Identification of Coherent Generators for Large-Scale Power Systems Using Fuzzy Algorithm

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Abstract: - This paper presents a new proposed method for identifying the coherent groups of generators for any large power system, this is based on two different techniques; the first one is based on applying two proposed coherency criterions introduced by using time response of the linearized power system model; the second one is based on the application of Fuzzy C-Means clustering algorithm (FCM). Also a new technique of constructing the dynamic equivalent of power system is presented in this work. The proposed method is applied on two different power systems. The obtained results proved that the proposed technique is highly effective in determining the coherent groups of generators and in constructing the dynamic equivalent of power system with high accuracy.

Key-Words: - Coherent groups of generator, Fuzzy C-Means Clustering Algorithm, Dynamic equivalents, Network reduction, Dynamic aggregation, Large-scale power system.

1 Introduction

Because modern power systems are so large, power system analysis programs do not usually model the complete system in detail [1]. This problem of modeling a large system arises for a number of reasons including: Practical limitations on the size of computer memory, the excessive computing time required by large power systems; particularly when running dynamic simulation and stability programs, parts of the system far away from a disturbance have little effect on the system dynamics and it is therefore unnecessary to model them with great accuracy, often parts of large interconnected systems belong to different utilities, each having its own control centre which treats the other parts of the system as external subsystems, finally Even assuming that full system data are available, maintaining the relevant databases would be very difficult and expensive. The computational time can be reduced if the transient stability is determined in a reduced order equivalent model of the original system. In order to overcome all these problems, power system can be divided to two parts one of them is called the internal subsystem, or the study system which is modeled in detail. The remainder of the system, called the external system, is represented by simple models referred to as the equivalent subsystem or simply as the equivalent. The internal subsystem includes the disturbance and a small number of generators of great concern. These generators are severely disturbed and are in general responsible for the system instability. The system states like voltage, current, angle and speed of these generators are very important for control and protection purposes. The rest of generators are considered in the external system. The generators in the external system do not contribute significantly to the system instability. Thus the dynamic equivalencing technique is applied to these generators only. Fig. 1 illustrates such division.

In [7] the power system division is based on that the generators close to fault have a tendency accelerate much faster than the generators away from the disturbance.

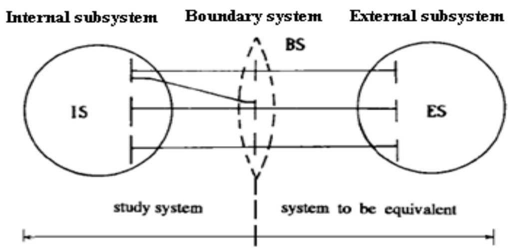

Fig. 1 Separation of the Power System

Coherency is an observed phenomenon in an interconnected power system where certain generators tend to swing together after a disturbance; these generators are referred to as a group of coherent generators. A coherent group of generating units, for a given disturbance, is a group of generators oscillating with the same angular speed, and generator terminal busbar voltages in a constant complex ratio. The general method of determining coherent generator is through observing the swing curves generated by numerical integration of system dynamic equations; however, the computation involved in this general technique is greatly high and may offset the advantages of the dynamic equivalencing strategy.

Mathematically a generator pair (*i*,*j*) in the external system is said to be coherent if there exists a constant a_{ij} such as:

$$\delta_i(t)\text{–}\delta_j(t)=\alpha_{ij} \qquad (1)$$

Where $\delta_i(t)$ and $\delta_j(t)$ are the rotor angels of i^{th} and j^{th} generators, respectively. A group of generators is said to be coherent if each pair of generators in the group is coherent. Each generator pair (*i*,*j*) is said to be perfectly coherent if α_{ij} =0.

A great deal of work has been reported in the literature on determination of the coherent generators in power systems. The previous methods can be divided to two strategies, one depends on the linearized swing equation and the other depends on the actual swing equation. Reference [2] proposed the solution of linearized swing equations and identification of machines swinging together through a clustering algorithm, it is computationally prohibitive especially in the case of large systems and the second assumption is not valid especially if the disturbance is severe. Reference [3] used the linearized equation and split the power system into three circles and a pattern recognition approach based on the faulted machine acceleration is suggested; it may sometimes fail to identify correct group of coherent generators or may recognize a non-coherent group as coherent. Reference [4] suggested a method of identifying coherent generators based on the generator inertias and system reduced admittance matrix obtained by eliminating the load buses. It has disadvantage which is the assumption of negligible transfer conductance in the coherency identification process gives erroneous results. Reference [5] proposed a method of coherency identification technique based on equal acceleration and velocity concepts, but this method is prohibitively large when several studies have to be made to assess coherency in relation to fault location. Reference [6] suggested a method for coherency identification; it based on using singular points or unstable equilibrium points (UEP) and admittance distance; the disadvantage of this method is that the identification of expected mode of instability and computations of the corresponding UEP by iterative method is not easy and may not even converge to proper UEP. Reference [7] proposed a method of determining the coherent generator using a combination of Taylor series, this technique required large computer memory. Reference [8] established the dynamic equivalent models of large-scale power systems based on the usage of phase shifting transformer. Reference [9] proposed a method of dynamic aggregation using the complex power invariance principle, it is time consumed method. Reference [10] proposed a new method of constructing the electromechanical equivalent, dynamic load modeling and dynamic load aggregation of power system for transient stability studies. Reference [11] established a new technique of determining the dynamic equivalent of external power system using artificial neural networks (ANN). Transient stability indices like peak over shoot, decay constant, natural frequency of oscillation, etc. are utilized to predict the inertia constant, the reactances and other parameters of the equivalent machine. Two ANN-the back propagation (Bp) and radial-basis function (RBF) have been trained. Reference [12] proposed an optimization problem, solved to estimate parameters of fictitious generators that represent a dynamic equivalent of an external subsystem. In that technique the option of eliminating all nodes of the external system, except the frontier nodes, is elected. The dynamic equivalent is based on the minimization the sum of the difference between the set of electromechanical modes with relevant contribution of generators of the studied system; and the associated set of electromechanical modes of the reduced system. Reference [13] presented a reduced-order method for swing mode eignvalues calculating based on fuzzy coherency recognition. Reference [14] presented the application of fuzzy c-means (FCM) clustering to the recognition of the coherent generators in power systems. Reference [15] suggested a technique to identify coherent generators in large interconnected power system using measurements of generator speed and bus angle data, based on the application of principal component analysis (PCA) to measurements obtained from simulation studies that represent examples of inter area events. In the most previous methods there are some weaknesses such as computationally prohibitive, required large computer memory and the effect of transmission lines conductances are neglected.

This paper presents a new simple, accurate and effective method of dynamic reduction and dynamic equivalent of power system that required less computer memory and less time consumed, based on three main steps: (1) Identification of coherent generators, (2) Aggregation of generators in each of the coherent group, and (3) Construct the reduced form of the transmission network. In order to ensure the validity of the proposed coherency criterions, the first technique in determining the coherent generators is based on two different proposed coherency criterions introduced by using time response of the linearized power system model; the second one is based on the application of Fuzzy C-Means clustering algorithm (FCM). These main steps are shown in Fig. 2. First a static reduction is performed to eliminate all load buses. Finally; the construction of power system dynamic equivalent is obtained which is based on the dynamic aggregation of the coherent groups of generators and reduction of transmission network.

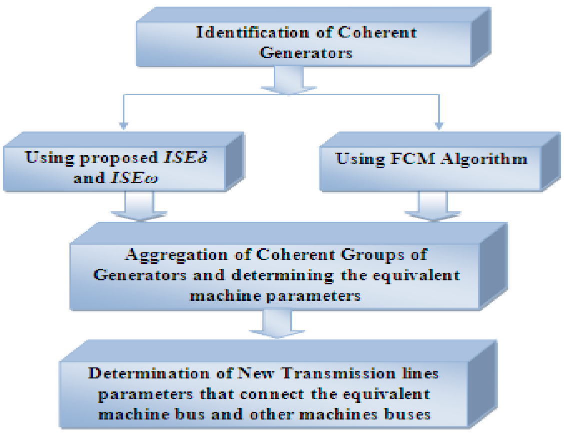

Fig. 2 The block diagram of the main steps of the construction of power system dynamic equivalent

2 Problem Formulation

2.1 Mathematical Model

The classical model is the simplest model used in studies of power system dynamics and requires a minimum amount of data. This model is based on the following assumptions.

1. Mechanical power input is constant.
2. Damping or asynchronous power is negligible.
3. Constant-voltage-behind-transient-reactance model for the synchronous machines is valid.
4. The mechanical angle of a machine coincides with the angle of the voltage behind the transient reactance.
5. Loads are presented by passive impedances.

The swing equation for machine number *i* can be described in a linearized form as follows:

$$M_i \frac{d\Delta\omega_i}{dt} = \Delta P_{mi} - \Delta P_{ei} - D_i\omega_i \, , i = 1,2,\dots,n \quad (2)$$

$$\frac{d\Delta\delta_i}{dt} = \Delta\omega_i \, , i = 1,2,\dots,n \quad (3)$$

The power into the network at node *i*, which is the electrical power output of machine *i*, is given as follows:

$$P_i = Re\,(\bar{E}_i \bar{I}_i^{\,*}) \quad (4)$$

$$P_{ei} = E_i^{\,2} G_{ii} + \sum_{\substack{j=1\\ j\neq i}}^{n} E_i E_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j), i = 1,2,\dots,n$$

$$= E_i^{\,2} G_{ii} + \sum_{\substack{j=1\\ j\neq i}}^{n} E_i E_j [B_{ij} \sin(\delta_i - \delta_j) + G_{ij} \cos(\delta_i - \delta_j)], i = 1,2,\dots,n \quad (5)$$

The set of equations (2) and (3) are sets of *n*-coupled nonlinear second-order differential equations. It can be rearranged in state space model for n generators as follows:

$$\begin{bmatrix} \Delta\dot\delta_1 \\ \Delta\dot\delta_2 \\ \vdots \\ \Delta\dot\delta_n \\ \cdots \\ \Delta\dot\omega_1 \\ \Delta\dot\omega_2 \\ \vdots \\ \Delta\dot\omega_n \end{bmatrix} = \begin{bmatrix} & & & & \vdots & 1 & & \\ & & & & \vdots & & \ddots & \\ & 0 & & & \vdots & & & \ddots \\ & & & & \vdots & & & & 1 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ K_{11} & \cdots & \cdots & K_{1n} & \vdots & D_1 & & \\ K_{21} & \ddots & \cdots & K_{2n} & \vdots & & D_2 & \\ \vdots & \vdots & \ddots & \vdots & \vdots & & & \ddots \\ K_{n1} & \cdots & \cdots & K_{nn} & \vdots & & & & D_n \end{bmatrix} \begin{bmatrix} \Delta\delta_1 \\ \Delta\delta_2 \\ \vdots \\ \Delta\delta_n \\ \cdots \\ \Delta\omega_1 \\ \Delta\omega_2 \\ \vdots \\ \Delta\omega_n \end{bmatrix} + \begin{bmatrix} 1 & & & \\ & \ddots & & \\ & & \ddots & \\ & & & 1 \\ \cdots & \cdots & \cdots & \cdots \\ \frac{1}{M_1} & & & \\ & \frac{1}{M_2} & & \\ & & \ddots & \\ & & & \frac{1}{M_n} \end{bmatrix} \begin{bmatrix} \Delta P_{m1} & \Delta P_{m2} & \cdots & \Delta P_n \end{bmatrix} \quad (6)$$

Where $\Delta\delta_i$ is the angle deviation in radians, ΔP_{mi} is the change in mechanical input power in *P.U.*, ΔP_{ei} is the change in electrical output power in *P.U.*, $\Delta\omega_i(t)$ is the rotor speed deviation in radian/sec., M_i is the inertia constant of machine *i*., D_i is the damping coefficient of machine *i*., $G_{ij}+jB_{ij}$ is transfer conductance and susceptance of the transmission line between the i^{th} and j^{th} machines. The diagonal and off-diagonal elements K_{ii}, K_{ij} are as follows:

$$K_{ij} = -\frac{1}{M_i}\frac{\partial \Delta P_{ei}}{\partial \Delta\delta_j}\; i \neq j = -\frac{1}{M_i}[E_i E_j Y_{ij}\sin(\delta_i - \delta_j - \theta_{ij})] \quad (7)$$

$$K_{ii} = -\frac{1}{M_i}\frac{\partial \Delta P_{ei}}{\partial \Delta\delta_i} = -\frac{1}{M_i}[\sum_{\substack{k=1 \\ k\neq i}}^{n}[E_i E_j Y_{ik}\sin(\delta_i - \delta_k - \theta_{ik})]] \quad (8)$$

A static reduction is performed on the original power system in order to obtain the generator nodes only. This reduction is obtained by the following expression.

$$Y^{red} = (\overline{Y}_{mm} - \overline{Y}_{mr}\overline{Y}_{rr}^{-1}\overline{Y}_{rm}) \quad (9)$$

Where subscript *m* denotes the generating bus and *r* denotes the load bus. The bus admittance matrix used in eqn. (7) and eqn. (8) is Y^{red} as model is used after static reduction of power system.

3 Proposed Technique for Coherency Identification

In order to investigate the validity of the proposed method of constructing the dynamic equivalent of power system and the validity of the application of fuzzy algorithms in constructing the dynamic equivalent of power system; two different proposed techniques of the identification of coherent generators; the first one is based on the intersection of the two following proposed coherency criterions:

(1) *ISEδ*: the integral of the square of the rotor angle difference.

$$S_1 = \sqrt{\left(\frac{1}{T}\int_0^T (\Delta\delta_i(t) - \Delta\delta_j(t))^2\, dt\right)} \quad (10)$$

(2) *ISEω*: the integral of the square of the rotor speed difference.

$$S_2 = \sqrt{\left(\frac{1}{T}\int_0^T (\Delta\omega_i(t) - \Delta\omega_j(t))^2\, dt\right)} \quad (11)$$

The obtained values of the coherency index (S_i, $i=1, 2$) are arranged in an ascending order. A generator pair (*i, j*) in the external system is said to be coherent if they satisfied the following condition:

$$S_i \leq \varepsilon_i \quad , i = 1,2 \quad (12)$$

Where ε_i is a predetermined accuracy tolerance for each proposed coherency criterion. The second proposed method of identification of coherent groups of generators using FCM is described. FCM is a method of clustering which allows one piece of data to belong to two or more clusters. This method (developed by Dunn in 1973 and improved by Bezdek in 1981) is frequently used in pattern recognition. FCM algorithm [16] uses concepts of n-dimensional Euclidean space to determine the geometric closeness of data points by assigning them to various clusters and then determining the distance between the clusters. The distance between points in the same cluster will be considerably less than the distance between points in different clusters. The most widely used objective function for fuzzy clustering is the weighted sum of the squared errors within groups. The objective function J_m can be defined as follows:

$$J_m(U, C_i, X) = \sum_{i=1}^{c}\sum_{j=1}^{n} \mu^m{}_{ij} d^2{}_{ij} \quad (13)$$

Where *X*: data space of generator time-domain responses, whose elements are $\{x_j\}$, *C*: number of cluster, *n*: number of generators, c_i: centre of cluster I, *U*: membership matrix whose elements are $\{\mu_{ij}\}$, μ_{ij}: degree of relation of generator *j* to cluster *i*, *m*: exponent on μ_{ij}, weighting coefficient and d_{ij}: distance from x_j to C_i. First; the coherency measures are derived from the time-domain response of generators to reveal the relations between any pair of generators then; finally; they are used as the initial membership matrix in the FCM clustering. It is hoped that the iterative times could be less. A time-domain coherency measure, C_{ij}, which is derived from the swing curves, is proposed to evaluate the coherency behaviours of system generators. In Ref. [14] the initial membership matrix is the mean value of the angle around a specific period of time but in this work the first and the second proposed coherency measures are *ISEδ* and *ISEω* respectively. The obtained results by each C_{ij} are compared. The index is further normalized to become:

$$S'_{ij} = \frac{S_{ij}}{\max(S_{ij})} \quad i=1,\ldots\ldots,c\;,\; j=1,\ldots\ldots,n \quad (14)$$

Finally, the coherency measure is obtained by

$$C_{ij} = 1 - S'_{ij} \quad (15)$$

Obviously, $0 \le C_{ij} \le 1$ and $C_{ii}=1$ and $C_{ij}=C_{ji}$ The relation between two generators can be evaluated by the value of C_{ij}. A larger indicates that generator *i* and generator *j* are more similar in the time domain. The proposed clustering procedures of using the coherency measures as initial values in the fuzzy c-means method can be formulated as the following steps.

1) Begin the procedure at the sampling instant t_0; construct ($n \times n$) fuzzy relation matrix *R* for *n*-generator with coherency measures C_{ij}, $i=1,\ldots\ldots, n, j=1,\ldots\ldots, n$.

$$R = [C_{ij}] \qquad 0 \le C_{ij} \le 1 \quad (16)$$

Select C the number of clusters, let l is the iterative time; initialize the ($C \times n$) membership matrix U with a sub matrix of R

$$U^l = [C_{ij}], \quad i = 1,\ldots,c, \; j = 1,\ldots,n \quad (17)$$

2) Begin a new iterative procedure at sampling instant t_k.

3) At the l^{th} iteration calculate the cluster center $c_i^{(l)}$.

$$C_i^l = \frac{\sum_{i=1}^{n} (\mu_{ij}^{(l)})^m x_j}{\sum_{j=1}^{n} (\mu_{ij}^{(l)})^m} \qquad i = 1,\ldots\ldots,c \quad (18)$$

Where: x_j is the time response value of generator *j*; μ_{ij} is the element of matrix U and expresses the degree of membership of generator *j* to cluster *i*. Note that the value of *m* normally falls in the range of $1.5 \le m \le 3$.

4) Compute the distance between generator *j* and cluster center *i* as following:

$$d_{ij}^{(l)} = d(x_j - C_i^l) = [\sum_{j=1}^{m} (x_j - C_i^l)^2]^{\frac{1}{2}} \quad (19)$$

5) Update the member ship matrix $U^{(l+1)}$ by

$$\mu_{ij}^{(l+1)} = \frac{1}{\sum_{k=1}^{c} (\frac{d_{ij}^{(l)}}{d_{kj}^{(l)}})^{\frac{2}{m-1}}} \qquad i = 1,\ldots,c, \quad j = 1,\ldots,n \quad (20)$$

6) Check if $\left\| U^{(l+1)} - U^{(l)} \right\| \le \theta$ where the θ is the convergent tolerance or a predefined number of iteration is reached, then stop; otherwise, set $l=l+1$ and go to step 4.

7) Use the convergent U at the sampling instant as the initial membership matrix to begin a new iterative procedure for the next sampling instant and go to Step 3 until the final sampling instant.

8) Defuzzify the convergent *U* of the final sampling instant. The defuzzification is called the maximum membership method for hardening the fuzzy classification matrix that is required to assign data into hard partitions.

4 Proposed Dynamic Aggregation

The second proposed step is that the dynamic aggregation of each coherent group, in this step the generators in each group can be aggregated to an equivalent generator. It is important to determine the parameters of the equivalent generator. The proposed form to calculate the mechanical power, inertia constant and damping coefficient of the equivalent generator is based on the sum of the input mechanical powers to the generators to be coherent and the weighted sum of both the coherent generators inertia constants and the damping coefficients as follows:

$$P_{me} = \sum_{i=1}^{m} P_{mi} \quad (21)$$

$$M_e = \frac{\sum_{i=1}^{m} S_i M_i}{S_T} \quad (22)$$

$$D_e = \frac{\sum_{i=1}^{m} S_i D_i}{S_T} \quad (23)$$

Where: P_{mi} is the mechanical input power to generator *i*, M_i is the inertia constant of generator *i*, D_i is the damping coefficient of generator *i*, S_i is the MVA of generator *i* and S_T is the total MVA of coherent generators.

5 Proposed Transmission Lines Parameters Calculation

The third proposed step in constructing the reduced dynamic equivalent of large power system is the calculation of the new transmission lines parameters that connect between the equivalent generator and the other non coherent generators. The proposed technique is based on that, the power injected at the equivalent bus must be equal to the sum of the powers injected at the aggregated bus of the coherent generators; a phase shifting transformer with complex turns ratio is proposed to transform the coherent generators buses to only one equivalent bus. Fig. 3 shows the usage of phase shifting transformer. The turn's ratio of the ideal transformer is given by:

$$\bar{a} = \frac{\dot{V}_k}{\dot{V}_t} \qquad (24)$$

Where $\dot{V}_k$ and $\dot{V}_t$ are voltages at buses k and t respectively.

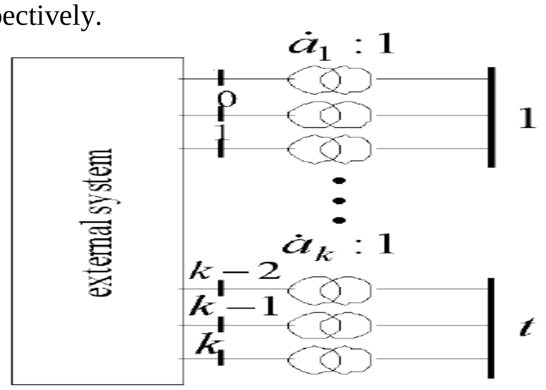

Fig. 3 Simulation of phase shifting transformer

The final form of the proposed symmetrical aggregated reduced bus admittance matrix can be written in the following form:

$$\begin{bmatrix} \bar{a}^{*T}\bar{Y}_{mm}\bar{a} & \vdots & \bar{a}^{*T}\bar{Y}_{mmt} \\ \cdots & \vdots & \cdots \\ (\bar{a}^{*T}\bar{Y}_{mmt})^T & \vdots & \bar{Y}_{mtmt} \end{bmatrix} \qquad (25)$$

Where subscript m denotes the coherent generators and subscript m_t denotes the total generators.

6 Numerical Analysis

In order to show the ability of the proposed method, it is applied on two different large-scale power systems with different topology.

1) The 68-Bus, 16 Machines System.
2) The 118-Bus, 20 Machines IEEE System.

The single line diagram of 68 buses, 16 Machines system is shown in Fig. 4 and the data are given in [17]. Assuming a symmetrical three-phase short circuit fault occurs at bus 29 which cleared after three cycles by removing line (28-29). The speed deviation of the generator No. 6 and No. 1 in the original system and in the reduced system are compared in Fig. 5 and Fig. 6 respectively, also the obtained results are compared to those obtained in [10]. The proposed values of the error levels are assumed as a percentage of maximum value of the proposed coherency criterions ε_1=0.04, ε_2=0.005; the obtained coherent groups under this disturbance according to the first proposed coherency criterions are divided to three groups Group I: G_2, G_3, G_4, G_5, G_7 and G_8. Group II: G_{10} and G_{11}. Group III: G_{14} and G_{15}. The proposed FCM clustering algorithm is applied and the obtained coherent groups of generators are identified as given in Table 1. The proposed value of θ (error level) is 0.001 and iteration step is 0.1 sec.

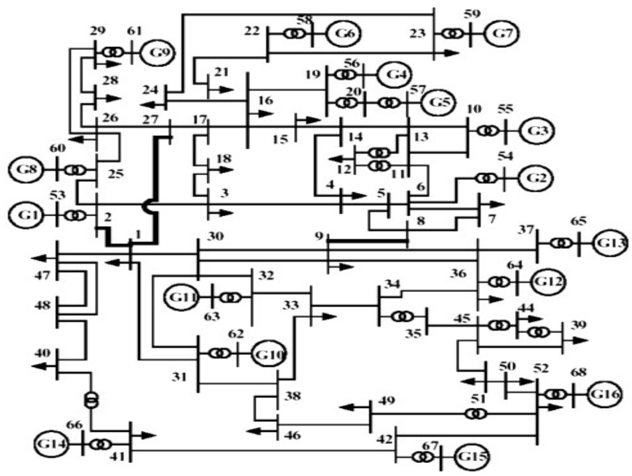

Fig. 4 Single line diagram of 68 bus system

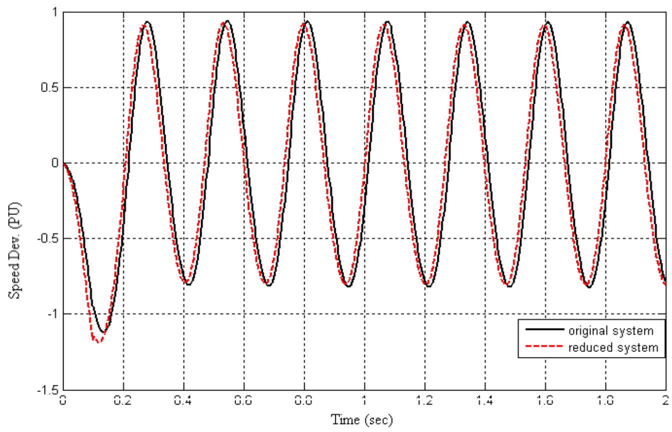

Fig. 5 Speed deviation of generator No. 6 in the original system and in the reduced system

It is shown that the speed deviation of the generator No. 1 and the speed deviation of generator No. 6 in the original system and in the reduced system are very closely to each others.

Table 1 the coherent generators of 68-Bus system using FCM algorithm

ISEδ as Input Membership Matrix		ISEω as Input Membership Matrix	
Group1	G_1	*Group1*	G_1
Group2	G_2	***Group2***	$\boldsymbol{G_{10}, G_{11}}$
Group3	G_3	*Group3*	G_3
Group4	$\boldsymbol{G_{10}, G_{11}}$	*Group4*	G_{12}
Group5	G_6	*Group5*	G_{13}
Group6	G_{12}	*Group6*	G_2
Group7	$\boldsymbol{G_4, G_5, G_7, G_8}$	*Group7*	G_{16}
Group8	$\boldsymbol{G_{14}, G_{15}}$	***Group8***	$\boldsymbol{G_4, G_5, G_7, G_8}$
Group9	G_9	***Group9***	$\boldsymbol{G_{14}, G_{15}}$
Group10	G_{16}	*Group10*	G_6
Group11	G_{13}	*Group11*	G_9
Total Number of Iteration			
43		***44***	

From Table 1 it is shown that the same coherent groups are obtained for both inputs *ISEδ* and *ISEω to* FCM algorithm. Fig. 7 shows the membership matrix and cluster centre for each iteration.

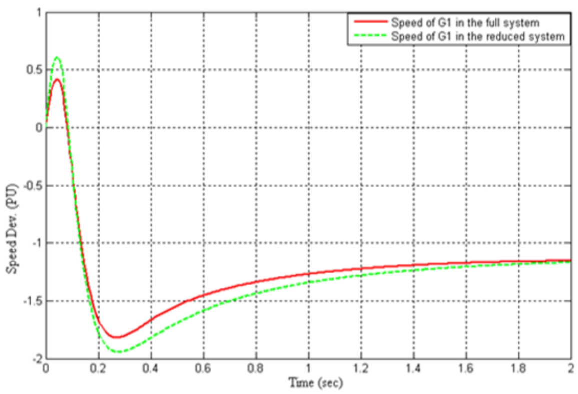

Fig. 6 speed deviation of generator no. 1 in the original system and in the reduced system

Table 2 shows a comparison between the results obtained by the proposed method and those obtained in [10]. Finally one can get that the original system has 68 nodes, 16 Machines and 83 transmission lines; while the reduced system has 9 Machines, 9 nodes and 33 transmission lines.

Table 2 a comparison between the results obtained by the proposed method and Ref. [10]

Fault at Bus #	**Line tripped between buses**	**Coherent generators by proposed method**	**Coherent generators by method of ref. [10]**
		(2,3,4,8)	(2,3,4,5,7)
#29	28-29	(10,11)	(10,11,12,13)
		(14,15)	(14,15)

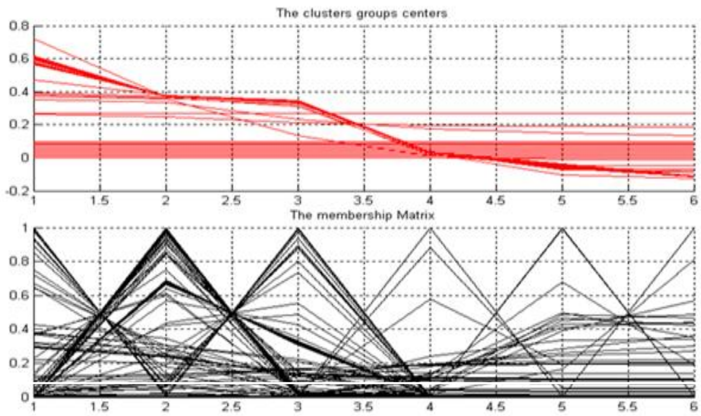

Fig. 7 The membership matrix and cluster center for each iteration for 68-Bus system

The single line diagram of 118 bus, 20 Machines IEEE system is shown in Fig. 8. The system parameters are given in [7]. Assuming three-phase short circuit fault occurs at bus no. 25 and cleared by opening the line (25-26) after (0.278 sec). The coherency criterions are calculated and compared with the proposed values of the error levels which are as follows: ε_1=0.1 rad, ε_2=0.38 rad/sec., it is found that the coherent groups of generators are shown in Table (3). From Table (3) one can get the final groups of the coherent generators as follows: *Group I:*(G_6 *and* G_7)*, Group II:* (G_1, G_2, G_3, G_5 *and* G_{19})*, Group III:*(G_{17}, G_{18} *and* G_{20})*.* The time response of machines after clearing fault is shown in Fig. 9. The proposed FCM algorithm is applied to 118 bus IEEE system and the final obtained results are shown in Table 4 which are the same results that are obtained in the Table 3. Fig. 10 Shows the membership matrix and clusters centers for each iteration.

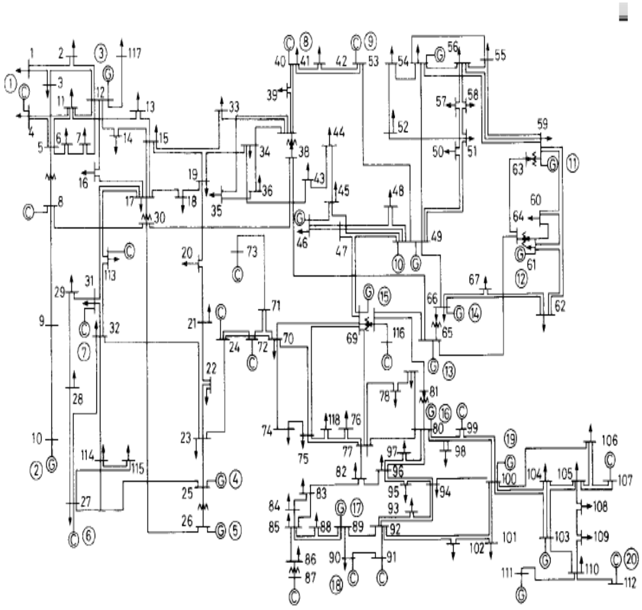

Fig. 8 Single line diagram of 20-machines IEEE-test system

Table 3 The final coherent groups of 118-Bus IEEE system

	Group No.	Coherent groups of generators
According toISEδ	*Group I*	*(G_6 and G_7)*
	Group II	*(G_1, G_2, G_5 and G_{19})*
	Group III	*(G_{17} and G_{18})*
According toISEω	*Group I*	*(G_{17}, G_{18})*
	Group II	*(G_6 and G_7)*
	Group III	*(G_1, G_2, G_5 and G_{19})*

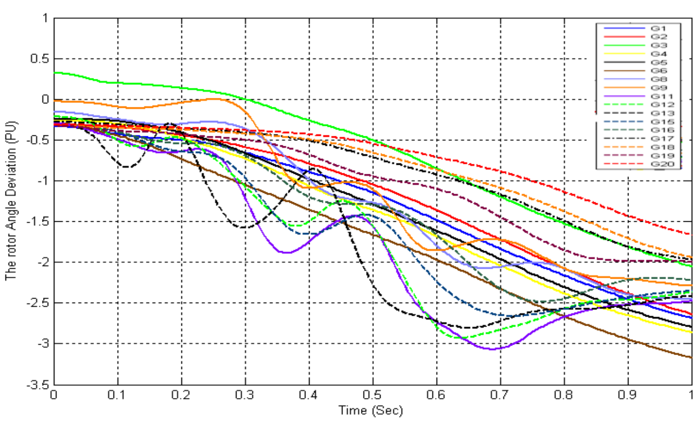

Fig. 9 the time response for 118-Bus IEEE system machines after clearing fault

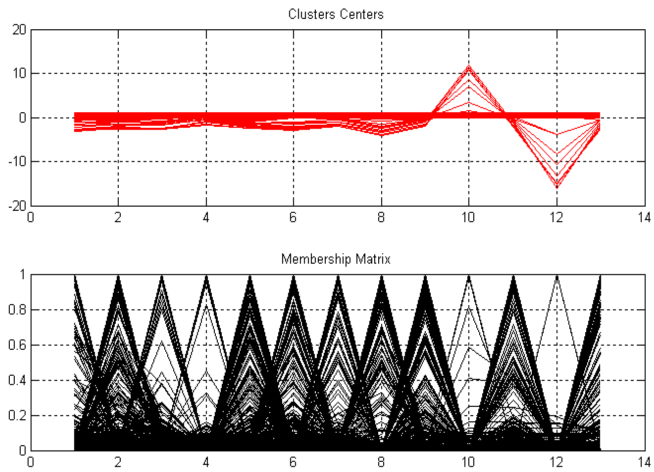

Fig. 10 the membership matrix and the clusters centers for each iteration for 118-Bus IEEE system

Table 4 The final coherent groups of generators for 118-Bus IEEE system

ISEδ as Input Membership Matrix		**ISEω as Input Membership Matrix**	
Group1	*G4*	*Group1*	*G4*
Group2	*G8*	*Group2*	*G13*
Group3	*G14*	*Group3*	*G10*
Group4	*G17, G18*	*Group4*	*G6, G7*
Group5	*G11*	*Group5*	*G1, G2, G5, G19*
Group6	*G15*	*Group6*	*G8*
Group7	*G16*	*Group7*	*G3*
Group8	*G10*	*Group8*	*G14*
Group9	*G6, G7*	*Group9*	*G11*
Group10	*G9*	*Group10*	*G20*
Group11	*G20*	*Group11*	*G17, G18*
Group12	*G1,G2, G5, G19*	*Group12*	*G16*
Group13	*G13*	*Group13*	*G12*
Group14	*G3*	*Group14*	*G9*
Group15	*G12*	*Group15*	*G15*
Total Number of Iteration			
64		***62***	

Fig. 11 shows a comparison between the angle deviation of the generator No. 9 in the original system and in the reduced system and they are closely to each others. Finally, one can say that the original system has118 nodes, 20 Machines and 186 transmission lines; while the reduced system has 13 Machines, 13 nodes and 60 transmission lines.

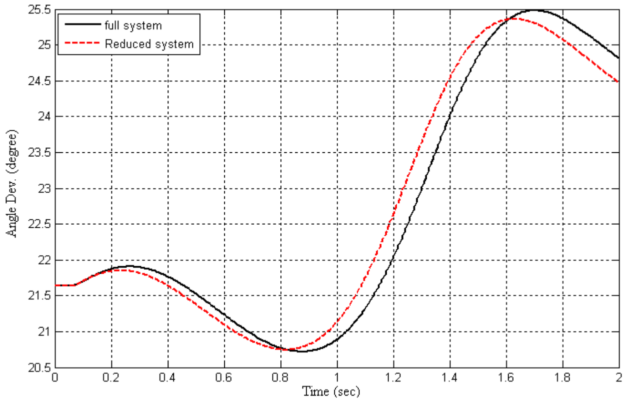

Fig. 11 speed deviation of generator no. 9 in the original system and in the reduced system

7 Conclusion

This paper presents a new effective technique of the construction of dynamic equivalent for any large-scale power system, based on three main stages; the first proposed stage is identifying the coherent groups of generators. The second proposed stage is the dynamic aggregation in which each coherent group of generators are replaced by one equivalent machine that its parameters are calculated. The third proposed stage is the calculation of the new transmission lines parameters that connect between the equivalent machine and other non coherent machines. The proposed FCM technique gives a fast and flexible method for clustering analysis in determining the coherent groups of generators. The obtained results by the proposed coherency criterions are the same results obtained by FCM clustering algorithm. The obtained results showed that the proposed method is highly effective in determining the coherent groups of generators and in constructing the dynamic equivalent of power system as shown from the comparison results.

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