DECENTRALIZATION OF THE UNIFIED POWER SYSTEM OF EGYPT

Samir Deghadie, M. El-Gammal and M.Adel Abd Alla
Department of Electrical Engineering, Faculty of Engineering,
Alexandria University, Alexandria, Egypt.

ABSTRACT

In order to meet the increased load demand, the unified power system (U.P.S) of Egypt has been expanding at high rate. The decentralization of such unified grid has become a necessity in order to carry on dynamic stabilization during contingencies for the interconnected system based on local information. This paper developed a methods for the decentralization of the U.P.S of Egypt. The integrated system is decomposed into number of weakly coupled subsystems. A coherency measure based on the principle of weak coupling is used to define the different coherent generating units which could be included within each subsystem. A simplified method based on network topology is used to obtain the network constraints for the decomposed subsystems as well as the interconnected systems. The problem of dimensionality which often defeats the practical implementation of decentralized controllers are avoided by using the approximate One-Axis model state-space representation for simulating the coherent machines.

NOMENCLATURE

Variables:

- E' voltage behind transient reactance.
- δ torque angle.
- ω generator rotor speed.
- Efd generator open-circuit field voltage.
- pm shaft power input to generator
- I armature current

Parameters:

- $[y_{red}]$ $\{y_{i,j}\}$; i,j = 1,2,...,NG
- $Y_{i,j}$ $G_{ig} + j B_{ig}$
- R_a armature resistance.
- X' machine transient reactance.
- X_{ffd} machine field winding self reactance.
- T'_{do} d-axis open-circuit time constant
- M,D inertia and damping time constants
- t time in normalized radians
- k_a, T_a the gain and time constant of the thyrite-type AVR.
- T_t the chest (or reheat)delay time constant for steam-turbine.
- T_w water time constant for hydro-turbine.

Suffices:

- D,Q direct and quadrature axes of the network reference frame
- d,q direct and quadrature axes of the machine reference frame
- o subscript to denote pre-fault operating point.

1.INTRODUCTION

The unified Egyption electrical power grid Figure (4) is a typical example of an integrated large-scale dynamical system. Insuring a reliable supply to milions of consumers in a vast area has required meshed network including 72 bus-bar 101 high-voltage (at 500, 220 and 132 KV) transmission circuits [1]. Random changes in 61 load centers are taken place at any time, with subsequent adjustment of generation in 22 major generating power plants [1]. Furthermore, major changes do take place frequently, e.g., a fault on the network, failure in a piece of equipment, sudden application of a major load, or loss of line or, generating unit. We may look at any of these as changes from an equilibrium state to another. It might be tempting to say that successful operation of the Egyption power system requires only that the new state be a :stable state". Ideally, a full dynamic centralized stabilizing control would be needed with a known stability region covering all practical conditions.

However, developing a centralized computer control for the large-scale power system requires the controller to act in a fractionofa second time-scale with very fast information interchanges. The centralized control may also decide the need for a severe load shedding action, even for a major load at a very far distance from the disturbance area. This situation effectively rules out centralized computer control based on full system model and leaves the challenging task of using local information to achieve system-wide stabilization.

In this paper, a description of a method developed for decentralization of a electric power system, the U.P.S of Egypt as an example, into a number of weakly coupled subsystems is given.

2.IDENTIFICATION OF COHERENT GROUP

Any power usually grows from a number of isolated subsystems into an interconnected large-scale network. Decentralization of the composite system into a number of weakly coupled subsystems is required in order to perform an efficient decentralized control strategy.

In this paper the method of Lamba et. al [2] is used to identify the coherent generators in a large scale interconcted power grid (the U.P.S of Egypt is taken as an example). The method is based on the concept of weak coupling and uses a linearized representation of the total system. The method has proved its high accuracy in coherency measures [2] and could be easily implemented using simplified programming technique. The linearized state model of N-machine system are:

$$\begin{bmatrix} \dot{\underline{X}}_1 \\ \dot{\underline{X}}_2 \\ \cdot \\ \cdot \\ \cdot \\ \dot{\underline{X}}_N \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1N} \\ A_{21} & A_{22} & \cdots & A_{2N} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ A_{N1} & A_{N2} & & A_{NN} \end{bmatrix} \begin{bmatrix} \underline{X}_1 \\ \underline{X}_2 \\ \cdot \\ \cdot \\ \cdot \\ \underline{X}_N \end{bmatrix}$$

where : $\underline{X}_i = [\Delta\delta_i, \Delta\omega_i]^T$,

$$A_{ii} = \begin{bmatrix} 0 & 1 \\ -P_{ii}\, E_{qi}(0)/(2H_i) & 0 \end{bmatrix}, \quad A_{ij} = \begin{bmatrix} 0 & 0 \\ -P_{ij} E_{qj}(0)/(2H_i) & 0 \end{bmatrix}$$

$$;\ i \neq j \ \text{ and } \ P_{ij} = [B_{ij} \cos \delta_{ij}(0) - G_{ij} \sin \delta_{ij}(0)]\, E_{qi}(0) \qquad (1)$$

According to the algorithm of reference [2], the total system eq. (1) could be decomposed into two subsystems corresponding to the weakest interconnection. The first subsystem comprising n1 machines. A measure for the smallness of the off-diagonal terms in comparison with the diagonal terms (corresponding to the first n1 machines can be expressed by the coupling factors S (n1) as:

$$S\,(n1) = SI/(ST - SI) \qquad (2)$$

where:

$$ST = \sum_{i=1}^{N} \sum_{i=1}^{N} A_{ji}, A_{ij} = -P_{ij} E_{qj}(0)/(2H_i),$$

$$SI = \sum_{j=n1+1}^{N} \sum_{i=1}^{N} (A_{ij} + A_{ji})$$

A computer algorithm, based on the coupling factor, for arranging the machines in order of their relative couling S (n1) within the system is shown in Figure (1). For more delatils on this coherency measure, the reader is referred to ref [2].

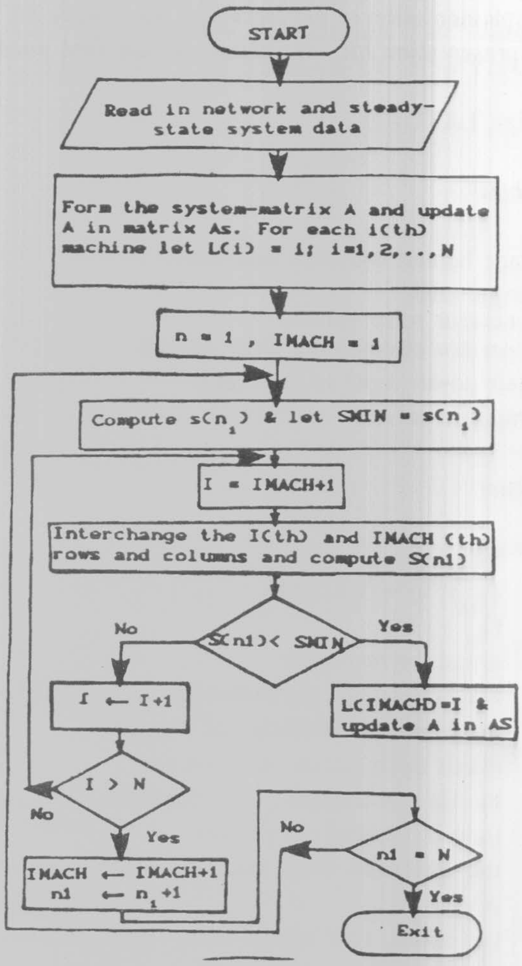

Figure 1. Computer program for arranging the different machines in order of their relative coupling S (n1).

Applying the previous coherency algorithm on the Egyptian power system grid Figure (4), the results are plotted in the called "coupling graph the coherent machine groups (i.e. subsystems) based on the principle of weak coupling are then tabulated as:

Table (1).

Subsystem code number (i)	Number of coherent units (1i)	Machine codes (Gi)
1	6	1,2,3,4,5,6
2	6	7,8,9,10,11,12
3	5	13,14,15,16,17
4	5	18,19,20,21,22

The results of the coherency measures Table (1) has proved that the decentralization of the Egyptian power grid Figure (4) is consistent with the geographical locations of the generating plants.

Table (2). Egyptain Grid Data (based on 100 mva).

Gen No.	1	2	3	4	5	6	7	8	9	10	11
Name Type	H. Dam. Hydro.	Aswan D Hydro.	Assuit steam	Ayat steam	. Tebbin steam	C. S. steam	C. L. steam	C. W. steam	C. N. steam	Shoubra steam	Hilliopolis steam
Nominal Rating MVA	12x175	7x46 - 2x15 + 3x75	3x30	384	320	4x60- 2x7.5	2x30 3x20 1x23	4 x87	2x30 3x20 1x23	4x300	3x1.5
1985 ME	1471	500	40	380	190	130	40	250	45	300	35
Max. MVR output	1400	521	44.72	382.7	212	145	44.7	254.8	50.5	381.7	39.4
Xd p.u	0.575	1.24	22.17	4.65	7.1	5.8	22.17	4.32	15.36	2.92	38.67
Xq p.u	0.34	0.8	21.67	4.63	6.8	5.5	21.67	4.0	15.01	2.87	38.08
Ra p.u	0.001	0.006	0.0	0.01	0.007	0.0	0.056	0.01	0.050	0.0015	0.007
Xd' p.u	0.17	0.64	3.83	0.94	1.36	1.11	3.83	0.8	2.71	0.5	6.55
T'do S.	7.5	5.6	5.5	5.25	5.9	6.5	5.5	6.5	5.0	5.0	5.5
Xffd p.u	0.476	0.343	21.68	4.56	6.88	6.1	21.68	4.67	15.03	2.84	38.85
Rfd p.u	0.0002	0.0005	0.014	.0001	0.0004	0.0003	0.014	.0003	.001	0.0002	0.0225
H p.u	9.2	4.52	0.47	1.68	1.47	1.65	0.47	2.41	0.56	3.3	0.26
D p.u	3.5	1.154	0.12	0.768	0.44	0.36	0.12	0.525	0.17	1.2	0.071
Tw	1.0	1.0	-	-	-	-	-	-	-	-	-
TA S.	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
KA p.u	50	50	300	300	300	300	300	300	300	300	300
Tt S.	-	-	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Kg p.u	-	-	-	-	-	-	0.05	0.05	0.05	0.05	0.05

3. *Linearized State-Space Model of the Decomposed System*

The network is assumed to be represented by the reduced model admittance matrix equations:

$$In = [Y_{red}\} E'n \qquad (3)$$

where: $In = [(IQ1+jID1),...,(IQn+JIDn)]^T$

$$E'n = [(E'Q1+jE'D1),...,(E'QN+jE'D)]^T$$

This $[Y_{red}]$ matrix is the internal description of the system where all nonsynchronous loads are represented by constant admittance and incorporated into $[Y_{red}]$ by eliminating all non-generator buses. The reduced bus admittance matrix $[Y_{red}]$ is obtained in the following procedures [6]:

Step 1:

Compute the elements of the bus impedance matrix of the interconnected network $[Z_{bus}]$ using network topological algorithm by firstly adding tree branches to the reference sequentially, where each added element will form one bus in the system. The admittance of each element may include the constant admittance representation of the load, the generator transient inductive susceptance and the charging line admittance which could be connected at the constructed bus. Finally the cotree links which include the admittances of the transmission systems are added sequentially between the buses to form $[z_{bus}]$ of the connected network.

Step 2:

The reduced admittance matrix $[Y_{red}]$ is then computed

$$\text{as } [Y_{red}] = [Y_A] - [Y_B\}$$

$$[Y_A] = \text{Diag. } [1/jx'_{d1},...,1'jx'dn]$$

$$[Y_B] = [-[Y_A]: [0]]$$

Now, the modified network constraint equations (3) can be decomposed into NSUB-weakly coupled subnetwork equations each containing li-coherent interconnected machines, i=1,2,..., NSUB, via matrix partitioning of $[Y_{red}]$, and manipulating using perturbation form, we arrive at:

$$\underline{AIN^i} = [y(i)\underline{\Delta e'N^i}$$

$$+ \sum_{j=1,\neq i}^{NSUB} [Y(i,j))]\Delta EN^j, i, i = 1,2,...,NSUB \qquad (5)$$

The linearized state-space one-axis model representation [4] for i-th subsystem comprising the states of machines, excitation and turbine-governer system is as follows:

$$\begin{bmatrix}\dot{\underline{X}}_m^i\\ \Delta\dot{\underline{E}}_{fd}^i\\ \Delta\dot{\underline{P}}_m^i\end{bmatrix} = \begin{bmatrix}[A_m^i] & [BME]^i & [BMG]^i\\ -[AT^i] & -[TE]^i & \\ & & -[B_G^i]\end{bmatrix}\begin{bmatrix}\underline{X}_m^i\\ \Delta E_{fd}^i\\ \Delta \underline{P}_m^i\end{bmatrix} + \begin{bmatrix} & \\ [BE^i] & \\ & [B_G^i]\end{bmatrix}\begin{bmatrix}\Delta\underline{U}_A^i\\ \Delta\underline{U}_G^i\end{bmatrix}$$

$$+ \sum_{j=1,\neq i}^{NSUB}\begin{bmatrix}[A_m(i,j)] & & \\ -[A_T(i,j)] & & \\ & & \end{bmatrix}\begin{bmatrix}\underline{X}_m^j\\ \Delta\underline{E}_{fd}^j\\ \Delta\underline{P}_m^j\end{bmatrix} \quad (6)$$

(6)

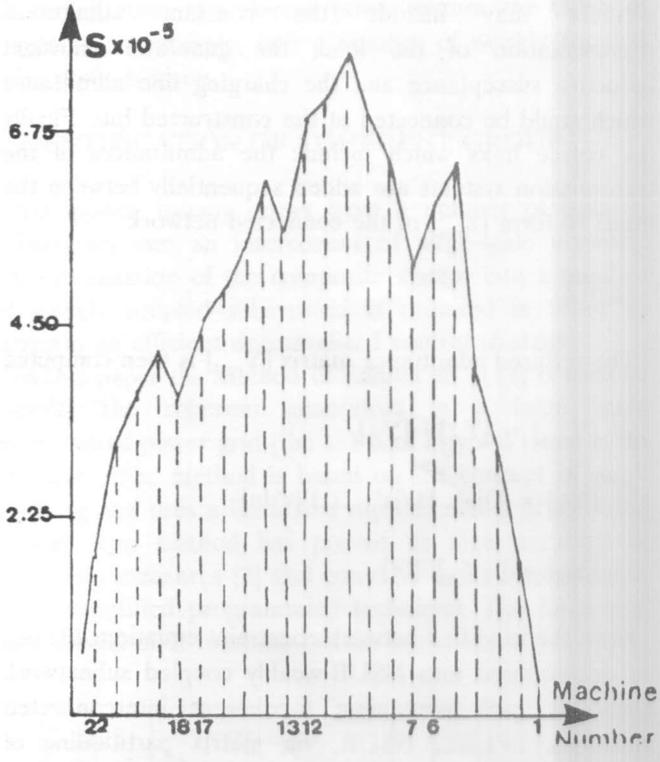

Figure 2. Coupling graph.

The use of the approximate one-axis simulating model in the design procedures of the decentralized controllers has proved its validity and practical applicability [4].

For the computer dimension difficulties we use the one state approximation for the AVR and governer system as illustrated in Figure (3).

The subsystem sub matrices are defined as:

$$[Am^i] = [Em^i] + [AF^i] + [AH^i]$$

$$[AF^i] = [FM^i][Y(i,j)](TM^i][TB^i],[AH^i] = [FM^i][JM^i][TA^i]$$

$$[Am^{ij}] = [FM^i][KM^i][Y(i,j)](TM^j][TB^j],$$

$$[AT^i] = [BE^i][AR^i] + [AS^i] + [VS^i])$$

$$[AR^i] = [CM^i][KM^i][Y(i,j)](TM^j][TB^j],$$

$$[AS^i] = [CM^i][JM^i][AT^i]$$

$$[VS^i] = [VM^i][TD^i], \quad [AT^{ij}] = [BE^i[KM^i][Y[i,j)]TM^j][TB^j]$$

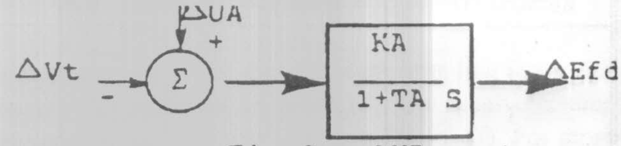

Fig.3a AVR-system

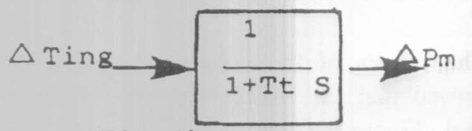

Fig.3b Steam turbine

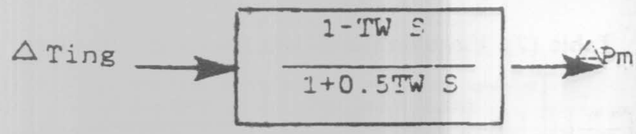

Figure (3-C). Hydro-turbine.

each ith subsystem submatrix of EM^i, FM^i ,KM^i ,TM^i, JM^i ,CM^i VM^i,TB^i,TA^i,TD^i (1 =1,2,...,Nsub) is represented as li-block diagonal submatrices Ej^i, Fj^i, Kj^i, Tj^i,Jj^i, cj^i, vj^i, Td^i, Taj^i, Tdj^i, Tdj^i (j=1,2,..,li) respectively. Omitting the upper suffix for the ith subsystem, and the lower suffix j for suffix j for each machine; each block submatrix is defined as

$$E = \begin{bmatrix} & 1 & \\ & -D/M & -Iq(0)/M \\ & & -1/T'do\end{bmatrix}, \quad F = \begin{bmatrix} & \\ F21 & F22\\ F31 & \end{bmatrix}$$

$$F21 = (xq-x'q)Iq(0)/M \ , F22 = [E'q(0)-(xq-X'd)Id(0)]/M,$$

$$F31 = (xq-x'd)T'do$$

$$\begin{bmatrix}\cos\delta(0) & -\sin\delta(0)\\ \sin\delta(0) & \cos\delta(0)\end{bmatrix}, \quad T = \begin{bmatrix}E'Q(0) & \sin\delta(0)\\ -E'D(0) & \cos\delta(0)\end{bmatrix}, \quad J = \begin{bmatrix}-Iq(0)\\ Id(0)\end{bmatrix}$$

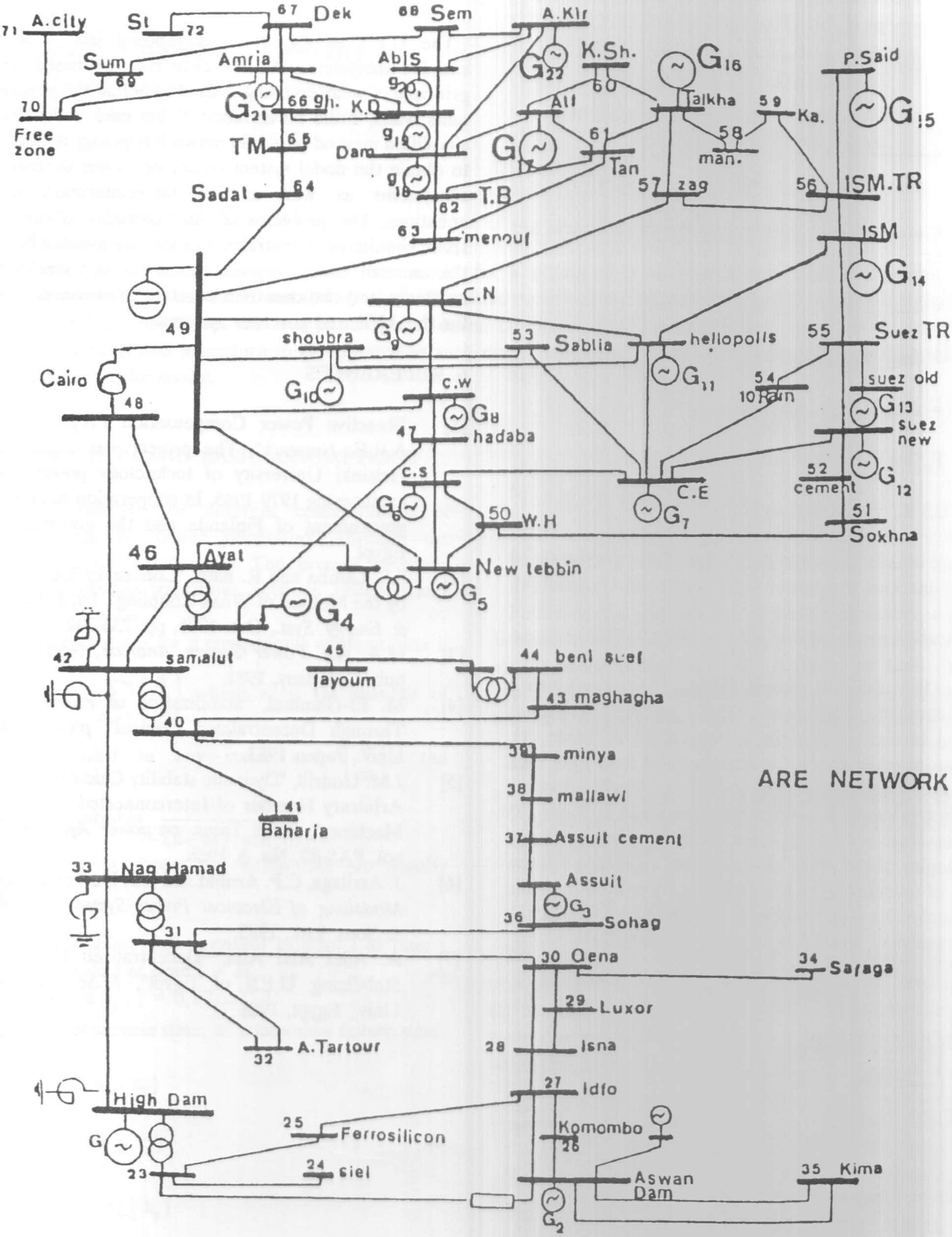
ARE NETWORK
A.city
St
72
67 Dek
68 Sem
A.Kir
Sum
69
Amria
AbIS
K.Sh.
60
G16
P.Said
70
Free zone
G21
66
K.D
G22
Talkha
59
Ka.
G15
TM
65
Dam
61
58
man.
Tan
Sadal
64
T.B
62
57 zag
56 ISM.TR
63 menouf
ISM
G14
C.N
49
shoubra
G9
53 Sablia
heliopolis
55 Suez TR
Cairo
G10
G11
54
10 Ram
suez old
48
c.w
G8
G13
47 hadaba
suez new
c.s
C.E
52 cement
G12
G6
50 W.H
G7
51 Sokhna
46 Ayat
New lebbin
G5
G4
42 samalut
45 fayoum
44 beni suef
43 maghagha
40
39 minya
38 mallawi
41 Baharia
37 Assuit cement
33 Nag Hamad
Assuit
G3
31
36 Sohag
30 Qena
34 Safaga
29 Luxor
28 Isna
32 A.Tartour
27 Idfo
High Dam
25 Ferrosilicon
Komombo
26
G
23
24 siel
Aswan Dam
35 Kima
G2

Figure 4.

$$C=[(-RaV(0)+X'dVq(0))/Vt(0))$$
$$(xqVd(0)\ RaVq\ (0))/Vt(0)]$$
$$V = [vq\ (0)\ /Vt\ (0)]$$

$$Tb = \left[\begin{array}{c|c|c} 1 & & \\ \hline & & 1 \end{array}\right],\quad Ta = [1\ ,\ 0\ ,\ 0\ ],\quad Tm = [0\ ,\ 0\ ,\ 1\ ]$$

The AVR and governer submatrices for ith subsystem are defined as:

$$[TE^i] = \text{diag}\ [1/Ta1^i,...,1/Tali^i]$$

$$[BE^i] = \text{diag}\ [Ka1^i,...,kali^i/Tali^i]$$

$$[BG^i] = \text{diag}\ [1/Tg1,...,1/Tgli^i];$$

$$T_g = T_t \text{ (for steam-turbine)}$$

$$T_g = 0.5\ T_w \text{ (for hydro-turbine)}$$

For more details about the derivation of the decentralized system equations, the reader is referred to El-Gammal [4].

4. *Application to the unified power system (UPS) of Egypt*

The U.P.S of Egypt Figure (4) is decomposed into 4 weakly-coupled subsystems. The coherent machines included in each subsystem are identified in Table (1). The transmission system parameters and load flow data (for heavily loading condition) are obtained from reference [1]. The equivalent generator data are listed in Table (2)

The machine no 1 "High Dam" is taken as reference and rotor angles of the other machines are expressed relative to that of machine no. 1 Hence $S1^1$ is eliminated from the state vector Xn_1 and the corresponding changes in the system matrices are made as given by Undrill [5].

Table (2). Contin.

Gen No.	12	13	14	15	16	17	18	19	20	21	22
Name Type	Sues New steam	Sues Old steam	Tom. PS steam	P. Said steam	Talkha steam	[illegible]	Dam steam	K.D. steam	Abis steam	Amria steam	A. Kir steam
Nominal Rating MVA	2x250	4x25 1x17	3x150	3x20	3x15.6 3x30 3x34	[illegible]	2x25 3x60 4x25	3x110	3x110	1x75	4x150
Turb MW	300	50	380	40	370	270	270	250	150	80	430
Max. MVR output	357.5	55.9	388.4	20	301.9	270.9	190	190.7	187.7	67.1	392.1
Xd p.u	3.44	16.67	3.44	16.67	4.34	[illegible]	[illegible]	3.07	10.53	14.6	1.95
Xq p.u	3.4	18.27	3.4	18.27	4.26	6.43	5.5	3.6	10.25	31.07	2.56
Ra p.u	0.06	0.0027	0.008	0.019	0.007	0.007	0.014	0.012	0.019	0.04	0.006
Xd' p.u	0.67	3.093	0.67	3.093	0.784	0.756	4.11	0.73	1.33	2.47	0.5
T'do S.	5.0	5.0	5.0	6.0	6.0	4.[illegible]	6.0	6.0	5.9	6.2	4.5
Xffd p.u	2.65	16.31	2.65	16.31	4.25	[illegible]	6.065	4.232	10.85	14.32	1.98
Rfd p.u	0.00017	0.01	0.0002	.0009	.0003	[illegible]	.00032	0.0002	0.0005	0.0003	.0001
M p.u	2.18	0.63	2.18	0.63	2.4	2.[illegible]	1.65	2.9	1.067	0.735	2.03
D p.u	0.92	0.15	0.9	0.15	0.085	0.[illegible]	0.36	0.6	0.32	0.15	1.2
Tw	-	-	-	-	-	-	-	-	-	-	-
TA S.	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05
KA p.u	300	300	300	300	300	300	300	300	300	300	300
Tt S.	5.0	5.0	8.0	6.0	6.0	5.0	5.0	6.0	5.0	5.0	5.0
Kg p.u	-	-	-	-	-	-	-	-	-	-	-

5. CONCLUSION

The U.P.S of Egypt is decomposed into 4 weakly-coupled subsystems. A coherency measure based on the principle of weak coupling is used to define the generating units which could be included within each subsystem. A simplified method based on network topology is then used to obtain the nodal system equations of the decomposed subsystems as well as the interconnection system equations. The problems of dimensionality of the state-space simulating decentralized model are avoided by using the one-axis model representation for the synchronous machines and the one time constant approximate model for the AVR and governer systems.

6. REFERENCES

[1] "Reactive Power Compensation Project. In The A.R.E. Network", The project was organized at Helsinki University of technology power system engineering 1979-1985. In cooperation between the government of Finlanda and the government of Egypt.

[2] S.S. Lamba and R. nath, "Coherency Identification by the Method of Weak Coupling", *Int. J. Electrical & Energy Syst.*, Oct. 1985, pp. 233-242.

[3] M.A. Rai, *Power System Analysis*, North-Holand pub. Company, 1981.

[4] M. El-Gammal, "Stabilization of Power Systems Through Decentralized Control", *ph.D.* Tohoku Univ., Japan 1983.

[5] J.M. Undrill, "Dynamic stability Calculations for an Arbitrary Number of Interconnected Synchronous Machines", *IEEE Trans. on power App. and syst.*, vol. PAS-87, No. 3, 1968.

[6] J. Arrilaga, C.P. Arnold and B.J. Harker, *Computer Modelling of Electrical Power System* John Wiely & Sons. Ltd., 1983.

[7] A. Adel Abd Alla, "Decentralized Control For Stabilizing U.P.S of Egypt", *M.Sc.*, Alexandria Univ., Egypt, 1988.