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Factors affecting Small Signal Stability in Two Area System

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Abstract—**Small signal stability both inter and local area oscillation are affected by many factors, these factors should be concerned when performing a dynamic study of an interconnected system, therefore,**

This paper concentrated on factors affecting the small signal stability that could change the system stability such factors are: The amount of power transferred on the Tie Line, the weakness and strong of interconnected line between two areas, the type of exciter used, also the type of PSS insulted on the exciter system. In addition, value of parameters used in the exciter and PSS systems were investigated.

The analysis is to determine the nature of inters area and local area modes in power systems. By using Kundur (two area system), the system eigenvalues, eigenvectors, and participation factor were computed for a number of different system conditions and configurations, related to the previous mentioned factors. The study was carried out on Kundur Network system which consists of two area connected by tie line of 220km long. The results show that the small signal stability can be improved selecting the best parameters of that factors.

Keywords—Low frequency oscilation, global and Local area Oscillations. Small Signal Stability; Power System Stabilizer.

I. INTRODUCTION

Electro mechanical oscillations between interconnected synchronous generators are occurrences essential to power system. An unexpected change of load, and generator shaft speed change may increase the oscillations of low frequency. These oscillations are undesirable as they have an effect on the power transfer capability of transmission lines and induce stress in generator shaft [1].

The stability of these oscillations is of great importance, and is a requirement for secure system operation. for many years, the oscillations detected to be troublesome in power system, were associated with a single generator, or a very closely connectedgroup of units at a generating plant. Some low frequency unstable oscillations were also detectedwhen large systems were connected by somewhat weak tie lines, and special control methods were used to stabilize the interconnected system. These low frequency modes were discovered to include groups of generator, or generating plants, on one side of the tie oscillating against group of generators on the other side of the tie.

Many researchers have studied small signal stability for power systems. Among them are:

In 1990 ,M.Klein, G.J.Rogers and P.Kundur [2] , focused on Inter- area oscillations in power systems. The objective of the research have determined the fundamental nature of low frequency inter area modes of damping to develop analysis techniques for large power system. Where in 2016 S.Bagchi.S.Goswami, R.Bhaduri ,M.Ganguly and A Roy [3] have studied small signal stability analysis incorporating Doubly Fed Induction Generator (DFIG) by analyzing and comparing two shunt connected FACTS devices Such as STATCOM and SVC.

This paper presents factors affecting the small signal stability such as power transferred, tie line impedance, adding exciter and PSS systems. In addition, PSS and Exciter will be tuned to find the optimum parameters that achieve the best system stability performance

Small signal stability is defined as the ability of the system to maintain synchronism when small disturbances appeared [4]. such this disturbance happens on the system because of small variation in loads and generation.

A disturbance is considered to be small if the linearized system still represents the dynamics of the original system under this disturbance [5].

Small signal stability is largely a problem of deficient damping of oscillations. Where the types of oscillations is of concern:

- Local mode problems may also be associated with oscillations between the rotors of a few generators close to each other.Local modes normally have frequencies in the range 0.7 to 2.0 Hz. [6].
- Global or inter area small-signal stability problems which are caused by interactions among large groups of generators have widespread effects. Inter area oscillations have frequencies in the range 0.1 to 0.8 Hz [6].

Eigen values, Eigen vectors and participation factor analysis are the most effective method to analyze the small signal stability of any state space system which in form of equation 1.

$$\dot{X} = AX + BU \quad (1)$$

Where A is the system state matrix of size n x n ,and B is the input matrix.

Stability of the linearized system is explained by the eigenvalues of the state matrix A.Eigenvalues can be found from the state

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equation given by is extra analyzed by taking the Laplace transform.Then the new equation 2 will be derived as:

$$\det(S[I] - [A]) = 0 \quad (2)$$

Where λ is the eigenvalue of the system. For an n x n matrix they have n eigenvalues. A real eigenvalue, or a pair of complex eigenvalues, is usually referred to as a mode

For a complex mode:

$$\lambda = \sigma \pm j\omega \quad (3)$$

From this mode two quantities are of main interest:

- Frequency (in Hz) $f = \frac{\omega}{2\pi}$ (4)
- Damping Ratio (in %) $= \frac{-\sigma}{\sqrt{\sigma^2+\omega^2}}$ (5)

Eigenvectors can be satisfied from eigenvalue because each eigenvalue has eigenvector .For any eigenvalue $\lambda_{i,}$ the column vector x_i that satisfies is called the right eigenvector for $\lambda_{i,}$ and the next equation shows how to find the eigenvectors:

$$Ax_i=\lambda_i x_i \quad (6)$$

Where $$x_i = \begin{bmatrix} x_{1i} \\ x_{2i} \\ \vdots \\ x_{ni} \end{bmatrix} \quad (7)$$

The right eigenvector show the distribution of the modes of response (eigenvalues) through the power system state variables. So from right eigenvector mode shape can be knownthe observability of the mode, and from left eigenvector knows the controllability of the mode or illustrates participation factors[7].

II. MODEL USED FOR THE STUDY

Two area Kundursystem is tested in this paper where it is consisted of two similar areas connected by a weak tie . Each area consists of two coupled units, each unit having 900MVA and 20KV. The system parameters have found in appendix [2].

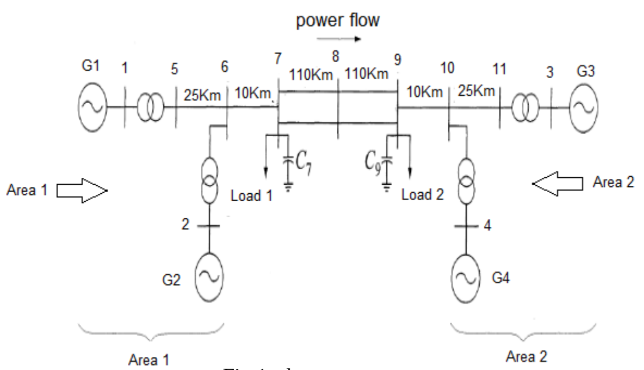

Fig.1. shows two area system

III. SIMULATION AND RESULTS

In this section, simulation of three different scenarios are analyzed to determine the nature of inter area and local area modes in power system.the system eigenvalues, eigenvectors, and participation factor were computed for a number of different system conditions and configuration as following:

Senario 1 : Effect of Amount Power Flow on Tie Line

Three cases were evaluated to investigate the effect of power flow in tie line on damping of system oscillations .

. Case 1 (No Power Flow on Tie Line)

In this case, both area are producing power about 1400MW and feeding a load of 1367MW so no power will be flows in the tie line .So Effect of Frequency and Damping Ratio are of the inter and local area mode represented in table 1.

TABLE 1 EIGENVALUE OF THE SYSTEM, FREQUENCY AND DAMPING RATIO

Eigenvalue Real Part	Eigenvalue Imaginary Part	Damping Ratio	Frequency	Maximum Participated State Variable
1/s	1/s	-	Hz	
-0.033				GEN 1 (ID=3271): dwr
-0.140				GEN 3 (ID=3272): psi_fd
-0.148	-3.613	0.041	0.575	GEN 3 (ID=3272): dwr
-0.148	3.613	0.041	0.575	GEN 3 (ID=3272): dwr
-0.160				GEN 1 (ID=3271): psi_fd
-0.368				GEN 2 (ID=3273): psi_fd
-0.568	-7.072	0.080	1.126	GEN 4 (ID=3274): dwr
-0.568	7.072	0.080	1.126	GEN 4 (ID=3274): dwr
-0.585	-6.845	0.085	1.089	GEN 2 (ID=3273): dwr
-0.585	6.845	0.085	1.089	GEN 2 (ID=3273): dwr
-2.312				GEN 3 (ID=3272): psi_1q
-3.269				GEN 1 (ID=3271): psi_1q
-4.707				GEN 2 (ID=3273): psi_1q
-4.777				GEN 4 (ID=3274): psi_1q
-29.150				GEN 3 (ID=3272): psi_2q
-30.362				GEN 1 (ID=3271): psi_2q
-34.157				GEN 3 (ID=3272): psi_1d
-35.114				GEN 1 (ID=3271): psi_1d
-35.939				GEN 3 (ID=3272): psi_2q
-36.149				GEN 2 (ID=3273): psi_2q
-37.186				GEN 3 (ID=3272): psi_1d
-37.258				GEN 2 (ID=3273): psi_1d

From the above table, It concludes that 0.575Hz frequency is the inter area oscillation, with damping ratio of 0.041, and the 1.089Hz mode is the inter machine oscillation local to area(1), with damping ratio of 0.085, while the 1.126Hz mode is the inter machine oscillation local for area(2), with damping ratio of 0.080.Where the location of the roots on s-plan are shown in figure (2).

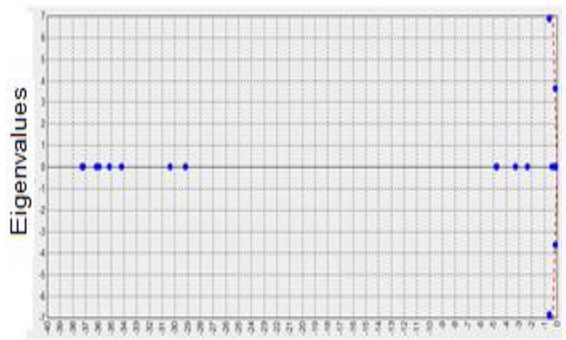

Figure (2)locations of the roots on s-plan of case 1

Figure (2) shows three pair of roots cause the oscillation, one of the pair of roots cause inter area oscillation, while the two other roots cause local area oscillation.

Figures (3) and (4) show The mode shapes (normalized eigenvector components corresponding to rotor speeds of four machine), for both inter and local area oscillation are shown respectively.

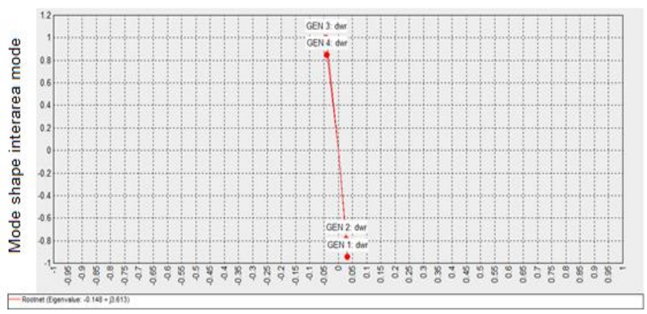

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Figure (3) mode shape of inter area oscillation

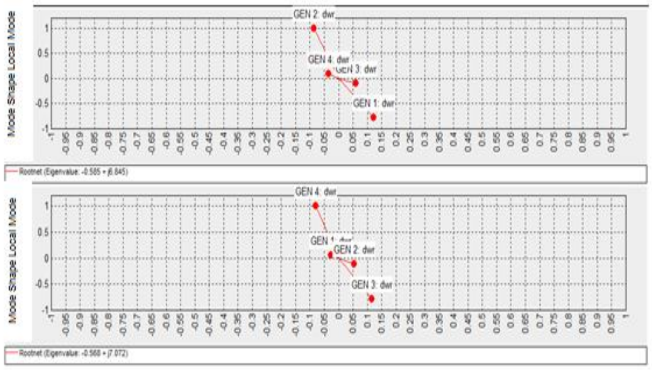
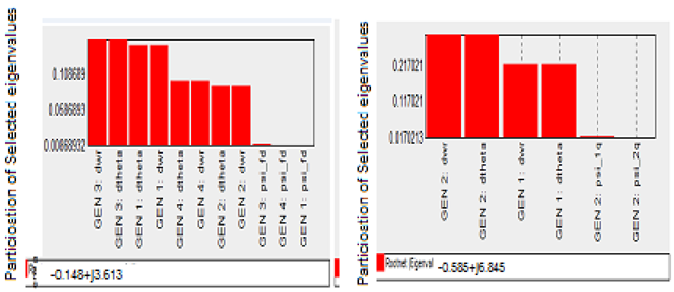


Figure (4.) mode shape of local area oscillation

It is clear that from the mode shape that illustrates in figure(3), the generating units in one area oscillate in anti-phase to the once in the second area(G1 versus G3) and (G2 versus G4), for the root value of (-0.148+j3.613).

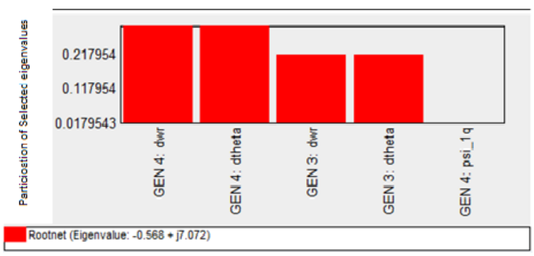
Figure(4) shows the oscillation of local area(1) (the higher figure) byroot (-0.585+j6.845), and the oscillation of local area(2) (the lower one), by the root (-0.568+j7.072).It is noted that generator(1) swinging against generator(2), and generator(3) swinging against generator(4).

Figure (5) shows the participation factor for both inter and local area oscillation .



(a) (b)

Figure (5) Participation factor for the roots of inter and local area, (a) inter area mode, (b) local area 1 mode.



(c)

Figure (5c) Participation factor for the roots of local area 2 mode .

From figure(5a), it is clear that the G3 and G1 are more sensitive than G2 and G4 in inter area oscillation, while in figure(5b) generator 2 is more sensitive than generator 1 in local area 1 oscillation, where figure(5c) shows that G4 is more participate than G3 in local area2 oscillation.

Case 2 (200MW Transferred From Area1 To Area2):

In this case, both area are producing power about 1400MW where the first area is feeding a load of 1167MWand the other area load is1567MW so 200MWof power flows in the tie line .Damping Ratio are of the inter and local area mode represented in table 2.

TABLE 2 EIGENVALUE OF THE SYSTEM, FREQUENCY AND DAMPING RATIO

Eigenvalue Real Part	Eigenvalue Imaginary Part	Damping Ratio	Frequency	Maximum Participated State Variable
1/s	1/s	-	Hz	
-0.033				GEN 3 (ID=3272): dwr
-0.138	-3.579	0.039	0.570	GEN 3 (ID=3272): dtheta
-0.138	3.579	0.039	0.570	GEN 3 (ID=3272): dtheta
-0.148				GEN 4 (ID=3274): psi_fd
-0.162				GEN 1 (ID=3271): psi_fd
-0.363				GEN 2 (ID=3273): psi_fd
-0.580	-7.063	0.082	1.124	GEN 4 (ID=3274): dwr
-0.580	7.063	0.082	1.124	GEN 4 (ID=3274): dwr
-0.587	-6.836	0.086	1.088	GEN 2 (ID=3273): dwr
-0.587	6.836	0.086	1.088	GEN 2 (ID=3273): dwr
-2.372				GEN 1 (ID=3271): psi_1q
-3.269				GEN 3 (ID=3272): psi_1q
-4.695				GEN 2 (ID=3273): psi_1q
-4.754				GEN 4 (ID=3274): psi_1q
-29.226				GEN 1 (ID=3271): psi_2q
-30.355				GEN 3 (ID=3272): psi_2q
-34.171				GEN 3 (ID=3272): psi_1d
-35.100				GEN 3 (ID=3272): psi_1d
-35.946				GEN 3 (ID=3272): psi_2q
-36.148				GEN 2 (ID=3273): psi_2q
-37.189				GEN 3 (ID=3272): psi_1d
-37.259				GEN 2 (ID=3273): psi_1d

From the above table, the 0.570Hz frequency is the inter area oscillation, with damping ratio of 0.039, and the 1.088Hz mode is the inter machine oscillation local to area(1), with damping ratio of 0.086 while the 1.124Hz mode is the inter machine oscillation local for area(2), with damping ratio of 0.082, and the location of the roots on s-plan are shown in figure(6) ,where there are three pair of roots cause the oscillation, one pair cause inter area oscillation and two cause local area oscillation.

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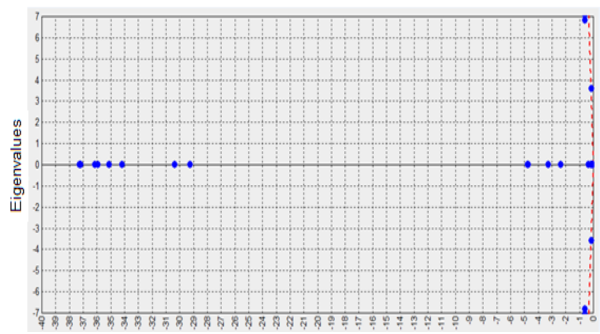

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Figure (6)locations of the roots on s-plan of case 2

Figures (7) and (8) illustrate The mode shapes (normalized eigenvector components corresponding to rotor speeds of four machine), for both inter and local area oscillation are shown in respectively

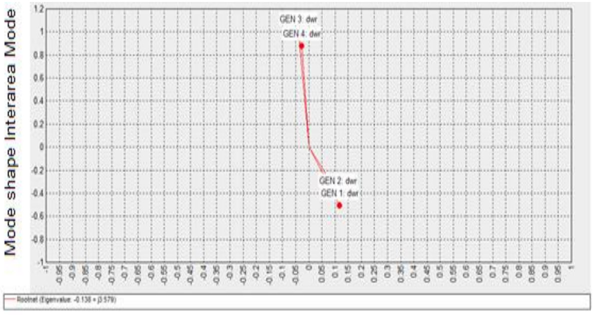

Figure (7) mode shape of inter area oscillation

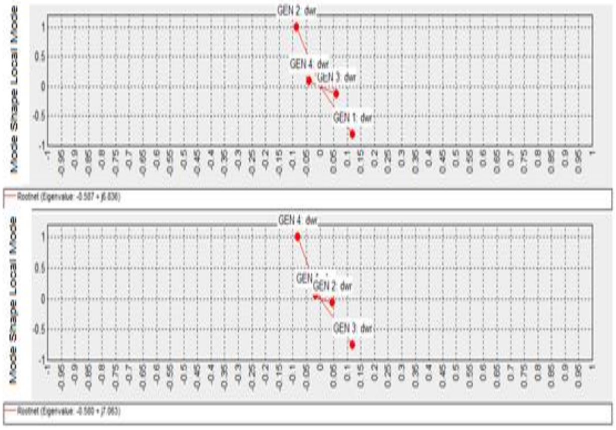

Figure (8) mode shape of local area oscillation

It is clear that from the mode shape shown in figure(7), the generating units in one area oscillate in anti phase to the once in the second area(G1 versus G3) and (G2 versus G4), for the root value of (-0.138+j3.579).Figure(8) shows the oscillation of local area(1) by the root (-0.587+j6.836) (the higher figure), and the oscillation of local area(2) (the lower one), by the root (-0.580+j7.063). It is noted that generator(1) swinging against generator(2), and generator(3) swinging against generator(4).

Case 3 (400MW Transferred From Area1 To Area2):

In this case, the first area is feeding a load of 967MWand the other area load is1767MW so 400MWof power flows in the tie line .the damping Ratioof the inter and local area mode are represented in table 3.

TABLE 3 THE EIGENVALUE OF THE SYSTEM, FREQUENCY AND DAMPING RATIO.

Eigenvalue Real Part	Eigenvalue Imaginary Part	Damping Ratio	Frequency	Maximum Participated State Variable
1/s	1/s	-	Hz	
-0.035				GEN 3 (ID=3272): dwr
-0.131	-3.417	0.038	0.544	GEN 3 (ID=3272): dtheta
-0.131	3.417	0.038	0.544	GEN 3 (ID=3272): dtheta
-0.168				GEN 4 (ID=3274): psi_fd
-0.172				GEN 1 (ID=3271): psi_fd
-0.354				GEN 1 (ID=3271): dwr
-0.601	-6.809	0.088	1.084	GEN 2 (ID=3273): dwr
-0.601	6.809	0.088	1.084	GEN 2 (ID=3273): dwr
-0.605	-7.033	0.086	1.119	GEN 4 (ID=3274): dwr
-0.605	7.033	0.086	1.119	GEN 4 (ID=3274): dwr
-2.499				GEN 1 (ID=3271): psi_1q
-3.277				GEN 3 (ID=3272): psi_1q
-4.651				GEN 2 (ID=3273): psi_1q
-4.694				GEN 4 (ID=3274): psi_1q
-29.409				GEN 1 (ID=3271): psi_2q
-30.383				GEN 3 (ID=3272): psi_2q
-34.213				GEN 1 (ID=3271): psi_1d

The Results which are given in table 3show that 0.544Hz frequency is the inter area oscillation, with damping ratio of 0.038, and the 1.084Hz mode is the inter machine oscillation local to area(1), with damping ratio of 0.088 while the 1.119Hz mode is the inter machine oscillation local for area(2), with damping ratio of 0.086, and the location of the roots on s-plan are shown in figure(9).

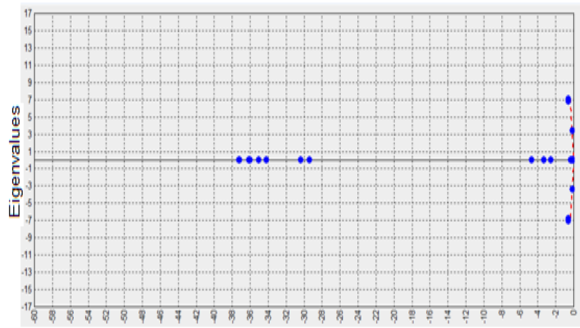

Figure (9)locations of the roots on s-plan of case 3

Figures (10) and (11) illustrate The mode shapes (normalized eigenvector components corresponding to rotor speeds of four machine), for both inter and local area oscillation are shown respectively.

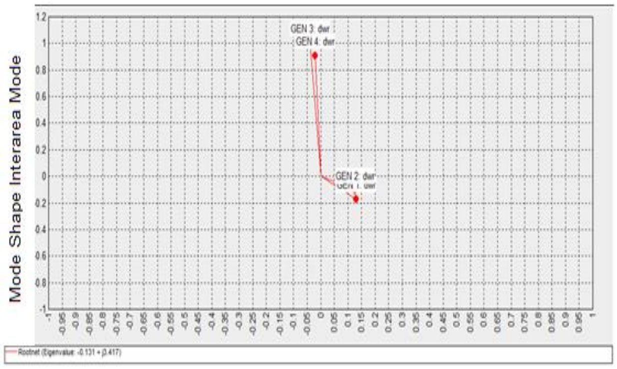

Figure (10) mode shape of inter area oscillation

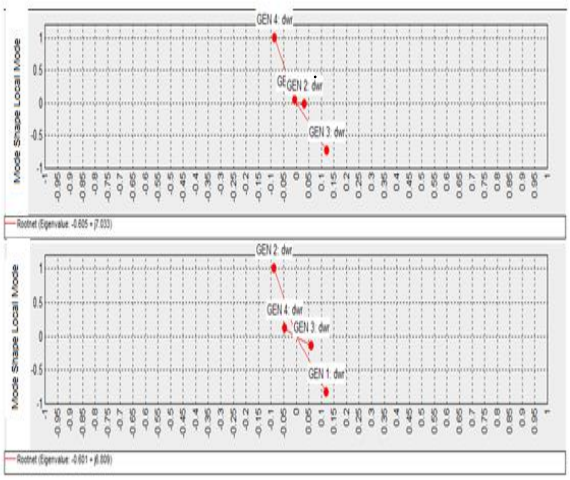

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Figure (11) mode shape of local area oscillation

Figure (10), shows that the generator (G1) oscillated in anti-phase with generator (G3), and generator (G2) oscillated in anti-phase with generator (G4) for the root value of (-0.131+j3.417) . Figure(11) shows the oscillation of local area(1) (the higher figure) by the root(-0.601+j6.809), and the oscillation of local area(2) (the lower one), bythe root (-0.605+j7.033).

It is noted that generator(1) swinging against generator(2), and generator(3) swinging against generator(4).

Table 4 shows results of the three case for scenario 1.

TABLE 4 RESULTS OF TIE LINE POWER TRANFFERRED

Power flow (MW)	Inter area mode		Local area 1 mode		Local area 2 mode	
	Damping ratio	***Freq* (Hz)**	***Damping ratio***	***Freq* (Hz)**	***Damping ratio***	***Freq* (Hz)**
0	0.041	0.575	0.085	1.089	0.080	1.126
200	0.039	0.570	0.086	1.088	0.082	1.124
400	0.038	0.544	0.088	1.084	0.086	1.119

From table4 it concludes that when tie line power flow increase, the damping ratio of inter area mode decrease.

Scenario 2 : Effect of Tie Line Impedances

In this scenario, three different cases will be investigated by increasing the number of tie line .Firstly two parallel tie lines .Secondly three parallel tie lines .Finally four parallel tie lines. The power flow in tie line for all three cases is 400MW.

Table 5 shows results of the three cases for this scenario .

TABLE 5 RESULTS OF TIE LINE IMPEDANCE EFFECT

Number of tie line	Inter area mode		Local area 1 mode		Local area 2 mode	
	Damping ratio	***Freq* (Hz)**	***Damping ratio***	***Freq* (Hz)**	***Damping ratio***	***Freq* (Hz)**
2	0.036	0.700	0.084	1.092	0.082	1.129
3	0.036	0.641	0.086	1.089	0.084	1.124
4	0.038	0.544	0.088	1.084	0.086	1.119

From table 5 it can conclude that when a number of tie line increase the damping ratio of inter area mode increase.

For all cases in this scenario were investigated as scenario one , in which the effect of Frequency and Damping Ratioof the inter and local area mode and Mode shape of the system were studied.

Senario 3 : Effect of exciter and PSS

In this scenario, four different cases will be performed. Firstly adding Exciter without tuning where the power provided by each area is about 1400MW, the load of area(1) is 967MW and the load of area(2) is1767MW so 400MWof power flows in the tie line. the type of exciter will be used is (TYPE 15). Secondly adding Tuning Exciter with the same data of case 1. Then the third case adding PSS without tuning, where the type of PSS is SYSTEM STABILIZER PSS2. Finally adding tuning PSS with similar data of case 3.

For all cases in this scenario were investigated as scenario one where effect of Frequency and Damping Ratioof the inter and local area mode and Mode shape of the system were studied.

Type of control	Inter area mode		Local area 1 mode		Local area 2 mode	
	Damping ratio	***Freq* (Hz)**	***Damping ratio***	***Freq* (Hz)**	***Damping ratio***	***Freq* (Hz)**
Exciter without . tuning	-0.023	0.549	0.082	1.089	0.080	1.125
Exciter with tuning	0.061	0.549	0.088	1.084	0.081	1.125
PSS without tunig	0.131	0.581	0.091	1.084	0.104	1.161
PSS With tunig	0.413	0.456	0.092	1.084	0.316	1.032

Table 7 shows results of the all cases of this scenario.

TABLE 6 RESULTS OF TIE LINE IMPEDANCE EFFECT

From table6, It concludes that when adding a control devices to the system. The devices is needed to tuning, in order to increasing damping ratio. Also, using PSS help to increasing damping ratio, and this case is the best case.

IV. Conclusion

From the results obtained some conclusion can be outlined.

- The damping ratio of inter area mode derease As the amount of power inrease.
- The generators in one area swing in anti phase with the generators in the other area, in case of zero power flows on the tie line, as shown in inter area mode shape, while with 200MW & 400MW tie line flow condition, the inter area mode shape shows no longer oscillate purely in anti phase.
- The damping ratio of the system increase when the tie line impedance increases
- Selecting the suitable excitation system adopting to the machine will improve the damping ratio, and adding Powr System Stabilizer to the excitation system is best than using excitation alone in damping ratio.
- Good tuning of Power System Stabilizer will improve the system stability.

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APPENDIX

A. Generators Data.

The generator parameters in per unit on the rated of MVA and kV base are the follows:

X_d=1.8 X_q=1.7 X_l=0.2 X'_d=0.3 X'_q=0.55
X''_d=0.25 X''_q=0.25 Ra=0.0025 T'_{d0}=8s T'_{q0}=0.4s
T''_{d0}=0.03s T''_{q0}=0.05s Asat=0.015 Bsat=9.6 ψT1=0.9
H=6.5 (for G1 and G2) H=6.1725 O(for G3 and G4)
K_D=0

B. Transformer Data.

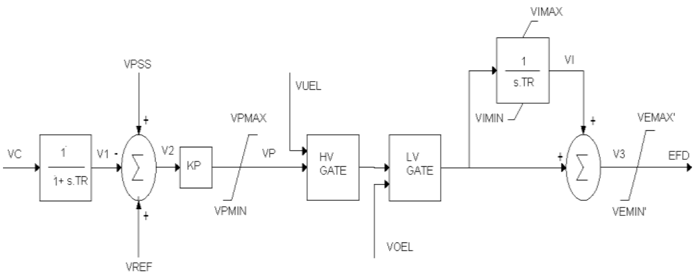
There are two step up transformer and each one has an impedance of 0+j0.15 per unit on 900MVA and 20/230kV base , and has off- nominal ratio of 1.

C. Trtansmission Line Data.

The transmission system nominal voltage is 230kV. The line lengths are showed in figure 1. The parameters of line in per unit on 100MVA, 230kV base are

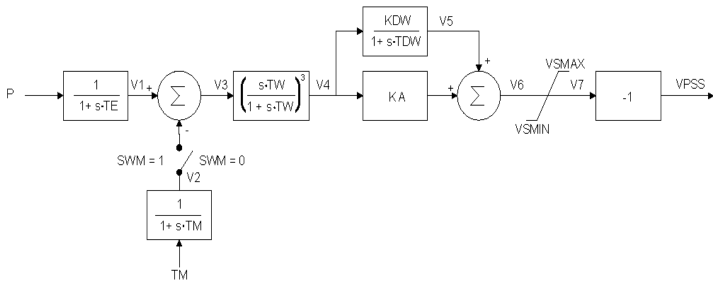
R=0.0001 pu/km x_L=0.001pu/km b_C=0.00175 pu/km

D. Exciter-Type15 Configration and Data.



SWPS=2 KP=20 VPMAX=14 VPMIN=-10 UEB=-0.1 UID=-0.1 TI=3 UEMAX=6 UEMIN=-5 VIMAX'=4 VIMIN'=-1.

E. system Stabilizer PSS2 Configration and Data.



SWPS=2 KP=20 VPMAX=14 VPMIN=-10 UEB=-0.1 UID=-0.1 TI=3 UEMAX=6 UEMIN=-5 VIMAX'=4 VIMIN'=-1.

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