Stability Analysis Based on Direct Method for Power System
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Abstract— The main purpose of this paper is to check the stability for power system with the help of Energy Preserving Function (Energy Based Direct Method). In this method we compute Total Energy gained by the system during the Fault and by comparing this energy with Critical Energy we found out CCT (Critical Clearing Time). The Critical Energy was found with the help of Closest Unstable Equilibrium Point method (C-UEP).

Keywords: Transient Stability, Critical Clearing Time (CCT), Energy Function, Critical Energy, Closest Unstable Equilibrium Point Method (C-UEP)

I. INTRODUCTION
Power system stability can be defined as the ability of a power system to remain in a state of operating equilibrium during normal conditions, and to regain an accepted state of operating equilibrium after a disturbance. During normal operating conditions of the power systems (in steady state), two main conditions should be satisfied for generators: (1) Rotors should be in synchronism. (2) The generated voltages are sinusoidal waveforms with the same frequency. These conditions are violated when any type of disturbances are developed on the power system. Due to these disturbances instability in power system is developed. These disturbances may be small or large. Power system must be able to withstand against these disturbances. The ability of a power system to recover and maintain synchronism is called rotor angle stability. Small signal stability is the ability of the power system to maintain synchronism under small disturbances. Transient stability is the ability of the power system to maintain synchronism under large disturbances.

The rotor of synchronous generator is driven by prime mover. The frequency of the terminal voltage of the generator depends on the speed of rotor. Rotor mechanical speed is synchronized with the frequency of the stator electrical quantities. When two or more synchronous generators are inter connected, stator voltage and current of each generator must have the same frequency. The rotors of all interconnected generators must be in synchronism during normal operating conditions of power system. Mechanical input power (Pm) from prime mover to generator shaft and generated electrical power (Pe) should be in balanced condition. When large disturbances (like a fault on the network, failure of equipments, sudden change in load, and loss of a line or generator) are developed on power system, the maintenance of rotor angle stability is known as transient stability. Due to these disturbances the synchronous machines may loss synchronism.

It is important to note that, steady-state stability is a function of only the operating condition, whereas transient stability is a function of both the operating condition and the disturbances. This complicates the analysis of transient stability considerably. Transient Stability requires analysis for different disturbances. Transient stability analysis in a power system is the ability of power system to remain in synchronism before the large disturbance as well as after the large disturbance. Now a day’s transient stability analysis of power system is mainly performed by simulations. Calculation of critical clearing time (CCT) for a fault is a main assessment in the transient stability analysis. Transient stability of synchronous generator in power system can be analyzed by swing equation which is a nonlinear differential algebraic equation. Conventional method (Time Domain Method) used for solution of this swing equation consumes more computational time. This method can be applied for any level of modeling of the system.

Direct methods without the solution of differential equations can be used to determine the transient stability analysis of power system. This method is the Lyapunov’s direct method (second method). The energy based method is a special case of Lyapunov’s direct method. These techniques are extensions of the equal area criterion to power systems with more than two generators represented by the classical model. Basic approach developed is practical, enough accurate and apply to practical power system for better planning and operation [3, 5]. The authors of paper [4] proposed direct method that uses individual machine or group of machines energy function. The Energy function of each machine is compared to a Critical Energy which can be determined by Potential Energy Boundary Surface (PEBS) method or Boundary Controlling UEP (BCU) method or Closest Unstable Equilibrium point. The Papers [6-8] introduced newly direct methods C-UEP and BCU method. The Problem occurs during BCU method discussed in paper [13].

II. DIRECT METHODS FOR STABILITY ANALYSIS
The transient energy approach can be understood by the example of rolling ball inside the bowl. The inside area of bowl is considered as stable region and outside area as the unstable. Initially ball is at bottom that point is considered as the stable equilibrium point (SEP).

![Fig. 1: A ball rolling on the inner surface of the bowl](image)

When some kinetic energy is given to ball then ball starts to move in particular direction. The point where ball will stop depends on initial given kinetic energy. The surface inside the bowl represents Potential Energy surface. The rim of the bowl represents the Potential Energy Boundary Surface (PEBS). Consider the potential energy at rim is PI, and given kinetic energy is KI.

If, KI > PI => Ball will cross the rim => Unstable condition.
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KI < PI => Ball will not cross the rim => Stable condition.

Transient Energy function is representation of total energy gained during fault in terms of Kinetic and Potential energy. If fault occurs then during Fault on Period, the rotor of synchronous machine accelerates and acquires some kinetic energy. Same way angular position of rotor also changed. Overall we can say it acquires both Kinetic as well as Potential energy. Potential energy depends upon the angular position of rotor with respect to stable operating angular positions. If system is capable of absorbing completely the kinetic energy then it is stable system. Same Concept can be applicable for the power system. Total energy gained by the system during the fault is compared with the Critical Energy. If Total energy during fault exceeds Critical energy then system becomes unstable. With the help of this direct method we can also find out Critical Clearing Time (CCT). Critical Energy of the system can be found out with the help of Closest Unstable Equilibrium Point method or BCU or PEBS method.

III. PROPOSED DIRECT METHOD

This paper represents transient stability analysis with the help of Energy based direct method. Here Critical Energy calculated with the help of Closest Unstable Equilibrium Point method.

A. Problem Formulation:

The Considered test system for transient stability analysis was standard 3 Machine 9 Bus System [9].

Machine number 3 is considered as reference machine. Load is connected at bus num 5, 6 and 8. Fault occurs at bus num 7 and it is cleared by removing transmission line (5 to 7).

![Fig. 2: 3 Machine 9Bus System [9]](image)

Pre fault and Post fault Stable Point Calculation:

Power System Dynamics are governed by the equations:

\[ \frac{dH}{dt} = \omega - \omega_n \]

\[ p_m = E_E G_n + \sum_{i=1}^{n} E_i E_j G_{ij} \cos(\theta_i - \delta_i) \]

Now at Pre fault and Post fault Stable Point can be found out by equating mechanical input (Pmi) and electrical power outputs (Pei).

For machine 1,

\[ P_{m1} = (E12 * G11) + (E1E2 G12 \cos(del1 - del2)+E1E3G13cos(del1-del3)+E1B2B12sin(del1-del2) +E1E3B13sin(del1)) \]

For machine 2,

\[ P_{m2} = (E22 * G22) + (E1E2G12cos(del2-del1)+E2E3G23cos(del2-del3)+E1E2B12sin(del2-del1) +E2E3B23sin(del2)) \]

Now for Solving above two equations in matlab Model we get answers:

Pre fault Stable point: del1= 0.3116 del2= 0.1949

Post fault Stable point: del1=0.7435 del2=0.4828

![Fig. 4: Pre Fault and Post fault Stable Point calculation- Matlab Model](image)
C. Identification of Closest Unstable Equilibrium Point (C-Uep):

Total energy During Fault (Es) is calculated by

\[ E_s = \sum_{i=1}^{n} \frac{1}{2} M_i \omega_i^2 - \sum_{i=1}^{n} (P_{mi} - P_{ei})\delta_i + \sum_{i=1, k > i}^{n} P_{ik} \cos(\delta_i - \delta_k) \]

Total Energy during Fault is identified as a Sum of Kinetic and Potential Energy of the system. Now Closest Unstable Equilibrium Point (C-UEP) can be identified with partial Derivative of Potential Energy and then find closest equilibrium point from Post fault Stable point for that we plot Contour graph and mesh grid Plots identified Closest Unstable Equilibrium Point (CUEP) From Graphs is (1.55,1.45) which is also known as Critical Point. The Potential Energy at CUEP point is known as Critical Energy (Ecr). Now Total Energy during fault is compared with Critical Energy so we can find out Critical Clearing Time (CCT) .we got nearly 0.17 sec CCT time. It means if fault must be cleared maximum up to CCT time then we can say that system is stable otherwise its unstable.

![Potential Energy Curve](image1)

![Potential Energy Contour Graph](image2)

![Total Energy During Fault Vs Time](image3)

![Critical Energy Vs Time](image4)

![Comparison between Total Energy and Critical Energy](image5)
IV. CONCLUSION

This paper presents the transient stability analysis for power system with the help of Energy based direct method. Total Energy during fault is compared with Critical Energy and the Critical Clearing Time (CCT) obtained using this direct method was nearly 0.17 second. Here Critical Energy found by Closest Unstable Equilibrium Point (C-UEP) method.

REFERENCES