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A CORRELATION BASED APPROACH FOR POWER NETWORK REDUCTION

GÜÇ SÝSTEMLERÝNDE KORELASYONA DAYALI ÝNDÝRGEME YAKLAª IMI

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ABSTRACT

This study presents a power network reduction algorithm based on coherency. Since electrically close generators tend to swing together upon a disturbance, we determined coherent generator groups using their mutual electrical proximity. Rank correlation coefficient was defined as a measure for the degree of this proximity. These coefficients were calculated from the bus admitance matrix of the system. This measure could be used to determine the degree of the proximity of any two buses in the system also, hence served as a network partitioning algorithm. The order of partitioning could be chosen so as to one of the partitions include a pre-defined study area. We used Kron reduction to eliminate load buses. The algorithm was tested on a 39-bus system and Turkish 380 kV system. Power flows through the lines and generator swing curves in the reduced network model were compared with those in the full network model. Results are satisfactory. We found that an electrical proximity based coherency technique was proper for power network reduction.

Keywords: *Coherency, network reduction, rank correlation*

OZET

Bu çalýþma, jeneratörlerin uyumluluk davranýþýna dayalý bir güç sistemi indirgeme algoritmasý sunmaktadýr. Bir arýza durumunda elektriksel olarak yakýn jeneratörler beraberce salýnmaya yöneldiklerinden, uyumlu jeneratör gruplarýný karþýlýklý elektriksel yakýnlýklarýna baðlý olarak belirledik. Rank korelasyon katsayýsý bu yakýnlýðýn bir ölçütü olarak tanýmlandý. Bu katsayýlar sistemin bara admitans matrisinden elde edildi. Bu ölçüt, sistemdeki herhangi iki bara arasýndaki elektriksel yakýnlýðýn bir ölçüsü olarak kullanýlabileceðinden sistem bölümlenmesi amacýyla da kullanýlmýþtýr. Sistem bölümlenmesinin derecesi, bölümlerden birisi önceden tanýmlanmýþ çalýþma alanýný içerecek düzeyde belirlenebilmektedir. Yük baralarýnýn yokedilmesinde Kron indirgeme yöntemini kullandýk. Algoritma 39-baralý bir test sisteminde ve Türkiye 380 kV sisteminde test edildi. Ýndirgenmiþ sistemde; hatlardaki yük akýþlarý ve jeneratörlerin salýným eðrileri, sistemin tam *modelindeki karþý gelen deðerleri ile karþýlaþtýrýldý. Sonuçlar tatmin edicidir. Böylece, elektriksel yakýnlýða dayalý bir uyumluluk tekniðinin, güç sistemi indirgenmesi amacýna uygun olduðu sonucuna ulaþtýk.*

Anahtar kelimeler: *Uyumluluk, sistem indirgeme, rank korelasyonu*

1. INTRODUCTION

Since modern electric power systems cover very large geographic areas, and include many generators, load buses and lines, it is a common practice to reduce the network by representing parts of the system by equivalents.

An effective power network reduction algorithm should meet basically these two requirements:

- The algorithm should achieve reductions in the size of the transient stability model without introducing significant differences between the equivalent and full system simulations.
- The equivalents should be efficiently computed. The computer effort for calculating an equivalent should be much less than the effort for a transient stability run on the original system.

Dynamic equivalency studies goes back to 1960’s and use various approaches. These approaches include principally two techniques to determine the groups of generators to be aggregated. One of them is the modal equivalent technique and the other one is the coherency technique [1 - 5].

Dynamic equivalency studies using modal analysis are based on state space representations of power system. However, the need for solving the eigenvalue problem appears as an obstacle in applying this approach to large systems with hundreds of generating units when the models of each unit may have 10 to 20 state variables.

Coherency means that upon a remote disturbance some groups of generators swing together and can therefore be represented by a single equivalent machine.

Power network reduction studies based on coherency technique can be taken up in three major steps [6].

- Definition of the study area.
- Identification of groups of generators, which are valid for faults in the study area.
- Reduction of generator and load buses.

The coherency-based technique requires calculating generator swing curves to identify coherent generators upon a fault in a defined study area. Generally, a generating station and its local transmission system could be defined as the study area.

In literature, comparisons of these techniques are reported considering various performance criteria such as the order of reducing the system, computer timing and the order of accuracy, applying them to very large power systems [7-9]. Even though they have some differences depending on the application, reduced models obtained by these techniques reflect the general behavioural characteristics of the system and save the computer time about 50 %.

Despite all these improvements brought out by these techniques they never eliminate the need to calculate the eigenvalues of the system or the swing curves of the generators.

In this study, we developed a coherency based power network reduction algorithm. We used the concept of electrical distance to identify coherent generator groups. Since electrically close generators tend to swing together upon a disturbance, we defined the rank-order correlation coefficient as a measure for their coherency behaviour. We calculated these coefficients from mutual electrical distances of all buses of the system. This measure was used to group the generators at different degrees of coupling. Correlation coefficients could be used to determine the proximity of any two buses. In this sense, our algorithm served as a network partitioning procedure to determine coherent areas. The order of partitioning could be chosen such that one of the partitions was the study area. For the 39-bus test system we obtained coherent generator groups similar to those in [6], and coherent areas for 6-area partitioning similar to those in [10]. We simplified and used the method in [6] to reduce the generator buses. Kron reduction was used to reduce the load buses, which were modelled by constant impedances. The algorithm produced similar reduced network parameters to those in [6]. To test the validity of the reduced network parameters for Turkish 380 kV interconnected system, we compared the swing curves of the generators and power flows through the lines in the study area in reduced model with those in full model. Results are satisfactory. We found that a rank correlation based coherency technique was proper for power network reduction.

2. METHOD

In this study we used simplified generator models by the following assumptions:

1- Coherent generator groups are independent of the size of the disturbance. This assumption may be confirmed by considering a fault on a certain bus and observing that the coherency behaviour of the generators are not significantly changed as the fault clearing time is increased.

2- The coherent groups are independent of the amount of detail in the generating unit models.
3- We defined two generators as coherent if they become synchronized in the first two seconds after the disturbance. Since automatic voltage regulators and speed governors are not in action in two seconds, if two generators become synchronized within this period they continue to swing together. This definition is different from the one made in [6] which defines two generators as coherent if their angular difference is constant within a certain tolerance over a certain time interval.
4- Distances are measured from generator terminals.

2. 1. Identification of Coherent Generators

We used a rank-correlation method to identify coherent groups of generators. This method was based on electrical distance concept. Since electrically close generators tend to swing together we obtained a proximity measure to determine electrically close generators. This measure was calculated from the ranks of the generator bus distances to other all buses.

Non-parametric or Rank Correlation

The most widely used measure of association between variables is the linear correlation coefficient:

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}} \qquad (1)$$

where $\bar{x}$ is the mean of x_i 's, $\bar{y}$ is the mean of y_i 's for at least 20 measurements, where x_i 's and y_i 's represent generator distances between each other in this study. However, r is a poor statistic for deciding whether an observed correlation is statistically significant, or whether one observed correlation is significantly stronger than another [11].

The uncertainity in interpreting the significance of the linear correlation can be overcome by nonparametric or rank correlation, where value of each x_i is replaced by the value of its rank among all the other x_i 's in the sample that, is, 1, 2, 3, ...N.

There is, of course, some loss of information in replacing the original numbers by ranks. However, when a correlation is demonstrated to be present nonparametrically, then it is really there.

Let R_i be the rank of x_i among the other x_i 's, S_i be the rank of y_i among the other y_i 's, then the rank-order correlation coefficient is defined to be the linear correlation coefficient of the ranks,

$$r_s = \frac{\sum_i (R_i - \bar{R})(S_i - \bar{S})}{\sqrt{\sum_i (R_i - \bar{R})^2 \sum_i (S_i - \bar{S})^2}} \qquad (2)$$

is the measure of the degree of the 'closeness' of two generators, or any two buses, where R_i and S_i correspond to the ranks of magnitutes of their distances to other buses.

2. 2. Definition of Study Area

When applied to all the buses in the system, Equation (2) produces network partitions. Depending on the size and bus distribution of the study area, correlation level could be chosen in grouping process so as to one of the network partitions consists of at least the study area. This process divides the network into coherent areas.

2. 3. Reduction of Generator Buses

We simplified and used the method developed in [6] to reduce the generator buses:

Let m+1, m+2,...,n be the generator buses to be reduced, and t be the equivalent bus.

- Where $\left|\tilde{V}_t\right|$ is the magnitude and Θ_t is the angle of the equivalent bus voltage,

$$\left|\tilde{V}_t\right| = \frac{1}{(n-m)} \sum_{k=m+1}^{n} \left|\tilde{V}_k\right|; \quad \Theta_t = \frac{1}{(n-m)} \sum_{k=m+1}^{n} \Theta_k \qquad (3)$$

- The bt^th term of the generator buses reduced admittance matrix is

$$\tilde{Y}_{bt} = \sum_{k=m+1}^{n} \frac{\tilde{V}_c}{\tilde{V}_t} \tilde{Y}_{bk} \qquad (4)$$

Where b is a boundary node.

- The tb^th term of the generator buses reduced admittance matrix is

$$\tilde{Y}_{tb} = \sum_{k=m+1}^{n} \frac{\tilde{V}_k^*}{\tilde{V}_t^*} \tilde{Y}_{kb} \qquad (5)$$

Where b is a boundary node.

- The tt^th term of the generator buses reduced admittance matrix is

$$\tilde{Y}_{tt} = \sum_{k=m+1}^{n} \sum_{c=m+1}^{n} \frac{\tilde{V}_k}{\tilde{V}_t} \tilde{Y}_{ck} \frac{\tilde{V}_c^*}{\tilde{V}_t^*} \qquad (6)$$

- The generation at the equivalent bus is the sum of the generation at each bus eliminated.
- The load at the equivalent bus is the sum of the load at each bus eliminated.

Since we determined coherent generator buses based on electrical proximity, we assumed

$$\tilde{V}_{m+1} \cong \tilde{V}_{m+2} \cong, \ldots, \tilde{V}_n \cong \tilde{V}_t \,.$$

And $\dfrac{\tilde{V}_k}{\tilde{V}_t} \cong \dfrac{\tilde{V}_k^*}{\tilde{V}_t^*} \cong 1$, which simplifies the above equations.

2. 4. Reduction of Load Buses

We used constant impedance load models to use Kron reduction for reducing load buses. Let

$\mathbf{I} = \mathbf{YV}$ be the generator buses reduced admitance matrix of the system. **Y** and **V** can be partitioned to get

$$\begin{bmatrix} \mathbf{I_n} \\ 0 \end{bmatrix} = \begin{bmatrix} \mathbf{Y_{nn}} & \mathbf{Y_{nr}} \\ \mathbf{Y_{rn}} & \mathbf{Y_{rr}} \end{bmatrix} \begin{bmatrix} \mathbf{V_n} \\ \mathbf{V_r} \end{bmatrix} \qquad (7)$$

where the subscript **n** denotes generator and load buses, which are to be retained, and **r** denotes the load buses to be eliminated. Expanding (7)

$$\mathbf{I_n} = \mathbf{Y_{nn}}\mathbf{V_n} + \mathbf{Y_{nr}}\mathbf{V_r}\,, \quad 0 = \mathbf{Y_{rn}}\mathbf{V_n} + \mathbf{Y_{rr}}\,\mathbf{V_r}$$

from which we eliminate $\mathbf{V_r}$ to find $\mathbf{I_n} = (\mathbf{Y_{nn}} - \mathbf{Y_{nr}}\mathbf{Y_{rr}^{-1}}\mathbf{Y_{rn}})\mathbf{V_n}$.

The matrix $(\mathbf{Y_{nn}} - \mathbf{Y_{nr}}\mathbf{Y_{rr}^{-1}}\mathbf{Y_{rn}})$ is the resulting bus admitance matrix of the reduced system.

2. 5. Aggregation of Generating Units

Let i and j be coherent generator buses. Then equations of motions are given by

$$\frac{2H_i}{\omega_R}\frac{d\omega_i}{dt} + D_i\omega_i =$$

$$P_{mi} - \left[E_i^2 G_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} E_i E_k Y_{ik} \mathrm{Cos}(\theta_{ik} - \delta_i + \delta_k) \right]$$

$$\frac{2H_j}{\omega_R}\frac{d\omega_j}{dt} + D_j\omega_j =$$

$$P_{mj} - \left[E_j^2 G_{jj} + \sum_{\substack{k=1 \\ k \neq j}}^{n} E_j E_k Y_{ik} \mathrm{Cos}(\theta_{jk} - \delta_j + \delta_k) \right]$$

For coherency conditions $\omega_i \cong \omega_j \cong \omega$, and summing the equations of motions

$$\frac{2(H_i + H_j)}{\omega_R}\frac{d\omega}{dt} + (D_i + D_j)\,\omega = P_{mi} + P_{mj} - (P_{ei} + P_{ej})$$

namely, inertial time constant and damping factor of the equivalent generator is the sum of inertial time constant and damping factor of each generating unit eliminated, respectively.

2. 6. Test System

In the sample system, there are 10 generators, 39 buses and 46 lines [6]. We used 39x39 rank-order correlation matrix, which was determined from electrical distance values, to identify coherent generators and network partitions for different degrees of coupling, which are given in Table. 1. Bus numbers 30-39 correspond generator buses.

Rank correlation coefficients {0.9, 0.8, 0.7, 0.6, 0.5} correspond to different degrees of generator coupling. We grouped the buses such that each bus has been correlated with at least the specified coefficient to all the buses within the group. At the correlation level which produces the study area that was defined in [6], external areas were reduced, and reduced system parameters were compared with those in [6].

Turkish 380 kV Interconnected System

This system consists of 95 buses including 28 generators and 123 lines.

We determined generator groupings and network partitions corresponding to different correlation levels. In order to test the validity of the reduced network upon a 0.12 second three-phase short circuit fault in the study area, we compared swing curves and power flows through the lines in reduced model with those in full model.

Necessary data about these two systems was presented in Appendices (A – B).

3. RESULTS

Table 1. and Table 2. show generator groups corresponding to different correlation levels in the 39-bus sample system and in 95 bus Turkish 380 kV system, respectively.

The rank correlation coefficient $r_s \geq 0.9$, which is given by Equation (2), represents the association of the mostly coupled generators and buses. We obtained the 6-area partition of the 39-bus system at the correlation level $r_s \geq 0.8$ and results are similar to those reported in [10]. In addition, $r_s \geq 0.5$ has produced the study area defined in [6] in the 39-bus system and the North-West section of Turkish 380 kV system, which was defined as the study area.

Table. 3. gives reduced system parameters of 39-bus system, which were produced by the algorithm and found in [6] for comparison. Results are satisfactory.

Reduced network for Turkish 380 kV system consists of 38 buses, 11 generators and 77 lines. To test the validity of this reduction, we compared the power flows through the lines and generator swing curves upon a 0.1 second three phase short circuit in the study area, which were obtained in both full and reduced system models. These results are also satisfactory. Table. 4. gives power flows and Figures. (1.-4.) give generator swing curves in the study area for both reduced and full system models.

4. CONCLUSIONS

We developed a power network reduction algorithm based on electrical proximity concept. This algorithm identifies coherent generators, and coherent areas by network partitioning. In this algorithm rank-order correlation coefficients were defined as the measure of the electrical proximity between the buses of the system. This measure was determined by network parameters, especially by line reactances, without taking up time consuming calculations and simulations. Different correlation levels produces different orders of network partitions, and network was reduced at the correlation level which identifies the study area. The network reduced by the algorithm reflects the general behavioural characteristics of the full system model for transient stability and power flow studies. We found that an electrical proximity based coherency technique was proper for power network reduction. However, the algortihm needs to be tested on large power systems to be furtherly improved.

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TABLES

Table. 1. Generator groupings of the 39-bus sample system at different correlation levels

r_S >=0.9	r_S >=0.8	r_S >=0.7	r_S >=0.6	r_S >=0.5
1	1, 8	1, 8	1, 8, 9	1, 8, 9
2	2, 3	2, 3	2, 3, 10	2, 3, 10
3	4, 5	4, 6, 7	4, 5, 6, 7	4, 5, 6, 7
4, 5	6, 7	5		
6, 7	9	9		
8	10	10		
9				
10				

Table. 2. Generator groupings of Turkish interconnected system at different correlation levels

r_s >=0.9	r_s >=0.8*	r_s >=0.6	r_s >=0.5
1,2,3,25,28	1,2,3,11,12, 25,28	1,2,3,11,12,25,28	1,2,3,11,12,25,28
4,5	6,7,8,9,26	6,7,8,9,10,26	6,7,8,9,10,26
6, 26	10	4,5,27	4,5,27
7,8,9	4,5,27	13,14,15	13,14,15
10	13,14,15	16,17,18,24	16,17,18,19,20, 21,22,23,24
11, 12	16,17,18,24	19,20,21,22,23	
13,14,15	19,20,21,22,23		
16,17,18,24			
19			
20,21,22,23			
27			

* : Generator groupings for r_s >=0.7 are the same as those for r_s >=0.8

Table. 3. (a) Reduced network parameters for the 39-bus system.

		Line parameters found in [6]			Line parameters produced by the algorithm		
BUS	BUS	R	X	B	R	X	B
1	2	.0035	.0411	.6987	.0035	.0410	.6987
1	39	.0010	.0250	.7500	.0010	.0250	.7500
2	25	.0070	.0096	.1460	.0070	.0086	.1460
2	30	.0000	.0181	.0000	.0000	.0181	.0000
25	26	.0032	.0323	.7802	.0032	.0323	.7802
25	37	.0006	.0232	1.0290	.0006	.0232	1.0290
26	28	.0043	.0474	.2490	.0043	.0470	.2490
26	29	.0057	.0625	.0000	.0057	.0625	.0000
28	29	.0014	.0151	.0000	.0014	.0150	.0000
29	38	.0008	.0156	.0000	.0008	.0156	.0000
2	26	.0025	.1491	.0000	.0151	.1473	.0000
2	31	.0101	.0948	.0000	.0047	.0924	.0000
2	39	.0491	.4783	.0000	.0469	.4882	.0000
2	33	.0100	.0982	.0000	.0077	.0988	.0000
26	33	.0067	.0871	.0000	.0061	.0875	.0000
26	31	.0392	.2803	.0000	.0186	.02756	.0000
26	39	.2299	1.5786	.0000	.1873	1.6307	.0000
31	33	.0186	.1060	.0000	.0043	.1057	.0000
31	39	.0110	.1160	.0000	.0036	.1143	.0000
33	39	.1192	.6353	.0000	.0608	.6681	.0000

Table. 3. (b) Reduced network parameters for the 39-bus system.

	Bus parameters found in [6]		Bus parameters produced by the algorithm	
BUS	G SHUNT	B SHUNT	G SHUNT	B SHUNT
2	6.4372	.0316	6.3400	.8400
26	4.8951	.1064	4.9200	.1530
31	8.9294	3.3741	8.4580	3.3740
33	17.4906	4.6222	17.2700	4.8300
39	2.4413	.8474	2.2600	.6500

Table 4. Power flows through the lines in the North-West area of Turkish interconnected system for full and reduced models.

Bus No	Bus No	Full Model Power (MW)	Reduced Model Power (MW)	Error (%)
1102	1201	264.8	265.3	-0.18
1200	1202	436.0	436.0	0.00
1201	1307	-445.1	-442.0	0.78
1201	1308	-227.1	-225.0	0.85
1202	1307	-30.4	-28.4	6.38
1300	1305	384.4	395.3	-2.84
1300	1306	-200.4	-216.0	-7.87
1300	2200	-186.1	-185.0	0.73
1300	2201	-204.8	-214	-4.72
1305	1307	812.5	811.8	0.09
1305	1308	817.9	816	0.24
1305	2206	-260.5	-254	2.56
1307	2206	-262.8	-258	1.81

FIGURES

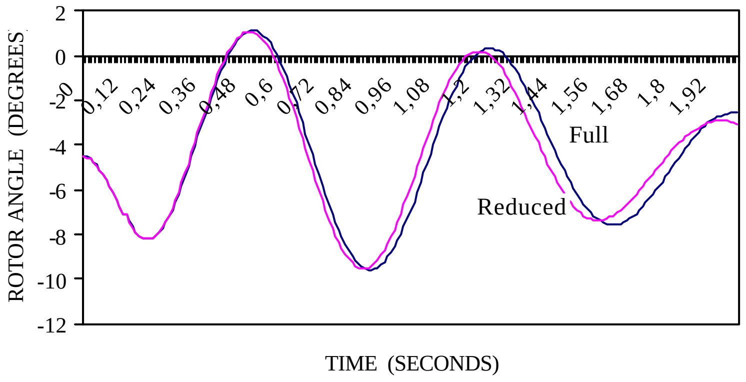

Figure 1. Swing curves of generator 1 in Turkish interconnected system

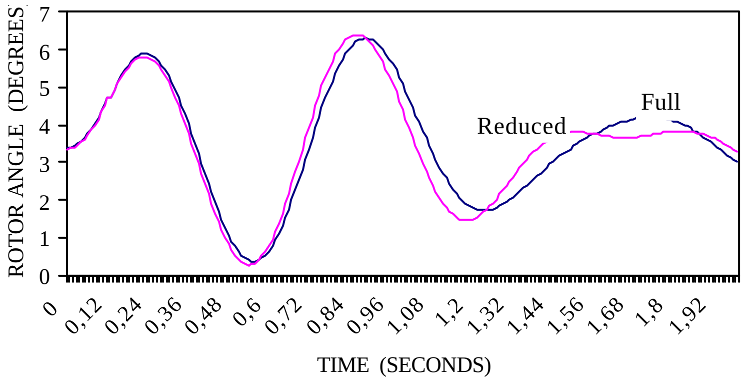

Figure 2. Swing curves of generator 3 in Turkish interconnected system

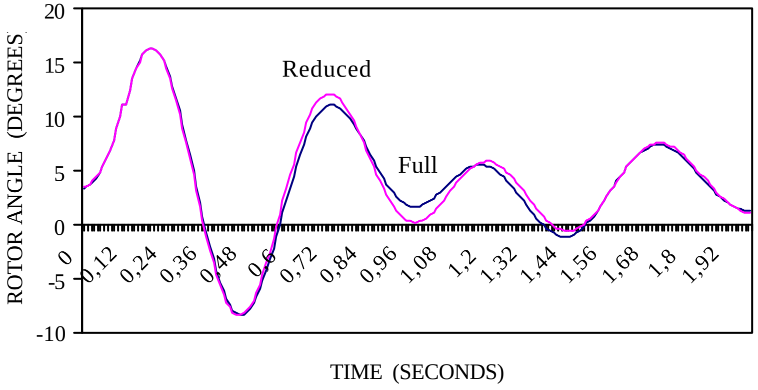

Figure 3. Swing curves of generator 11 in Turkish interconnected system

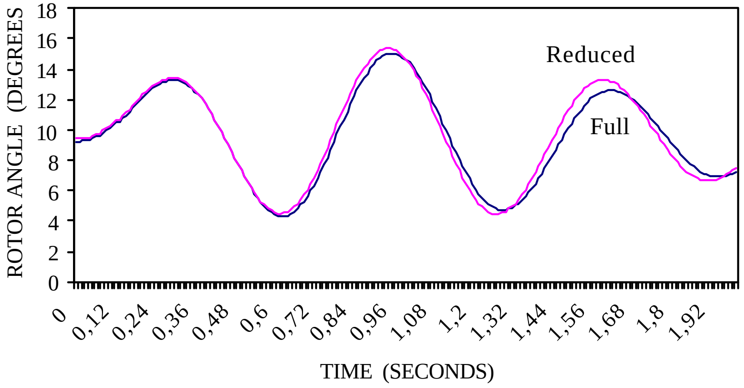

Figure 4. Swing curves of generator 25 in Turkish interconnected system

APPENDIX A

Table. Magnitudes of distances (admittances) between generators and all the buses in 39 bus sample system, (p.u.)*

	30	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
30	14.96	0.83	1.07	1.07	0.38	0.95	0.79	2.72	1.34	4.72	5.71	20.37	11.78	6.57	4.95	4.82	3.82	3.89	1.64	4.43
31	0.83	8.74	1.82	0.64	0.23	0.57	0.48	0.46	0.37	2.79	0.87	3.12	4.56	7.41	9.77	10.56	8.07	8.04	3.38	7.54
32	1.07	1.82	10.39	0.91	0.33	0.81	0.67	0.6	0.49	2.97	1.12	4.01	5.82	9.11	10.02	10.55	8.13	8.15	3.43	13.68
33	1.07	0.64	0.91	11.44	2.11	1.66	1.39	0.66	0.71	1.54	1.13	4.02	5.33	4.59	3.75	3.72	2.93	2.97	1.25	3.77
34	0.38	0.23	0.33	2.11	5.46	0.6	0.5	0.24	0.25	0.55	0.4	1.44	1.92	1.65	1.35	1.34	1.05	1.07	0.45	1.36
35	0.95	0.57	0.81	1.66	0.6	11.04	3.11	0.59	0.63	1.37	1	3.58	4.75	4.08	3.34	3.31	2.61	2.64	1.11	3.36
36	0.79	0.48	0.67	1.39	0.5	3.11	9.72	0.49	0.53	1.14	0.84	2.98	3.95	3.4	2.78	2.76	2.17	2.2	0.93	2.8
37	2.72	0.46	0.6	0.66	0.24	0.59	0.49	9.97	1.11	2.43	2.86	10.21	6.29	3.61	2.74	2.67	2.12	2.15	0.91	2.48
38	1.34	0.37	0.49	0.71	0.25	0.63	0.53	1.11	7.86	1.37	1.41	5.04	4.33	2.78	2.16	2.12	1.68	1.7	0.72	2.03
39	4.72	2.79	2.97	1.54	0.55	1.37	1.14	2.43	1.37	22.18	33.37	17.72	13.83	14.05	16.25	16.16	15.52	17.26	33.34	12.33

	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
30	4.38	2.11	4.5	5.44	5.15	6.78	7.93	8.24	3.15	1.95	3.94	3.29	3.06	4.94	13.31	6.67	6.05	3.01	3.09
31	8.15	3.58	6.98	6.68	4.09	4.06	3.65	3.5	1.89	1.17	2.36	1.97	1.84	2.96	2.25	1.82	2.12	0.82	0.84
32	12.15	5.73	12.02	10.06	5.97	5.76	4.98	4.65	2.68	1.66	3.35	2.79	2.6	4.2	2.92	2.43	2.87	1.1	1.13
33	3.62	1.79	3.94	5.05	7.7	11.83	8.28	6.28	17.3	10.69	6.88	5.74	5.35	8.63	3.21	3.52	4.5	1.59	1.63
34	1.3	0.64	1.42	1.82	2.77	4.25	2.98	2.26	6.22	6.8	2.47	2.06	1.92	3.1	1.16	1.26	1.62	0.57	0.59
35	3.22	1.6	3.51	4.5	6.86	10.54	7.38	5.59	4.9	3.03	11.07	15.55	11.99	8.87	2.86	3.13	4.01	1.41	1.45
36	2.68	1.33	2.92	3.75	5.71	8.78	6.14	4.66	4.08	2.52	8.16	10.72	13.12	7.9	2.38	2.61	3.34	1.18	1.21
37	2.44	1.18	2.52	3.07	3.09	4.16	4.96	4.79	1.94	1.2	2.42	2.02	1.88	3.04	12.47	5.5	4.48	2.48	2.55
38	1.98	0.96	2.09	2.59	3.11	4.48	5.57	4.47	2.09	1.29	2.6	2.17	2.02	3.27	5.41	9.46	6.77	10.54	13.87
39	13	5.86	11.74	12.15	8.68	9.76	10.03	10.06	4.54	2.81	5.67	4.73	4.41	7.12	11.86	6.83	6.8	3.08	3.17

- : Buses 30..39 represent buses of generators 1..10

APPENDIX B

Table. Magnitude of reduced admitance matrix of Turkish 380 kV interconnected system.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	31.9	5.12	4.4	0.55	0.31	0.3	0.05	0.06	0.03	0.23	2.01	0.63	0.2	0.18	0.3	0.2	0.24	0.53	0.18	0.09	0.06	0.13	0.12	0.1	3.65	0.12	2.06	10.3
2	5.12	29.6	4.54	0.56	0.32	0.31	0.05	0.06	0.03	0.24	2.08	0.65	0.2	0.18	0.3	0.21	0.26	0.56	0.18	0.1	0.06	0.14	0.13	0.11	2.92	0.12	2.11	7.95
3	4.4	4.54	34.4	1.22	0.72	0.72	0.1	0.13	0.07	0.47	4.17	1.37	0.36	0.34	0.56	0.4	0.48	1.05	0.34	0.18	0.11	0.26	0.24	0.2	3.87	0.28	4.98	4.1
4	0.55	0.56	1.22	34.6	6.96	2.05	0.98	1.31	0.68	2.98	4.13	3.17	0.17	0.16	0.27	0.54	0.65	0.83	0.17	0.16	0.1	0.18	0.17	0.33	1.27	2.02	5.07	0.53
5	0.31	0.32	0.72	6.96	21.3	1.46	0.36	0.47	0.25	0.98	1.58	1.11	0.08	0.07	0.12	0.19	0.23	0.31	0.07	0.06	0.04	0.07	0.07	0.12	0.62	0.85	4.48	0.3
6	0.3	0.31	0.72	2.05	1.46	32.5	2.4	2.78	1.74	0.82	0.87	0.47	0.05	0.05	0.08	0.1	0.12	0.19	0.05	0.04	0.02	0.04	0.04	0.06	0.51	11.3	5.71	0.29
7	0.05	0.05	0.1	0.98	0.36	2.4	30.3	9.84	8.48	2.02	0.25	0.16	0.01	0.01	0.02	0.1	0.12	0.12	0.02	0.02	0.01	0.02	0.02	0.07	0.09	5.07	0.52	0.04
8	0.06	0.06	0.13	1.31	0.47	2.78	9.84	31.4	6.64	2.89	0.33	0.21	0.02	0.02	0.03	0.14	0.17	0.16	0.02	0.03	0.02	0.03	0.03	0.09	0.12	5.84	0.64	0.06
9	0.03	0.03	0.07	0.68	0.25	1.74	8.48	6.64	23.6	1.37	0.17	0.11	0.01	0.01	0.01	0.07	0.08	0.08	0.01	0.02	0.01	0.01	0.01	0.04	0.07	3.67	0.37	0.03
10	0.23	0.24	0.47	2.98	0.98	0.82	2.02	2.89	1.37	20.7	1.27	0.57	0.1	0.09	0.15	1.51	1.81	1.49	0.14	0.34	0.2	0.26	0.24	0.98	0.48	1.39	0.93	0.22
11	2.01	2.08	4.17	4.13	1.58	0.87	0.25	0.33	0.17	1.27	44.9	7.16	1.03	0.96	1.58	1.12	1.35	3.73	1	0.61	0.37	0.93	0.86	0.58	5.5	0.53	4.64	1.99
12	0.63	0.65	1.37	3.17	1.11	0.47	0.16	0.21	0.11	0.57	7.16	22.2	0.25	0.23	0.38	0.28	0.33	0.8	0.24	0.14	0.08	0.2	0.19	0.15	1.8	0.34	2.08	0.63
13	0.2	0.2	0.36	0.17	0.08	0.05	0.01	0.02	0.01	0.1	1.03	0.25	21.5	8.19	7.41	0.14	0.17	0.45	1.63	0.23	0.14	0.43	0.4	0.07	0.91	0.03	0.33	0.2
14	0.18	0.18	0.34	0.16	0.07	0.05	0.01	0.02	0.01	0.09	0.96	0.23	8.19	20.6	6.89	0.13	0.16	0.42	1.51	0.22	0.13	0.4	0.38	0.06	0.84	0.03	0.31	0.19
15	0.3	0.3	0.56	0.27	0.12	0.08	0.02	0.03	0.01	0.15	1.58	0.38	7.41	6.89	22.9	0.21	0.26	0.68	2.48	0.36	0.21	0.66	0.62	0.11	1.38	0.04	0.5	0.31
16	0.2	0.21	0.4	0.54	0.19	0.1	0.1	0.14	0.07	1.51	1.12	0.28	0.14	0.13	0.21	53.5	26.7	6.36	0.56	3.92	2.35	1.73	1.61	9.14	0.44	0.1	0.36	0.2
17	0.24	0.26	0.48	0.65	0.23	0.12	0.12	0.17	0.08	1.81	1.35	0.33	0.17	0.16	0.26	26.7	58.9	7.63	0.67	4.7	2.82	2.07	1.93	11	0.53	0.12	0.43	0.24
18	0.53	0.56	1.05	0.83	0.31	0.19	0.12	0.16	0.08	1.49	3.73	0.8	0.45	0.42	0.68	6.36	7.63	41.7	1.73	3.49	2.1	5.31	4.93	3.59	1.36	0.14	0.88	0.53
19	0.18	0.18	0.34	0.17	0.07	0.05	0.02	0.02	0.01	0.14	1	0.24	1.63	1.51	2.48	0.56	0.67	1.73	22.5	2.36	1.42	4.63	4.31	0.26	0.77	0.03	0.3	0.18
20	0.09	0.1	0.18	0.16	0.06	0.04	0.02	0.03	0.02	0.34	0.61	0.14	0.23	0.22	0.36	3.92	4.7	3.49	2.36	48.6	16.3	8.31	7.72	1.66	0.26	0.03	0.16	0.09
21	0.06	0.06	0.11	0.1	0.04	0.02	0.01	0.02	0.01	0.2	0.37	0.08	0.14	0.13	0.21	2.35	2.82	2.1	1.42	16.3	35.7	4.98	4.63	0.99	0.16	0.02	0.1	0.06
22	0.13	0.14	0.26	0.18	0.07	0.04	0.02	0.03	0.01	0.26	0.93	0.2	0.43	0.4	0.66	1.73	2.07	5.31	4.63	8.31	4.98	44.3	15.2	0.81	0.41	0.03	0.22	0.13
23	0.12	0.13	0.24	0.17	0.07	0.04	0.02	0.03	0.01	0.24	0.86	0.19	0.4	0.38	0.62	1.61	1.93	4.93	4.31	7.72	4.63	15.2	42.2	0.75	0.38	0.03	0.21	0.13
24	0.1	0.11	0.2	0.33	0.12	0.06	0.07	0.09	0.04	0.98	0.58	0.15	0.07	0.06	0.11	9.14	11	3.59	0.26	1.66	0.99	0.81	0.75	29.2	0.22	0.06	0.19	0.1
25	3.65	2.92	3.87	1.27	0.62	0.51	0.09	0.12	0.07	0.48	5.5	1.8	0.91	0.84	1.38	0.44	0.53	1.36	0.77	0.26	0.16	0.41	0.38	0.22	33.9	0.23	3.3	4.61
26	0.12	0.12	0.28	2.02	0.85	11.3	5.07	5.84	3.67	1.39	0.53	0.34	0.03	0.03	0.04	0.1	0.12	0.14	0.03	0.03	0.02	0.03	0.03	0.06	0.23	35.1	1.83	0.12
27	2.06	2.11	4.98	5.07	4.48	5.71	0.52	0.64	0.37	0.93	4.64	2.08	0.33	0.31	0.5	0.36	0.43	0.88	0.3	0.16	0.1	0.22	0.21	0.19	3.3	1.83	42.8	1.96
28	10.3	7.95	4.1	0.53	0.3	0.29	0.04	0.06	0.03	0.22	1.99	0.63	0.2	0.19	0.31	0.2	0.24	0.53	0.18	0.09	0.06	0.13	0.13	0.1	4.61	0.12	1.96	35.4