Transient Stability Analysis of the IEEE 39-Bus Test System Using Dynamic Computation for Power Systems (DCPS)

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Abstract **– Transient stability analysis (TSA) plays an important role for maintaining security of power system operation. This paper covers the transient stability analysis using Dynamic Computation for Power Systems (DCPS) software. The general purpose of DCPS is as simulation program of power system to implement the algorithms described. Immediately after a disturbance, one is concerned with the system's ability to reach an acceptable steady-state operating condition. This is called transient stability. Transient stability occurs when the power system is able to withstand the transient conditions following a major disturbance or fault which may lead to harm the system. Therefore determination of critical clearing time (CCT) is crucial since such information enables the setting of relays to clear the fault for the protection. Definition for critical clearing time is a maximal fault duration for which the system remains transiently stable. This paper also analyzes the CCT of fault occurrence between transmission line near to the reference bus and far from the reference bus. By theory CCT should appears to be lesser when fault occurs at transmission line near to the reference bus. In addition, this investigation is also to analyze the characteristics of transient stability when fault occur at swing bus. The stability of the system has been observed based on the simulation graphs of terminal voltage of the machine, rotor angle, speed, and output electrical power.**

Keywords–Transient Stability Analysis; DCPS; Critical Clearing Time

I. INTRODUCTION

Power system stability has been recognized as an important problem for its secure operation and importance issue to power industry. The stability of power system can be defined as its ability to regain to an acceptable state of equilibrium after a disturbance [5]. Power system stability can be classified into three which are rotor angle stability, frequency stability and voltage stability. Rotor angle stability can be divided into two such as small signal stability and transient stability. Transient stability is concerned with sudden change in the network condition due to transmission system faults, loss of generating unit, three-phase fault, and sudden load changes. All these disturbances are termed as Faults. These disturbances may result in voltage or frequency fluctuation that may affect the other parts of the interconnected power system [7]. It is widely accepted that transient stability is an important aspect in designing and upgrading electric power system. As electric utilities have grown in size, and the numbers of interconnections have increased, planning for future expansion has become increasingly complex. When disturbance occurs, the system will be in unstable condition due to the rotor angle of machine does not swing together because of failure in magnetic coupling between the rotor and the stator [4]. The loss of synchronism between rotor and stator magnetic fields results in a large fluctuation voltage, current and power output. This is shows that the system must have its own protection or security in order to operate stable and efficiently. Therefore, the main objective is to determined critical clearing time for the circuit breakers and hence as security and protection to the system. The scope of this project is to analyze the transient stability problem of IEEE 39 Bus using DCPS in order to determine the CCT. This system consists of 10 generator, 29 load bus, 12 transformers, 34 transmission lines and 46 branches. Critical clearing time is the principal criterion to transient stability assessment and every generator connected to the power system should have CCT longer than the operational time or clearing time (CT) of circuit breaker in power system [1]. The stability analysis of power systems may consider the determination of the system critical clearing time, for a given fault in order to find the value of critical clearing time for which the system is still stable. If the fault is cleared within this time the system will remain stable and vise versa.

II. DYNAMIC COMPUTATION FOR POWER SYSTEMS (DCPS)

DCPS is most promising method to achieve substantial improvement in transient stability simulation speed. There are two major features that incorporated. Firstly the programmed able to manage the systems up to 1000 buses and 250 generators, and secondly the capability for easy extension. In addition, there are three program suites in DCPS which are LF for load flow, CG for coherency grouping and TS for transient stability. The LF is important since it is used as pre-requisite before produce transient stability. The CG program is used for coherency grouping while the TS program is the core of this research work. Many algorithms developed can be implementing in

TS program. In the DCPS environment, one can then write a command word and in some cases followed by several command parameters separated by commas for performing particular task. In DCPS, three load flow calculation method are implemented such as Gauss-Seidel, Decouple Newton and Fast Decouple method. But, from experience in using the DCPS it is better use Decouple Newton method because it has been found to perform satisfactorily on all ranges of system size [2].

III. The Modified Euler Method For Solving Differential Algebraic Equations (DAEs)

The three most important dynamic devices are machine or generator, exciter and turbine-governor. The exciter is use to control field current while governor is use to control buck opening and rotor angle. Figure 1 shows the output of the excitation controller is the field voltage (Efd), for example the voltage across the field winding of the synchronous generator located in the rotor. Field voltage and current will determine the reactive power output of the machine and thus the level of the terminal voltage.

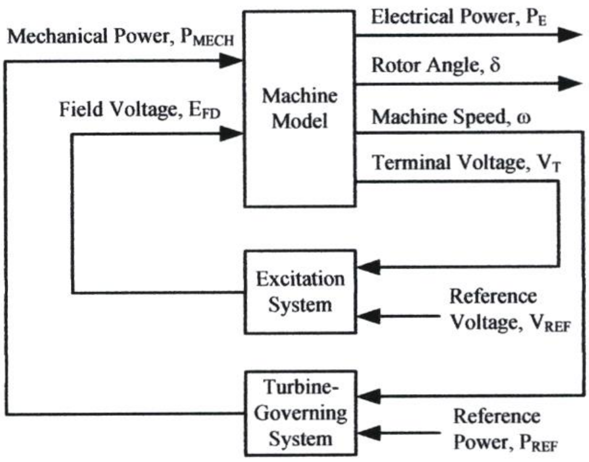

Figure 1. Output of excitation controller, machine model and turbine governor

In this paper, the Modified Euler Method is used to represent the integration technique developed in DCPS. In transient stability studies, the only method that gives satisfactory results is step by step integration method which is a conventional method and the most reliable one. The step by step integration method has the advantage because during the disturbances voltages and currents at various buses could be monitored as a function of time. Modified Euler's method is a method that is able to determine stability with explicitly integrating differential equations describing the post-fault system. Among many stability analysis methods, the Modified Euler's method is a Runge-Kutta based method is gain more popular because of its simplicity, better and high accuracy [3]. Figure 2 shows that better result after implement the Modified Euler Method.

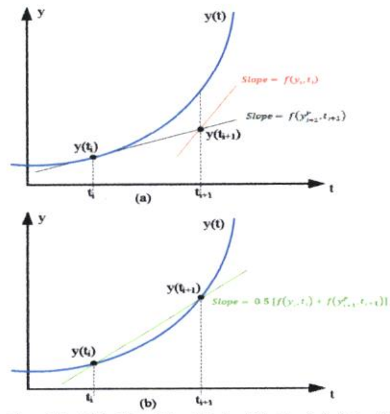

Figure 2. Graphical for Modified Euler Method; (a) Predictor and (b) Corrector

IV. Transient Stability Analysis

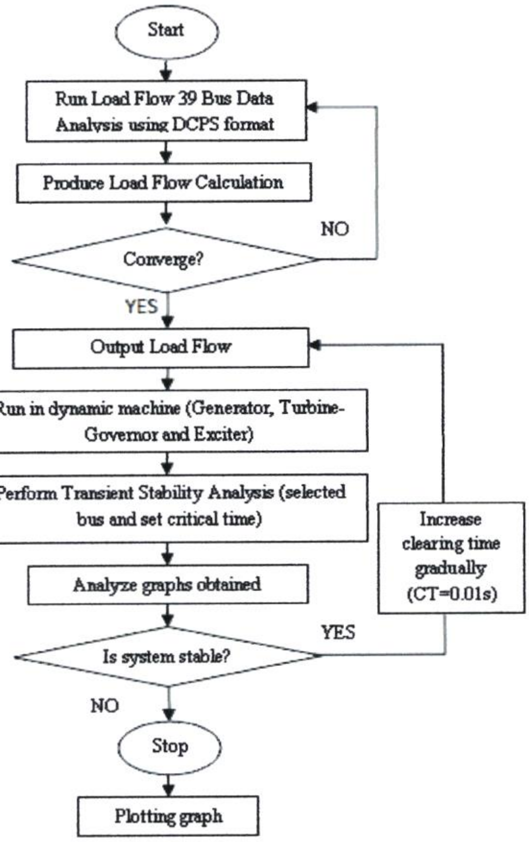

Figure 3. Flowchart to determined CCT

Figure 3 shows the overall process of performing TSA in DCPS. As mention earlier, load flow is a pre-requisite before perform TSA. It is because load flow analysis is the most important of all network calculations since it concerns the network performance in its normal operating conditions. After LF has converge or solve it will produce output load flow. Then, to calculate the initial conditions for dynamic models, all the values from that solution will be used. Dynamic model are namely as synchronous generators, exciters system and turbine governors system.

Next, perform TSA and set the critical time for the bus chosen. At this section, students need to choose the bus and set CT. Then analyze the graph obtained whether the system is stable or not. If the system is stable students have to increase CT with 0.01sec and repeat the same procedure until the system become in unstable condition. During the simulation, the system was inject by the fault at t = 1sec. For example at perform TSA section student select bus 30 and set the CT with 0.10 sec. Then, analyze the graph obtained. Let say the graph is stable so student has to increase the CT with 0.01 sec. Therefore the CT now will become 0.11 sec. Repeat the process again and analyze the graph again. If the system is in unstable condition so we can conclude that when fault occur at bus 30 the system is in stable condition when CT = 0.10 sec while the system is in unstable when CT= 0.11 sec. One of the most important parts of transient stability analysis is to estimate the critical clearing time. In this case CCT can be determined manually from the DCPS by increase the value of CT. Then, value between the time when the system starts to be unstable and the time where the system was last known in a stable state is the CCT for that particular case.

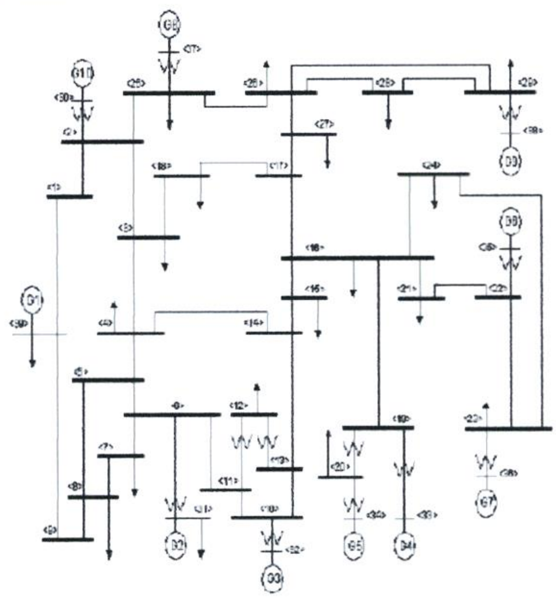

Figure 4. IEEE 39-Bus Test System

V. Results And Discussion

The TSA was carried out on IEEE 39-bus test system or well known as 10-machine New England Power System as shown in Figure 4. The load flow data was obtained from the internet that address at [9]. All the machine data for parameter that used in generators, turbine-governors and exciters were given as in the Appendix section. During the simulation all data values were kept constant. The swing bus or reference bus for this system is located at bus 38. In order to determined the critical clearing time, a three-phase fault has been applied at six difference buses namely bus 38(swing bus), bus 6, bus 10, bus 11, bus 22 and bus 28. The shortest reactance value from bus 38 used to describe the distance between each bus form swing bus. All result obtained was record in Table I.

The simulation graphs obtained from this analysis is for the case where the faults occur at swing bus which is bus 38 and being plotted as figure 5 until figure 12. All the simulation result was observed based on terminal voltage of the machine, rotor angle, output electrical power and speed. By theory it was clearly state that if the (CT<CCT) the system is in stable condition while if (CT>CCT) the system is said to be in unstable condition. Result shows that CT for this case where faults occur at bus 38 is 0.07sec. Therefore for figure 5-8 shows the system is in stable condition because CCT at this case is 0.074sec which is comply with (CT<CCT) requirement and vice versa. For figure 5, we can see that the terminal voltage was suddenly drop due to the fault occur at t=1 sec and the voltage was recovered after a few second and finally become to its steady state again. It is because the fault was cleared within the CCT. As was mention earlier, the system will be in unstable condition due to the rotor angle of machine does not swing together such as the result in Figure 10. From this analysis, the fastest CCT is 0.074 sec when fault occurred exactly at the reference bus or swing bus. While the longest CCT is 0.184 sec when fault occur at bus 11 which located far from swing bus. The same analysis is applied for six other buses and the result of this analysis was recorded and shown in Table I.

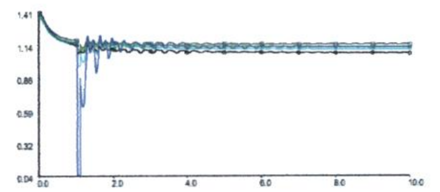

Figure 5. Plots of terminal voltage versus time for machine at all bus (CT=0.07). (Stable)

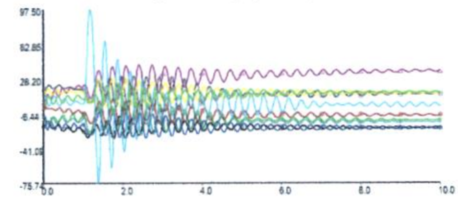

Figure 6. Plots of rotor angle versus time for machine at all bus (CT=0.07). (Stable)

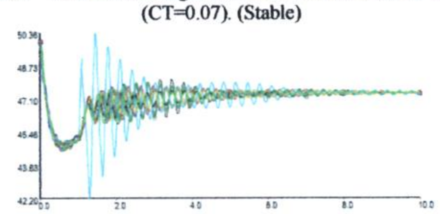

Figure 7. Plots of speed versus time for machine at all bus (CT=0.07) (Stable)

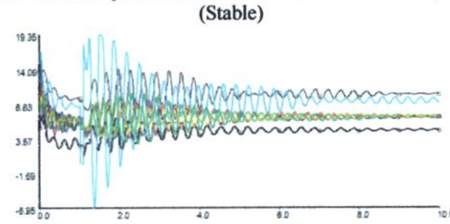

Figure 8. Plots of output electrical power versus time for machine at all bus (CT=0.07). (Stable)

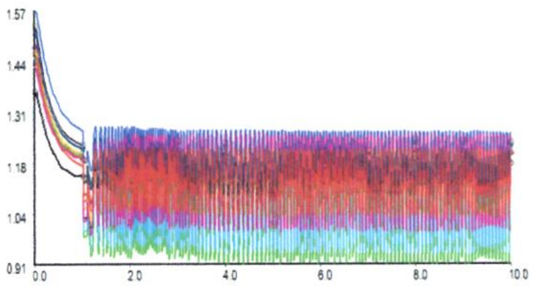

Figure 9. Plots of terminal voltage for versus time for machine at all bus (t_{cr}=0.08). (Unstable)

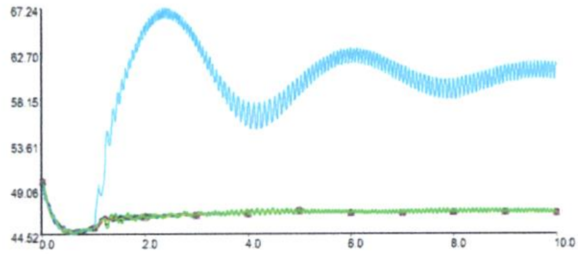

Figure 11. Plots of speed versus time for machine at all bus (CT=0.08) (Unstable)

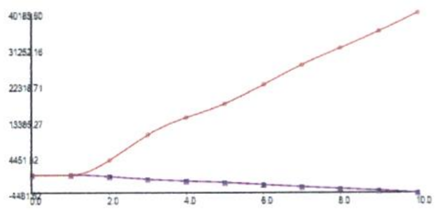

Figure 10. Plots of rotor angle versus time for machine at all bus (CT=0.08). (Unstable)

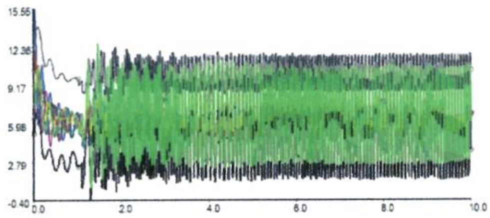

Figure 12. Plots of output electrical power versus time for machine at all bus (CT=0.08). (Unstable)

TABLE I. CCT when fault occurs at six different locations

No.	Faulted Bus	Shortest Reactance from Bus 38	CT (s)	Analysis graph	CCT (s)
1	38 (Reference Bus)	-	0.07	Stable	0.074
			0.08	Unstable	
2	28	0.0307 p.u	0.10	Stable	0.104
			0.11	Unstable	
3	22	0.1465 p.u	0.12	Stable	0.124
			0.13	Unstable	
4	10	0.1645 p.u	0.14	Stable	0.144
			015	Unstable	
5	6	0.1784 p.u	0.15	Stable	0.154
			0.16	Unstable	
6	11	0.2472 p.u	0.18	Stable	0.184
			0.19	Unstable	

VI. CONCLUSION

This paper has contributed to determine the critical clearing time of TSA for the IEEE 39-bus test system. In this proposed strategy for the power systems is to setting critical clearing time at the system from load flow and transient that being run in the DCPS program. In this analysis, six different locations which experiencing fault were chosen. This analysis allows to asses that the system is stable, unstable and hence to determine the critical clearing time of power system with three-phase faults. In addition, the Modified Euler Method is quite faster because gives the accurate results of stability and the critical clearing time. Critical clearing time decreases as the fault location becomes closer to the main generator. From Table I it can be conclude that CCT decrease as the fault location becomes closer to the main generator or in other word it can be said that when fault occurs far from the swing bus the duration of CCT is greater. Therefore in order to make the system operate in good, safe and efficient determination of CCT is crucial since such information of time need to be used for setting the relay time for breaker to clear the fault to protect the system. The requirement for estimation of critical clearing time should be implement to avoid any cascading outages which may lead to black out. Therefore, it can be concluded that it is crucial to determine an accurate critical clearing time for relays in order to remove the contingencies in order to ensure reliable power system operation. So, it is widely accepted that transient stability is an important aspect in designing and upgrading electric power system. These results can be used effectively in planning or operation of power systems.

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Appendix

Table II. Machine Data

Parameters	Generator	Turbine-Governor	Exciter
M	5	-	-
f	50 hz	-	-
X_d	0.2	-	-
X_d'	0.033	-	-
X_d''	-	-	-
T_{d0}'	8.0	-	-
T_{d0}''	-	-	-
X_q	0.19	-	-
X_q'	0.061	-	-
X_q''	-	-	-
T_{q0}'	0.4	-	-
T_{q0}''	-	-	-
X_l	0.022	-	-
V_{MAX}	-	0.6	-
V_{MIN}	-	-0.6	-
T_1	-	0.0	-
R	-	0.00028	-
E_{FDMAX}	-	-	10.0
E_{FDMIN}	-	-	-10.0
K_1	-	-	30.0
T_R	-	-	0.01