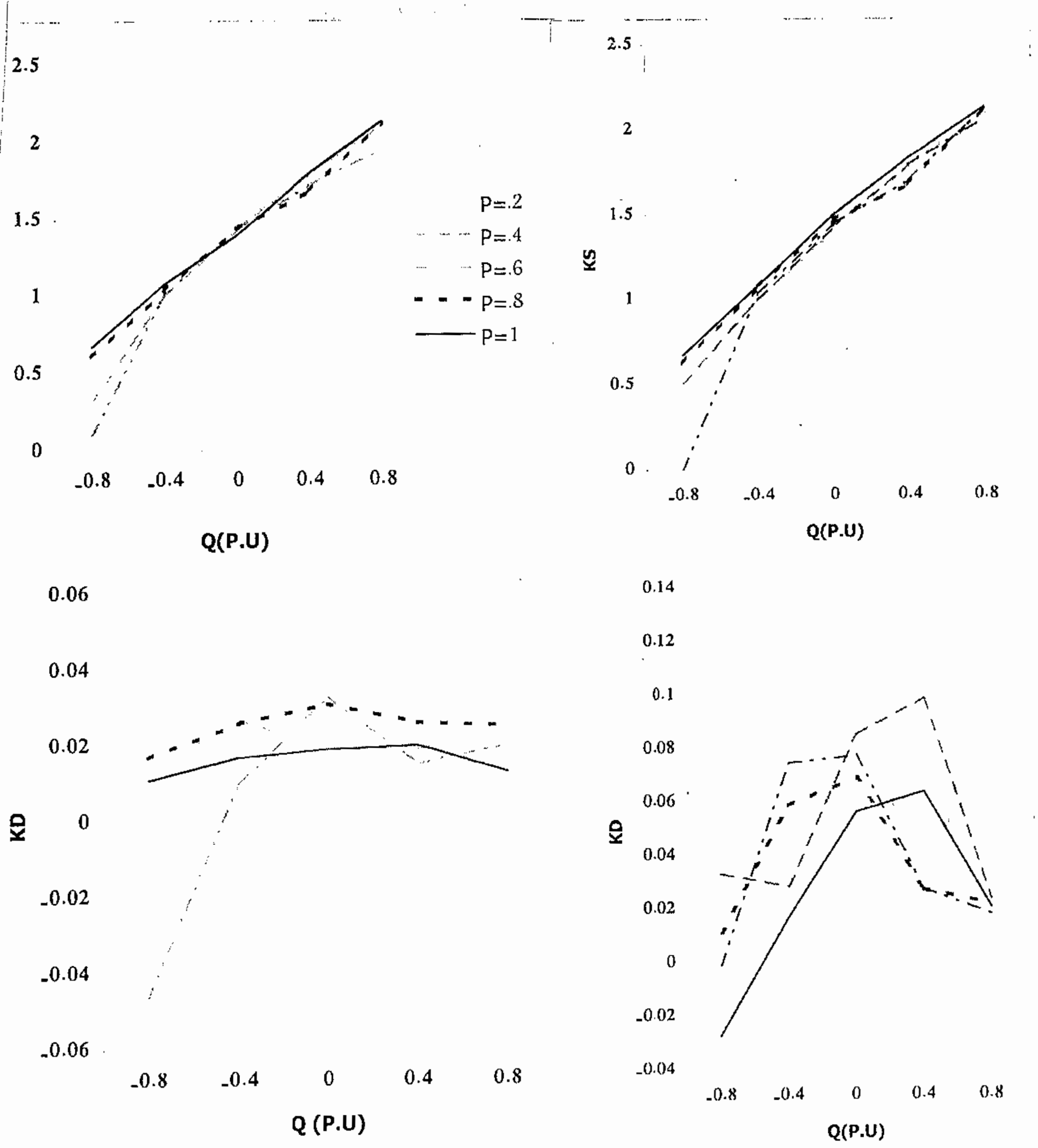
Fig.(7) SCG response to 10% step change in the reference input (UGR) for 100 ms (SG + PH.ADV.)



(a) L ag P.F

(b) Lead P.F

Fig.(8) SCG response to 10% step change in the reference input (UGR) for 100 ms [SG + PI]



(a) SG + PH.ADV.

(b) SG + PI

Fig.(9) Effect of the system loading on Ks and KD

تحليل أداء آلة فائقة التوصيل باستخدام
عزمى الاخماد والتزامن

د/ جمال عبدالوهاب مرسى   م/ هبه عبدالحميد خطاب   د/ عبدالمحسن محمد قناوى

يقدم البحث دراسة مستفيضه لتحليل أداء الآله فائقه التوصيل المربوطة مع شبكة كبيرة خلال خط نقل مزدوج ومحول وذلك بتطبيق طريقة تحليل رقمى لحساب ثوابت عزمى الاخماد والتزامن .

يتم التطبيق على النموذج المفصل للنظام وحساب عزمى الاخماد والتزامن والاستفادة من ذلك فى دراسة اداء النظام وتأثير تغير بارامتراته وأحماله فى حالة تشغيل الالة بدون نظام تحكم وكذلك عندما تعمل بنظم تحكم متعددة .

كذلك تتيح دراسة الاداء بتلك الطريقة امكانية تغيير بارامترات النظام والحصول على القيم المثلى لتلك البارامترات والتى تعطى أداء جيد .