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Analysis Transient Stability and short circuit of IEEE 9 Bus System by Power World Simulator

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Abstract: Transient stability is typically regarded as a vital aspect of electrical power system design and development. Investigating and understanding the power system's stability was the goal of this investigation. This study used the power world simulator to model and analyze transient stability on the IEEE-9 bus system. Furthermore, load flow investigations were conducted using the Newton-Raphson Method to ascertain the system's pre-fault state. Changes in the system's power angle and frequency were examined using a three-phase balanced fault. A dependable indicator for identifying power system flaws is frequency. In order to bring the system back to stability, an examination of the three-phase balanced fault's quick fault clearing time was also carried out. As a result, the system's protection mechanism ought to react quickly. This analysis suggests that load shedding and quick fault clearing techniques can be used to improve system stability.

Keywords: Transient stability, three-phase balanced faults, IEEE-9 bus system, short circuit, Power World Simulator.

1. Introduction

In the field of electrical engineering nowadays, maintaining the integrity and stability of power systems becomes crucial. Maintaining stability and balance becomes increasingly difficult as these systems evolve and become more complicated. Due to sudden changes in load, operational transitions, and unanticipated malfunctions, these systems experience a variety of disturbances, underscoring the urgent need to restore stability and balance after such disruptions [1][2]. Electrical systems are said to be stable if they can maintain synchronization during normal operating conditions and then regain this balance after disruptions. There are three main types of system stability: dynamic stability, transient stability, and static stability [1][3]. The transient stability of systems, also known as temporary stability, is the main subject of this study. It describes the system's capacity to maintain synchronization during disruptions that occur before regulating devices take effect. To ascertain whether stability is jeopardized during this primary phase, transient stability is analyzed within a brief timescale equal to the initial system oscillation [1]. The initial state of the system as well as its status throughout the disturbance are critical factors in transient stability. Initial swing instability, which is caused by non-periodic fluctuations brought on by insufficient synchronizing torque, is the outcome of these disturbances, which change the way the system operates and leave it in a post-disturbance state different from its initial configuration [4]. In electrical systems, transient stability analysis is the study of how these systems behave and remain stable when subjected to brief (transient) disruptions. An essential component in assessing the performance and stability of electrical power networks is this analysis [5]. A system's Critical Clearing Time (CCT) is the longest period of time it can withstand shocks without becoming unstable [6]. The algebraic/differential equations are solved using a methodical calculation process employing time domain simulation because transient stability is quite nonlinear. Newton Raphson's second technique can also be used to determine stability using the direct method[7]. Electrical currents and voltages fluctuate as a result of the system's equilibrium being upset by electrical disturbances such as breakdowns or variations in load. Understanding how the system responds to these disruptions and its capacity to quickly return to stability and balance is the goal of transient stability analysis.[5]. The pre-fault voltage magnitude must be known in order to perform transient stability analysis. Important details in the power flow research include the generator bus power flow, the power flow and losses in the transmission line, the bus voltage magnitude, the bus voltage phase angle, etc. [8]. The Newton-Raphson approach or the rapid de-coupled method can be used to extract pre-fault conditions from load flow. The reserve bus selection has no bearing on convergence in the Newton-Raphson approach. All unknown parameters are first estimated using this procedure [9]. The electrical power system is nearly interconnected in our day and age, so faults might happen and high-rate currents need to be interrupted before normal circumstances can be established. Both symmetrical and unsymmetrical flaws can occur in a variety of forms. The Three-phase or symmetrical faults are the most serious failures that cause the most disruption in network accessories [10].

Fault is an undesirable and unexpected circumstance that results in equipment failure, which affects costs in addition to stressing the network. Blocking the excessive current flow is essential before causing any damage to any equipment. An undesirable circumstance that increases the network's stress level is called a fault in a distribution network. A very high current flow is the result of a malfunction, and it must be stopped before it destroys any network segments [10]. One computer application that focuses on examining and modeling electric power systems is called Power World Simulator. With the help of Power World Simulator, electrical engineers may build intricate models of electrical power systems and examine how they behave under various scenarios. The tool allows for the simulation of network operation, pregnancy distribution analysis, dynamic stability testing, and operating effects study. Drawing the system's electrical circuits and determining various physical characteristics, including voltage, current, and other pertinent data, are made possible by Power World Simulator's user-friendly graphical interface. [11]

This work's investigation of the IEEE-9 bus system model's transient stability is its main goal, which the Power World Simulator technology was used to emulate. Transient stability refers to the system's capacity to maintain synchronization throughout the disruption and before the governors have a chance to take action. One swing's duration is the brief time frame within which the transient stability study is conducted. The purpose of this study is to determine whether or not the system becomes unstable during the initial swing. IEEE-9 bus power systems in both normal and abnormal operating conditions are used to test the proposed work.

This paper's succeeding sections are organized as follows: A power flow analysis is described in Section 2. Methods employed in Section 3 to use the IEEE-9 bus system model to analyze transient stability and short circuit. Results from the IEEE-9 bus system model and simulation are presented and discussed in Section 4. The results are shown in Section 5.

2. A Power Flow Studies

A recognition of the pre-fault voltage magnitude is necessary for transient stability studies. The generator bus power flow, transmission line power flow and losses, bus voltage magnitude, bus phase angle, and other important data are all included in the power flow analysis [8]. Newton Raphson or rapid decoupled methods can be used to obtain pre-fault circumstances based on load flow analysis [9].

2.1 Fast Decoupled Method

In order to solve power flow-related difficulties, this approach is thought to be quick and effective. This approach is essentially a continuation of the Newton-Raphson method. Stott and

Alsac initially introduced this technique in 1974[12-14]. This method quickly became the most often used approach in power flow problems because it is based on the Newton-Raphson method, which makes computations much simpler and yields solid answers with fast convergence. This method yields quick algorithms for power problems by using polar coordinates and a few approximations. But occasionally, non-convergence is also the result of using specific approximations. Examples include situations where low voltages occur at certain busses and situations where resistance-to-reactance ratios are high. When approximations cause the solutions to not converge cleanly, one must make certain assumptions in order to simplify the Jacobian matrix [15].

2.2 Newton-Raphson Method

This approach is named for Sir Isaac Newton and Raphson, who developed it. This approach uses an iterative process. This technique uses Taylor series to approximate nonlinear simultaneous equations into linear ones. But only the first order approximations of the Taylor series are enlarged.

When compared to similar techniques, this numerical method's strong convergence properties make it popular for power flow calculations.

shows up at some buses. In certain situations, one must make certain assumptions in order to simplify the Jacobian matrix because the solutions do not converge cleanly due to approximations [15]. Conditions before the fault can be derived from load flow analysis utilizing the rapid decoupled approach or Newton-Raphson method. The reserve bus selection has no effect on convergence in the Newton-Raphson approach. This approach begins by making an initial estimate for each unknown parameter [9].

It depends on establishing Taylor Series equations for power balance problems, which are essentially linear approximations to these equations. When working with a complex network, this is crucial. With the exception of the slack bus, it first concentrates on PQ buses, enabling actual and reactive power to be functions of angles and voltage [16].

First, the presence of a load bus and a distant PQ bus is investigated. In reference to the i_{th} bus:

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

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

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

$$|V| = \;(|V1|, \ldots., |Vn\,|^{T}\,)\delta = (\delta 1, \ldots., \delta n)^{T} \qquad (3)$$

$$Pi\;(|V|) = \;Pi(x) \qquad (4)$$

$$Qi\;(|V|) = Qi(x) \qquad (5)$$

$$x \;=\; \left[\frac{\delta}{|V|}\right] \qquad (6)$$

Assume that the load buses' scheduled powers are Pi and Qi. Using Newton Raphson's second technique, x should gravitate to that value during iteration, creating stability [11].

$$\frac{\partial Pi\,(x)}{\partial \delta k} = -\,|Vi|\,|Vk||\,Yik|\,\sin\sin\,(\theta ik\;+\delta k - \delta i\,), (i \neq k\,) \qquad (7)$$

$$\frac{\partial Pi\,(x)}{\partial \delta k} = \sum_{k=1\;k\neq i}^{n} \quad |Vi||Vk||Yik|\,\sin\sin\,(\theta ik + \delta k - \delta i)\,, (i = k) \quad (8)$$

$$\frac{\partial Pi\,(x)}{\partial |V_K|} = |Vi||Vk|\,\cos\,|Yik|\cos\,(\theta ik + \delta k - \delta i)\;\;, (i \neq k) \qquad (9)$$

$$\frac{\partial Pi\,(x)}{\partial |V_K|} = 2|Vi|\,cos\,|Yik| cos\,\theta ii\ + \sum_{k=1\ k\neq i}^{n} \quad |Vk||Yik| cos\,(\theta ik + \delta k - \delta i), (i = k) \quad (10)$$

$$\frac{\partial Qi\,(x)}{\partial \delta k} = |Vi||Vk||Yik|\,sin\,sin\,(\theta ik + \delta k - \delta i), (i \neq k) \quad (11)$$

$$\frac{\partial Qi\,(x)}{\partial \delta k} = \sum_{k=1\ k\neq i}^{n} \quad |Vi||Vk||Yik|\,cos\,cos\,(\theta ik + \delta k - \delta i)\ (i = k) \quad (12)$$

$$\frac{\partial Qi\,(x)}{\partial |V_K|} = |Vi||Yik|\,sin\,sin\,(\theta ik + \delta k - \delta i)\ (i \neq k) \quad (13)$$

$$\frac{\partial Qi\,(x)}{\partial |V_K|} = 2|Vi|\,sin\,|Yik| sin\,\theta ii\ + \sum_{k=1\ k\neq i}^{n} \quad |Vk||Yik| sin\,(\theta ik + \delta k - \delta i), (i = k) \quad (14)$$

3. METHODOLOGY

The Power World Simulator program was used for this investigation. The standard is used to conduct the load flow and short circuit studies initially.

The outcomes are documented for the IEEE 9-Bus system. Using the Newton-Raphson iterative approach, the software has assessed the load flow. The two studies described above are then carried out once again after one generator has been taken out of the test system. After being recorded, the outcomes of these studies on this new system are compared to those derived from the conventional system.

3.1 Test System Specifications.

Comprising nine buses connected by transmission lines, an analysis and research tool for power systems is the IEEE 9 bus system. It is an eliminated model of a power distribution network and is frequently used to investigate a number of power system topics, encompassing load flow analysis, fault classification and detection, the impact of incorporating renewable energy, system stability analysis, and power flow optimization [15]. IEEE 9Bus Circuit: The IEEE 9 bus circuit is a famous model in the field of electric power systems, consisting of Nine buses, three generators, three loads, and three transformers make up the typical IEEE 9 bus system, as shown in figure (1)[11].

Furthermore, the IEEE-9 bus system's standard parameters for each bus are shown in table (1), followed by table (2). Provide the IEEE-9 Bus System's line information.

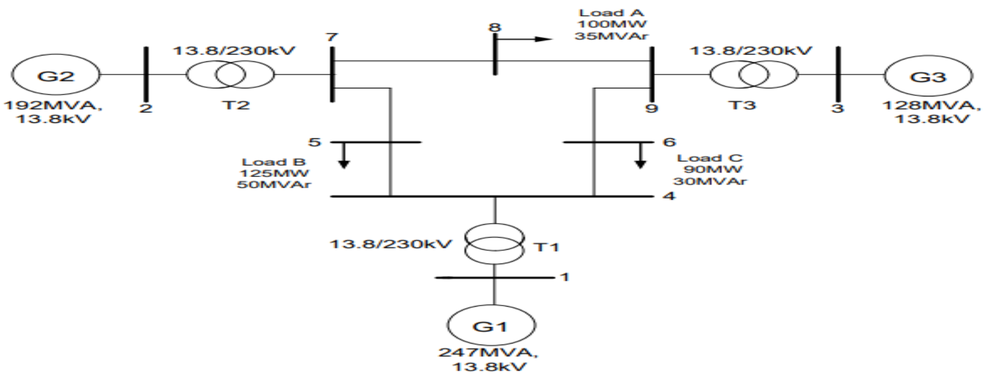

Fig. 1 Single line diagram of IEEE-9 bus test system.

Table1. Data for each bus of IEEE-9 Bus System.

NO	Type	V(p.u)	V (kv)	Angle (Degree)
1	Slack	1.04	16.5	0.0
2	PV	1.025	18.0	9.3
3	PV	1.025	13.8	4.7

4	PQ	1	230	2.2
5	PQ	1	230	4.0
6	PQ	1	230	-3.7
7	PQ	1	230	3.7
8	PQ	1	230	0.7
9	PQ	1	230	2.0

Table 2. Line data of IEEE-9 Bus System

From	To	R(p.u)	X(p.u)	B(p.u)
1	4	0	0.0576	0
4	5	0.01	0.085	0.176
4	6	0.017	0.092	0.158
6	9	0.039	0.17	0.358
5	7	0.032	0.161	0.306
9	3	0	0.0586	0
7	2	0	0.0625	0
9	8	0.0119	0.1008	0.209
7	8	0.0085	0.072	0.149

The study of transient stability examines the impact of significant, abrupt disruptions, such as a large-scale cable outage, a fault, or the abrupt load removal or application. The purpose of transient stability analysis is to make sure that a system can withstand the transient state that follows a disturbance. In Power World Simulator, follow these steps for transient stability analysis:

Step One: an IEEE-9 bus system is chosen. The power world simulator implements and runs the system model, and load flow is carried out. The Newton Raphson approach aids in the load flow analysis of a nine-bus system.

Step Two: Following load flow, the system's initial parameters, such as bus voltages, bus frequencies, bus power angles, and generator power angles, are examined.

Step Three: Using the Newton-Raphson Method, a three-phase balanced fault is delivered to a transmission line at different buses, and tests the increased and decreased load in bus 5 and 6 and test outage the generator the outcomes are displayed in Power World Simulator.

Step Four: Use Power World Simulator to investigate how load switching affects the IEEE 9 bus model. The transient stability analysis is carried out for a short time

4. RESULTS AND DISCUSSION

The system model has been loaded and it simulated by used Power World Simulator software ware to generate the output results as well as the load flow analysis using the Newton Raphson technique at different as following:

Case 1: Before the fault

1. Load flows

The load flow analysis and transient stability for the standard IEEE, Bus system are performed as indicated in Table (3).

Table 3 Outcomes of the IEEE 9 Bus system's fault-free load flow analysis

Sr. No	Bus No	Area	Nom (kV)	p.u. (kV)	Volt (kV)	Angel (Deg)	Load (MW)	Load (Mvar)	Gen (MW)	Gen (Mvar)
1	BUS1	1	16.50	1.040	17.160	0.00	0	0	71.6	27.91
2	BUS2	1	18.00	1.025	18.450	9.35	0	0	163.00	4.90

3	BUS3	1	13.80	1.025	14.145	5.14	0	0	85.00	-11.45
4	BUS4	1	230.00	1.025	227.01	-2.22	0	0	0	0
5	BUS5	1	230.00	0.999	220.25	-3.68	125.00	50.00	0	0
6	BUS6	1	230.00	1.012	224.36	-3.57	90.00	30.00	0	0
7	BUS7	1	230.00	1.026	229.12	3.80	0	0	0	0
8	BUS8	1	230.00	1.017	226.70	13.4	100.00	35.00	0	0
9	BUS9	1	230.00	1.032	230.78	2.44	0	0	0	0

2. The Power flows

For examining these needs, the power flow is the fundamental instrument. The voltage magnitude and angle at each bus in a power system operating in a balanced three-phase steady-state condition are determined by the power flow. As seen in Table (4), it also calculates the actual and reactive power flows for every piece of equipment that connects the buses.

Table .4 Outcomes of Fault-Free Power Flow Analysis

From Bus	To Bus	Branch Device Type	MW from Bus	Mvar from Bus	MVA from
8	9	Line	-24.01	-0.4	34.2
6	4	Line	-30.56	-13.69	33.5
7	8	Line	76.5	-0.25	76.5
9	6	Line	-59.45	-16.31	61.6
5	4	Line	-40.96	-35.71	54.3
7	5	Line	86.51	-2.54	86.5
4	1	Transformer	71.96	24.8	75.8
2	7	Transformer	-163	2.28	163
9	3	Transformer	85.01	-3.65	85.01

Case 2: Three phase short circuit balanced fault

In the overall scheme of electrical systems, transient stability analysis is the study of how these systems behave and remain stable when subjected to brief (transient) disruptions.

1. Fault between bus 4 and bus 5 at 1.0 s

The transmission line between buses 5 and 4 experienced a three-phase short circuit balanced fault at 1.0 seconds, which was resolved at 1.1 second. All three generators' rotor angles are displayed in figure 2. Additionally, Figure 3 shows the frequencies of the three generators.

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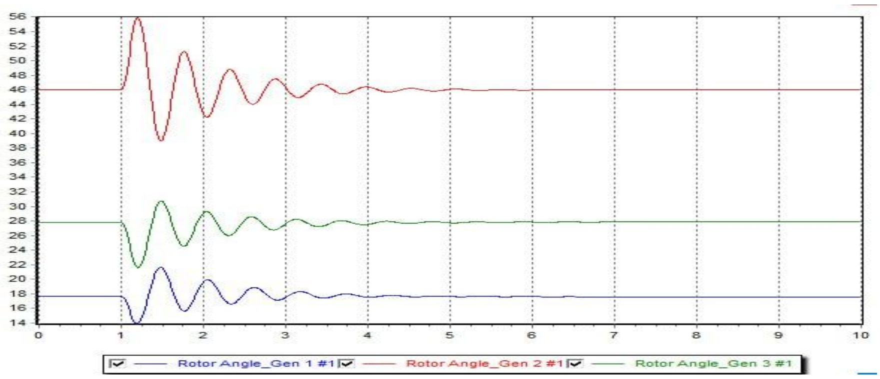

Fig.2: The rotor angles of three generators for a three-phase short circuit balanced fault between buses 4 and 5 at 1.0 seconds during the transmission line.

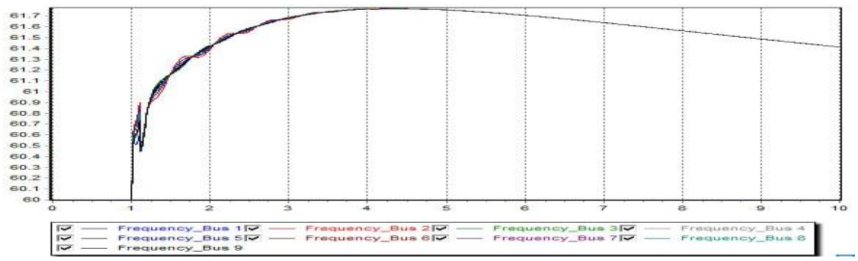

Fig.3: bus frequencies between buses 4 and 5 for the three-phase short circuit balanced fault on transmission lines at 1.0 second

Case 3: Increased load on buses

Here, at 1.0 s, bus 5 increases load 1 by 50% while bus 6 increases load 2 by 50%. Explain the effects of this load adjustment.

1. Increased load1 50% on bus 5 at 1.0s

In addition, bus 5's load is instantly reduced at 1.1 seconds after being raised by 50% at 1.0 seconds. Figure 4 displays the rotor angles of the three impacted generators. The system stabilizes after a while. Figure 5 displays the system's frequency response at each bus. Changes in the frequency of the linked system are also brought on by abrupt variations in load at bus 5. It rises as a result of unexpected loading and falls as an outcome of the system's heavy load at bus 5. Thus, the three generators on bus 5 will have their rotor speeds altered by the change in load 1 on bus 5, as shown in figure 6.

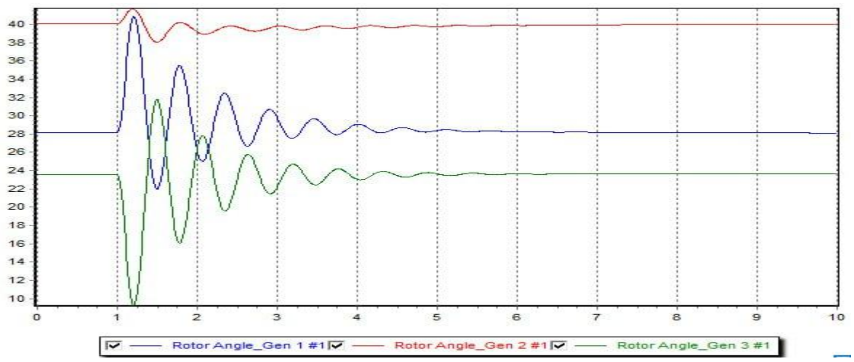

Fig.4: Three generators' rotor angles for an abrupt 50% load rise on bus 5 at 1 second

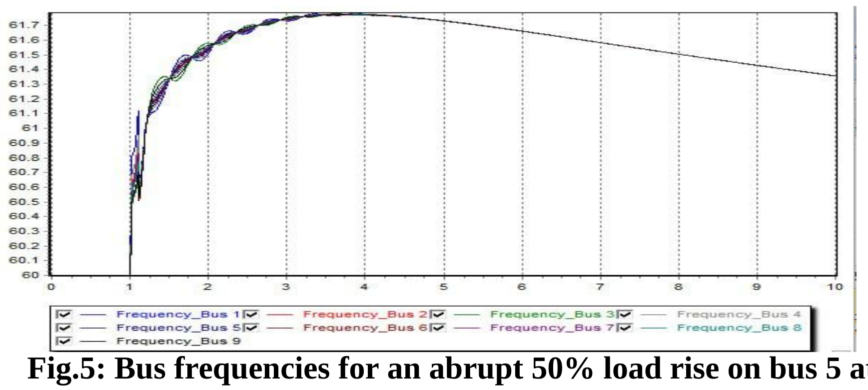

Fig.5: Bus frequencies for an abrupt 50% load rise on bus 5 at 1 second

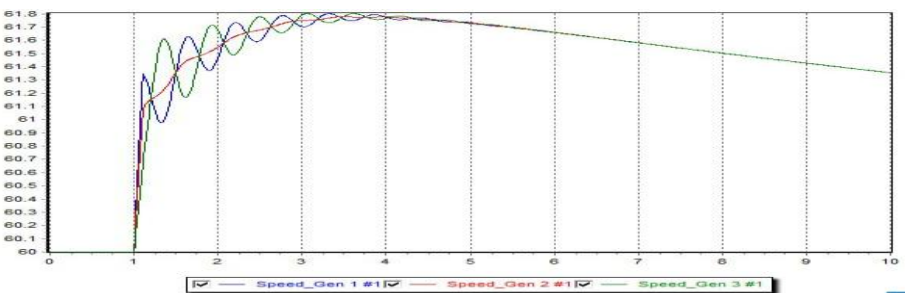

Fig. 6: Three generators' rotor speed for an abrupt 50% load rise on bus 5 at 1 second

2. Increased load2 50% on bus6 at 1.0s

This causes bus 6's load to spike by 50% at 1.0 seconds and then be instantly removed at 1.1 seconds. Figure 7 displays the three impacted generators' rotor angles. After a while, the system stabilizes. The response to frequency of the whole system at each bus is shown in figure 8. The frequency of the linked system varies as a result of the sudden changes in load at bus 5. When bus 6 is overloaded, the system's performance deteriorates, while unexpected loading causes it to grow. and the three generators on bus 6 will have their rotor speeds altered by the change in load 2 on bus 6, as illustrated in figure 9.

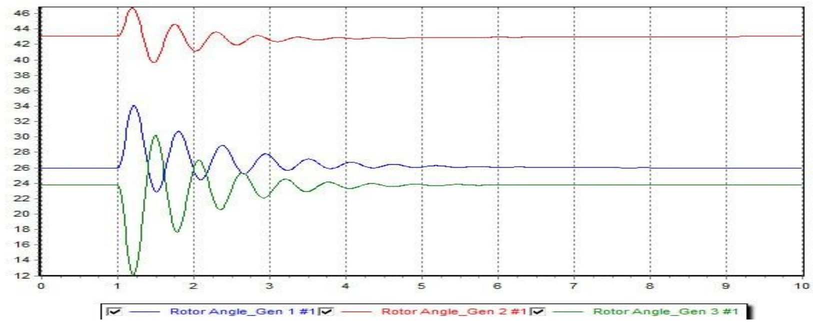

Fig.7: Three generators' rotor angles for a 50% load rise on bus 6 at 1 second

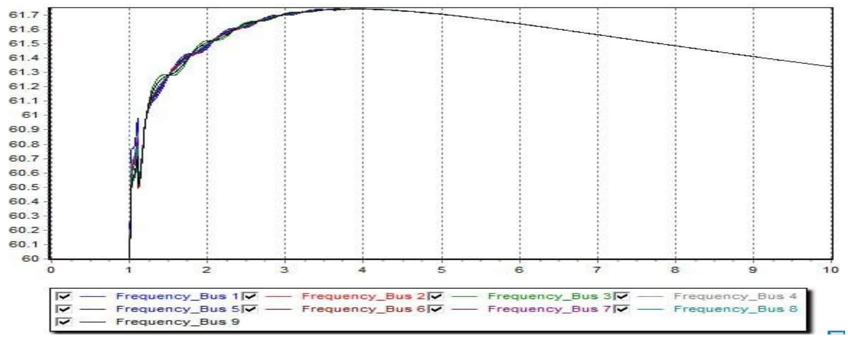

Fig.8: Bus frequencies for an abrupt 50% load rise on bus 6 at 1 second

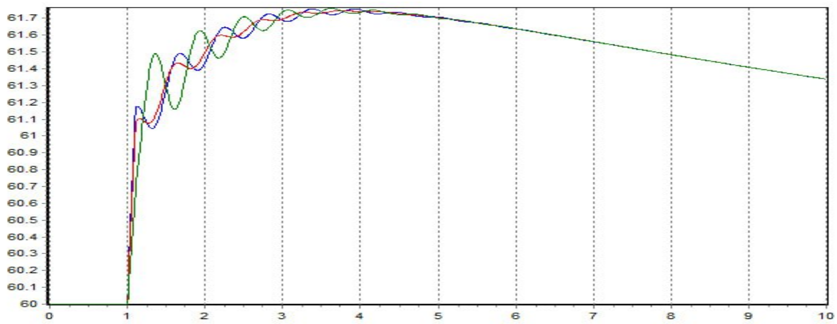

Fig. 9: Three generators' rotor speed for an abrupt 50% load rise on bus 6 at 1 second

Case 4: Decreased load on buses

In this case, load1 is decreased by 50% on bus 5 and load 2 by 50% on bus 6 at 1.0 s. Describe the impact of this load adjustment.

Although all three generators have a rotor angle divergence, the system eventually stabilizes. The angle difference, however, likewise rises as the CCT time does. This indicates that the system is operating in an unstable state. The CCT needs to be incredibly short to maintain system synchronization because if it takes longer to resolve the problem, the system will lose synchronization [17].

1. Decreased load1 50% on bus 5 at 1.0s

In Figure 10, the system buses' frequency response is displayed. Additionally, the unexpected load change at bus 5 causes a change in the frequency of the connected system. Figure 11 shows how the three generators' rotor angles changed when the load on bus 5 dropped by 50% at one second. Moreover, figure 12 illustrates the impact of an abrupt 50% drop in bus 5's load at a single minute in speed for the three generators' rotors.

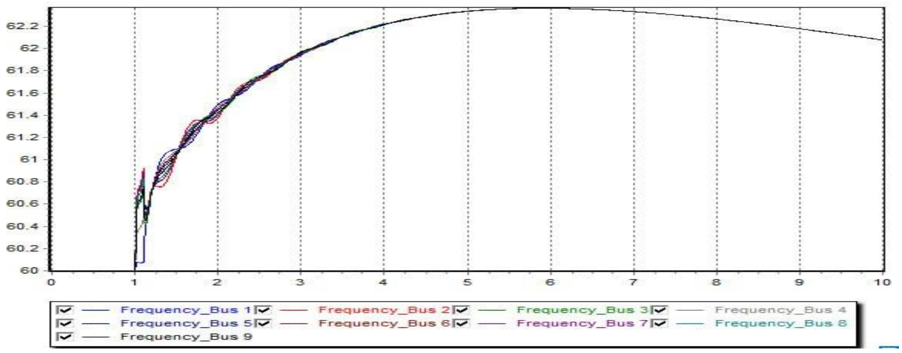

Fig.10: Bus frequencies for an abrupt 50% load decrease on bus 5 at 1 second

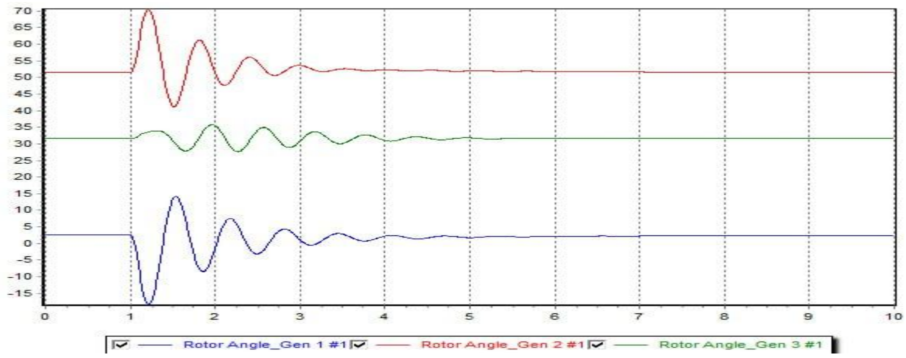

Fig.11: Three generators' rotor angles for a 50% load decrease on bus 5 at 1 second

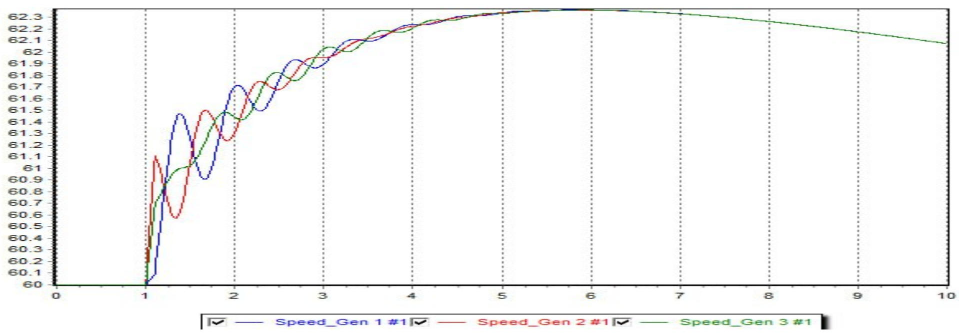

Fig. 12: Three generators' rotor speed for an abrupt 50% load decrease on bus 5 at 1 second

2. Decreased load2 50% on bus 6 at 1s

Figure 13 displays the system buses' frequency response. The sudden decrease in load at bus 5 also causes a change in the frequency of the connected system. Figure 14 shows the three generators' rotor angle changes for a 50% drop in bus 6 load at 1 second. Additionally, figure 15 illustrates the impact of a sudden 50% drop in bus 6's load at a single speed shift for the three generators' rotors.

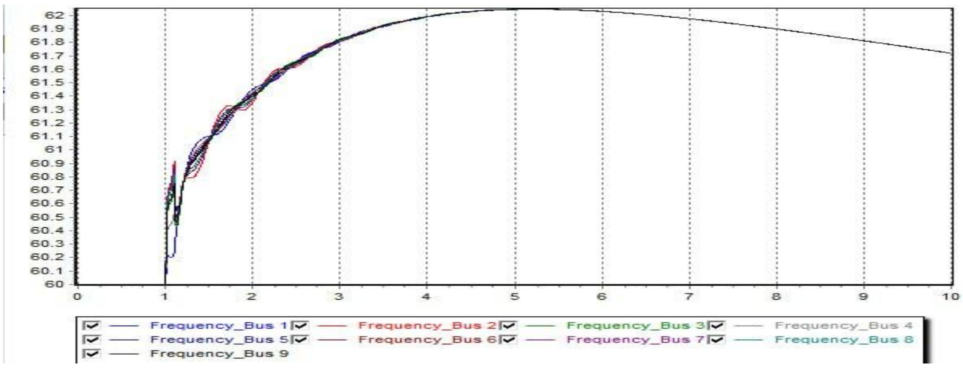

Fig.13: Bus frequencies for an abrupt 50% load decrease on bus 6 at 1 second

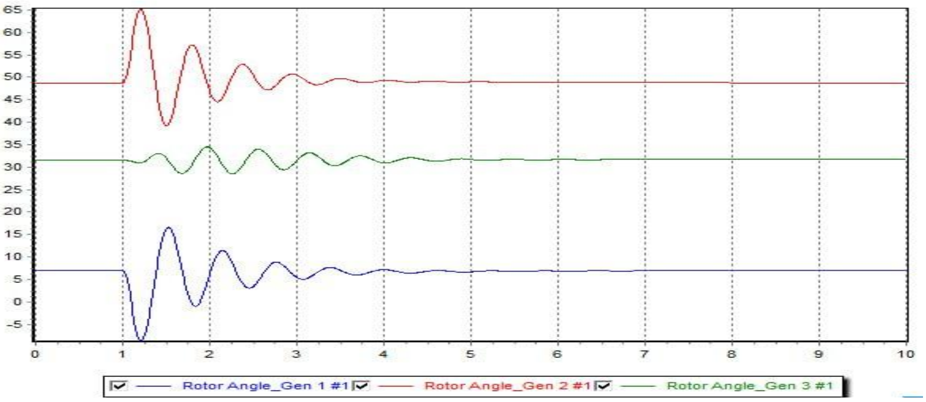

Fig.14: Three generators' rotor angles for a 50% load decrease on bus 6 at 1 second

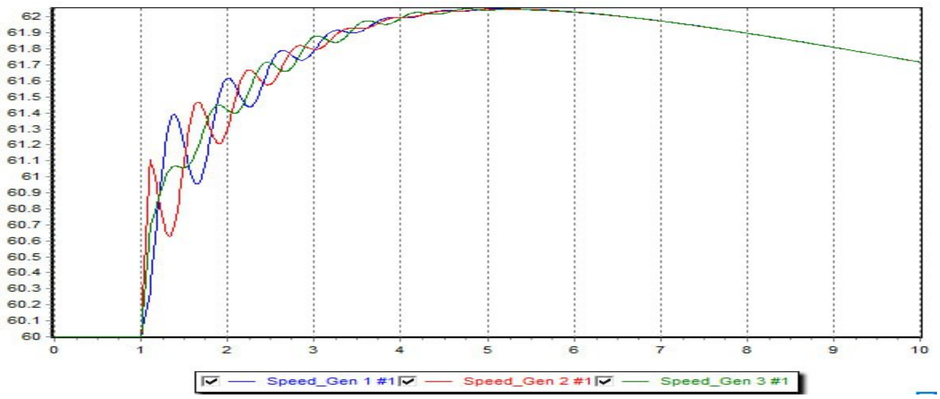

Fig. 15: Three generators' rotor speed for an abrupt 50% load decrease on bus 6 at 1 second

Case 5: Outage of generator

Figure 16 shows the rotor angles of the generators when generator 1 is not in use for 1.0 seconds. Because of the system outage, generator 1 does not have any rotor angle fluctuation, but generators 2 and 3 do. Figure 17 illustrates how changes in the frequency of the associated system are also brought on by the generator1 outage. Because the system has less generation as a result of the outage, the frequency of the system drops. Because bus 5 is no longer loaded due to a fault, the system's frequency rises as a result of less system loading.

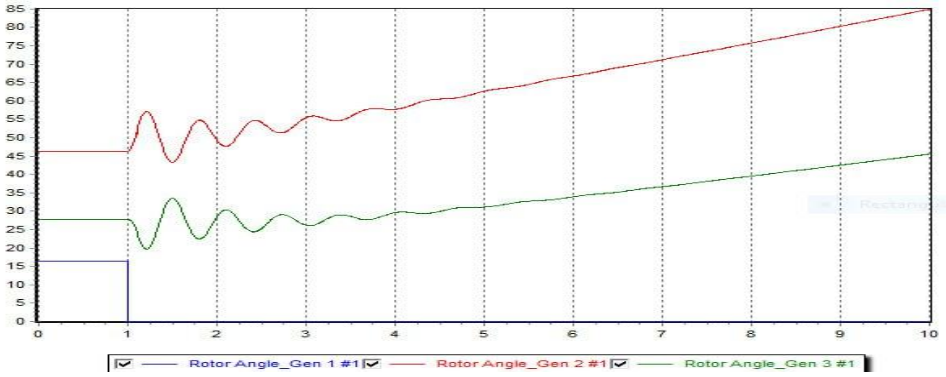

Fig.16: Three generators' rotor angles during a single generator outage 1 second

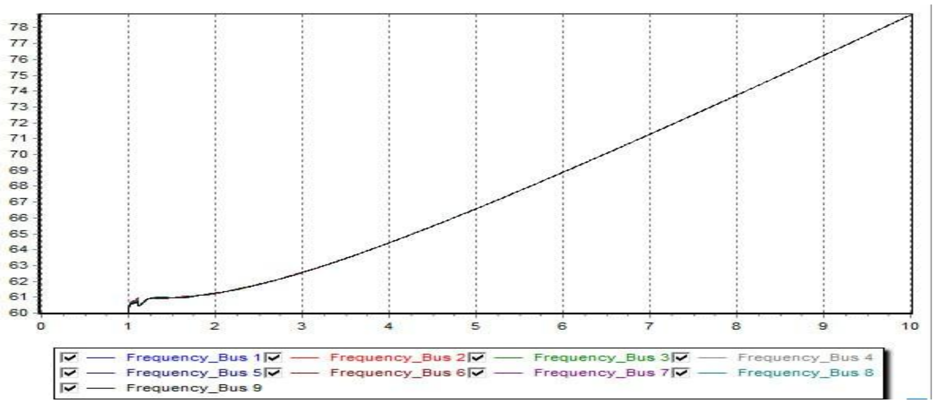

Fig.17: Bus frequencies during a 1.0 second generator1 outage

5. Conclusion

Considering generators 2 and 3 are closer to the problem point than generator 1, it can be concluded that their rotor angle deviation is the greatest. The system stabilizes after a period of time. A higher critical clearing time result in a greater angle difference. The system is in an unstable status as a result. If it takes longer to fix the issue, the system will be out of sync; hence, the CCT needs to be very tiny to keep the system in sync. Due to a transmission line problem between buses, the associated system's frequency also fluctuates. 4. and.5. As the load at bus 5 is eliminated owing to a malfunction, the system experiences less loading, which results in a rise in frequency.

Furthermore, graphs in the IEEE 9 bus architecture show that the power angle curves are not stable and the system's frequency suddenly decreases when the unexpected load is increased by 50%. Otherwise, all three generators exhibit a rotor angle deviation; however, the system eventually stabilizes. However, the angle difference likewise lengthens when the CCT duration is increased. This shows that there is instability in the system's operation. To maintain system synchronization, the CCT must be reasonably short since if more time is required to resolve the problem, the sudden change in the load on buses 5 and 6 would also cause the system to get out of sync.

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