

PREDICTING THE TRANSIENT STABILITY OF CEPS
USING AES METHOD

التنبؤ بالاتزان الديناميكي للمنظومات الكهربائية الكبيرة
بطريقة التقييم التقريبية

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الخلاصة - يقدم هذا البحث طريقة جديدة تطبيق لأول مرة على المنظومات الكهربائية الكبيرة للتنبؤ بالاتزان الديناميكي بها . والطريقة المقترحة تعتمد على عناصر المنظومة المختلفة وهي طريقة تقريبية ويطلق عليها اسم طريقة التقييم التقريبية وقد تم دراسة وتحليل المعادلات الرياضية الممثلة للمنظومة الكهربائية مع الدالتين المستخدمتين للطريقة المقترحة . وأيضا قدم هذا العمل الخوارزم الرياضى للطريقة المستخدمة الذى يبين كيفية التنبؤ بالاتزان الديناميكي بالمنظومة الكهربائية من عدمه . والدراسة المتقدمة اختارت مثال عددي مكون من ثلاث ماكينات وتم تطبيق هذه الطريقة عليه للتنبؤ بالاتزان الديناميكي ودراسة تأثير بعض العوامل على الاتزان . من هذه العوامل فترة استمرار الخطأ - القدرة المنقولة وكذلك معامل التضاؤل . ومن الدراسة والتحليل الرياضى توصل البحث الى أن الطريقة المقترحة سهلة التطبيق وسريعة التنبؤ بالاتزان بشرط أن تكون السرعة النسبية لاحدى الماكينات أقل بكثير من الأخرى.

ABSTRACT: Analysis of the stability of power systems following a transient disturbance involves the study of a large set of nonlinear differential equations. A new approach to the quantitative study of the transient stability of complex electric power systems (CEPS) is presented, using approximate evaluation of stability method (AES).

The analytical steps for this method are detailed in this study. Also a constraint, which depends on the relative speed of angle variations, in applying this method for predicting the stability of CEPS is explained.

The present work aimed to study the effect of many factors on the transient stability of a power system. These factors are fault clearing time (t_c), damping factor (P_d) and transmitted power (P).

A suggested flow chart of this method and results of its application to a 3 - machine system are given

INTRODUCTION:

The problems of power system stability conservation are considered very important. The control of the transient conditions seems very suitable for stability investigation. The optimal control problem has been investigated. However, this technique is not able to overcome all the aspects of the problem. This is due to the cascaded growth of disturbance in the power systems.

Therefore, the stability characteristics of the electrical power system (EPS) during transient disturbances are analyzed from stability nature of its mathematical model. A set of differential equations describing EPS is given. These equations are non-linear with constant coefficients under the assumptions of constant emf behind transient reactance and constant input to the machines.

The stability of linear differential equations can be established from the roots of its characteristic equation [1]. Thus, the stability obtained implies the stability of the system in the entire state space. On the other hand, in a nonlinear system, such an inference is invalid [2] because its stability depends upon the initial conditions as well as the system parameters. Therefore, a set of initial conditions defining the region of stability has to be found .

This paper deals with the methods, allowing forecasting the mutual stability of EPS at large disturbance. This disturbance occurs in the first stage of transient processes because of the variations in the parameters of EPS operation conditions [3].

NOMENCLATURE

- $\Delta(t)$, $a_0(t)$ and $a_1(t)$ - functions of regime parameters ;
- δ - Generator angle ;
- P_T - Power of turbine ;
- P_e - Electrical power ;
- T_J - Inertia constant of generating unit ;
- δ_s - Stable value of angle ;
- δ_u - Unstable value of angle ;
- E - Generator bus voltage magnitude ;
- P - Transmitted power ;
- Y - Complex admittance .

PROBLEM FORMULATION

The theoretical study of ability to use nonlinear relations $\Delta(t)$ and $a_1(t)$, in case of fulfillment of defining conditions of AES method, is demonstrated in ref [4]. Moreover, this reference presents the basic analysis of the mutual stability of electrical machines in CEPS, but the results of stability study on these systems have not been listed. However, the capability to use these nonlinear relations, which are considered important parameters for this regime, for analyzing the stability of simple power system is

A logical extension of the regime in ref. [4], using AES method for studying mutual stability of CEPS of a radial three-machine system shown in Fig. 1, is given. It should be noticed, that in radial three - machine system, where one machine returns power to the others, all characteristics of CEPS are satisfied [5]. These characteristics are restricted by the mutual effect of power transmissions , e.g., the disturbance of stability in one transmission leading to asynchronous regime for others, existence of stability limit in one power transmission depends on the power which is transmitted by other and similarly.

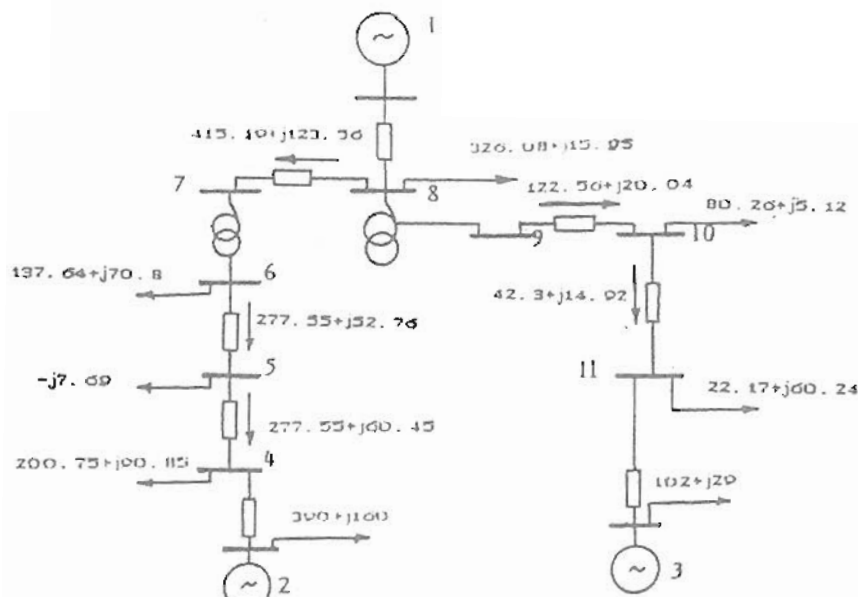


Fig.1. System under study

THE PROBLEM SOLUTION

Electromechanical transient process in CEPS which consists of three - machine, is described by the following differential equations [6]:

$$T_{ji} \ddot{\delta}_i + P_{di} \dot{\delta}_i = P_{Ti} - P_{ei} \quad (1)$$

Set $P_{di} = 0$

$$\ddot{\delta}_i = \frac{P_{Ti} - P_{ei}}{T_{ji}} \quad (1)$$

where

$$\begin{aligned} i &= 1, 2, 3, \text{ - Number of machines;} \\ \ddot{\delta} &= d^2\delta / dt^2; \\ P_{ei} &= \frac{1}{T_{ji}} - [P_{Ti} + \sum_{\substack{j=1 \\ i \neq j}}^3 P_{ij} \sin(\delta_{ij} - \alpha_{ij})] \end{aligned} \quad (2)$$

Assume the e.m.f. and the torque of turbine are constant, also the loads are represented by constant resistances. Let the relations:

$$\begin{aligned} \delta_{ij} &= \delta_i - \delta_j; \quad \delta_{ji} = \delta_j - \delta_i \text{ and } \alpha_{ij} = \alpha_{ji} \text{ (where } i = 1, 2 \text{ \& } 3; \\ j &= 1, 2 \text{ \& } 3 \text{ and } i \neq j) \text{ in equations (1) \& (2) Then:} \end{aligned}$$

$$\ddot{\delta}_{12} = \frac{P_{T12} - P_{e12}}{T_{12}} \quad (3)$$

$$\ddot{\delta}_{13} = \frac{P_{T13} - P_{e13}}{T_{13}} \quad (4)$$

where

$$P_{12} = \frac{P_{T1}}{T_{J1}} - \frac{P_{T2}}{T_{J2}} ; \quad P_{13} = \frac{P_{T1}}{T_{J1}} - \frac{P_{T3}}{T_{J2}} ;$$

$$P_{o12} = P_{o1} - P_{o2}$$

$$= \frac{1}{T} [P_{11} + P_{12} \sin(\delta_{12} - \alpha_{12}) + P_{13} \sin(\delta_{13} - \alpha_{13})]$$

$$- \frac{1}{T_{J2}} [P_{22} + P_{12} \sin(-\delta_{12} - \alpha_{12}) + P_{23} \sin(\delta_{23} - \alpha_{23})]; \quad (5)$$

$$P_{o13} = P_{o1} - P_{o3}$$

$$= \frac{1}{T_{J1}} [P_{11} + P_{12} \sin(\delta_{12} - \alpha_{12}) + P_{13} \sin(\delta_{13} - \alpha_{13})]$$

$$- \frac{1}{T_{J3}} [P_{33} + P_{13} \sin(-\delta_{13} - \alpha_{13}) + P_{23} \sin(-\delta_{23} - \alpha_{23})]. \quad (6)$$

Similarly, equations using δ_{21} ; δ_{23} or δ_{13} , δ_{32} can be formulated. In the following, the suggested method is applied for study of mutual stability between first and second machines. In addition the analysis can be extended to study the mutual action between any two machines of system under study.

The nonlinear relations due to performance of variation can be formulated as follows :

$$\Delta(t) = (\ddot{\delta}_{12})^2 + (\dot{\delta}_{12})^2 \frac{dP_{o12}}{d\delta_{12}} ; \quad (7)$$

$$a_1(t) = -(\ddot{\delta}_{12})^2 \frac{d^2 P_{o12}}{d\delta_{12}^2} / \Delta(t) \quad (8)$$

where

$$\dot{\delta} = \frac{d\delta}{dt}$$

The derivative of function P_{o12} with respect to angle δ_{12} can be obtained using parametrical differentiation method [7]. Noticing that:

$$\delta_{23} = \delta_{13} - \delta_{12} ; \quad \dot{\delta}_{23} = \dot{\delta}_{13} - \dot{\delta}_{12} ; \quad \ddot{\delta}_{23} = \ddot{\delta}_{13} - \ddot{\delta}_{12}$$

and also

$$\ddot{\delta}_{23} \dot{\delta}_{12} - \ddot{\delta}_{12} \dot{\delta}_{23} = \dot{\delta}_{12} \ddot{\delta}_{13} - \ddot{\delta}_{13} \dot{\delta}_{12} \quad (9)$$

Substituting from eqn.(9) in equation (5),

$$\begin{aligned} \frac{dP_{e12}}{d\delta_{12}} &= \frac{P_{12}}{T_{J1} T_{J2}} [T_{J2} \cos(\delta_{12} - \alpha_{12}) + T_{J1} \cos(\delta_{12} + \alpha_{12})] \\ &+ \frac{P_{13}}{T_{J1}} \cos(\delta_{13} - \alpha_{13}) - \frac{\delta_{23}}{T_{J1} T_{J2} \delta_{12}} [T_{J1} P_{23} \cos(\delta_{23} - \alpha_{23}) \\ &- T_{J2} P_{13} \cos(\delta_{13} - \alpha_{13})] ; \end{aligned} \tag{10}$$

$$\begin{aligned} \frac{d^2P_{e12}}{d\delta_{12}^2} &= - \frac{P_{12}}{T_{J1} T_{J2}} [T_{J2} \sin(\delta_{12} - \alpha_{12}) + T_{J1} \sin(\delta_{12} + \alpha_{12})] \\ &- \frac{P_{13}}{T_{J1}} \frac{\delta_{13}}{\delta_{12}} \sin(\delta_{13} - \alpha_{13}) + \frac{P_{23}}{T_{J2}} \frac{\delta_{23}}{\delta_{12}} \sin(\delta_{23} - \alpha_{23}) \\ &- \frac{\delta_{13} \delta_{12} - \delta_{12} \delta_{23}}{T_{J1} T_{J2} (\delta_{12})^3} [T_{J1} P_{23} \cos(\delta_{23} - \alpha_{23}) \\ &- T_{J2} P_{13} \cos(\delta_{13} - \alpha_{13})]. \end{aligned} \tag{11}$$

The sufficient constraint for usability AES method for studying mutual action of rotors of system is available no more at extremum for the equation (5) in every interval of the mutual angle variations possibility $[\delta_{12a}, \delta_{12u1}]$ & $[\delta_{12a}, \delta_{12u2}]$.

Set equation(10)equal to zero and $\alpha = 0$ to simplify the expression. Then, find value of δ_{12} , at which equation (5) has one extremum :

$$\begin{aligned} \cos\delta_{12} &= \left[\frac{\delta_{23}}{T_{J1} T_{J2} \delta_{12}} [T_{J1} P_{23} \cos(\delta_{23} - \alpha_{23}) - T_{J2} P_{13} \cos(\delta_{13} - \alpha_{13})] \right. \\ &\left. - \frac{P_{13}}{T_{J1}} \cos(\delta_{13} - \alpha_{13}) \right] / \left[\frac{P_{12} (T_{J1} + T_{J2})}{T_{J1} T_{J2}} \right]. \end{aligned} \tag{12}$$

Assume $\delta_{23} \ll \delta_{12}$ during transient process. That is in real EPS, for example, when operating conditions of machines 2 and 3 are in phase coincidence "i.e. $\delta_{23} \sim 0$ ". Under this condition the first term of equation (12) is infinitesimal and can be neglected. Then

$$\cos \delta_{12} = A \cos (\delta_{13} - \alpha_{13}) ; \quad (13)$$

where:

$$A = \frac{E_3 y_{13} T_{J2}}{E_2 y_{12} (T_{J1} + T_{J2})} \quad (14)$$

$$E_1 E_3 y_{13} = P_{13};$$

$$E_1 E_2 y_{12} = P_{12}$$

Calculated constraint of value A can be considered constant. If relations (12) & (13) has only one solution through interval $[\pi k, \pi(k+1)]$, where k=integer number, the value of mutual angle δ_{12} of function P_{o12} has only one extremum in the above interval. Also it can be indicated, that δ_{12} has only one extremum in case of the assumptions made for deduction of constraint (13) and first derivative (10) through the considered intervals.

According to the preceding it can be decided, that the required constraints in the relations of function P_{o12} are satisfied, hence, AES method is used to determine the mutual transient stability in the system under study.

Suggested algorithm of AES method for stability determination between stations during transient process is shown in Fig. (2) in the form of flow - chart.

RESULTS AND DISCUSSION

The transient operating conditions have been investigated for several factors affecting the stability of power system. These factors are, time elapsed before clearing the fault, damping coefficient, and the power transmitted by this line. The effect of each factor is numerically computed while the other factors are kept constant. Therefore, the effect of changing the clearing time from 0.37 to 0.38 sec on the stability of the power systems has been revealed.

Assume a double line to ground fault occurred in the line connecting between buses 5 & 6. Working voltage of this part is 220 kv while transmitted power is 278 MW.

The curves at $t = 0.37$ sec., shown in Fig.3, describe the characteristics of mutual angle δ_{12} and nonlinear relations $\Delta(t)$ & $a_1(t)$ corresponding to the variation of δ_{12} . Fig.4 shows curves of δ_{12} , $\Delta(t)$ & $a_1(t)$ at $t_c = 0.38$ sec. From Fig.3 function $\Delta(t)$ has positive value during transient process and at $t = 0.415$ sec. $a_1(t)$ has an extremum. Then, mutual stability is conserved. But from Fig. 4, function $\Delta(t)$ has zero and negative values and $a_1(t)$ has an infinite value at $t = 0.5$ sec. Then, mutual stability is disturbed.

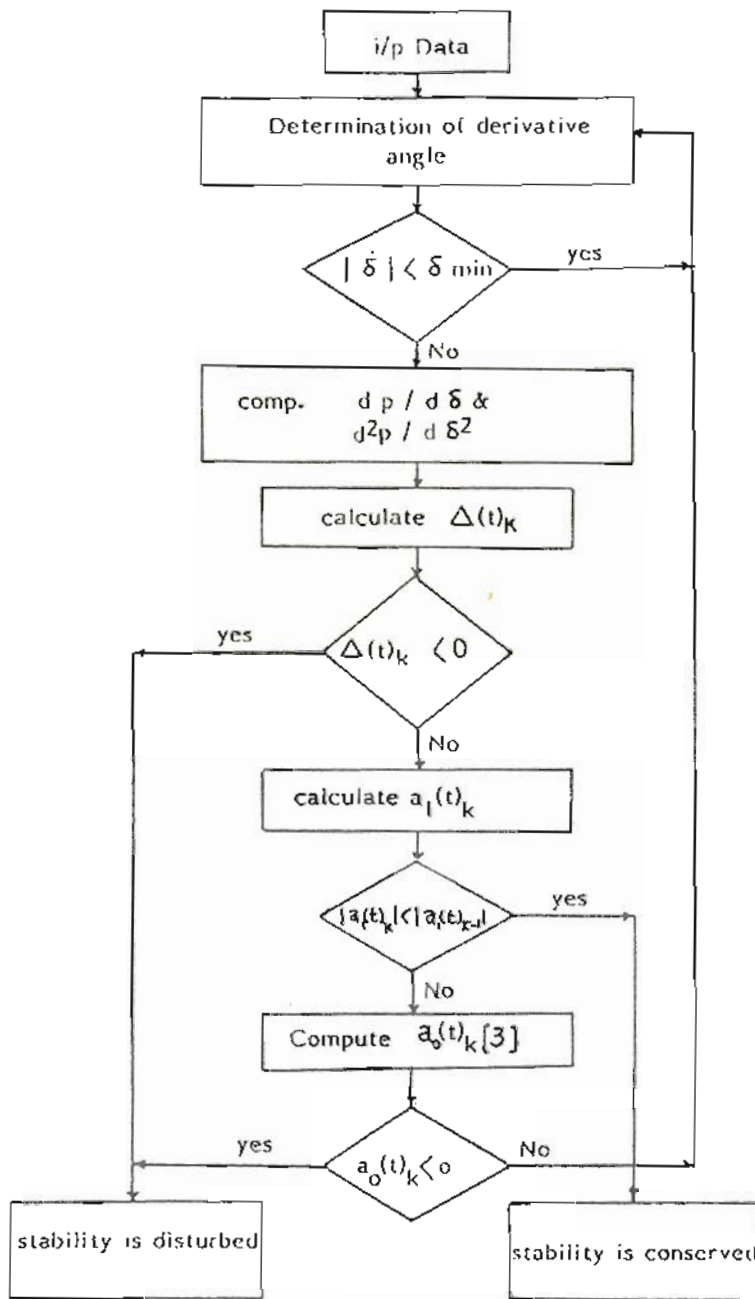


Fig.2. Block diagram of technique for prediction stability of EPS.

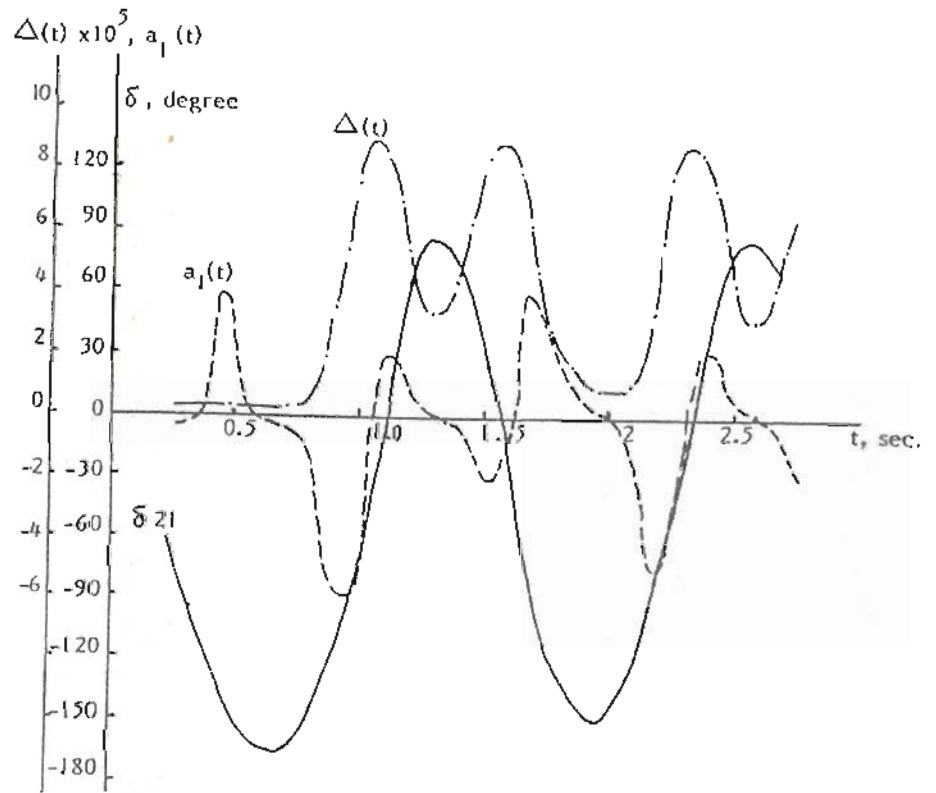


Fig.3. Change of mutual angle and functions $\Delta(t)$ and $a_1(t)$ during transient process in the case of $t_c=0.37$ sec.

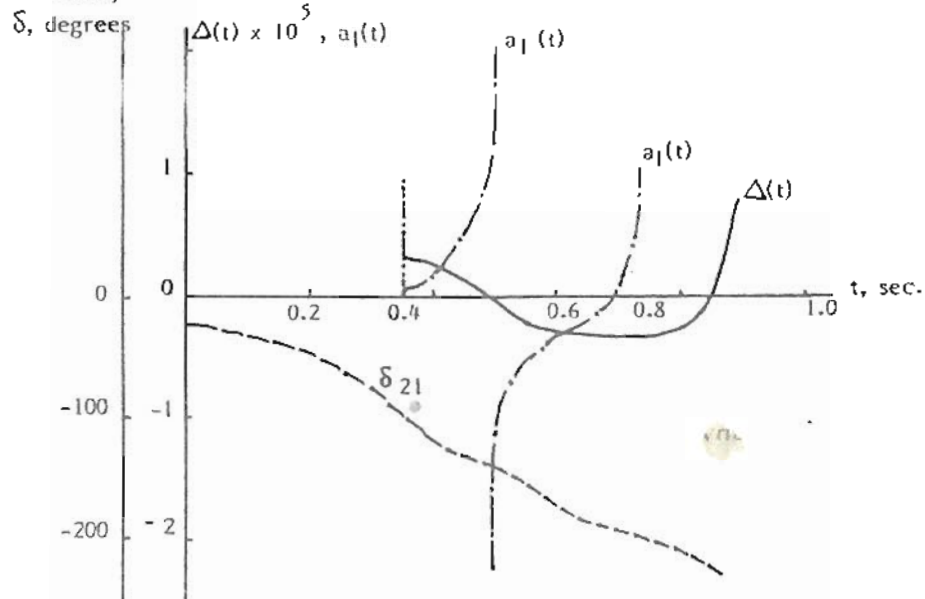


Fig.4. Change of mutual angle and functions $\Delta(t)$ $a_1(t)$ during transient process in the case of $t_c = 0.38$ sec.

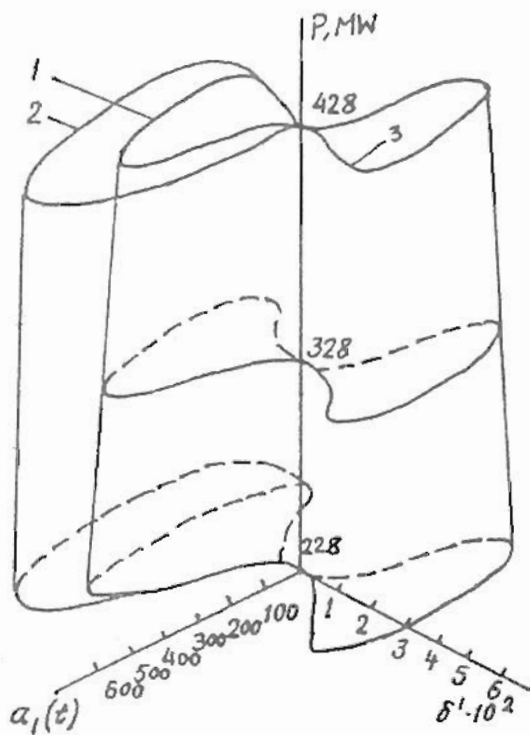


Fig.5. Regions of stability in coordinates $a_1(t)$ & in the case of transmitted power variations : 1- $p_d = 0.5$; 2- $p_d = 5$. and 3- for the 2nd half-phase swinging.

The effect of changing the transmitted power from 226 MW to 428 MW through the line connecting between buses 6&5 and also changing the damping factors from 0.5 to 5.0 on the mutual stability of the system under study are shown in Fig.5. From this figure at $P_d = 0.5$, note that loops in second and third quadrants represent the stability regions. But the loops in first and fourth quadrants are considered infinitesimal and indicate trajectory in the second half-phase swinging. Also these loops do not represent in any form the stability limitations for given half-phase swinging.

From Fig.5 it can be concluded, that when transmitted power increases bounded region has tendency to get reduced.

CONCLUSIONS

In this paper, a new approach for the applicability of AES method is introduced. The approach can be used to predict the mutual transient stability of CEPS. This occurs in the first half-phase swinging under certain constraint. The constraint is that, the relative speed of mutual angle variations must be appreciably less than the other speed.

For real EPS, in the structure of stability regions, AES method can be used for determination of mutual stability, during transient process.

In the existence of important variations of system parameters (P_d , P), an indication of the applicability of AES method can be shown by the recent study.

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