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APPLICATION OF COHERNCY MEASURE TO IDENTIFY COHERENT CROUP IN POWER SYSTEMS

استخدام مقياس الترابط في تحديد المجموعات المترابطة في منظومات القوى الكهربائية

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الملخص:

ان الهدف الاساسي من هذا البحث يتركز في تحديد المجموعات المترابطة في نظام القوى الكهربائية لاستخدامها في الدراسات الديناميكية والعابرة. وقد تم اقتراح طريقة لهذا الغرض في الجزء الأول من البحث تأخذ في الاعتبار نظم التحكم في الاثارة وغيرها.

وفي الجزء الثاني من البحث تم اختبار الطريقة المقترحة بتطبيقها على شبكة الوجه البحرى لجمهورية مصر العربية والتي تحتوى على ٣١ قضيب توزيع وتم عمل الدراسات الاتية في البحث :

١ـ تحديد المجموعات المترابطة في المولدات.

٢ـ دراسة تأثير طوبوغرافية الشبكة على المجموعات المترابطة في حالة فصل بعض خطوط النقل المتصلة بين بعض خطوط النقل المتصلة بين بعض المحطات مثلا

٣ـ دراسة تأثير قيم المتغيرات الخاصة بالمولدات على المجموعات المترابطة.

وأثبتت نتائج المحاكاة بقابلية الطريقة المقترحة للتطبيق على نظم القوى الكهربائية كما تمتاز أيضا بسهولتها وفاعليتها.

ABSTRACT:

The main theme of this paper centers around the indentification of coherent groups in power systems for dynamic and transient stability studies. A proposed method which takes into account the effect of excitation systems is developed.

The method has been tested through its application to a 31 bus system representing the unified power system of lower Egypt. The simulation results showed the high capability of the proposed method to identify the coherent groups in large scale power systems.

INTRODUCTION

The development of extensive extra-high voltage networks has greatly expanded the size of the system representation required for transient and dynamic simulation studies. Large amounts of core size and computation time are required to carry out these studies. Hence, the need has been intensified for using dynamic equivalent modeling in power systems. Several methods have been developed in the literature to obtain these equivalent models. The major techniques are : the modal approach [1-6], the coherency approach [7-11] and the parameter estimation approach [12-14].

Dynamic equivalent modeling using the coherency approach is based on the fact that groups of generators tend to oscillate together for a particular disturbance. The main advantages of this approach are:

(i) The equivalent models obtained can be used in transient stability.

(ii) There is no need for computing system eigenvalues and eigenvectors.

(iii) The reduced equivalent model retains its physical meaning.

The overall procedure for forming coherency based dynamic equivalents involves three main steps:

(a) Identification of groups of coherent generators.

(b) The terminal buses for each group of coherent generators are replaced by a single equivalent bus. The generating units in each group appear in parallel on the equivalent bus.

(c) The models of the generating units of each coherent group are combined into one equivalent model.

The research work developed in the literature, using the coherency approach, suffers from the drawback that the generators representation is restricted to second order models, which is only suitable for transient stability studies. These models are obtained by neglecting the representation of excitation systems and governors [10-11]. In order to overcome this drawback a method has been developed, in this paper, for the identification of coherent groups. The proposed method takes into account the effect of excitation systems and hence coherent groups can be identified for transient, as well as, dynamic stability and control studies.

COHERENCY MEASURE

The dynamic model of a power system can be described in the discrete state space form as:

$$X(k+1) = A\,X(k) + B\,U(k) \tag{1}$$

where

A, B : constant matrices of dimension (n×n) and (n×m), respectively.

X(k), U(k): (n×1) and (m×1) state and input vectors at sample k, respectively.

A coherency measure C_{lp} between generators l and p is defined as [10-11]:

$$\begin{aligned} C_{lp} &= \{1/(ns+1)\}\, E(\Delta\delta_l(k)-\Delta\delta_p(k))^2 \\ &= \{1/(ns+1)\}\,[\,E(\Delta\delta_l^2(k))+E(\Delta\delta_p^2(k)) \\ &\qquad -2E(\Delta\delta_l(k)\Delta\delta_p(k))\,] \end{aligned} \tag{2}$$

$$l=1,2,..,NG-1$$
$$p=1,2,..,NG$$

Equation (2) can be written in the form

$$\begin{aligned} C_{lp} &= [1/(ns+1)]\,[\mathrm{var}\,\Delta\delta_l(k) + \mathrm{var}\,\Delta\delta_p(k) \\ &\qquad -2\,\mathrm{cov}[\Delta\delta_l(k),\Delta\delta_p(k)]\,] \end{aligned} \tag{3}$$

$$l=1,2,...,NG-1$$
$$p=l+1,...,NG$$

COHERENCY MEASURE CALCULATION

In order to calculate the coherency measure, a matrix p(k+1) of order (ns×ns) is defined as follows:

$$\begin{aligned} p(k+1) &= \mathrm{cov}[X(k+1)\ ,\ X^t(k+1)] \\ &= E\,[X(k+1) - m_{k+1})(X(k+1)-m_{k+1})^t] \end{aligned} \tag{4}$$

To calculate the elements of the covariance matrix p(k+1) the following assumptions are made:

a) $U(k)$ is a discrete Gaussian white noise and hence $[U(k), U(k-1), \ldots, U(0)]$ is a sequence of independent random vectors such that

$$E(U(k)) = 0, \text{ and}$$
$$E(U(k)U^t(j)) = H\theta_{kj} \qquad k, j = 1, 2, .., ns \quad (5)$$

b) $X(k)$ is a Gaussian random variable having a zero mean uncorrelated with $[U(k), U(k-1), \ldots, U(0)]$,

hence $E(X(k)U^t(j)) = 0 \qquad k, j = 1, 2, .., ns \qquad (6)$

c) The random input vector $U(k)$ is given by

$$U(k) = Y(k) + W(k)$$

For studies around an operating condition, $Y(k)$ is set to zero and hence $U(k)$ has a zero mean. A computer program based on the developed method in [15] is used for generating the random vector $W(k)$. Taking the transpose of eq. (1) gives

$$X^t(k+1) = X^t(k)A^t + U^t(k+1)\, B^t \qquad (7)$$

Substituting for $X(k+1)$ and $X^t(k+1)$ from eqns. (1) and (7) into eq. (4) and taking into account that both m_{k+1} and $m^t_{k+1} = 0$, gives

$$p(k+1) = E(AX(k)X^t(k)A^t) + E(BU(k)U^t(k)B^t)$$
$$+ E(AX(k)U^t(k)B^t) + E(BU(k)X^t(k)A^t) \qquad (8)$$

using eqns. (5) and (6), $p(k+1)$ becomes

$$p(K+1) = AE(X(k)X^t(k))A^t + BE(U(k)U^t(k))B^t$$
$$= A\, p(k)\, A^t + B\, Q(k)\, B^t \qquad (9)$$

where the covariance matrix $p(k)$ is given by:

$$p(k) = \begin{bmatrix} var(X_1(k)) & cov(X_1(k), X_2(k)) \ldots cov(X_1(k), X_{ns}(k)) \\ cov(X_2(k), X_1(k)) & var(X_2(k)) \ldots\ldots\ldots cov(X_2(k), X_{ns}(k)) \\ \vdots & \\ cov(X_{ns}(k), X_1(k)) & cov(X_{ns}(k), X_2(k)) .. var(X_{ns}(k)) \end{bmatrix}$$

The computation procedure of coherency measure C_{1p} is then summarized in the following steps:

1) The power system model is put in the linear discrete form as given in eq. (1).

2) Set $k = 0$.

3) Set initial value of the covariance matrix $p(0) = 0$

4) Calculate covariance matrix $p(k+1)$ as given by eq. (10)

5) If $k=ns$, step 6 is executed, otherwise set $k=k+1$ and return to step 4

6) Compute coherency measure C_{1p} as given by eq. (3) where $var(\Delta\delta_1(k))$, $var(\Delta\delta_p(k))$, $cov(\Delta\delta_1(k),\Delta\delta_p(k))$ are obtained from the element $p(k)$.

7) Rank the coherency measure C_{1p} from the smallest to the largest values in a ranking table.

8) Allow the commutative rule to progress through the table merging coherent generators for each coherency measure [10-11].

APPLICATION OF THE PROPOSED METHOD TO THE UNIFIED POWER SYSTEM OF EGYPT

In order to test the capability of the proposed coherency identification method, an application has been made to the unified power system of Egypt (UPS) shown in fig. (1). This system consists of 19 generating power stations and 53 transmission lines. The models of the exciters are included. The linearized dynamic model in discrete form is given by eq. (1).

where:

$$\begin{aligned}
X &= (\Delta\delta \quad \Delta\omega \quad \Delta i_f \quad \Delta V_f)^t \\
\Delta\delta &= (\Delta\delta_1 \quad \Delta\delta_2 \quad \ldots.\Delta\delta_{19})^t \\
\Delta\omega &= (\Delta\omega_1 \quad \Delta\omega_2 \quad \ldots.\Delta\omega_{19})^t \\
\Delta i_f &= (\Delta i_{f1} \quad \Delta i_{f2} \quad \ldots.\Delta i_{f19})^t \\
\Delta V_f &= (\Delta V_{f1} \quad \Delta V_{f2} \quad \ldots\Delta V_{f19})^t \qquad \text{and} \\
U &= (\Delta P_{m1} \quad \Delta P_{m2} \quad \ldots\Delta P_{m19})^t
\end{aligned}$$

The dimension of A and B matrices are (38×38) and (38×19) respectively as given in [16]. Data concerning number and installed capacity of each unit power stations is given in table (1). Transmission line parameters are given in [16].

The main objective of the study are:

1. Identification of coherent groups of generators.
2. Investigating the effect of network topology on coherent groups.
3. Investigating the effect of generator parameters on coherent groups.

The results of the above studies are given below:

1- Identification of coherent groups

In this study, 9 generator are retained. Four of these generators are equivalent corresponding to the coherent groups obtained by the proposed method. Fig. (2) shows this model ,as well as, the coherent groups corresponding to a 6 generators equivalent model. The 9 generators equivalent model will be considered as a base model for comparison.

2- Effect of network topology

Two cases are studied

i) The C.E.-C.W. transmission line is disconnected

ii) The C220-C.W. transmission line is disconnected

The corresponding coherent groups (with 9 retained generators) are shown in fig. (3). It can be seen that, the number of generators in some of the coherent groups are different from those corresponding to the base case model. Disconnecting a transmission line reduces the coupling between the two generating power stations at both ends of the line. This leads to an increase of the coherency measure as compared with the base case.

3- Effect of power station size

Two cases are considered:

i) One generating unit of 150 MVA is disconnected at SUEZ power station.

ii) One generating unit of 65 MVA is disconnected at DMNH power station.

Table (1) Installed capacity of power stations

power station	installed capacity (MVA)
C.N.	2×10 + 2×30 + 1×20 + 1×20
C.S.	4×60
C.W.	4×87.5
N.TB	3×15 + 2×24
DMNH	2×15 + 3×65 + 1×300 + 3×33
TLKH	3×30 + 3×13 + 8×24
K.D.	3×110
ABKR	4×150
ABIS	2×30 + 2×26 + 4×16 + 2×12.5 + 6×33 + 1×26 + 2×15
SUEZ	2×150 + 1×300
SUZ2	4×25 + 1×17
ISM.	4×150 + 1×20
H.D.	12×175
C.E.	2×22.5
HLOP	3×13
ATF	2×50 + 2×50 + 8×25
GAZL	1×20
SHPS	3×300
C220	1×150

LIST OF SYMBOLS

$\Delta\delta$: incremental change in rotor angle, rad.
$\Delta\omega$: incremental change in angular velocity of machine, rad./sec.
ns : number of samples
E : expected value
m_{k+1} : mean value of vector x_{k+1}
w(k) : random input variable
Y(k) : deterministic value
cov : a centered second order moment.
NG : number of generators
θ : crolinker, $\theta = 0 \quad k \neq j$; $= 1 \quad k = j$
Δi_f : incremental field current
Δv_f : incremental field voltage
Δp_m : incremental mechanical input power
x(k) : state vector at sample k
Var : second order moment centered around the mean value.
t : means the transpose

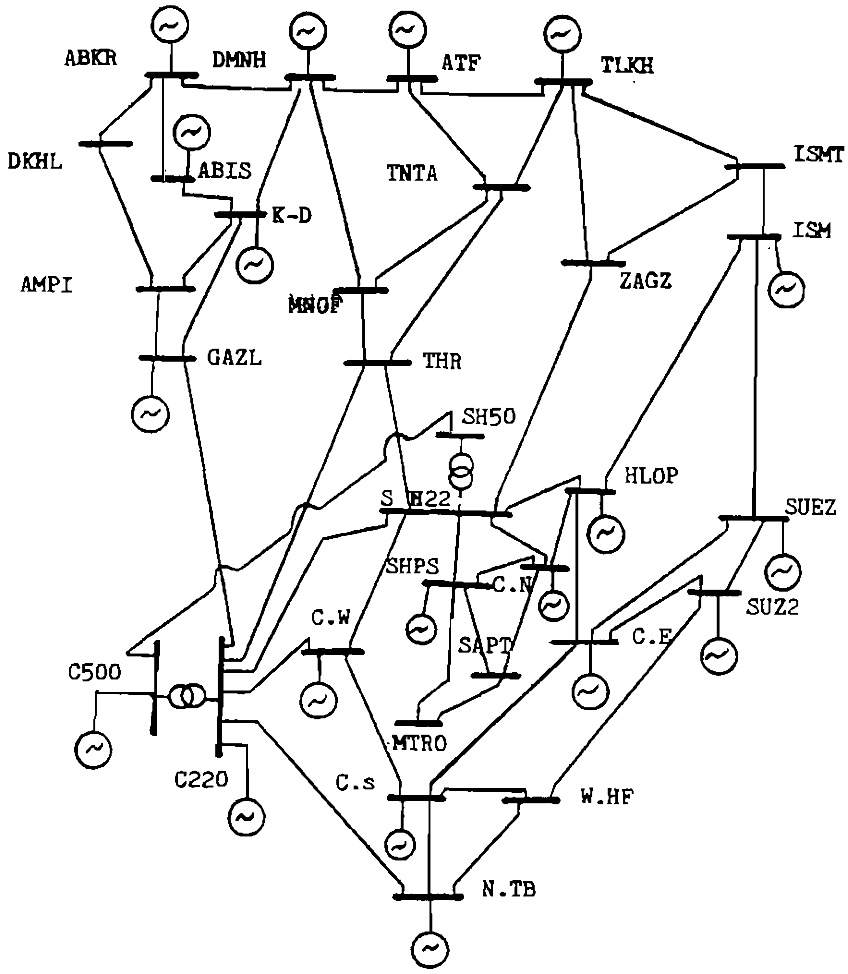

Fig. (1) Network Configuration

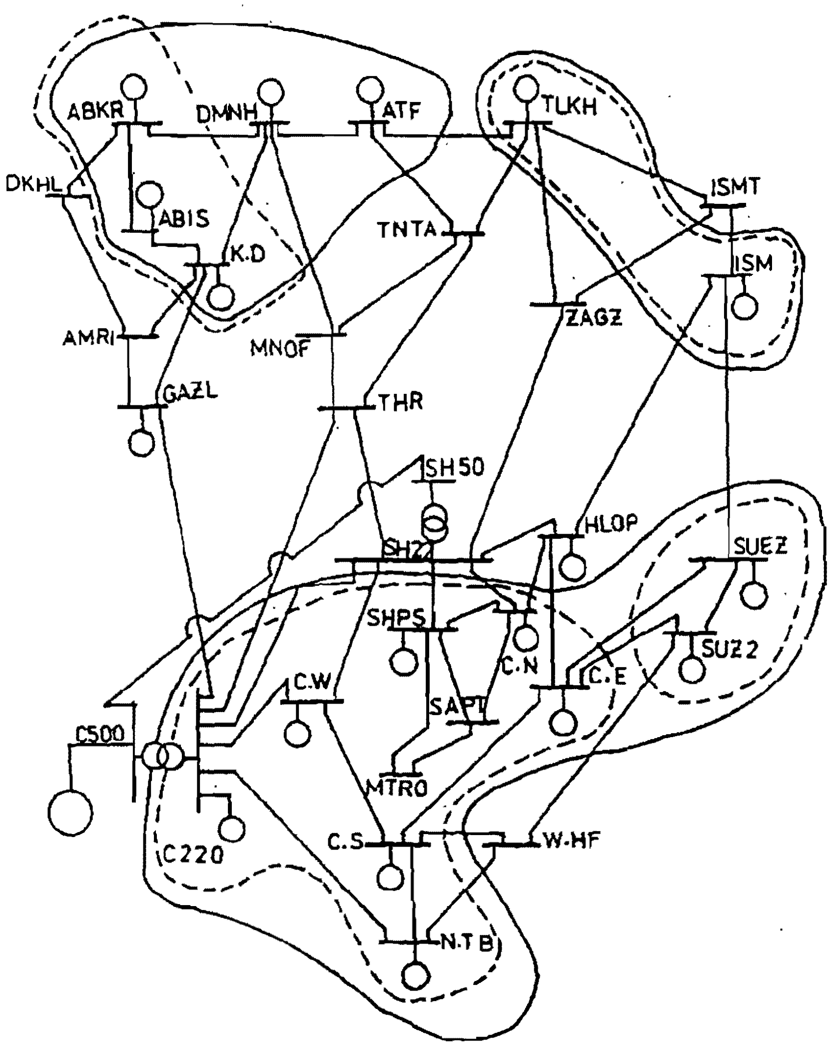

Fig. (2) Coherent groups of UPS of lower Egypt
—— 6 Power stations equivalent model
---- 9 Power stations equivalent model (base case)

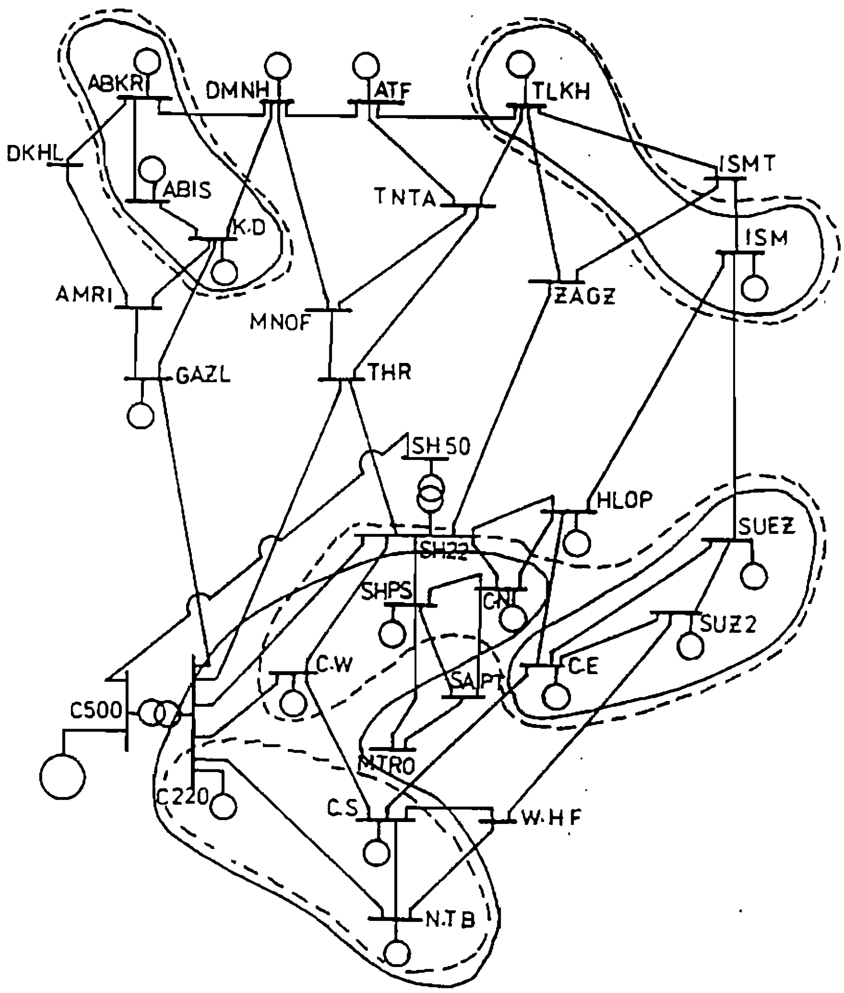

Fig. (3) Effect of network topology on coherent groups
—— C.E.-C.S. T.L. open circuited
---- C.W.-C220 T.L. open circuited

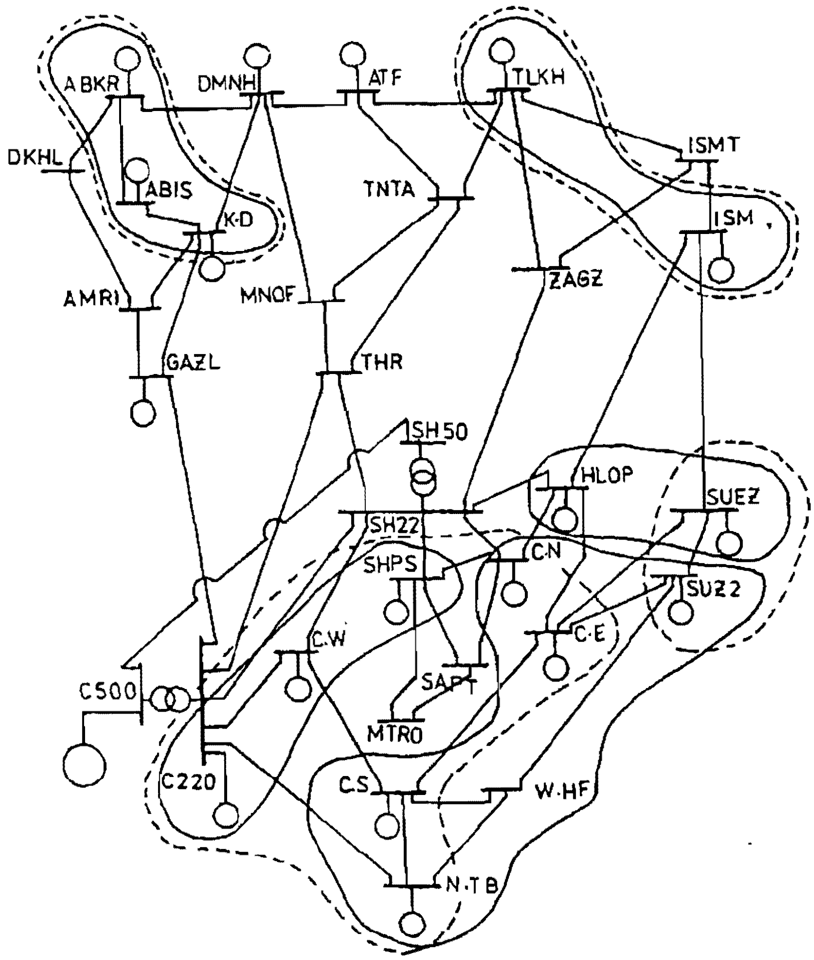

Fig. (4) Effect of power station size on coherent groups
______ 150 MVA unit disconnected at Suez
----- 65 MVA unit disconnected at Dmnh

The coherent groups corresponding to (i) and (ii), (with [illegible] retained generators) are shown in fig. (4). It is seen that the coherent groups are affected by power station size. This is due to the fact that changing the size of the power station leads to changing the inertia constant and the transient reactance and hence the elements of the A matrix. Therefore, the coherency measure C_{1p} attains different values leading to different coherent groups

The above study was repeated neglecting the effect of excitation system. It has been found that it has a negligible effect upon the obtained coherent groups. This is because the identification of coherent groups is greatly dependent on system inertia and not on the excitation.

CONCLUSION

A method has been developed for the identification of coherent groups in power systems, for dynamic and transient stability studies. The method gives the facility for more accurate representation of generators, and excitation system.

The developed method greatly simplifies the design of controllers since each control group can be considered as single equivalent generator. On the other hand the stability studies can be investigated through the use of coherent group instead of considering all the generators in the system. This lead to great simplifications in the dynamic calculations.

The effectiveness of the proposed method has been tested through the application of the unified power system of lower Egypt. Coherent groups have been identified. The effect of network topology and power station size has been also investigated.

REFERENCES

1. J.M. Undrill and A.E. Turner," Construction of power system electromechanical equivalents by modal analysis", Trans. Power App. and Syst. Vol.PAS-91, No.4, pp.2049-2059, Sep./Oct. 1971.

2. J.M. Undrill, J.A. Casazza, E.M. Gulachenski and L.K. Kirchmayer, " Electromechanical equivalents for use in power system stability studies " ibid, Vol. PAS-91, No. 5, pp. 2060-2071, Sep./Oct. 1971.

3. W.W. Price, E.M. Galackenski, P. Yunder and [illegible].J. Lange" Testing of the modal dynamic equivalents techniques" ibid, Vol. PAS-97, No. 4, pp. 1366-1372, July/Aug. 1987.

4. W.W. Price and B.A. Roth, "Large-scale implementation of modal dynamic equivalents", Ibid , Vol. PAS-100, pp. 3811-3817, Aug. 1981.

5. T.L. Baldwin, L. Mili and A.G. Phadke," Dynamic ward equivalents in transient stability analysis, ibid, Vol. 9 , No. 1, pp. 59-67, Feb. 1994.

6. P.M. Van Oirsauw," A dynamic equivalent using modal coherency and frequency response", ibid, Vol. 5, No.1, pp. 289-302, Feb. 1990.

7. B.D. Splang, H. Yee and D.B. Goudie, "Coherency recognition for transient stability studies using singular points", ibid, Vol. Pas-96, No. 4, July/Aug. 1977.

8. H. Rundinck, R.I. Patino and Brameller," Power system dynamic equivalents:Coherency recongnition via the rate of change of kinetic energy",IEE Proc., Vol. 128, pt.c, No. 6 , Nov. 1981.

9. S.T.Y. Lee and D.C. Schweppe," Distance meadure and coherency recognition for transient stability equivalents: IEEE Trans. power App. and syst. Vol. PAS-92, pp. 1550-1557, Feb.1973.

10. J.S.Lawler, R.A. Achlueter, P. Rusche and D.L. Hackett," Modal-Coherent equivalents derived from an R.M.S Coherency measure" ibid, Vol. PAS-99, No. 4, pp. 1415-1425, July/Aug. 1980.

11. J.S.Lawler and R.A. Schlueter," Computational algorithm for constructing modal-coherent dynamic equivalents", ibid., Vol. PAS-101, No.4, pp. 1070-1080, May 1982.

12. W.W. Price, D.N. Ewart, E.M. Gulachenski and R.F. Silva," Dynamic equivalents for on line measurements", ibid., Vol. PAS-94, No. 4, pp. 1349-1357, July/Aug. 1975.

13. M.A.H. Ibrahim, O.M. Mostafa and A.H. EL-Abiad, "Dynamic equivalents using operating data and stochastic modeling", ibid., Vol. Pas-95, No.5, pp. 1713-1722, Sept./Oct. 1976.

14. Yao-nan Yu and M.A. EL-Sharkawi,"Estimation of external dynamic equivalents of thirteen machine system", ibid., Vol. Pas-100, pp. 1324-1331, March 1981.

15. A.Y. Mostafa," Generators of uniform random numbers for different digital computers", Computer center, American University in Cairo, Techanical Paper, Aug. 1974.

16. A.A. EL-Emary," Identicication of coherent groups for dynamic studies in power systems", Ph.D Thesis, Faculty of Eng., Cairo Univ. 1987.