Mansoura Engineering Journal

Volume 14 | Issue 2 Article 10

5-25-2021

# Stability Analysis of Power System Using DSM.

Ibrahim Mansy
*Assistant Professor of Computers and Control Engineering Department, Faculty of Engineering, Mansoura University, Mansoura, Egypt.*

# STABILITY ANALYSIS OF POWER SYSTEM USING DSM

تحليل اتزان منظومات القوى الكهربية باستخدام طريقة فصل المتغيرات

I.I.I.Mansy A.E.E.Ibrahim

Faculty of Engineering Faculty of Education

University of El Mansoura

الخلاصة : فى هذا البحث تم تطوير طريقة الفصل بحيث تستخدم لدراسة اتزان منظومات القوى الكهربية. واقترح خوارزم للطريقة لإمكانية تطبيقها على المنظومات البسيطة والكبيرة. واختبر جزء من شبكة ج.م.ع. ذات الضغط العالى ٥٠٠ ك.ف.

ويهدف البحث الى تحديد مناطق الاتزان للمنظومة الكهربية فى حالة توصيل مكثفات على التوالى دون الوصول الى حالة التذبذبات الأقل من المتزامنة ودراسة ذلك فى حالة تغير مقاومة العضو الدوار والحمل وكذلك عدد الدوائر.
وقد توصل الى انه يمكن توصيل مكثفات تعويض حتى ٢٢٪ لدائرة واحدة و ٤٤٪ لدائرتين، ويوصى بتقليل مقاومة العضو الدوار بقدر الإمكان وذلك عند تصميمه حتى لاتؤدى الى نشوء ظاهرة التوافق غير المتزامن. تكون منظومة القوى اكثر اتزانا عند الحمل الكامل.

ABSTRACT: In this paper, the Domain of Separation Method (DSM) is developed for studying stability of power system. Suitable algorithms of DSM for single and multi-machine power systems are proposed. The method and algorithms are used to investigate stability of the 500 Kv portion of the Egyption grid in the case of using series capasitor compensation under different system parameter variations and also under system planning conditions. The main goal of this study is to determine the limitations of stability zones of the system under study without risking subsynchronous oscillations (SSO).

## INTRODUCTION

Improving of large scale power system steady-state stability has received a great attention in recent years. Methods used to improve the stability conditions of the system include the addition of series or shunt compensation with the transimission lines [1]. At some levels series compensation, the system will suffer a risk to subsynchronous resonance ( SSR ), which leads to SSO [2].

Therefore, a balance condition between series compensation level and other system parameters is required for system stability.

Many techniques are used to investigate system stability. Common techniques are : frequency scanning technique; eigenvalue technique and Nyquest technique [2&3].

The DSM , which is developed in this paper, is very simple, less expensive and has less computer memory compared with other techniques. The DSM depends on seperating two variables of system parameters while others taken fixed [4&5]. Each of these variables is considered function of frequency. The obtained values are plotted in S or complex plane.

Stability of the system is determined from these plots, when the curves pathes in anticlockwise direction n quadrants of the complex plane being from the first quadrant [4&5]. The sides of the D-seperation curve is shaded depending on the sign of the principal determinant (D).

The method is used directly to determine the overall system stability and also the optimal parameters for stability can be achieved. The method is used for simple and large scale power systems through algorithms, which are also presented in this work.

## DSM FORMULATION

This method depends on the transformation of system variables into S plane as follow:

$$D(S) = R(S) + X_L(S) + X_C(S) \tag{1}$$

Where: $R$, $X_L$ & $X_C$ are resistance, inductive and capacitive reactance respectivily.

The above equation can be also put in the following form:

$$D(S) = R(S) + X(S) \tag{2}$$

Where: $X(S) = X_L(S) + X_C(S)$.

Equation (2) takes a generalized form and may contain all transimission line nodes and therefore it is formulated in a matrix form, which is reduced by any technique, like Gauss elemination technique to obtain a reduced matrix at buses of the generators of the system under study.

The variables in concern must be seperated in the form of real and imaginary parts, which represent the first and the second variables.Stability can be determined by changing S and plot the two values in complex plane,this is possible by transforming from S-plane to complex plane by substituting $S=j\omega$ and $\omega$ varies from $-\infty$ to $+\infty$ . Stability are determined when the plots of imaginary and real part of $D(j\omega)$ pathes in anticlockwise direction n quadrant of the complex plane being from the frist quadrant.The regions of steady state stability are found by dashing the curve at left hand side when $|D| > 0$ and at right hand side when $|D| < 0$.

## PROPOSED ALGORITHMS FOR THE METHOD

In this paper, two algorithms are proposed,the first algorithm for simple power system, while the other for large scale power system

### Algorithm for simple power system

1-Transform transmission line parameters from phase quantity to direct and quadrant quantities, this is available using the following relations [6,7&8]:

$$(R)_{dq} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} .R \tag{3}$$

$$(X_L)_{dq} = \begin{bmatrix} S & -1 \\ 1 & S \end{bmatrix} .X_L \tag{4}$$

$$(X_c)_{dq} = \begin{bmatrix} S & 1 \\ 1 & S \end{bmatrix}^{-1} . X_c \qquad (5)$$

Equations 3,4&5 can be grouped in one equation representing the transmission impedance in S-plane as follows:

$$(Z_N(S))_{dq} = \begin{bmatrix} R+S\left[X_L + \dfrac{X_c}{(S^2+1)}\right] & -\left[X_L + \dfrac{X_c}{(S^2+1)}\right] \\ \left[X_L + \dfrac{X_c}{(S+1)^2}\right] & R+S\left[X_L + \dfrac{X_c}{(S+1)^2}\right] \end{bmatrix} \qquad (6)$$

2- The synchronous generator in the case of frequency variations is modeled by its induction machine equivalent. This model, however, is dependent on frequency [9&10]. Therefore this model after its transformation to S-plane becomes:

$$(Z_G)_{dq} = \begin{bmatrix} \dfrac{R_g + S\,X_d(S)}{X_d(S)} & \dfrac{-X_q(S)}{R_g + SX_q(S)} \end{bmatrix} \qquad (7)$$

Where $R_g = R_a + R_r / S$;

and the values of X(S) are obtained for d and q axes from the following equation [7&8]:

$$X(S) = X \left[ \frac{(1+S.T_o'.X'/X)\ (1+S.T_o''.X''/X')}{(1+S.T_o')\ \ (1+S.T_o'')} \right] \qquad (8).$$

3- Compute the total impedance of the system by adding Eqns (6) & (7)

$$Z(S) = (Z_N(S))_{dq} + (Z_G(S))_{dq} \qquad (9)$$

4- Calculated the determinant of Z (S)

$$D(S) = \| Z(S) \| \qquad (10)$$

5- Then the values of $K_{i1}$, $K_{i2}$ are calculated from the following relations:

$$K_{i1} = \text{Imag.}(D(S)) \qquad (11.1)$$

$$K_{i2} = \text{Real}(D(S)) \qquad (11.2)$$

6- Repeat all the above steps for different values of S [7].

The curve can be also plotted in a complex plane by substituting $S = j\omega$ in the above steps, where $\omega$ changes from $-\infty$ to $+\infty$.

7- Plot DS curves.

## PROPOSED ALGORITHM FOR LARGE SCALE POWER SYSTEM

1- Construct $Z_N(s)$ using equation (2) for each node of the network.

2- Transform $Z_N(s)$ into $Y_N(S)$.

3- Append $Y_{ij}(S)$(admittance matrix)for the overall system using any technique.

4- Construct the $Z_g(S)$ matrix for all generators [7]. .

5- Transform $Z_g(S)$ into $Y_g(S)$ except the generator under study $Z'_g(S)$.

6- Construct the all system admittance matrix from the following equations:

$$Y_T(S) = Y_g(S) + Y_N(S)$$

7- Invert and eliminate the total matrix by Gauss elemination technique to obtain a reduced impedance matrix at the bus of the generator under study.

8- The DSM function is obtained from the sum of the reduced impedance matrix and that of the generator under study.

$$D(J\omega) = Z_T(J\omega) + Z_g(J\omega)$$

9- The two seperated values $K_{i1}, K_{i2}$ are obtained using relation(11).

10- Repeat all steps with $\omega$ changes from $-\infty$ to $\infty$ .

11- Plot DS curves.

## STUDY SYSTEM

In this paper a 500 Kv 664 Km portion of the Egyptian electric network is investigated comprehensively using the DSM,the selection of this portion is due to its long length, high voltage and the possibility of introducing series capacitor in the future.The single line diagram of this portion is shown in Fig.1 while the data necessary are listed in tables 1,2,3&4 [11].

The rest of the system outside this portion is represented by constant loads having impedances of infinite values connected to ground.

The flowchart in Fig. 2 shows the main steps for the FORTRAN IV program developed to cover this study. The program is simple and easy to be extended to more complicated power systems.

## RESULTS AND DISCUSSION

### a- Series capacitor variations

The system is firstly considered without series compensation

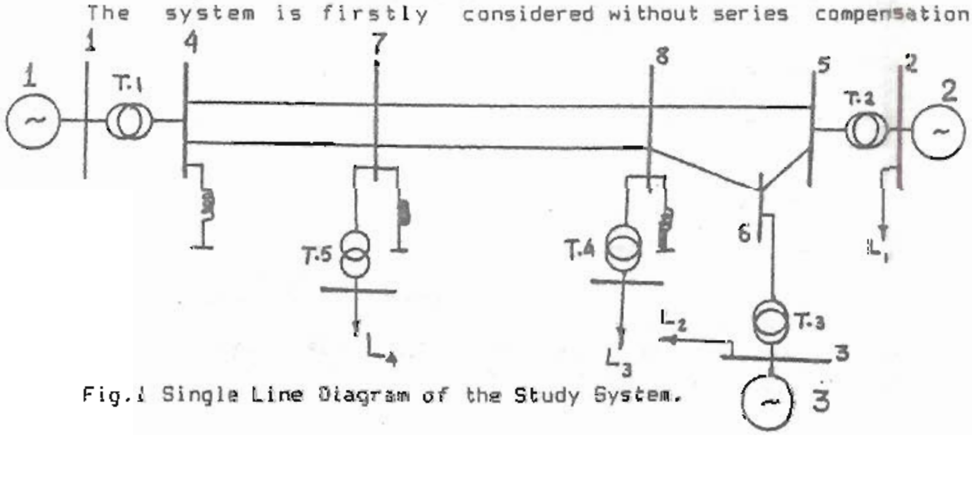


Fig.1 Single Line Diagram of the Study System.

Table.1 Generators data in p.u.

| G.N | $X_d$ | $X_q$ | $X_f$ | $X_{ad}$ | $X_{aq}$ | $X'_d$ | $X'_q$ | H |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.53 | 0.97 | 1.88 | 1.35 | 0.79 | 1.79 | 1.17 | 9.5 |
| 2 | 1.88 | 1.88 | 1.92 | 1.24 | 1.24 | 1.15 | 0.92 | 6.7 |
| 3 | 1.88 | 1.88 | 1.92 | 1.24 | 1.24 | 1.15 | 0.92 | 5.2 |

Table.2 Transmission line data in p.u.

| BUS — BUS | | LENGTH | KV | R | X | Y |
|---|---|---|---|---|---|---|
| 4 | 7 | 236 | 500 | 0.1012 | 1.403 | 5.283 |
| 7 | 8 | 343 | 500 | 0.147 | 2.055 | 3.614 |
| 8 | 6 | 204 | 500 | 0.080 | 1.097 | 6.776 |
| 6 | 5 | 184 | 500 | 0.036 | 0.506 | 14.70 |
| 5 | 8 | 85 | 500 | 0.090 | 1.2424 | 5.970 |

Table 3 Load data in p.u.

| LOAD NO. | R | X |
|---|---|---|
| $L_1$ | 1.328 | 0.823 |
| $L_2$ | 15.737 | 9.753 |
| $L_3$ | 24.313 | 15.068 |
| $L_4$ | 1.747 | 1.083 |

Table 4 Transformer data in P.U.

| TRANSFORMER NO. | X |
|---|---|
| 1 | 0.138 |
| 2 | 0.117 |
| 3 | 0.234 |
| 4 | 0.090 |
| 5 | 0.090 |

(Fig.3),the loci of this figure indicate that the system is stable, this is true because the system has no resonance conditions.

The series capacitor is then taken as 0.2 P.U., the loci of Fig.4 illustrate this case ,the loci are changed to symetrical bounderies form ,but this reveals a stable system.In the shaded areas the system has negative resistance,this means that the system may suffer torsional interaction instability.

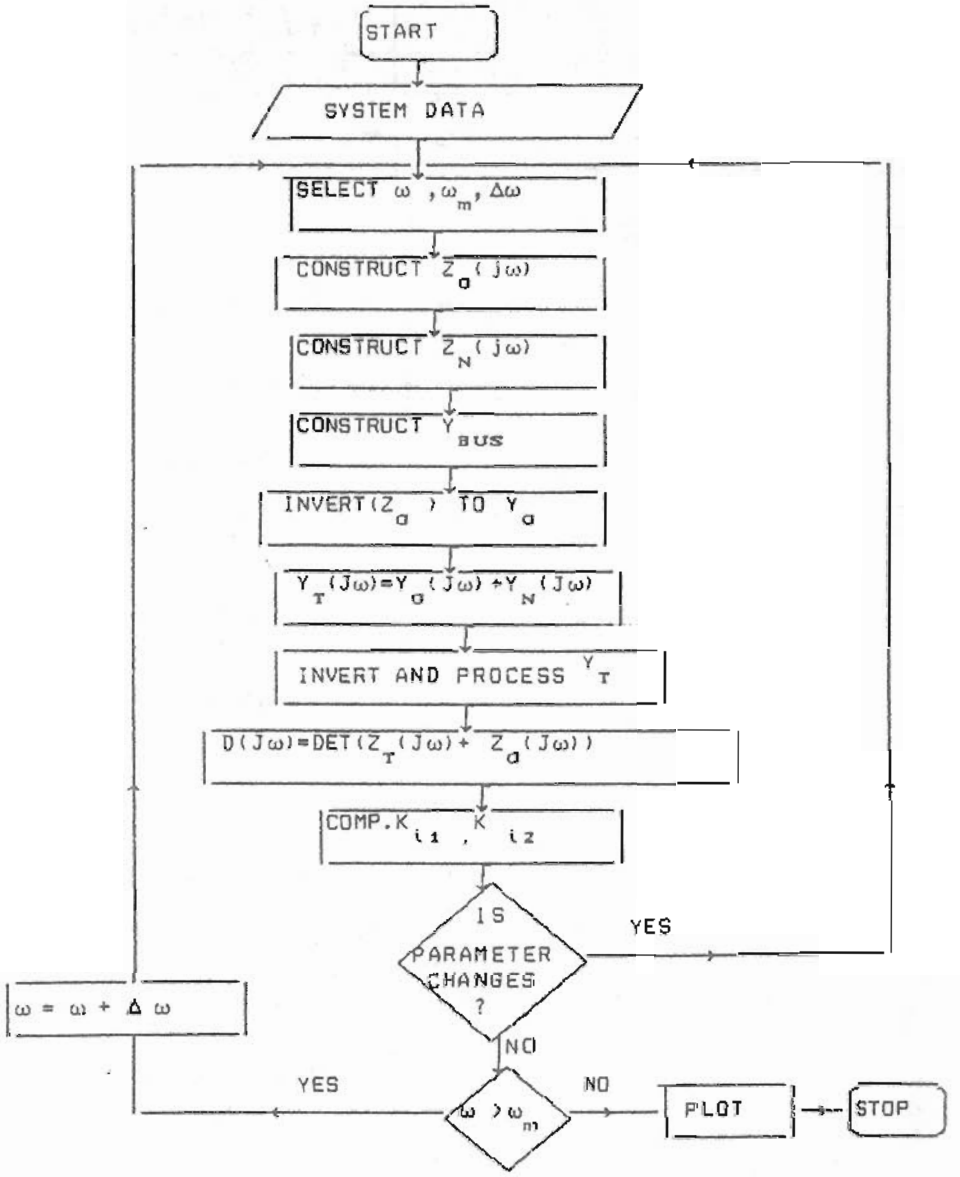


Fig.2 Flowchart of DMS

Then the value of series compensation is taken 0.4 p.u. the loci drawn in Fig.5 show , that the trajectory closes a circle in the clockwise direction and this means that the system still stable. The loci reveals also that negative resistance appears in this case.

Fig.6 shows the same result for a value of 0.6 p.u. series capacitor.The system is still stable in this case, also the system will reveal a negative resistance.

Figures 7& 8 are curves for 0.8 p.u.and 1.0 p.u.series capacitor values, which reveals that the system is still stable.

Fig.9 illustrates the DS curves for 1.5 and 2 p.u. series capacitor values. From this figure, the system is unstable in both cases.

From the above results,it may be concluded that the long transmission line of the Egyptian network can be compensated up to 1. p.u. (22% series compensation level) without risking the SSD.

## b- Effect of rotor resistance ($R_r$)

In the case of frequency dependent analysis, the synchronous machine is represented by its induction equivalent model in which the rotor resistance is a function of frequncy [8]. Therefore, the value of this resistance is considered variable to show its effect on overall system stability. The values of this resistances are taken 0.0 , 0.02, 0.2 and 0.5 individually.

Fig.10 shows the curves in domain of seperation.Curve 1 is drawn for the value of $R_r$ = 0.0. In this case, the system is stable and has no negative resistance, which means that there is no risk to SSR. In curve.2, the trajectory crosses the vertical axis which reveals that the system will contain negative resistance, but is stable. Curve.3 shows that, when the roror resistance is raised to 0.2 p.u. the system is pulled towards instability and thevalue of negative resistance is increased.

Finally the rotor resistance is increased to 0.5 p.u. which push the system towards instability and because the value of negative resistance is more increased.

The critical value can be obtained when the trajectory of the DS crosses the origin. In this system, a 0.5 p.u. rotor resistance is critical and any increase over than this value leads the system to instability.

## c- Effect of connecting parallel lines

In the real power systems, the system may be subjected to faults which require to connect or disconnect parallel lines. Therefore,the effect of connecting the two lines is considered in two series compensation values, 1.5 P.U.and 2.0 P.U., which are the highest values considered in the recent study.

Fig.11 shows the plots of curves,when one line is considered alone and when the two lines operates in parallel for X = 1.5.In this figure, the negative resistance, in the case of using one circuit,has higher value than in two circuits. Therefore, the system is stable in the second case,but in one circuit is unstable.

Fig.12 illustrates the case when the series compensation is

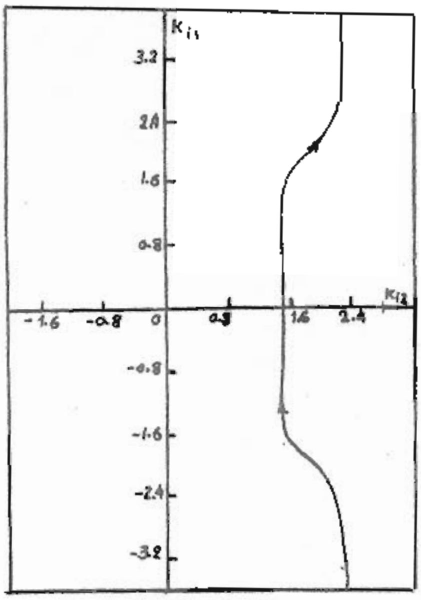


Fig.3 DS and Stability Regions for Zero Series Compensation.

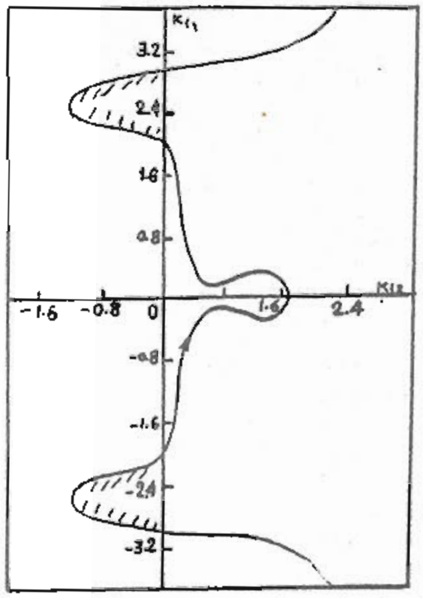


Fig.4 DS and Stability Regions for 0.2 p.u. Series Compensation.

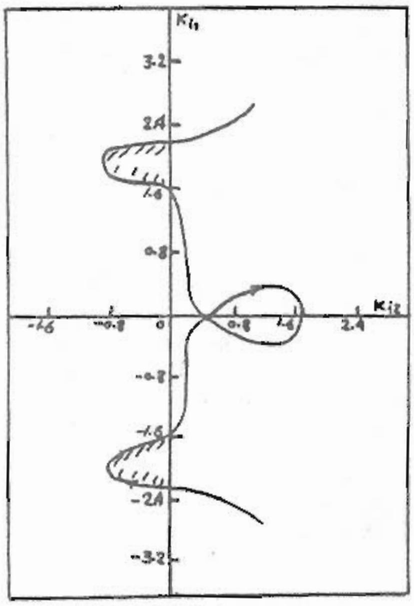


Fig.5 DS and Stability Regions for 0.4 p.u. Series Compensation.

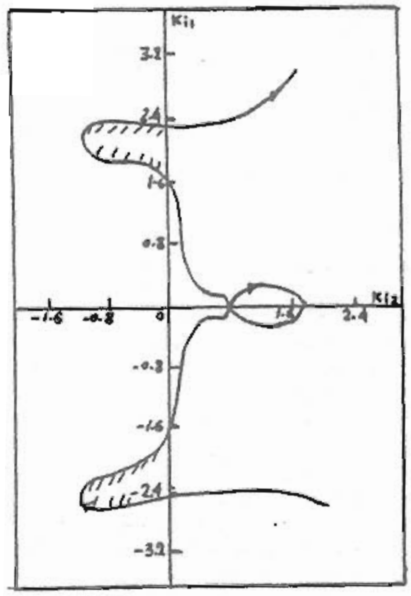


Fig.6 DS and Stability Regions for 0.6 p.u. Series Compensation.

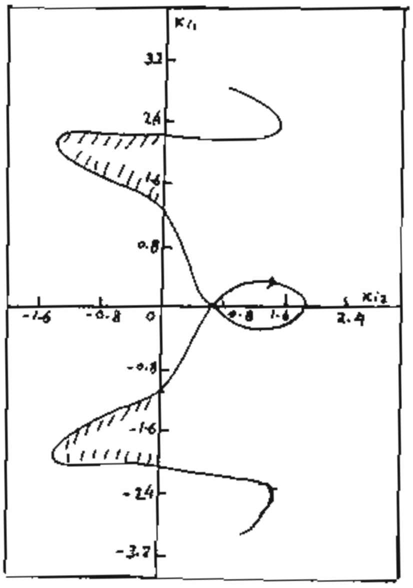

Fig.7 DS and Stability Regions for 0.8 p.u. Series Compensation.

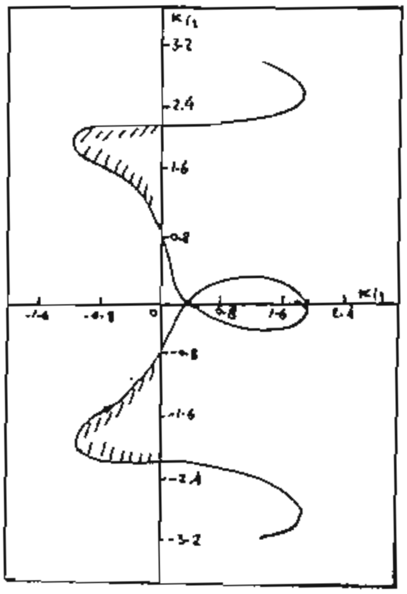

Fig.8 DS and Stability Regions for 1.0 p.u. Series Compensation.

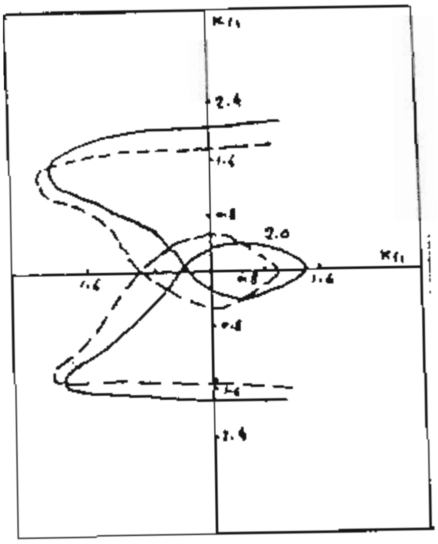

Fig.9 DS and Stability Regions for 1.5&2. p.u. Series Compensation.

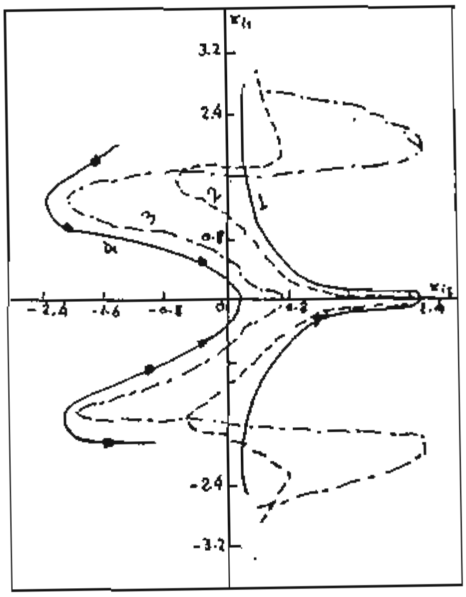

Fig.10 DS and Stability Regions for Rotor Resistances.

taken 2.0 p.u.. In this figure the above results is also satisfied.

d- Effect of loads

In this study two cases are considered when the series compensation is taken 1.5 p.u.and at 2.0 p.u. Fig.13 shows the effect of the loads on the stability in the cases of full-load and 1.5 load. From these curves of this figure, it is obvious, that the system is stable in both cases. This is because the load effect as positive resistanse connected in series with the transmission line ( more stable system). Fig. 14 as Fig.13 but in the case of using 2.0 p.u. series compensation (44% of series compensation leve) without risking SSO.

## CONCLUSIONS

From the obtained results, the following conclusions may be considered:

1- Algorithms are proposed and Fortran program is developed for DSM as a method of predicting stability.

2- The 500 KV transmission system of the Egyptian network can be compensated to 22% when one line operates and to 44% with two lines operate without risking SSR.

3- The rotor resistance of the study machine affects system stability. Therefore, the rotor resistance must be taken as small as possible in the case of designed machine to aviod instability.

4-Connecting parallel lines may lead to more increasing in the series compensation levels.

5- The system operates more stable at full load and 1.5 full load under SSR condition.

## REFERANCES

[1]Edward W.kimbark,"How to improve system stability without risking SSR",IEEE on power apparatus & systems,vol.pas-96,NO.5,sept loct 1977.

[2]B.L.Agrawal,R.G.Former"Use of Frequency-Scanning technique for SSR Analysis."IEEE Transactions on Power Apparatus and Systems,Vol.PAS.98, March/April 1979,pp 341-349.

[3]G.N.Zhenenko and A.A.Fouad,"Steady State Stability Analysis with Frequency Method;optimization of Excitation System Parameters."IEEE Transactions on power apparatus and systems,VOL.PAS.103,NO.4,April 1984.

[4]V.Venikov,"Transient Process In Electrical power system, Book, Mir Publishers.Moscow,1985(in russian).

[5]G.N.Zhenko and A.A.Fouad"Steady-State Stability Analysis with Frequency methods: Optimization of Excitation System Parameters." IEEE Transaction on Power Apparatus and Systems,Vol.PAS-103,NO.4,April 84, pp. 715 722.

[6]N.R.Watson and J.Arrilaga"Frequency-dependant AC System Equivalent for Harmonic Studies and Transient Convertor Simulation".IEE on Power Delivery,Vol.3,No.3,July 1988.

[7]I.M.Canay,"A Novel Approach to the Torsional Interaction And Electrical Damping Of The Synchronous Machine part.1",IEEE Transaction on power apparatus and systems,VOL.PAS.101,NO.10 october 1982.

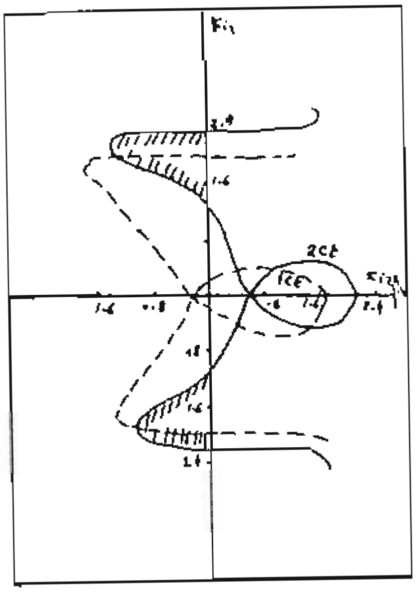

Fig.11 DS and Stability Regions for 1.5 p.u. Series Compensation in Case of One and Two Lines

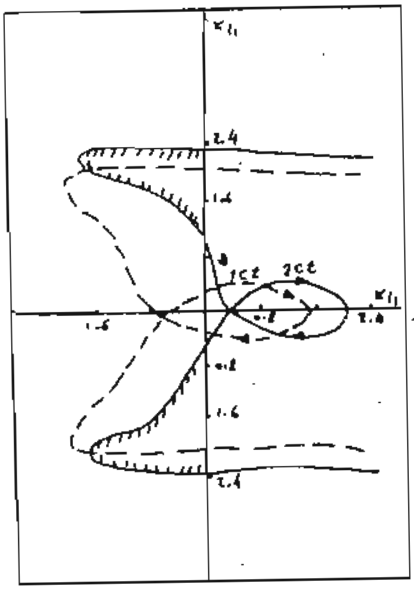

Fig.12 DS and Stability Regions for 2.0 p.u. Series Compensation in Case of One and Two Lines

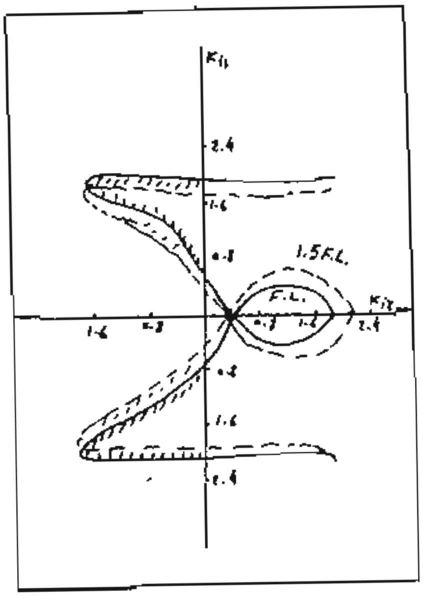


Fig.13 DS and Stability Regions for 1.5 p.u. Series Compensation in Case of(100&150)% Full Load.

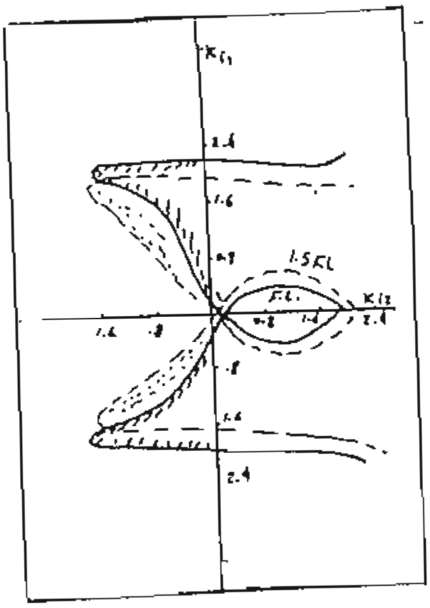


Fig.14 DS and Stability Regions for 2.0 p.u. Series Compensation in Case of(100&150)% Full Load.

[8]I.M.canay "A novel Approach to the torsional interaction and electrical damping of the synchronous machine part.2",ibid.
[9]L.A.Kilgore,D.G Ramey and M.C.Hall,"Simplified transmission and generation system analysis proposed for SSR Problems" , 1976 winter meeting and Tesla symposium.
[10]S.S.Mirthy, B.P.Singh,C.Nagamani and K.V.V.Satyanarayana "Studies of the use of conventional IM as self-excited induction generator." - IEEE on Energy conversion,vol.3,NO.4,Dec.1988.
[11]Electrical Network of Egypt,"The Government Printing Press." 1981.