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A New and Simple Approach to Coherency Identification for Multi-Machine Power System

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Abstract— This paper presents a new simple method of identifying the coherent groups of generators for coherency based analysis technique for network reduction to carry out transient stability analysis for multi-machine power system. This technique is based on two different indices, the first one is inertia condition index and second one is initial power variation index. The new coherency identification method has the capacity to identify the perfect coherent groups in a very simple way, so that the nature of the machines in the reduced order system is exactly similar to those of the full system. Each coherent group is replaced by a single machine using the method of dynamic equivalent construction. The proposed method is applied on 39-Bus New England test power system. The obtained results proved that the proposed method is highly effective in determining the coherent groups of generators with high accuracy.

Keywords— Coherent generators, dynamic equivalents, inertia constant, initial power variation, swing curve.

I. INTRODUCTION

Increasing interconnection of power plants in modern large electric power systems has made power system dynamic studies much more complex. Under the deregulated business environment, the interconnections are increasingly being used for trading between utilities. 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 in details. The computational time can be reduced if the transient stability is determined in a reduced order equivalent model of the original system. Coherency-based approaches to dynamic equivalents have been adopted in reducing the size of the power system model [2]-[4].

For system reduction, coherency based method for transient stability study being most popular because the coherent generator technique is an elegant and powerful tool through construction of simplified reduced order dynamic models which can represent the entire system without loss of system significant characteristics [5]. The reduction is based on the impact of large disturbances in a particular area known as the study system, while system external to study area are not of direct interest in stability analysis; and are thus represented by dynamic equivalents in recognition of its influence on the response of the study area to disturbances.

To find out coherent generators, a large multi-machine system is divided into a study sub-system and an external sub-system depending on power variation of the generators at the instant of initiated fault [6]. The internal sub-system 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 rest of generators are considered in the external system. The generators in the external system do not contribute significantly the system instability. Thus the dynamic equivalencing technique is applied on these generators only. Power system division is based on the generators close to fault have a tendency accelerate much faster than the generators away from the disturbance [7].

For coherency identification this paper presents a new simple method based on two different indices, the first one is inertia condition index and second one is initial power variation index. The proposed method has been applied on 10 M/C, 39-bus New England test power system in two separate fault locations and a satisfactory result has been obtained.

II. PROPOSED COHERENCY IDENTIFICATION METHOD

Coherency is defined by the property that following any disturbance of the difference of rotor angles of the coherent machines remains constant in time [8], [9], i.e:

$$\delta_i(t) - \delta_j(t) = \delta_{ij} = constant = \delta_{ij}^{\circ} \quad (1)$$

Where, $\delta_{ij}^{\circ} = (\delta_i^{\circ} - \delta_j^{\circ})$ is the difference of the pre-fault values.

2.1 Inertia Condition Index

Inertia Constant is a basic parameter of the machines. This constant can help to find out the coherent groups. This index is based on normalized value of inertia differences among the machines. Inertia Condition index β_{ij} is defined by the expression

$$\beta_{ij} = |M_i - M_j| \,/\, \mathrm{Max}(M_i, M_j) = \beta_{ji} \leq 0.2 \quad (2)$$

for i=2, 3, 4…n; j= 1, 2, 3…(i-1).
Where,

$M_i - M_j$ = Inertia difference between machine no i & j.

For perfect coherency, β_{ij} must be identically equal to zero. This condition rarely satisfied in practical systems. If one of the inertias tends to infinity β_{ij} will tend to 1 indicating generators deviating from each other [8]. However, in practice $\beta_{ij} \leq 0.2$ is considered to be satisfactory to conclude that the machines are coherent.

2.2 Initial Power Variation Index

The nature of rotor angle variation of a machine is depended on its power variation. By using this power variation of machines at initial condition, a new coherency index, named initial power variation index may be evaluated. This index may be used further in coherency group identification test. Power variation among the machines at initial condition can give a clear conception of coherency for a particular load arrangement. This index is based on normalized value of power variation among the machines at initial condition. It is defined as:

$$IPV_{(ij)} = \left| \frac{|P_{e(i)}| - |P_{e(j)}|}{Max\,(p_{e(i)}, P_{e(j)})} \right| \qquad (3)$$

Where, i= 2, 3, 4….n & j= 1, 2, 3… (i-1);

n = Total number of machines.

Here, (Real Power)

For initial condition,

$P_{e(i)} = E_i^* I_i\,;\; i = 1, 2, 3 \ldots n;$

$And, \quad E_i = V_i + X'_{di} I_i$

Where,

V_i = Terminal voltage of i^{th} machine and

X'_{di} =Transient racarance.

2.3 Stepwise Procedure of This New Coherency Identification Method

Step-1; Machines are classified into study and external areas depending upon their power variation at the instant of initiating fault. The machines with power variation less than 30% are grouped together as external area machines. The external area machines are considered for coherency grouping test.

Step-2; Choosing a reference machine in the external area, all other machines in that area which satisfy Equation (2) are grouped together.

Step-3; The initial power variation index, IPV_{ij} is evaluated for the machines carried over from step-2. If the inequality $IPV_{ij} \leq 0.03$ is satisfied then the machines will from a coherent group.

III. CONSTRUCTION OF DYNAMIC EQUIVALENTS

The concept of dynamic equivalent in this text is based on Kimbark's method. Also the property of power invariance [10], [11] is included. This states that whenever number of machines in a coherent group is replaced by a single machine then total power delivered from the group of machines should be equal to the power delivered by the single machine.

3.1 Mathematical Formulation

Formulas for construction of dynamic equivalents are given below [8]:

$$E_e = \left(\sum_{i=1}^{m} (E_i^* I_i / I_e)^* \right) \qquad (4)$$

Where,

$I_e = \sum_{i=1}^{m} I_i;$ vector sum of currents of the coherent group.

E_e = The voltage of the equivalent machine. And m is the number of machines in the coherent group. The inertia constant (H_e), damping coefficient and mechanical power of the equivalent machine are obtained respectively as.

$$H_e = \sum_{i=1}^{m} H_i \qquad (5)$$

$$D_e = \sum_{i=1}^{m} D_i \qquad (6)$$

$$P_{me} = \sum_{i=1}^{m} P_{mi} \qquad (7)$$

The modified transient reactances are:

$$X'_{dei} = [(E_e - V_i)/\,(E_i - V_i)]X'_{di} \qquad (8)$$

Where, X'_{dei} is the transient reactance connecting the equivalent machine to the i^{th} terminal bus.

IV. RESULTS AND DISCUSSION

The proposed coherency identification method has been applied to a multi-machine power system. More over construction of dynamic equivalents were done for the system. The one line diagram of the power system is given below.

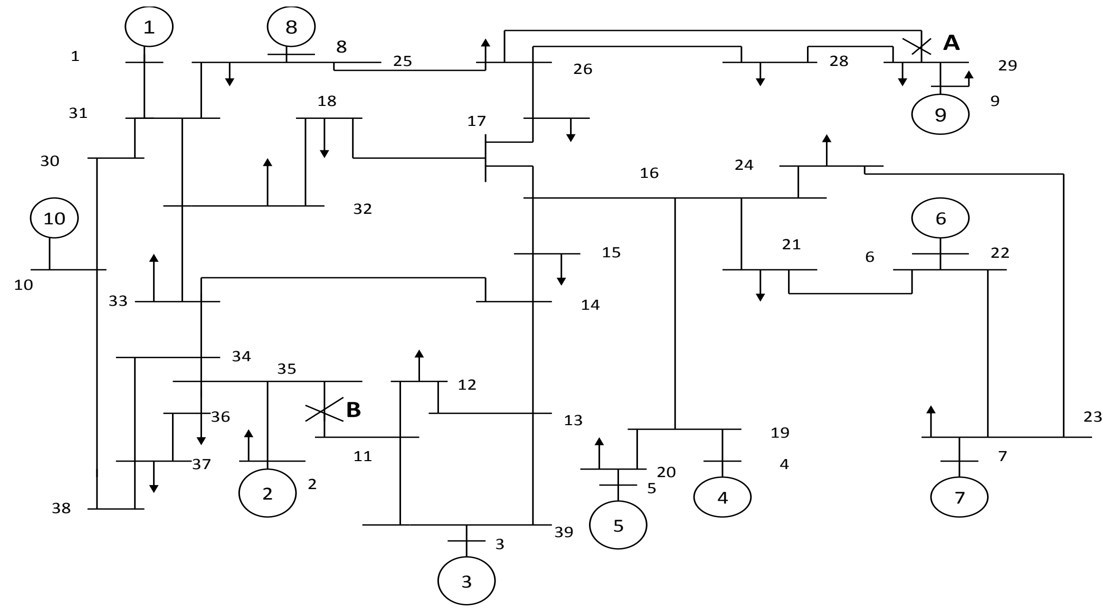

Fig: 1 Single line diagram of 10-M/C, 39-bus, New England test power system.

Two separate studies were under taken, at first A 3-phase to ground fault was assumed to occur at bus-29 (point A) and secondly another fault was assumed to occur at bus-11 & 35 (point B) and both the faults were cleared automatically at 0.1 sec.

For first case, power variation of generator 9 was more than 30% at the instant of initiating fault, so it was in study area and rest of the generators were in external area. For both cases generator 10 was assumed as a reference. By using equation 2 and 3, β and IPV indices were evaluated. After satisfying the conditions of β and IPV indices,
Coherent groups:
Group I (gen 2, 3, 4, 6 & 7); was found.
For second case, generator 2 and 3 were in study area. And,
Coherent groups:
Group I (gen 4, 6 & 7); was found.
After solving the swing equations [12] - [14], swing curves for both full and equivalent systems are given below:

For fault location at point A

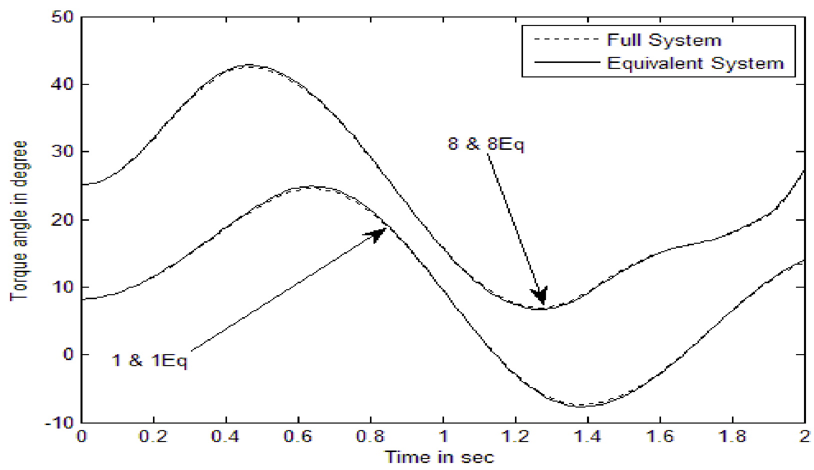

Fig: 2 Swing curves

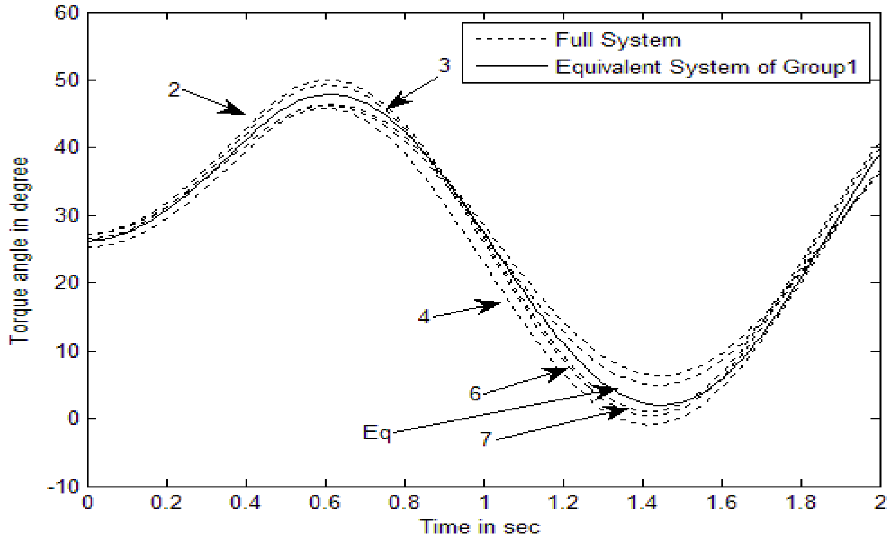

Fig: 3 Swing curves

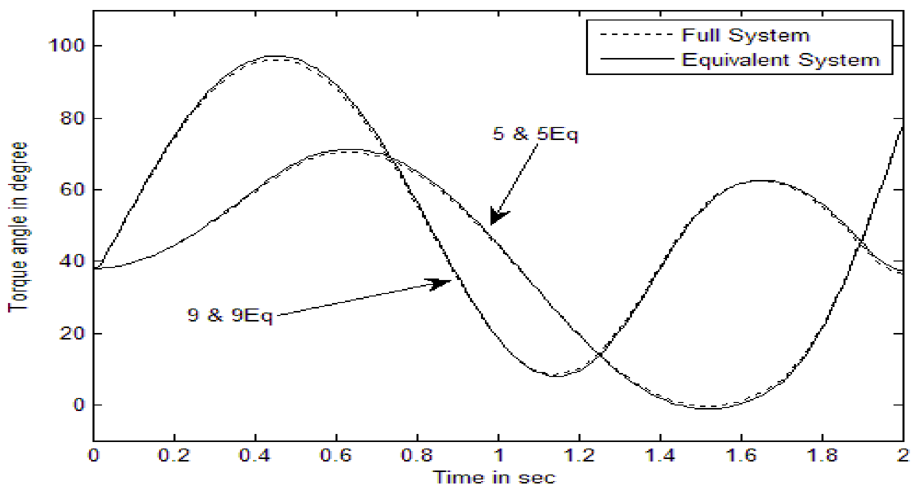

Fig: 4 Swing curves

For fault location at point B

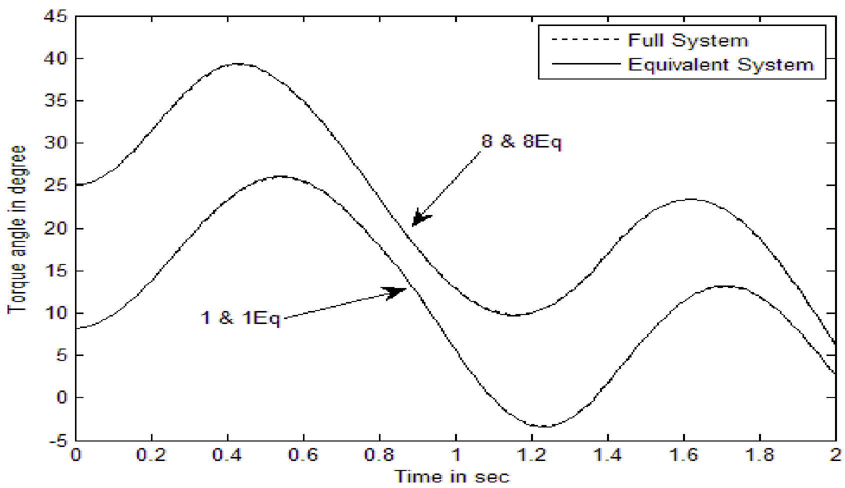

Fig: 5 Swing curves

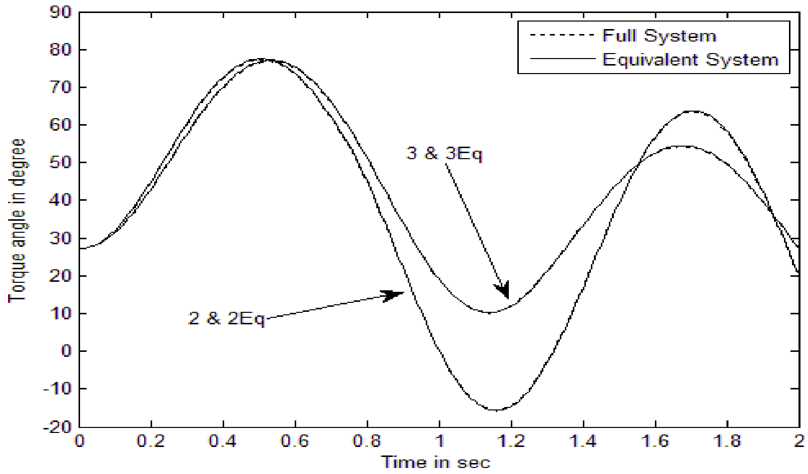

Fig: 6 Swing curves

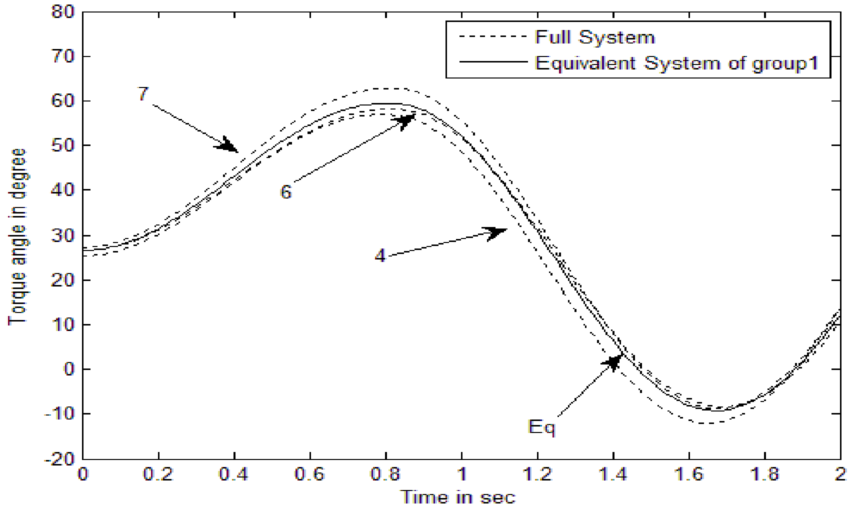

Fig: 7 Swing curves

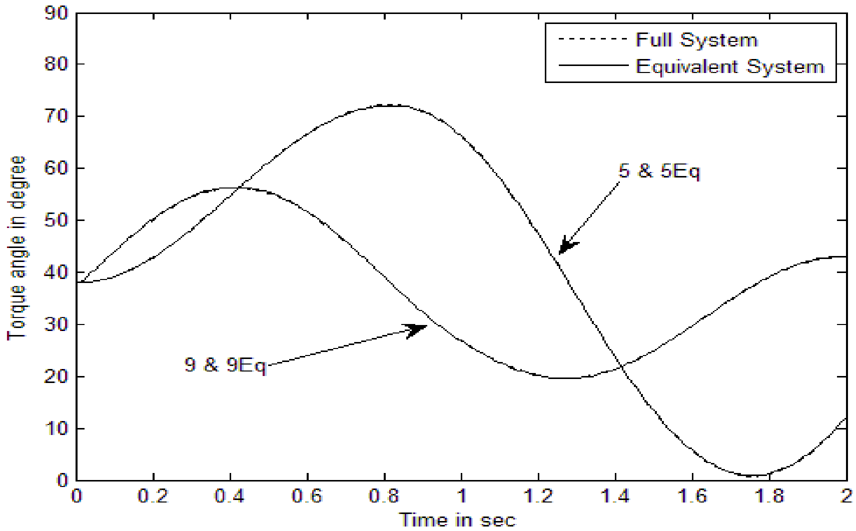

Fig: 8 Swing curves

V. CONCLUSION

This paper presents a new simple and an accurate method of identifying the coherent groups of generators. It is necessary to preserve the general behavioral characteristics of the system whenever system is reduced, which can be achieved by using this proposed coherency identification method. This method is based on two different simple indices, the first one is inertia condition index and second one is initial power variation index. The method has been applied to 10 M/C, 39-Bus New England test power system for two different fault locations and the results are found more accurate and satisfactory.

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