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Transient Stability Analysis of IEEE 9 Bus System in Power World Simulator

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ABSTRACT
It is widely accepted that transient stability is an important aspect in designing and upgrading electric power system.
The objective of this paper was to investigate and understand the stability of power system
In this paper, modelling and transient stability analysis of IEEE 9 bus system was performed using POWER WORLD SIMULATOR. The load flow studies were performed to determine pre-fault conditions in the system using Newton-Raphson method. With the help of three-phase balanced fault, the variations in power angle and frequency of the system were studied. Frequency is a reliable indicator if deficiency condition in the power systems exists or not. For three-phase balanced fault, fast fault clearing time was analysed to bring back the system to the stability. Further, comparison between Runga method and Euler method for better results was performed. Hence, impact of load switching on system was also computed so as to bring system to steady state.
Keywords: power system stability, clearing time, transient stability, load switching, three-phase balanced fault, steady state.

I. INTRODUCTION

Now-a-days, it has become a necessity to maintain synchronism because the system is expanding day-by-day and these results in installation of larger machines. Due to this, transient disturbances are increasing continuously in power system. The transient disturbances are caused by the changes in the load, switching operations, faults and loss excitations. Thus, it is very important to regain synchronism or equilibrium after disturbances in the electrical utilities. Hence, thorough analysis of transient stability is required to reduce problems such as blackouts, loss of synchronism, etc.

The term stability refers to maintenance of synchronism and stability limit refers to maximum power flow possible in the system or a part of system at which system is operating with stability. Power system stability is the property of power System that enables it to remains in a state of equilibrium under normal operating conditions an to regain equilibrium after being subjected to disturbances.

Power system stability can be broadly grouped into steady state stability, transient stability and dynamic stability. Steady state stability is the capability of an electric power system to maintain synchronism between machines when small slow disturbance occurs. Dynamic stability is the ability of a power system to remain in synchronism after the initial swing until the system has settled down to the new steady state equilibrium conditions.

In this paper, the main emphasis is given to transient stability of system. Transient stability is the ability of system to remain in synchronism during the period of disturbance and prior to the time that the governors can act. The transient stability analysis is carried out for a short time period that will be equal to the time of one swing. This analysis is carried out to determine whether the system losses stability during the first swing or not.

Transient stability depends on both initial operating state of system and state when disturbance occurs. The disturbance alters the system such that the post disturbance steady state operation will be different from that prior to the disturbance. Instability is in the form of aperiodic drift due to insufficient synchronizing torque, and is referred to as first swing stability.

In this paper, Transient stability analysis is performed with the help of three-phase balanced fault. A fault which gives rise to equal fault currents in the lines with 120 degree displacement is known as three phase fault or symmetrical fault.

Faults could happen when a phase establishes a connection with another phase, lightning, insulation deterioration, wind damage, trees falling across lines, etc.

To analyse swing behaviour of system it is solved by two methods i.e. Runga method and Euler method. Swing equation is the electromechanical equation describ-ingrelative motion of the rotor load angle (δ) with respect to the stator field as a function of time is known as Swing equation. In most disturbances, linearization is not per-missible and the nonlinear swing equation must be solved because oscillations are of such magnitude.

Power flow analysis is called the backbone of power system analysis. Power system fault analysis is one of the basic problems in power system engineering.

The single line diagram of IEEE 9 bus model is shown in figure1:

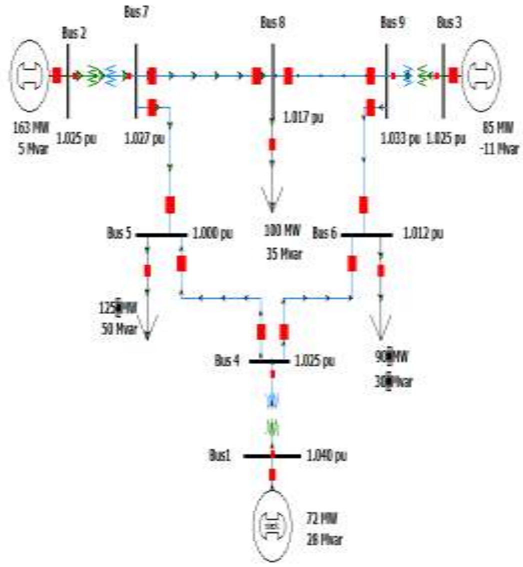


Figure1: IEEE 9 BUS MODEL in power world simulator

II. PROBLEM FORMULATION

A. Power Flow Studies

In transient stability studies, it is necessary to have the knowledge of pre-fault voltages magnitudes. The main information obtained from the power flow study comprises of magnitudes and phase angles of bus voltages, real and reactive powers on transmission lines, real and reactive powers at generator buses, other variables being specified. The pre-fault conditions can be obtained from results of load flow studies by the Newton-Raphson iteration method.

The Newton-Raphson method is the practical method of load flow solution of large power networks. Convergence is not affected by the choice of slack bus. This method begins with initial guesses of all unknown variables such as voltage magnitude and angles at load buses and voltage angles at generator buses. Next, a Taylor Series is written, with the higher order terms ignored, for each of the power balance equations included in the system of equations.

We first consider the presence of PQ buses only apart from a slack bus.

For an ith bus,

$$Pi = \sum_{k=1}^{n}|Vi||Vk||Yik|\cos(\theta ik+\delta k-\delta i) = Pi(|V|,\delta) \quad (1)$$

$$Qi = \sum_{k=1}^{n}|Vi||Vk||Yik|\sin(\theta ik+\delta k-\delta i) = Qi(|V|,\delta) \quad (2)$$

i.e., both real and reactive powers are functions of (|V|, δ), where

$|V| = (|V_1|,....,|V_n|^T)$ $\delta=(\boldsymbol{\delta}_{1,....,}\boldsymbol{\delta}_n)^T$

We write

Pi (|V|,) = Pi(x)

Qi (|V|,) =Qi(x)

Where,

x = [$\boldsymbol{\delta}$/|V|]

Let Pi and Qi be the scheduled powers at the load buses. In the course of iteration x should tend to that value which makes

$$Pi - Pi(x) = 0 \text{ and } Qi - Qi(x) = 0 \quad (3)$$

Writing equation (3) for all load buses, we get its matrix form

$$f(x) = \begin{bmatrix} P(scheduled)-P(x) \\ Q(scheduled)-Q(x) \end{bmatrix} = \begin{bmatrix} \Delta P(x) \\ \Delta Q(x) \end{bmatrix} = 0 \quad (4)$$

At the slack bus, P_1 and Q_1 are unspecified. Therefore, the values $P_1(x)$ and $Q_1(x)$ do not enter into equation (3) and hence (4). Thus, x is a 2(n-1) vector (n-1 load buses), with each element function of (n-1) variables given by the vector x= [$\boldsymbol{\delta}$/|V|]

We can write,

$$f(x) = \begin{bmatrix} \Delta P(x) \\ \Delta Q(x) \end{bmatrix} = \begin{bmatrix} -J11(x) & -J12(x) \\ -J21(x1) & -J22(x) \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \quad (5)$$

Where, $\Delta\boldsymbol{\delta} = (\Delta\boldsymbol{\delta}_2,....,\Delta\boldsymbol{\delta}n)^T$

$\Delta|V| = (\Delta|V_2|... \Delta|Vn|)^T$

$$J(x) = \begin{bmatrix} -J11(x) & -J12(x) \\ -J21(x) & -J22(x) \end{bmatrix} \quad (6)$$

J(x) is the jacobian matrix, each J_{11}, J_{12}, J_{21}, J_{22} are (n-1) × (n-1) matrices.

$$-J_{11}(x) = \frac{\partial P(x)}{\partial\delta}$$
$$-J_{12}(x) = \frac{\partial P(x)}{\partial|V|} \quad (3.18)$$
$$-J_{21}(x) = \frac{\partial Q(x)}{\partial\delta}$$
$$-J_{22}(x) = \frac{\partial Q(x)}{\partial|V|}$$

The elements of $-J_{11}$, $-J_{12}$, J_{21}, $-J_{22}$ are

$\frac{\partial Pi(x)}{\partial\delta k}, \frac{\partial Pi(x)}{\partial|Vk|}, \frac{\partial Qi(x)}{\partial\delta k}, \frac{\partial Qi(x)}{\partial|Vk|},$

Where i = 2... n; k = 2... n.

From equation (1) and (2), we have

$$\frac{\partial Pi(x)}{\partial\delta k} = -|Vi||Vk||Yik|\sin(\theta ik+\delta k-\delta i) \quad (i=k$$
$$= \sum_{\substack{k=1\\k\neq i}}^{n}|Vi||Vk||Yik|\sin(\theta ik+\delta k-\delta i)\ (i=k) \quad (7)$$

$$\frac{\partial Pi(x)}{\partial|Vk|} = |Vi||Yik|\cos(\theta ik+\delta k-\delta i)(i\neq k) \quad (8)$$
$$= 2|Vi||Yii|cos\theta ii + \sum_{\substack{k=1\\k\neq i}}^{n}|Vk||Yik|\cos(\theta ik+\delta k-\delta i(i=k)$$

$$\frac{\partial Qi(x)}{\partial\delta k} = |Vi||Vk||Yik|\sin(\theta ik+\delta k-\delta i)\ (i\neq k)$$
$$= \sum_{\substack{k=1\\k\neq i}}^{n}|Vi||Vk||Yik|\cos(\theta ik+\delta k-\delta i)\ (i=k \quad (9)$$

$$\frac{\partial Qi(x)}{\partial |Vk|} = |Vi||Yik| \sin(\theta ik + \delta k - \delta i) \ \ (i \neq k)$$

$$= 2|Vi||Yii| sin\theta ii + \sum_{\substack{k=1 \\ k\neq i}}^{n} |Vk||Yik| \sin(\theta ik + \delta k - \delta i) \ \ (i=k) \qquad (10)$$

An important observation can be made with respect to the elements of Jacobian matrix. If there is no connection between ith and kth bus, then Yik =0. The process continues until a stopping condition is met.

B. Transient stability analysis

Transient stability studies deals with the effect of large, sudden disturbances such as effect of large sudden outage of line, occurrence of fault, or the sudden application or removal of loads. To ensure that a system can with stand the transient condition following a disturbance, transient stability analysis should be performed.

Steps for transient stability analysis in POWER WORLD SIMULATOR:

Step 1: An IEEE- 9 bus system is taken. System model is implemented and executed in power world simulator and load flow is performed. The load flow analysis of 9 bus system is done with the help of Newton Raphson method.

Step 2: After load flow, the initial parameters of the system e.g. bus voltages, bus frequency, bus power angles, generator power angles are studied.

Step 3: A three-phase balanced fault is applied on transmission line with different clearing times and the results are taken in Power World Simulator using Runga and Euler method.

Step 4: Comparison of results taken in step 3 by both methods is done and it is computed that which method is best suited for transient stability analysis.

Step 5: Study of impact of load switching on IEEE 9 bus model in Power World Simulator.

C. Standard Parameters

TABLE I: LINE PARAMETERS OF 9 BUS SYSTEM

Line	Resistance (PU)	Reactance (PU)	Susceptence (PU)
1-4	0.0000	0.0576	0.0000
4-5	0.0170	0.0920	0.1580
5-6	0.0390	0.1700	0.3580
3-6	0.0000	0.0586	0.0000
6-7	0.0119	0.1008	0.2090
7-8	0.0085	0.0720	0.1490
8-2	0.0000	0.0625	0.0000
8-9	0.0320	0.1610	0.3060
9-4	0.0100	0.0850	0.1760

TABLE II: MACHINE DATA OF 9 BUS SYSTEMS

Parameters	M/C 1	M/C 2	M/C 3
H(sec)	23.64	6.4	3.01
Xd(PU)	0.146	0.8958	1.3125
X'd(PU)	0.0608	0.1198	0.1813
Xq(PU)	0.0969	0.8645	1.2578
X'q(PU)	0.0969	0.1969	0.25
T'd0(PU)	8.96	6.0	5.89
T'q0(PU)	0.31	0.535	0.6

TABLE III: EXCITER DATA OF 9 BUS SYSTEMS

Parameters	Exciter 1	Exciter 2	Exciter 3
K_A	20	20	20
T_A(sec)	0.2	0.2	0.2
K_E	1.0	1.0	1.0
T_E(sec)	0.314	0.314	0.314
K_F	0.063	0.063	0.063
T_F(sec)	0.35	0.35	0.35

III. RESULTS AND DISCUSSION

The load flow analysis and transient stability for the standard IEEE-9 bus system are performed. The standard IEEE 9 bus system consists of 9 buses, 3 generators, 3 loads and 3 transformers. Table IV & V shows load flow analysis carried out using Newton-Raphson method. Table VI shows the comparison between Runga and Euler method when three-phase balanced fault is applied on transmission line between bus 5 and 7. Graph I depicts variations between Runga and Euler method.

TABLE IV: POWER FLOW LIST OF SIMULATED MODEL USING NEWTON RAPHSON METHOD

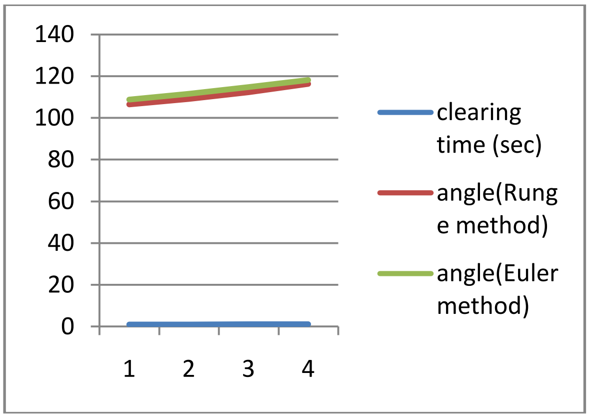
From Bus	**To Bus**	**Branch Device Type**	**MW From**	**Mvar From**	**MVA From**	**MW Loss**	**Mvar Loss**
4	1	Transformer	-72	-24.8	75.8	0	3.15
2	7	Transformer	163	4.9	163	0	15.8
9	3	Transformer	-85	15.6	86.4	0	4.1
5	4	Line	-43	-39.6	58.5	0.3	-16
6	4	Line	-28	-16.9	32.9	0.1	-16
7	5	Line	84.2	-10.1	84.8	2.2	-21
9	6	Line	63.3	-17.8	65.7	1.5	-31
7	8	Line	78.8	-0.8	78.9	0.5	-12
8	9	Line	-22	-23.6	32.1	0.1	-21

TABLE V: BUS DATA OF IEEE 9 BUS MODEL

Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	16.5	1.04	17.16	0			71.63	27.91
2	18	1.03	18.45	9.35			163	4.9
3	13.8	1.03	14.15	5.14			85	-11.45
4	230	1.03	235.8	-2.22				
5	230	1	229.9	-3.68	125	50		
6	230	1.01	232.8	-3.57	90	30		
7	230	1.03	236.2	3.8				
8	230	1.02	234	1.34	100	35		
9	230	1.03	237.5	2.44				

TABLE VI: COMPARISION BETWEEN RUNGA METHOD AND EULER METHOD

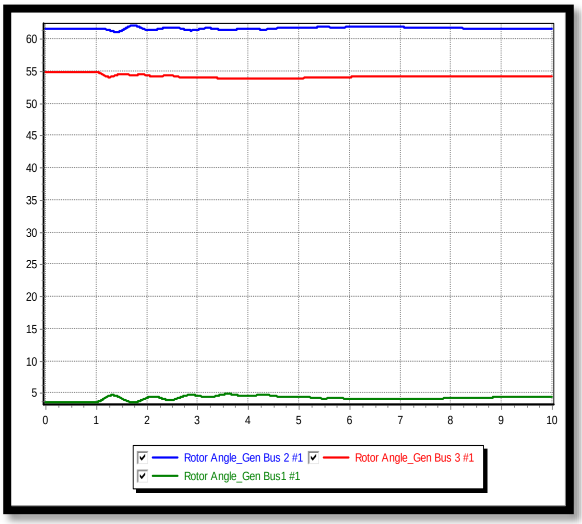
Clearing Time (Sec)	Angle(Runga Method) in Degree	Angle(Euler Method) in Degree
1.033	106.487	108.685
1.05	109.063	111.448
1.066	112.238	114.76
1.083	116.237	118.17



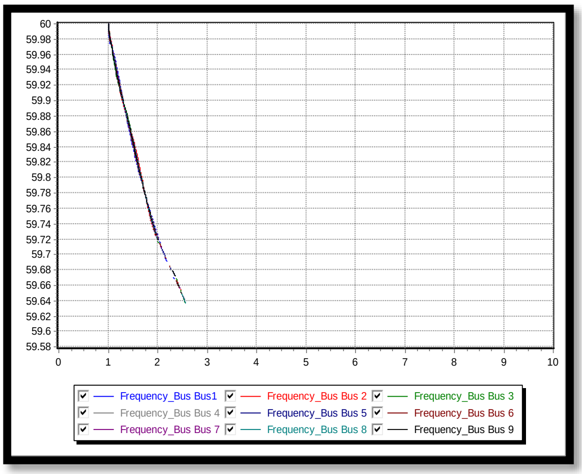
Graph I: variations between Runga and Euler method.

Firstly, we cleared fault after 1.033 sec and maximum angle difference between is 106.487deg (Runga Method) and 108.685deg (by Euler method). If we compare both methods Runga method gives fast response as compared to Euler method. The max difference between the angle is 108.685 deg and system is stable after some time when cleared after 1.033 sec, but when we increase the critical clearing time, the difference between angle is also increases, this means system is going towards un- stability mode .If we take more time to clear the fault, system will go out of synchronism, so our critical clearing time should be very low to keep the system in synchronism.

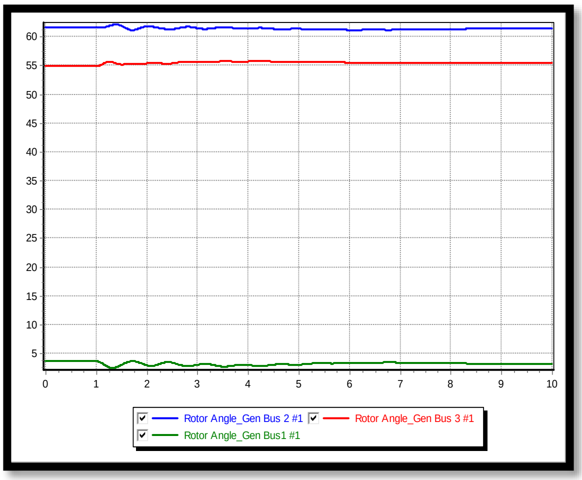
Graph II & III shows variations in power angle and frequency of system when load is increased by 50% at bus 5 respectively. Graph IV & V shows variations in power angle and frequency of system when load is decreased by 50% at bus 5 respectively.



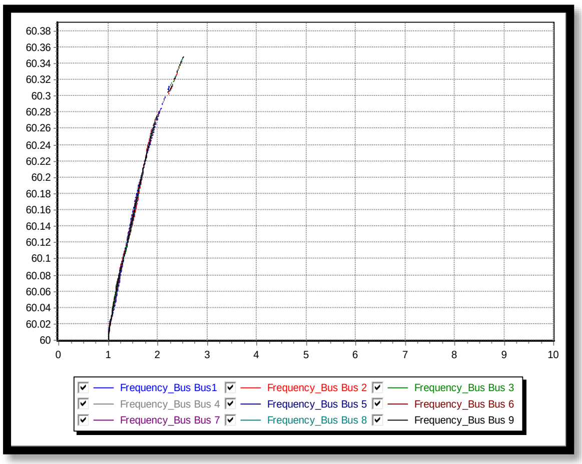
Graph II: Power angle v/s time when load is increased by 50%



Graph III: Bus frequency v/s time when load is increased by 50%



Graph VI: Power angle v/s time when load is decreased by 50%



Graph V: Bus frequency v/s time when load is decreased by 50%

In IEEE 9 BUS MODEL, when sudden load is increased by 50%, the power angle curves become unstable and frequency of system suddenly decreases as shown in graph II & III while when sudden load is increased by 50%, the power angle curves become unstable and frequency of system suddenly decreases as shown in graph IV & V.

IV. CONCLUSION

It is concluded that Power system should have very low critical clearing time to operate the relays, if we isolate the faulty section within very short time, thus system can obtain the stability otherwise it will go out of synchronism. In this research work, load flow studies are performed to analyse the transient stability of system. The behaviour of three phase balanced fault and impact of load switching is also investigated. Thus the protection system provided for the system should have fast response. According to this analysis, fast fault clearing and load shedding methodologies can be adopted for system stability.

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