THE APPLICATION OF PROGRAMMING FAST METHOD FOR CALCULATION THE CRITICAL CLEARING TIME IN TRANSIENT STABILITY ANALYSIS OF IRAQ SUPER GRID [+]

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Abstract:

A transmission line trip during a power swing may cause instability of a power system. It is necessary to recognize the power swing from fault based on stability boundary, the power swing blocking relays must be set to do that, power swing should be analyzed, a way of probability of occurrence of fault must be found, the critical condition under which the stability of a power system hasn't been disturbed is recognized & finally the settings of the power swing relays are calculated.

The main aim of this paper is to reduce the execution time of the process of finding of the Critical Clearing Time (CCT) using Programming Fast Method (PFM) and compare it with Bisection Method.

In practice however, calculating the CCT is computationally inefficient and not desirable because the Bisection method is a tedious and inefficient process. A proposed method for finding the CCT of the power system at any direct fault or indirect-fault is more efficient method in the accuracy & solution time to calculate (CCT) in transient stability analysis.

The results obtain by Bisection and proposed methods show that the proposed method reduce the execution time of the CPU about 8-10 times.

In this paper the CCT was calculated for two power systems (single machine and the Iraq Super Grid at 10 locations in the Iraqi transmission line network) by using Bisection & proposed methods.

MATLAB version 7 is used to implement several programs for the optimal execution time of the CPU time, with using PC4 and CPU speed 3 GHz.

Keyword: **Transient Stability Analysis, Power System Controls.**

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تطبيق طريقة برمجية سريعة لحساب وقت الازالة الحرج في تحليل الاستقرارية العابرة لشبكة الجهد الفائق العراقية

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المستخلص:

في نظام القدرة الكهربائية اي قطع او عطل في منظومة القدرة خلال تارجح الماكنة قد يسبب حالة عدم استقرار في نظام القدرة لذلك يكون من الضروري تمييز نظام القدرة خلال حدوث العطل ويتم ذلك عن طريق اجهزة حماية هذه الانظمة لايجاد طريقة افتراضية لحدوث العطل وتحديد الظروف الحرجة لأستقرارية منظومة القدرة وحسابات تارجح النظام.

ان الهدف الرئيسي من هذا البحث هو تقليل زمن الانجاز الازم لايجاد زمن الازالة الحرج في وحدة المعالجة المركزية بواسطة طريقة البرمجة السريعة ومقارنتها بطريقة التنصيف.

عمليا ,تكون طريقة التنصيف غير مرغوب فيها وتكون غير فعالة وشاقة جدا اما الطريقة المقترحة في عملية ايجاد زمن الازالة الحرج عند اي عطل مباشر او غير مباشر فوجد انها اكثر فاعلية من ناحية الدقة وزمن الحل لتقييم استقرارية القدرة.

تشير النتائج المستحصلة بالطريقتين الى تفوق الطريقة المقترحة على طريقة تنصيف الزمن. حيث وجد انها تقلل زمن الانجاز في وحدة المعالجة المركزية بمقدار يتراوح بين 8 – 10 مرات.

في هذا البحث تم حساب زمن الازالة الحرج لمنظومتين اختباريتين (الماكنة الاحادية و10 موقع لشبكة الجهد الفائق العراقية) بواسطة تطبيق طريقة التنصيف والطريقة المقترحة وذلك باستخدام برنامج الماتلاب (اصدار 7) وحاسبة بانتيوم 4 وسرعة المعالج 3 ميغا هيرتز.

1- Introduction :

Power system stability refers to the ability of synchronous machines to move from one steady-state operating point following a disturbance to another steady-state operating point, without losing synchronism. There are three types of power system stability: steady-state, transient, and stability [1].

Transient stability involves major disturbances such as loss of generation, line-switching operations, faults, and sudden load changes. A disturbance, a synchronous frequency and machine power angles change. The objectives of transient stability study to determine whether or not the machine will return to synchronous frequency with new steady-state power angle [2].

A large-scale power systems with many synchronous machine interconnected by complicated transmission networks, transient stability studies are best performed with a digital computer program. For a specified disturbance, the program alternately solves, step by step, algebraic power flow equation representing a network and nonlinear differential equations synchronous

machines. All of pre-disturbance, disturbance, and post-disturbance computations are preferred. The program output includes power angles and frequencies of synchronous machines, bus voltages, and power flows versus time [3].
In many cases, transient stability is determined during the first swing of machine power angles following a disturbance. During the first swing which typically lasts about 1 second, the mechanical output power and the internal voltage of a generating unit are often assumed constant. However where multi-swings lasting several seconds are of concern, models of turbine governors and excitation systems as well as more detailed machine models can be employed to obtain accurate transient stability results over the longer time period [4].
The system conditions before the fault occurs and the network configuration both during and after is occurrence, must be known in any transient stability study. Consequently, in the multi-machine case two preliminary steps are required:

1- The steady-state pre-fault condition for the system is calculated using a Production-Type Power-Flow program [PTPF].
2- The pre-fault network representation is determined and then modified to account for the fault and for the post fault conditions [5].

2- Literature Survey :

Several researchers studied the problem and put suggestions and trails to overcome instabilities. Review of many previously published works is presented as follows:-

- **Z. Q. WU, 2001[6],** the study aims at assessing multi-machine system stability by Single Machine Equal Area Criterion(SMEAC) and to compare it with Time Domain Simulation (TDS), by combining with the (TDS), using the rotor angle changes in the steps of time integration and deceleration power. The calculation method for the acceleration and deceleration areas of single machine was proposed. In this study also the stability margin and unstable margin were calculated.
- **A. M Abdul Majeed, 2006[7],** the study presented a program for handling and improving the transient stability of the Iraq Super Grid electrical network was developed. The work included in this study consists of three main parts. The first part was developing a load flow program using fast decoupled method and the transient stability program using modified Euler's method in the step by step solution (SBS). The second part was the engagement between the two programs and the third part was the application of the new program on the Iraq Super Grid network (400 KV).

3- Mathematical Model :

3.1 Numerical Integration of the swing equation:

The per unit swing equation, is the fundamental equation that determines rotor dynamic in transient stability studies [8].

$$\frac{2H}{w_{sys}} w_{P.U.}(t) * (d^2\,\delta(t)/dt^2)) = P_{m.p.u.}(t) - P_{e.p.u.} - \frac{D}{w_{sys}} \frac{d\,\delta(t)}{(dt)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$= P_{a.p.u.}(t)$$

Equation (1) is a second-order differential equation that can be rewritten as two first-order differential equations.

$$\frac{d\,\delta\,(t)}{dt} = w\,(t) - w_{sys} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 2$$

Using 2 in 1,

$$\frac{2H}{w_{sys}} w_{p.U.}(t) \frac{dw(t)}{dt} = P_{m.p.u.}(t) - P_{e.p.u.}(t) - \frac{D}{w_{sys}} \frac{d\delta(t)}{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

The real power delivered by the synchronous generator to the infinite bus is:

$$P_e = \left(\frac{\acute{E}\,V_{bus}}{X_{eq}}\right) \sin\delta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 4$$

During transient disturbances both $\acute{E}$ and V_{bus} are considered constant in 4. Thus P_e is a sinusoidal function of the machine power angle δ. [9,10]

Integrating twice with initial condition $\delta_{(0)} = \delta_0$ and $\frac{dt(0)}{dt} = 0$,

$$\delta_{(t)} = \frac{w_{sys}\,P_{m.p.u.}}{4H} t^2 + \delta_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 5$$

$$T_{cc} = \sqrt{\frac{4\,H}{w_{sys}P_{m.p.u.}} \quad (\delta(t) - \delta_0)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

For multi-machine stability problems, however, numerical integration techniques can be employed to solve the swing equation for each machine. The modified Euler's is applied method to calculate machine frequency w and power angle δ. Letting (δ, w) the old values at the beginning of the interval are denoted δ_t and w_t. From (1) and (2), the slopes at the beginning of the interval are. [10,11]

$$\frac{d\delta_t}{dt} = w_t - w_{syn} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 7$$

$$\frac{dw_t}{dt} = \frac{P_{a.p.u.t}\ w_{syn}}{2H\ w_{p.u.t}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 8$$

Where $P_{a.p.u.t}$ is the per-unit accelerating power calculated at $\delta = \delta_t$, and

$w_{p.u.t} = w_t / w_{syn}$. Applying (Euler's), preliminary values are:

$\breve{\delta} = \delta_t + (\frac{d\delta_t}{dt})$ Δt 9

$\breve{w} = w_t + (\frac{dw_t}{dt})$ Δt 10

Next, the slopes at $\breve{\delta}$ and $\breve{w}$ are calculated, again using (1) and (2):

$\frac{d\breve{\delta}}{dt} = \breve{w} - w_{syn}$ 11

$\frac{d\breve{w}}{dt} = \frac{p_{a.p.u.t} w_{syn}}{2H\ \breve{w}_{p.u.}}$ 12

Where $\breve{p}_{a.p.u.}$ is the per unit accelerating power calculated at $\breve{\delta} = \delta$, and $\breve{w}_{p.u.} = \breve{w} / w_{syn}$,

applying (Modified Euler's), the new values at the end of the interval are:

$\delta_{t+\Delta t} = \delta_t + \frac{\frac{d\delta_t}{dt} + \frac{d\breve{\delta}}{dt}}{2} \Delta t$ 13

$w_{t+\Delta t} = w_t + \frac{\frac{dw_t}{dt} + \frac{d\breve{w}}{dt}}{2} \Delta t$ 14

The procedure, given the equation from (7) to (14), begins at t=0 with specified initial values δ_0 and w_0, and the iteration will continues until the final solution time, a specified final time calculations are best performed using a digital computer. [11,12]

3.2 Multi-machine Stability:

The numerical integration methods (modified Euler's & Rung Kutto) can be used to solve the swing equations for multi-machine stability problem. However, a method is required for computing machine output powers for a general network. Figure (1) shows a general N-bus power system with M synchronous machines, each machine is represented by the simplified model, and the internal machine voltages are denoted $E'_1, \acute{E}_2, \ldots, \acute{E}_n$. The M machine terminals are connected to system buses denoted $G_1, G_2, \ldots, G_m$. in figure (1). All loads are modeled here as constant admittances. Noted equations for this network. [11,12].

$\begin{bmatrix} Y_{11} & Y_{12} \\ Y^T{}_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} V \\ E \end{bmatrix} = \begin{bmatrix} 0 \\ I \end{bmatrix}$ 15

Where V is the N vector of bus voltages
E is the M vector of machine voltages.
I is the M vector of machine currents.

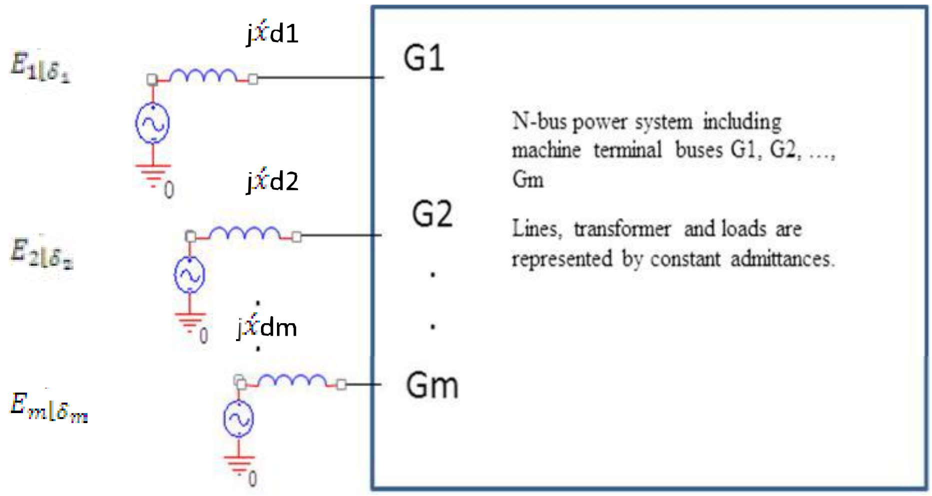

Figure (1): N-bus power system representation for transient stability studies

$\begin{bmatrix} Y_{11} & Y_{12} \\ Y^T{}_{21} & Y_{22} \end{bmatrix}$is an (N+M)*(N+M) admittance matrix……………………………….…. 16

The admittance matrix is partitioned in accordance with the N system buses and M internal machine buses, as follows

Y_{11} is N×N ; Y_{12} is N×M ; Y_{22} is M×M

Y_{11} is similar to the bus admittance matrix used for power flow except that load admittance and inverted generator impedance are include. That is, if a load is connected to bus n, then that load admittance is added to the diagonal element Y_{11nn}. Also, (1/j$\acute{X}_{dn}$) is added to the diagonal element Y_{11GnGn} .

Y_{22} is a diagonal matrix of interval generator impedances, that is,

$$Y_{22} = \begin{bmatrix} \frac{1}{jx\acute{d}_1} & 0 & \cdots & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \cdots & \frac{1}{jx\acute{d}_M} \end{bmatrix} \qquad \text{…………………………………………...…………….…. 17}$$

Also, the kmth element of Y_{12} is

$$Y_{12km} = \begin{cases} \frac{-1}{jx\acute{d}_n} & if\ k = G_n \quad m = n \\ 0 & otherwise \end{cases} \quad \ldots\ldots 18$$

Writing (15) as two separate equations,

$$Y_{11}V + Y_{12}E = 0 \quad \ldots\ldots 19$$

$$Y_{12}^T V + Y_{22} E = I \quad \ldots\ldots 20$$

Assuming E is known, equation (19) is a linear equation in V that can be solved iteratively by using iterative methods like the Gauss-Seidel or Newton Raphson. The K_{th} component of V is:

$$V_k(i+1) = \frac{1}{Y_{11kk}}\left[-\sum_{n=1}^{M} Y_{12kn} E_n - \sum_{n=1}^{k-1} Y_{11kn} V_n (i+1) - \sum_{n=k+1}^{N} Y_{11kn} V_n (i)\right] \ldots 21$$

After V is computed, the machine currents can be obtained from equation (20).

That is:

$$I = Y_{12}V + Y_{22}E \quad \ldots\ldots 22$$

The real electrical power output of machine n is then

$$P_{en} = R_e[E_n I_n] \quad n=1,2,3,\ldots,M \quad \ldots\ldots 23$$

4- Transient Stability Computational Procedure :

The procedure alternately solves the swing equation representing the machines and the above algebraic power-flow equations representing the network. We use the modified Euler method to solve the swing equations and the Gauss-Seidel or Newton Raphson iterative method to solve the power-flow equations. We now give the procedure in the following steps: [13,14].

1- Run a pre-fault power-flow program to compute initial bus voltages V_k ,k=2,3,…,N, initial machine currents I_n , and initial machine mechanical power outputs, P_{en} , n=1,2,..,M. Set machine mechanical power outputs, $P_{mn} = P_{en}$. Set initial machine frequencies, $w_n = w_{syn}$. Compute the load admittances.

2- Compute the internal machine voltages:

$E_n = E_n \lfloor\delta = V_{Gn} + (j\, X'_{dn})\, I_n$ n=1,2,…,M.

Where V_{Gn} and I_n are computed in step 1. The magnitudes E_n will remain constant throughout the study. The angles δ_n are the initial power angles.

3- Compute Y_{11}. Modify the (N×N) power-flow bus admittance matrix by including the load admittances and inverted generator impedances.

4- Compute Y_{22} from (17) and Y_{12} from (18)

5- Set t=0

6- Is there a switching operation, change in load, short circuit, or change in data? For a switching operation or change in load, modify the bus admittance matrix. For a short circuit, set the faulted bus voltage to zero.

7- Using the internal machine voltages $E_n = E_n \lfloor\delta$, n=1, 2… M, with the values of δ_n at time t, compute the machine electrical power P_{en} at time t from (21) to (23).

8- Using p_{en} computed in step 7 and the values of δ_n & w_n at time t, computes the preliminary estimates of power angles $\breve{\delta}_n$ and machine speeds $\breve{w}_n$ at time $(t + \Delta t)$ using equations from (7) to (10).

9- Using $E_n = E_n \lfloor\breve{\delta}_n$, n=1,2,…,m, compute the preliminary estimates of the machine electrical powers $\breve{p}_{en}$ at time $(t + \Delta t)$ from (21) to (23).

10- Using $\breve{p}_{en}$ computed in step 9, as will as $\breve{\delta}_n$ and $\breve{w}_n$ computed in step 8, computed the final estimates of power angles δ_n and machine speeds w_n at time $(t + \Delta t)$ from (11) to (14).

11- If $\delta_n(t + \Delta t) < \delta_n(t)$ set $t_c = t_c + \Delta t$. Return to step 5.

12- Set time $t = t + \Delta t$ Stop if $t \geq$ tf. Otherwise, return to step 6.

5- Critical Clearing Time Calculation :

This is a numerical pessimistic estimation of critical clearing time (CCT) based on bisection method. It is based on the following algorithm.[14,15]

1- The stability of the system is determined for the given period t_s and fault clearing time t_c .
2- If the system was stable for the given t_c then the test period will be between t_c and t_s. The new t_c is set in the middle between old t_c & t_s . If, however, the system was originally unstable then test period will be between 0 and t_c . The new t_c is set in middle between 0 and old t_c. The original system condition is recorded.
3- Steps 1 and 2 are repeated until the system condition in step 2 changes. If it did not change until t_c became very close to the period edge then the system remains on its original state whether stable or not and no critical clearing time can be calculated.
4- If the test period will not be between old t_c and new t_c. Set t_s equal new t_c and new t_c equal half the step between them. Steps 1,2 and 3 are then repeated until the difference between old t_c and new t_c is less than the pre-specified time step used in the main iteration of the stability program.
5- The critical clearing time is the last value reached for t_c.

Evidently, this requires a lot of time to find the critical clearing time. The solution time can be reduced by increasing the time step and reducing the study period. The best way is to get a fast – rough estimate of the critical clear in time then start the solution again and try to refine it.

6- Flowcharts :

The PFM has a loop that compare solution of time (t) with final solution time (tf), so the program will enter loop when the solution time is less than final solution time, then the program will check the solution time for several conditions to calculate acceleration Power at post fault (Papf). Finally the system will compare the current rotor angle $\delta(I)$ with previous rotor angle δ (I-1) to check whether the machine is stable or not as shown in figure (2) for single machine and figure (3) for multi machine.

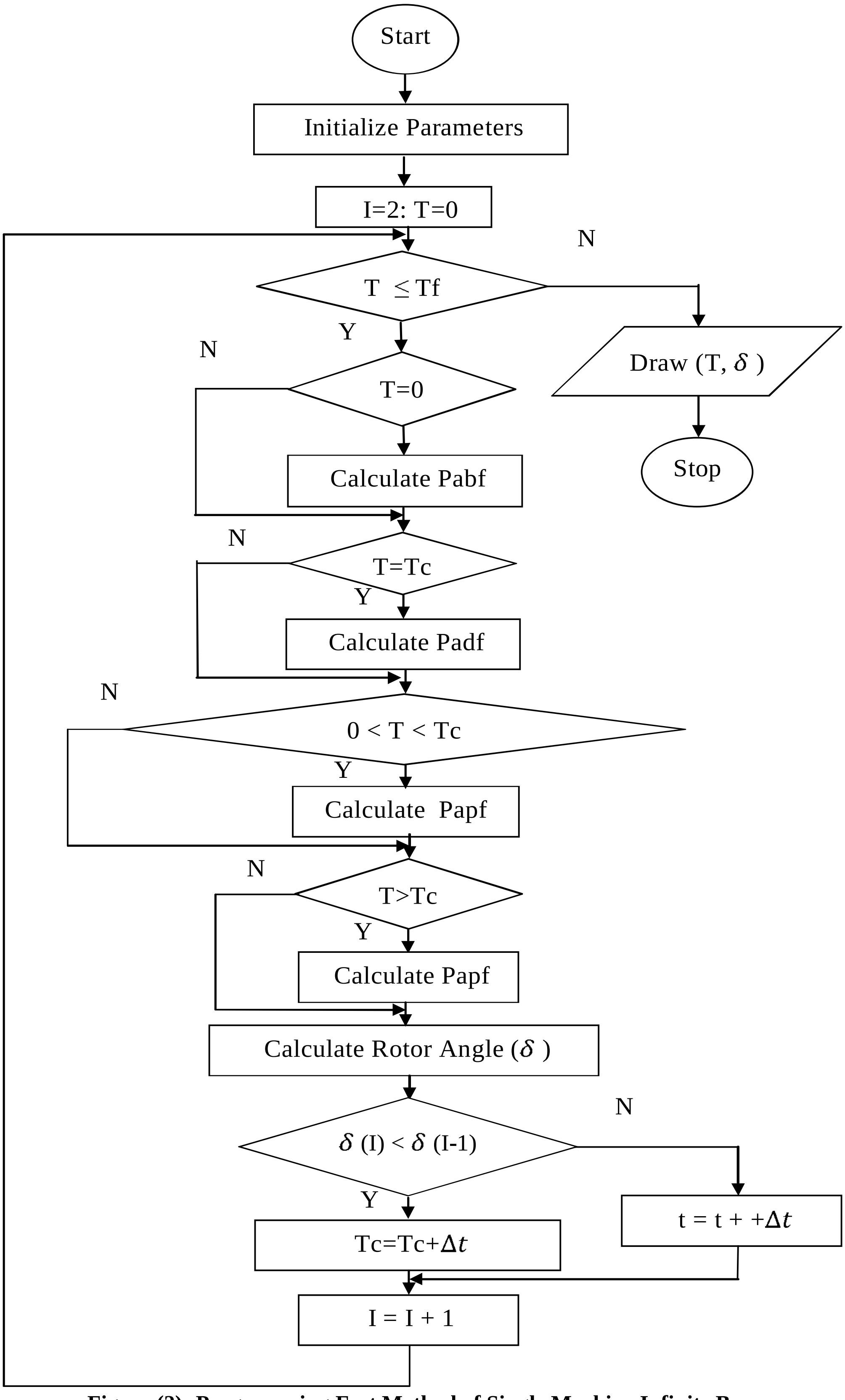

Figure (2): Programming Fast Method of Single Machine Infinite Bus.

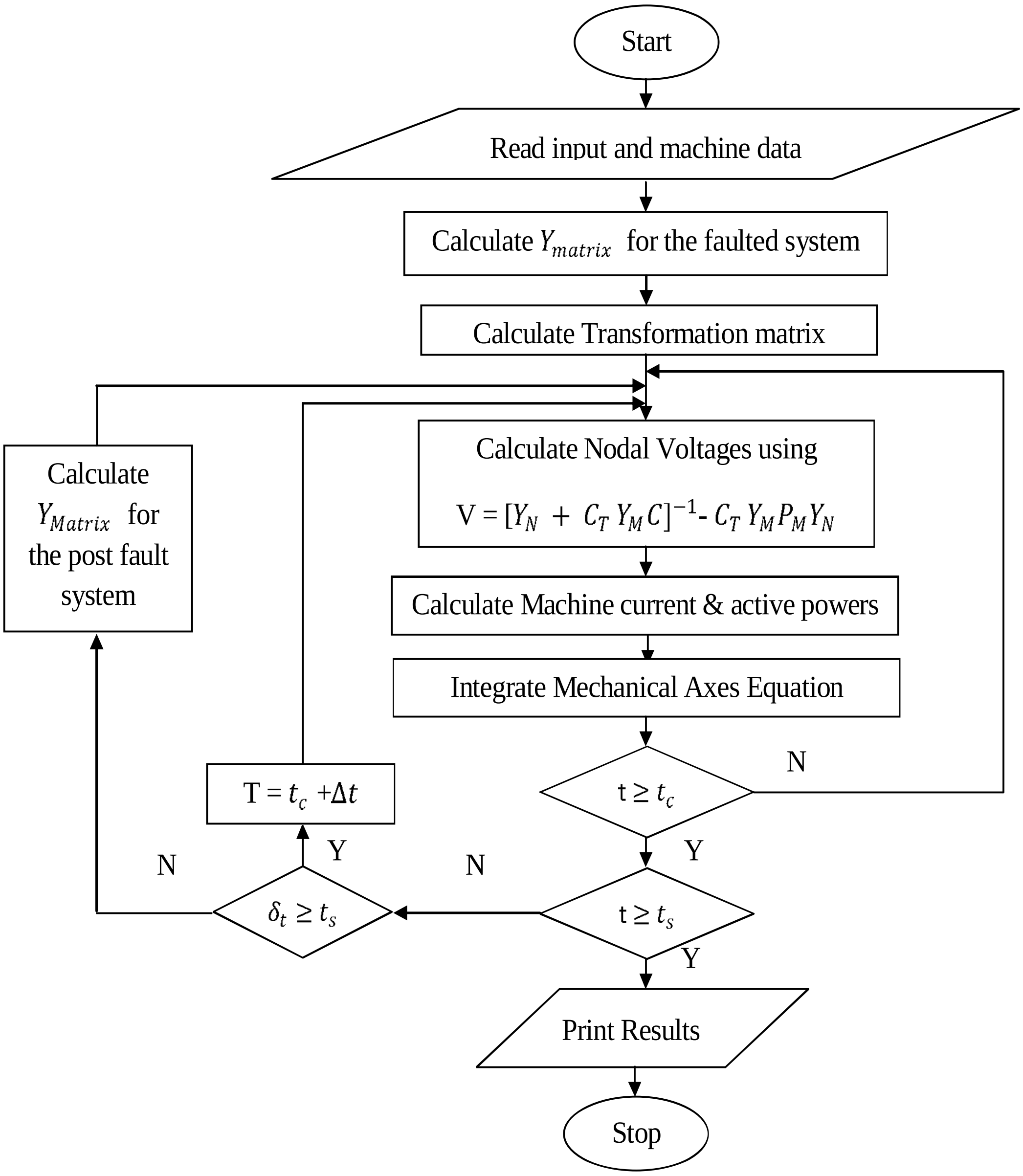

Figure (3): PFM of Multi-Machines

7- Validity of Proposal Determination CCT Method :

In order to illustrate that the CCT determine mathematical proof of the Bisection method. The CCT of the first test system shown in figure (4) was 41 msec. as reported by Saadat [7]. When the transient stability simulation program that employs step by step method is used to find the CCT, it is 41 msec. when the step size is 1 msec. The process of finding critical clearing time using the Bisection took 0.1996 second of the CPU time.
Then the transient stability program that uses the proposed method was employed. It uses the step-by-step solution method for calculated the CCT is depending on the value of δ_t & $\delta_{t+\Delta t}$.

The CCT reported by this method is 41 msce. when the step size is 1 msec. The executing time was 0.0229 sec. as shown in table (1). The simulation results are shown in figures(5,6).
MATLAB programming (M File) is used to solve the model in order to obtain critical clearing time of 3-phase fault at the terminal of the synchronous generator of the test system.

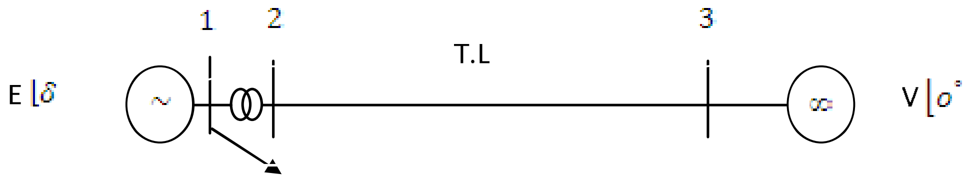

Figure (4): Test System (1) Single Machine connected to Infinite bus

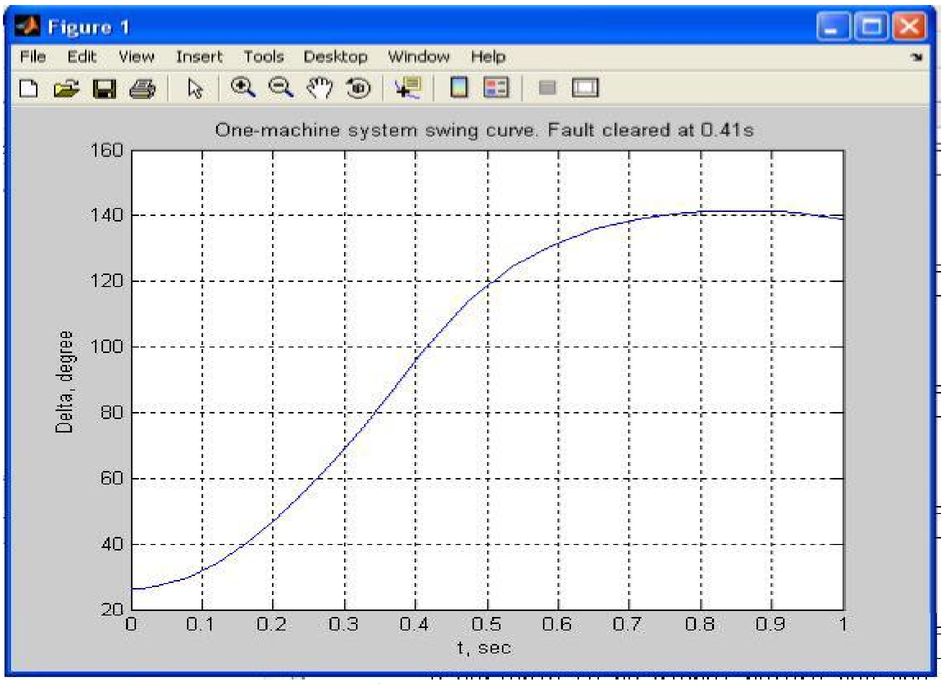

Figure (5): Variation of Rotor Angle with Time at tc = 0.41 sec.

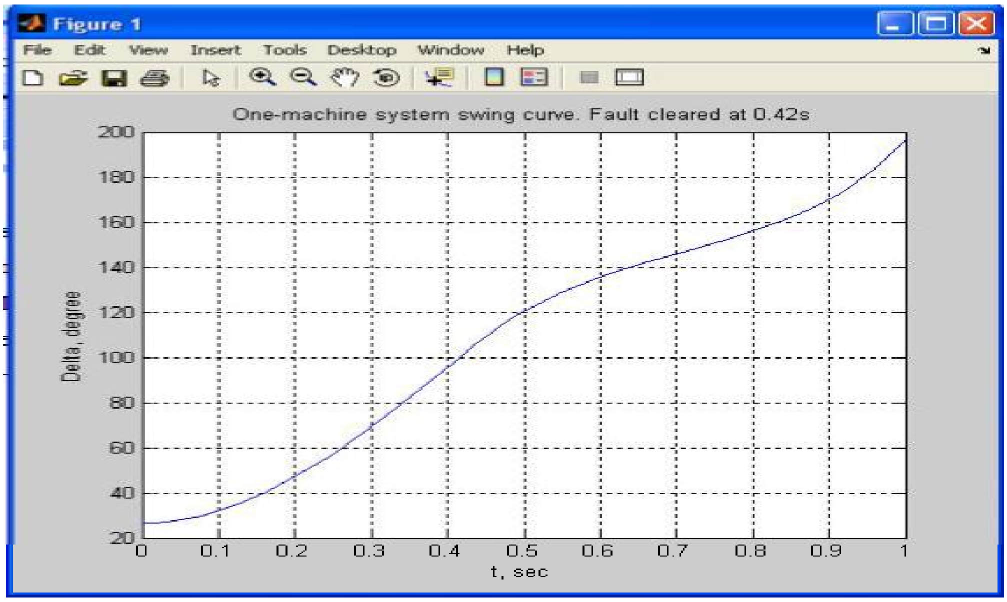

Figure (6): Variation of Rotor Angle with Time at tc = 0.42 sec.

Table (1): The case of single machine connected to infinite bus

Method of Solution	Determination of CCT	Execution Time /msec. Step Size of 1 msec.	Critical Clearing Time /msec.
Integration	Bisection Method	0.1996	41
	Proposed Method	0.0229	41

8- The Application of the Transient Stability Analysis on Iraqi Super Grid :

Iraqi Super Grid System which is shown in figure (7) has been examined with its data (as shown at appendix A) by applying PFM at faulted buses (2,3,5,6,9,12,13,14,16,&19). Simulation results are shown in figures (8, 9, 10, and the 11).

Table (2) illustrates the differences in the execution time CPU, time enhancements using Bisection method & programming fast method.

In order to reduce the total execution time and determine the CCT with a three-phase to ground fault at any fault location in order to setting the relays. This achieved by using the Bisection method and programming fast method.

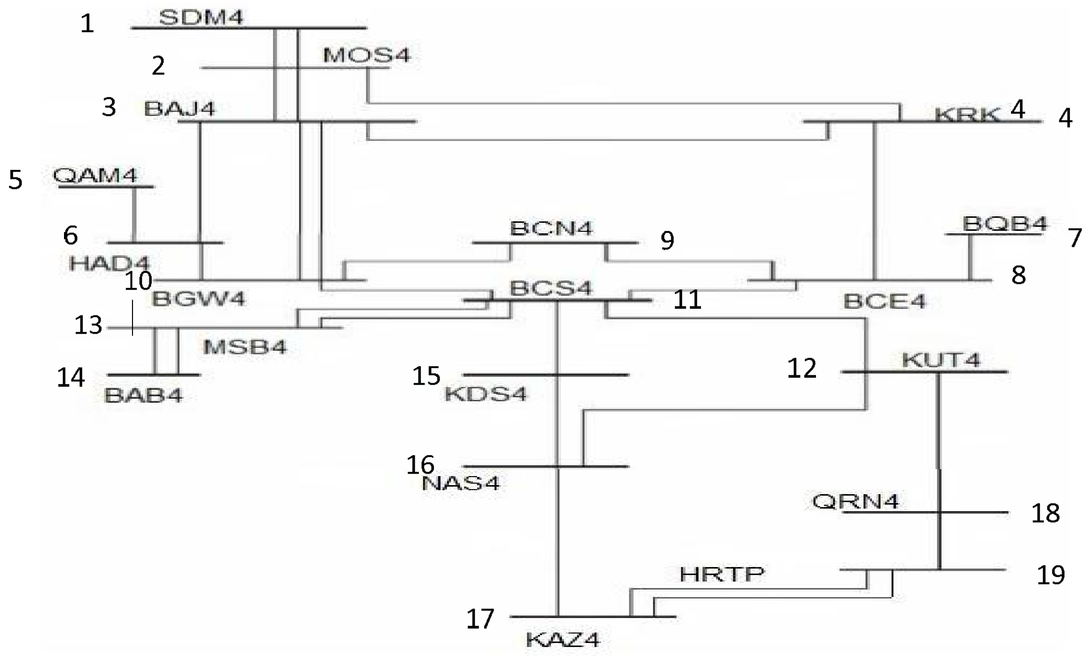

Figure (7): Test System (2) Iraqi Super Grid [16]

Table (1) shows the practical results of single machine with two methods solution. Table (2) shows the practical results of Iraqi transmission line network with two methods solution.

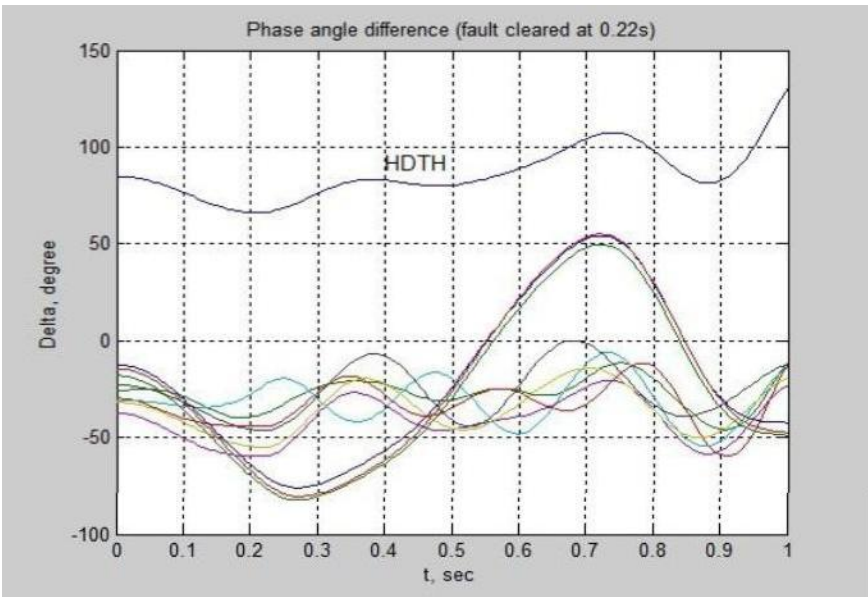

Figure (8): Variation of rotor angle with time, tc= 0.22 sec.at line[HDTH-BAJ4]

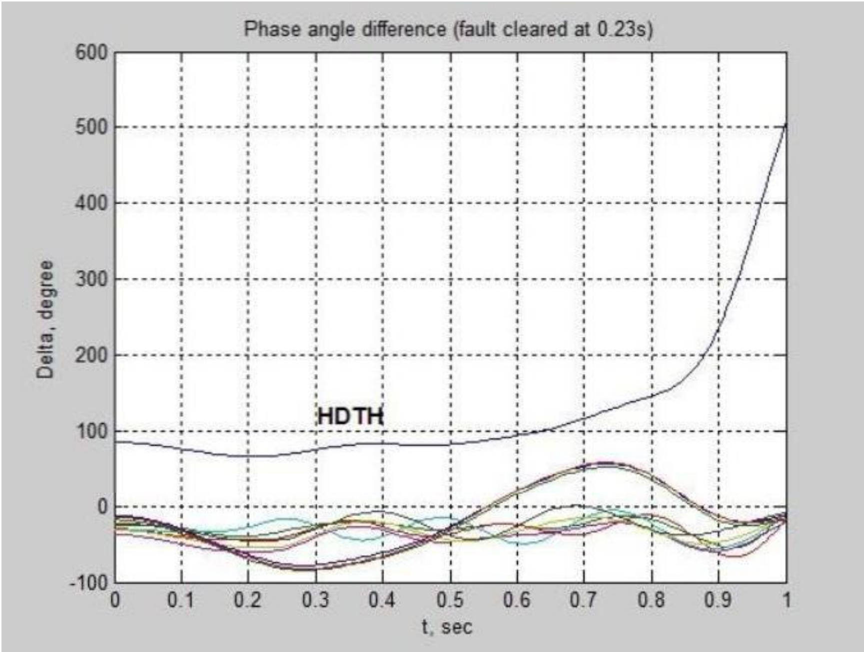

Figure (9): Variation of rotor angle with time, tc= 0.23 sec. at line [BAJ4-HDTH]

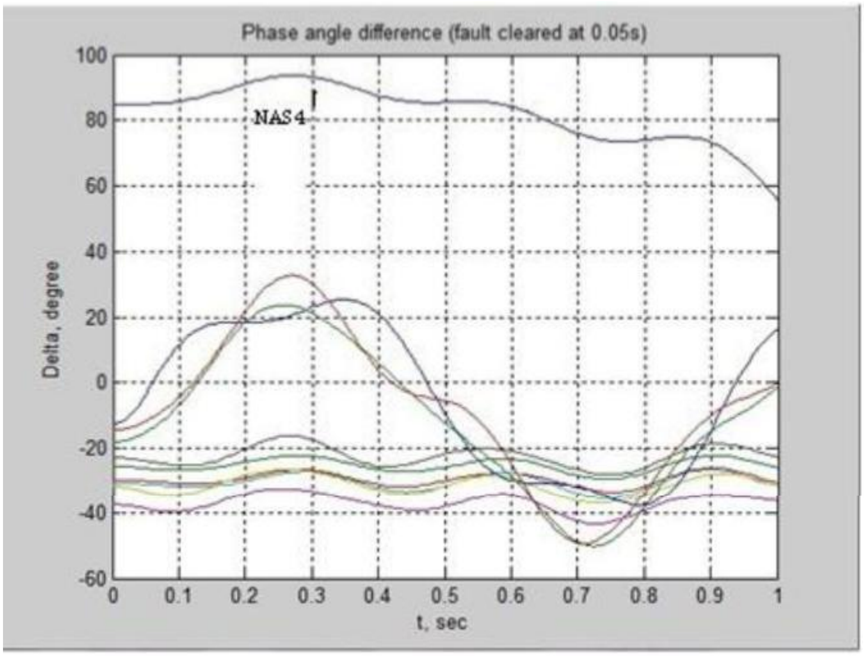

Figure (10): Variation of rotor angle with time, tc= 0.05 sec. at line [NAS4-KDS4]

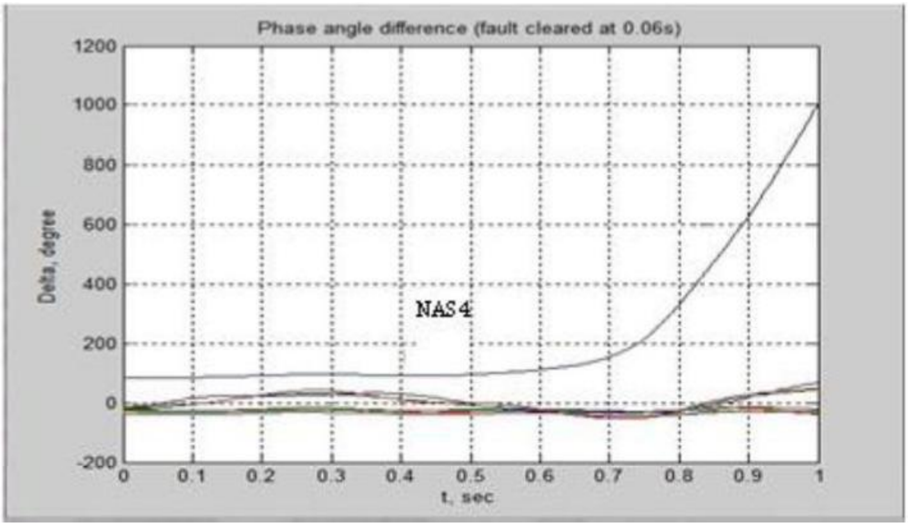

Figure (11): Variation of rotor angle with time, tc= 0.06 sec. at line [NAS4-KDS4]

Table (2): Results of Execution Time of Determine of CCT by Bisection Method & Programming

Faulted Bus No.	**Faulted bus name**	**Remove line**	**Method of determine of CCT**	**CCT(msec.)**	**Execution time/msec. Step Size of 1 msec.**
2	MOS4	MOS4-KRK	Bisection method	0.04	164.24
			Programming method	0.04	18.84
6	HAD4	HDTH-QAM4	Bisection method	0.210	166.75
			Programming method	0.210	19.13
3	BAJ4	BAJ4-HAD4	Bisection method	0.220	149.17
			Programming method	0.220	17.11
9	BCN4	BCN4-BCE4	Bisection method	0.110	120.8
			Programming method	0.110	13.85
5	QAM4	QAM4-HAD4	Bisection method	0.140	102.74
			Programming method	0.140	11.78
13	BSB4	BSB4-BCS4	Bisection method	0.100	163.91
			Programming method	0.100	18.80
14	BAB4	BAB4-MSB4	Bisection method	0.100	131.87
			Programming method	0.100	15.12
16	NAS4	NAS4-KDS4	Bisection method	0.05	144.5
			Programming method	0.05	16.57
12	KUT4	KUT4-NAS4	Bisection method	0.120	105.09
			Programming method	0.120	12.05
19	HRTP	HRTP-KAZ4	Bisection method	0.110	136.26
			Programming method	0.110	15.63
Total Execution Time / msec.			Bisection Method		1385.33
			Programming Method		158.88

9- Conclusion :

This paper suggests a simple method for performing the transient stability program for calculating critical clearing time .

Single machine and multi-machine system have been tested and the results are compared with the result of Bisectional time method. For all cases, the accuracy of the proposal method is 100% and the CPU execution time is reduced about 8-10 times.

The Iraqi super Grid is tested , and the fault clearing time for the 3-phase faults near bus bars in ten location are computed .

The minimum CCT at faulted buses 2 and 16 are 0.04&0.05 sec. respectively , according to stander practice for Extra High voltage, the critical generator group is (MOS4 and NAS4).

Results showed that the fault occurs in a certain area in the network, will effect only the station in these areas.

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Appendix – A

Table (A-1) Data of Iraqi super grid generators [19].

Full Name of Generator	Bus Name	Bus No.	$\acute{X}d_{p.u.}$	$H_{p.u.}$
Mosal dam-main power station	SDM4	1	0.038	4
Baiji power station	BAJ4	3	0.0324	2
Hadiytha Dam power station	HAD4	6	0.038	2
Krikuk power station	KRK4	4	0.0209	4
Musayab power station	MSB4	13	0.0446	4
Nassiriyah power station	NAS4	16	0.048	2
Hartha power Station	HRTP	19	0.0464	4
Khor Al-Zuber gas power station	KAZ4	17	0.0258	3

Table (A-2)Transmission lines parameters of the Iraqi super grid system[19].

Lin's Name	Bus No. from-to	R(p.u.)	X(p.u.)	B(p.u.)$\frac{1}{2}$
SDM4-Mos4	1-2	0.00144	0.01177	0.18220
MOS4-BAJ4	2-3	0.00420	0.03437	0.53213
BAH4-KRK4	3-4	0.00181	0.01654	0.24514
BAJ4-HAD4	3-6	0.00345	0.03132	0.46404
BAJ4-BCW4	3-10	0.00501	0.04590	0.66834
KRK4-BCE4	3-9	0.00505	0.04590	0.68001
QAM4-HAD4	5-6	0.00292	0.01331	0.37018
HAD4-BCW4	6-10	0.00485	0.04405	0.652258
BQB4-BCE4	7-8	0.00087	0.00788	0.11674
BCN4-BCW4	9-8	0.00029	0.00262	0.03882
BCN4-BCW4	9-10	0.00093	0.00847	0.12550
BCE4-BCS4	8-11	0.00125	0.00113	0.16927
BCW4-BCS4	10-11	0.00155	0.01417	0.21012
MSB4-BCS4	14-11	0.00122	0.01015	0.15948
MSB4-BAB4	14-15	0.00018	0.00673	0.10583
BCS4-KDS4	11-16	0.00308	0.02795	0.41414
KUT4-QRN4	12-19	0.00479	0.04354	0.64499
KUT4-NAS4	12-17	0.00432	0.03928	0.58195
KDS4-NAS4	16-17	0.00383	0.03485	0.51628
QRN4-HRTP	19-20	0.00290	0.02640	0.39108
NAS4-KAZ4	17-18	0.00439	0.03993	0.59158
HRTP-KAZ4	20-18	0.00118	0.01075	0.15935
BCS4-KUT4	11-12	0.02360	0.19784	0.16256

Table (A-3) Bus-data of Iraqi super grid

Bus No.	Bus Code	|V| p.u.	Ang. (deg.)	Load		Gen		Gen. Mvar		Injected Mvar
				MW	Mvar	MW	Mvar	Min	Max	
1	1	0.982	0	195	158	0.0	0	0	0	0
2	0	1.0	0	576	387	0.0	0	0	0	0
3	2	0.982	0	0.0	0.0	360	0	-160	200	0
4	2	0.977	0	281	189	220	0	-130	140	0
5	0	1.0	0	70	10	0	0	0	0	0
6	2	1.0	0	119	74	190	0	-150	180	0
7	0	1.0	0	110	46	0	0	0	0	120
8	0	1.0	0	192	91	0	0	0	0	90
9	0	1.0	0	387	100	0	0	0	0	90
10	0	1.0	0	500	322	0	0	0	0	90
11	0	1.0	0	125	100	0	0	0	0	90
12	0	1.0	0	181	100	0	0	0	0	0
13	2	0.972	0	210	161	720	0	-320	400	0
14	0	1	0	187	131	0	0	0	0	60
15	0	1	0	194	175	0	0	0	0	0
16	2	0.972	0	252	228	480	0	-240	320	0
17	2	0.969	0	132	139	220	0	-100	140	0
18	0	1	0	175	75	0	0	0	0	60
19	2	0.963	0	127	94	300	0	-150	200	0

Power Flow Solution by Newton-Raphson Method
Maximum Power Mismatch = 5.77351e-006
No. of Iterations = 10

Bus No.	Voltage Mag.	Angle Degree	------Load------		---Generation---		Injected
			MW	Mvar	MW	Mvar	Mvar
1.	0.982	0.000	195.000	158.000	981.000	-338.281	0.000
2.	0.986	-0.544	576.000	387.000	0.000	0.000	0.000
3.	0.992	1.013	0.000	0.000	360.000	-540.490	0.000
4.	0.967	-23.081	281.000	189.000	220.000	17.223	0.000
5.	1.049	0.906	70.000	10.000	0.000	0.000	0.000
6.	1.040	0.994	119.000	74.000	190.000	-586.121	0.000
7.	0.984	-26.487	110.000	46.000	0.000	0.000	120.000
8.	0.978	-26.059	192.000	91.000	0.000	0.000	90.000
9.	0.974	-26.488	387.000	100.000	0.000	0.000	90.000
10.	0.948	-31.296	500.000	322.000	0.000	0.000	90.000
11.	0.982	-27.278	125.000	100.000	0.000	0.000	90.000
12.	1.001	-26.868	181.000	100.000	0.000	0.000	0.000
13.	0.982	-26.981	210.000	161.000	720.000	-565.952	0.000
14.	0.985	-27.074	187.000	131.000	0.000	0.000	60.000
15.	0.988	-27.129	194.000	175.000	0.000	0.000	0.000
16.	0.972	-24.431	252.000	228.000	480.000	-74.457	0.000
17.	0.969	-23.323	132.000	139.000	220.000	116.957	0.000
18.	0.990	-26.219	175.000	75.000	0.000	0.000	60.000
19.	0.963	-23.504	127.000	94.000	300.000	-142.576	0.000
	Total		4013.000	2580.000	3471.000	-2113.697	600.000