TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
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DEPARTMENT OF ELECTRICAL ENGINEERING

A
FINAL YEAR PROJECT REPORT
ON

TRANSIENT STABILITY ANALYSIS OFAN INTERCONNECTED ELECTRICAL POWER SYSTEM

(Submitted to the Department of Electrical Engineering as a partial fulfillment of the requirement for the bachelor in electrical engineering)

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The undersigned certify that they have read, and recommend to the Institute of Engineering for acceptance, a project entitled **“’TRANSIENT STABILITY ANALYSIS OF PV INTEGRATED INTERCONNECTED ELECTRICAL POWER SYSTEM’** submitted by Deepak Poudyal and Raushan Kumar Jha in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering.

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ABSTRACT

Since solar power systems are connected to the grid using technologies other than those used by traditional power systems, the increased penetration of solar energy into the traditional power grid may modify certain of its transitory features. Particularly, the increased use of non-synchronous generators has an impact on the Critical Clearing Time (CCT), which is crucial for protective system performance during turbulent periods. In a typical IEEE 9 bus test system, this work examines the transient stability analysis of a power system and the effects of photovoltaic (PV) penetration on it. The simulation software ETAP is used to prepare the Simulink model for the transient stability of the IEEE 9 bus test system. The study takes into account three-phase faults, and several simulations are used to examine the stability of the rotor angle. Critical clearing time is used to compare the transient stability in various scenarios, such as with and without PV in the system, and is used as an index to examine the transient stability analysis of the IEEE 9 bus test system for base case. It has been discovered that transient stability depends on the fault's duration, position, and power. While it has improved in some places, the integration of PV into the system has decreased the transient stability of the power supply at important spots.

Table of Contents

LIST OF FIGURES

CHAPTER ONE : INTRODUCTION

1.1 Background

The ability of a power system to maintain synchronism under brief disturbances such a short circuit,vi transmission line failures, generator outages, etc. is known as transient stability. The stability of the rotor angle is mostly related to transient stability .Transient Stability Analysis (TSA) of the power system aids in understanding the behavior of rotor angle deviation during severe shocks . Large disturbances may cause the generators to lose synchronism and cause a system-wide blackout if they are not removed within a set amount of time. Critical Clearing Time (CCT) is a term used to describe the maximum amount of time that a fault should be cleared in order to ensure the stability of the system. When a fault is fixed within a predetermined CCT, the power system is regarded as stable. The CCT's value varies on a number of variables, including the generator's size, inertia, dispatch, line impedances, network structure, fault location, etc. The weather also affects the transient stability of the multi-machine system in addition to these factors . The environment is on the verge of irreversible climate change as a result of the rising use of fossil fuels in recent years . By 2020–2025, a renewable source must account for 15–30% of all power sales, according to the Renewables Portfolio Standards (RPS). A significant field of research is being focused on photovoltaic systems as a result of the growing penetration of renewable energy sources, particularly photovoltaic power. Additionally, based on historical statistics, the demand for PV has grown by 20% to 25% annually over the last 20 years due to the expansion of grid-connected applications. However, switching from traditional synchronous to non-synchronous generators may result in a number of problems, including voltage fluctuations, a lack of reactive power, and a loss of inertia, which ultimately endanger the stability and dependability of the entire network. Non-synchronous generators' short-circuit current characteristics have been found to differ significantly from those of synchronous generators .

There is a lot of research on how photovoltaics affect the grid investigated the effects of substituting a PV system for conventional generating units on voltage stability, whereas , investigated the effects on transient stability. Transient stability is typically assessed 3 to 5 seconds after a disturbance, with CCT being the most often used indication of transient stability as in . It was also preferred to undertake a more effective analysis in multi-machine systems for transient stability using rotor angle differences vs. time variation based on technique . After incorporating PV, certain buses have disruptions that lead to significant oscillation . The impact of PV is significantly determined by the location of the fault . By solving differential algebraic equations (DAE) based on straightforward assumptions, time-domain simulations have historically been used to examine the transient stability of multi-machine systems . Transient analysis is also carried out using a reference plane known as the center of inertia (COI) .

In [14], transfer conductance was taken into account in order to quickly approximate the rotor angle and angular velocities. The most crucial procedures, according to a comparison of the performance of the Lyapunov and Equal Area Criterion (EAC) approaches, appear to be the matrix reduction methodology and time domain simulation . Using the Prony analysis tool in DIgSILENT Power Factory , the transient analysis with high solar-PV generation was conducted while keeping the steady-state system parameters constant.

In order to evaluate the system's transient stability, the IEEE 9 bus test system is modelled in the ETAP software in this work. Three-phase faults are applied at various locations during simulation and cleared after a brief period of time. After applying the fault, rotor angle variations are seen, and CCT is calculated using them.

1.2 Problem statement

During sudden large disturbances such as short circuit on a transmission line, loss of a generator, loss of a load, gain of load or loss of a portion of the transmission network ,the rotor angle swings and cause rotor angle instability .If the fault is cleared below the critical time then the system itself regain its stability itself .So it is very difficult to calculate the critical clearing time of fault manually .

Also the intermittent nature of PV generation, combined with the complex dynamics of interconnected systems, introduces uncertainties and potential stability issues that need to be thoroughly investigated and mitigated.

1.3 Objective

The main objective of project are as follows:

1. To analyze the behavior of the synchronous machine in particular the angular position of the rotor with respect to time after the fault occurs

   in the system and calculate the critical clearing time using simulation software ETAP
2. To find the level of pv integration on the grid so that the existing system remains stable with the same circuit breaker of fault clearing time .

1.4. Scopes and limitation of the project

The proposed system has some scopes and limitations:

1. Scopes

- Dynamic Behavior Analysis: Examining the transient response of the system during disturbances, such as faults, sudden load changes, or grid events. This involves analyzing voltage and frequency stability, rotor angle stability, and power flow dynamics.
- Control Strategy Evaluation: Assessing the performance and effectiveness of control strategies implemented in PV inverters, synchronous generators, and other control devices for transient stability enhancement.
- PV Generation Variability: Investigating the impact of PV generation variability and its interaction with the overall system dynamics. This includes studying the effects of solar irradiance changes, cloud cover, and PV output fluctuations on transient stability.
- Integration Challenges: Addressing the challenges associated with integrating PV generation into interconnected systems. This includes analyzing the coordination between PV systems and conventional synchronous generators, power electronic converters, and protection systems.

2.Limitations

- Simplified Modeling: Due to the complexity of interconnected systems, certain simplifications may be necessary in the dynamic models used for transient stability analysis. These simplifications can introduce some degree of approximation and may not capture all system intricacies accurately.

- Uncertainties in PV Generation: The inherent uncertainties associated with PV generation, such as weather conditions and cloud cover, can pose challenges in accurately predicting the PV output during transient events. These uncertainties may impact the accuracy of the analysis results.

CHAPTER TWO:LITERATURE REVIEW

The ability of a power system to maintain synchronism under brief disturbances such a short circuit, transmission line failures, generator outages, etc. is known as transient stability [1].

The stability of the rotor angle is mostly related to transient stability [2]. Transient Stability Analysis (TSA) of the power system aids in understanding the behavior of rotor angle deviation during severe shocks [1].

Large disturbances may cause the generators to lose synchronism and cause a system-wide blackout if they are not removed within a set amount of time. Critical Clearing Time (CCT) [2] is a term used to describe the maximum amount of time that a fault should be cleared in order to ensure the stability of the system. When a fault is fixed within a predetermined CCT, the power system is regarded as stable. The CCT's value varies on a number of variables, including the generator's size, inertia, dispatch, line impedances, network structure, fault location, etc.

The weather also affects the transient stability of the multi-machine system in addition to these factors [4]. The environment is on the verge of irreversible climate change as a result of the rising use of fossil fuels in recent years [5].

By 2020–2025, a renewable source must account for 15–30% of all power sales, according to the Renewables Portfolio Standards (RPS) [6].

A significant field of research is being focused on photovoltaic systems as a result of the growing penetration of renewable energy sources, particularly photovoltaic power. Additionally, based on historical statistics, the demand for PV has grown by 20% to 25% annually over the last 20 years due to the expansion of grid-connected applications [7].

However, switching from traditional synchronous to non-synchronous generators may result in a number of problems, including voltage fluctuations, a lack of reactive power, and a loss of inertia, which ultimately endanger the stability and dependability of the entire network [8].

Non-synchronous generators' short-circuit current characteristics have been found to differ significantly from those of synchronous generators [9].

There is a lot of research on how photovoltaics affect the grid. [10, 11] investigated the effects of substituting a PV system for conventional generating units on voltage stability, whereas [12, 13, 14, 15] investigated the effects on transient stability. Transient stability is typically assessed 3 to 5 seconds after a disturbance [10], with CCT being the most often used indication of transient stability as in [7, 13, 14].

It was also preferred to undertake a more effective analysis in multi-machine systems for transient stability using rotor angle differences vs. time variation based on technique [15]. After incorporating PV, certain buses have disruptions that lead to significant oscillation [16]. The impact of PV is significantly determined by the location of the fault [10].

By solving differential algebraic equations (DAE) based on straightforward assumptions, timedomain simulations have historically been used to examine the transient stability of multimachine systems [4]. Transient analysis is also carried out using a reference plane known as the center of inertia (COI) [3].

In [14], transfer conductance was taken into account in order to quickly approximate the rotor angle and angular velocities. The most crucial procedures, according to a comparison of the performance of the Lyapunov and Equal Area Criterion (EAC) approaches, appear to be the matrix reduction methodology and time domain simulation [17].

Using the Prony analysis tool in DIgSILENT Power Factory [10], the transient analysis with high solar-PV generation was conducted while keeping the steady-state system parameters constant.

CHAPTER THREE :THEORETICAL BACKGROUND

The process of stability is also applicable to a power system. A power system will have a number of synchronous generators operating in parallel and inter-connected through transmission lines.

- The disturbance on a power system could be : short circuit on a line, sudden loss of a generator, sudden increase or decrease of large load, sudden increase or decrease of small load e.t.c. Power system stability refers to the capability of the system to remain in synchronism on the occurrence of a disturbance.

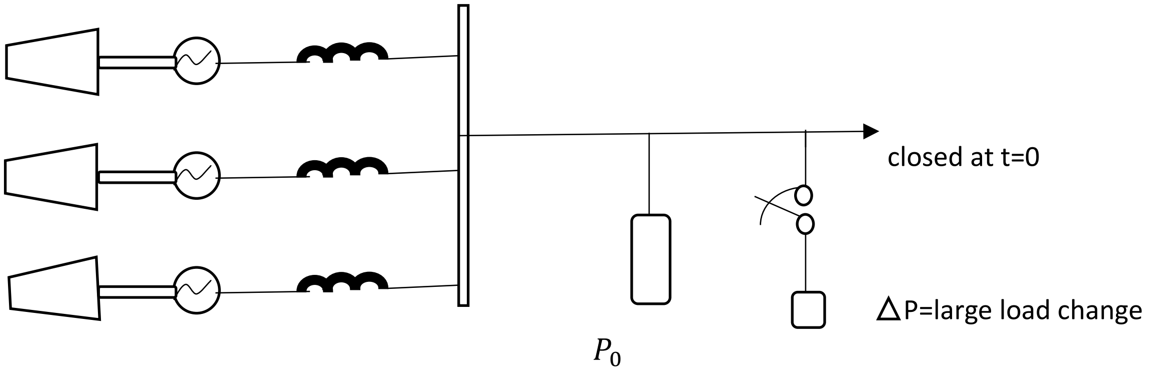


Fig 1 parallel operated generator supplying load

At steady state operation, power generated = power consumed by the load resulting in constant frequency operation. If a large load (ΔP) is switched on at t = 0, there will be a mismatch between power generated and power consumed and speed and frequency of generated voltage decreases.

There will be some oscillations in many parameters of the system.

If the oscillations die out, the system comes back to stable operation. If the oscillation goes on increasing, the system goes to un-stable operation.

In order to generate more power, the speed governor has to come into action to increase the flow of water into turbines. It will take some time for the turbine – generator coupled system to come back to constant frequency operation. Fig.2. shows the typical illustration of oscillation of power angle (δ) and frequency.

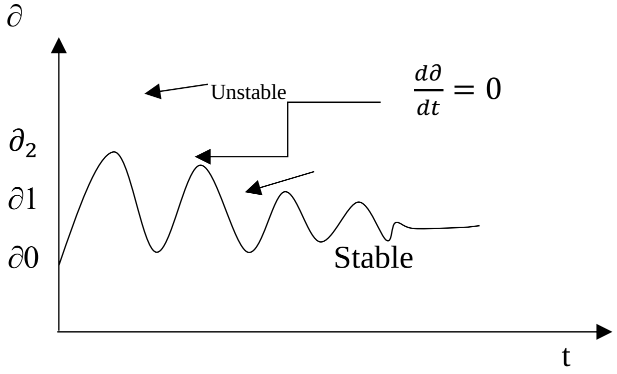
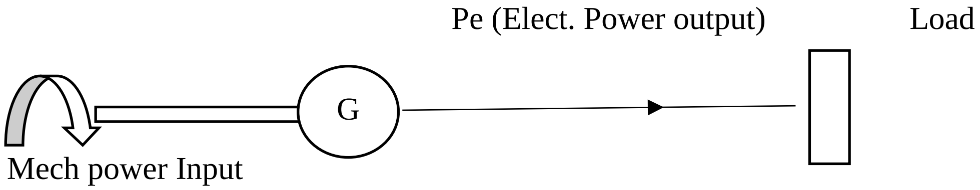


Figure 2. Typical illustration of oscillation of power angle(∂) and frequency

3.1. Rotor-Angle stability (or Frequency stability)



- Input Power = Output Power + Losses in the system (Power balance equation)
- If Input > Output + losses, then the system will accelerate and may become unstable
- If Input < Load demand + losses, then the system will de-accelerate and may become unstable
- If Input = Output + losses, then speed remains constant (i.e. stable)

3.2.Power Angle Curve

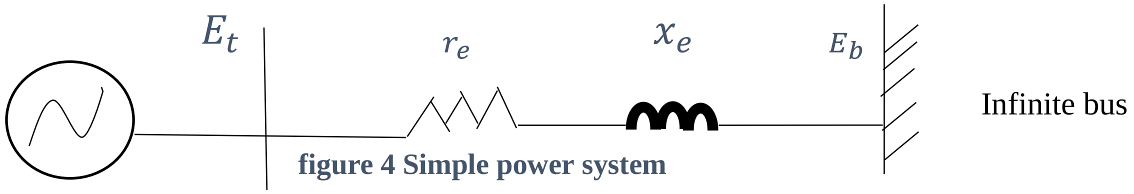


figure 4 Simple power system

Power delivered through the line is given by :

$$P = \frac{|V_s|.|V_r|}{x} \sin \partial \qquad (3.1) \qquad \text{(for transmission line) x}$$

$$P = Pm \sin\partial \qquad (3.2)$$

Equation (3.2) can be plotted as fallow:

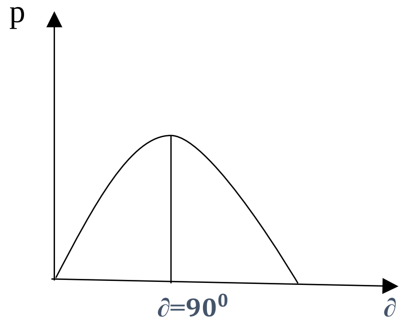


Figure 5 Power angle curve

When δ = 90^0, Power delivered is maximum. But this operating point could be very dangerous from the stability point of view. It may go to unstable operation even under the small disturbance.
It will discuss this issue in more detail later.

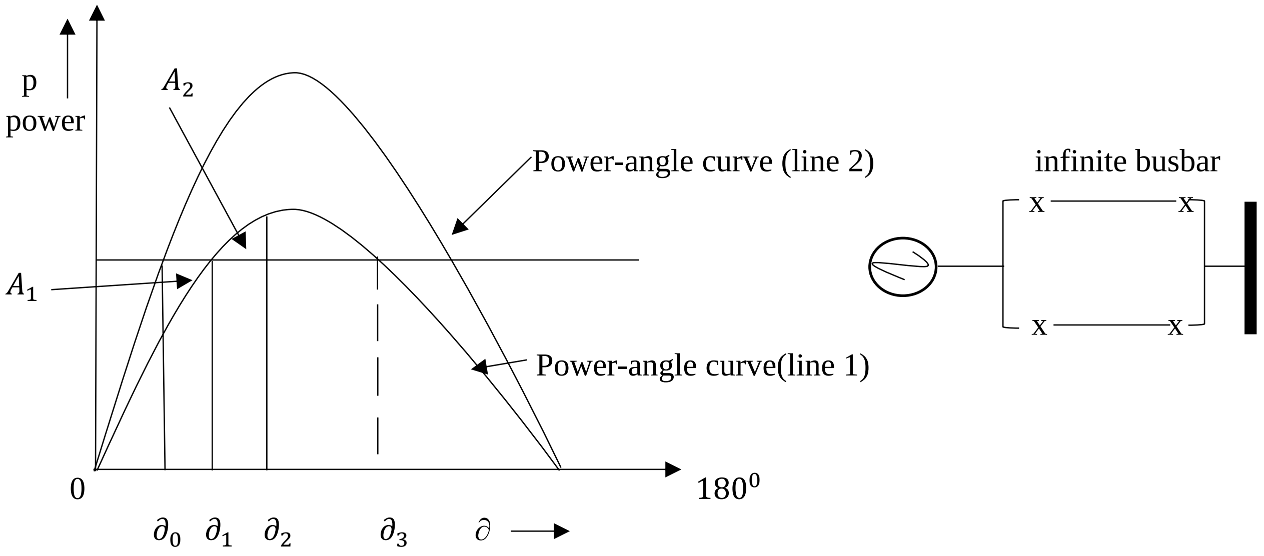


Figure 6 A generator connected to an infinite bus and its power angle curve

Suppose the generator is operating at steady state at power angle δ_0 and delivering a power P_0. If the power delivered to the infinite bus decreases to P_1 which corresponds to the power angle δ_1, then input power to Generator (P_m) > output power $P_{1.}$

Therefore, the rotor angle (δ) of the generator will accelerates say up to δ_2

At δ_2, the input power to Generator (P_m) < output power P_2

This will cause the-acceleration of rotor angle(δ). In this way the system will oscillate around δ_0 becomes stable after some time, provided the system has capability to damp the oscillation

On the other hand , if the generator is operating at steady state at power angle δ_0' and delivering a power P_0 and If the load on the infinite bus decreased to P_1 which corresponds to the power angle δ_1‘, then the input power to Generator (P_m) > output power P_1
Therefore, the rotor angle will further accelerate and can not come back to its original stable position of δ_0'.

Therefore, if the system is operated at a power angle δ > 900, the system will go to unstable operation when a disturbance occurs. Even the system operating at a power angle δ = 900 will have no stability against the disturbance. Therefore, a system always shall be operated at a power angle δ < 900 to have better stability.

3.3. Swing Equation :

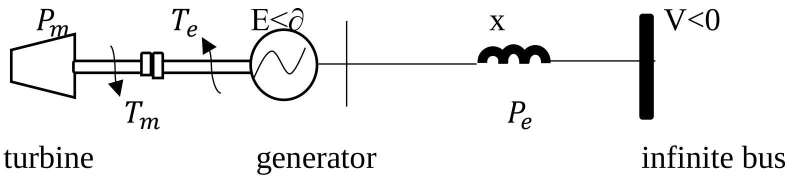


Figure 7 A generator driven by turbine and supplying power to infinite bus

A generator receives mechanical torque (Tm) from the turbine and develops counter electromagnetic torque (Te) which will oppose the input mechanical torque.

The accelerating torque is given by : TA = Tm - Te

If Tm = Te , i.e. TA = 0 , then system will be operating in steady state

If Tm > Te , i.e. TA = Positive , then rotor angle δ accelerates

If Tm < Te , i.e. TA = Negative , then rotor angle δ de-accelerates

When some disturbance occurs on the system, the system will accelerate or de-accelerate depending upon the nature of disturbance and the system undergoes through a transient oscillation. The oscillation of such system is described by a SWING EQUATION :

$$M\frac{d^2\partial}{dt^2} = P_m - P_e \qquad (3.3\}$$

Where,

P_m= Mechanical power input = TS . ωS z

P_e = Electrical power output = TE . ωS

M = Angular Momentum of the rotating system = I. ωS

I = Moment of Inertia of the rotating system ωS = Speed
of the system (rad/sec)

When there is a large disturbance on a power system, the difference (Pm – Pe) will be significantly high. This will cause an oscillation of the system described by eqn (2.3). Suppose the system shown in Fig.2.14 is operating at steady state with a power angle of δ0 and delivering a power P0 as shown in Fig.2.15. If the input power is suddenly increased by a large amount of ΔP (i.e. power increased to P1), the power angle δ can not suddenly increase to δ1 due to heavy mass of the rotor. The rotor will accelerate causing a larger value of power angle. At δ1 input power = output power (possible new stable operating point), but the rotor can not stop accelerating here due to heavy inertia. Let us say that the rotor stops accelerating at δ2. At this point Input power P1 < output power P2. Therefore the rotor again retards back and oscillation will take place around δ1. If the system has capability to come back to stable operation, the system will oscillate around the δ1. The oscillation will die out after some time and becomes stable at new equilibrium position of δ1

If the rotor inertia is very low or the disturbance is very large, the oscillation may swing beyond δm. In such cases Input power > output power again and the rotor accelerates further and further and the system becomes unstable.

3.3 Equal angle criteria

This method is applicable only for a single machine connected to an infinite bus. Fig.2.17 shows a synchronous generator connected to an infinite bus and Fig.2.18 shows its power angle curve.

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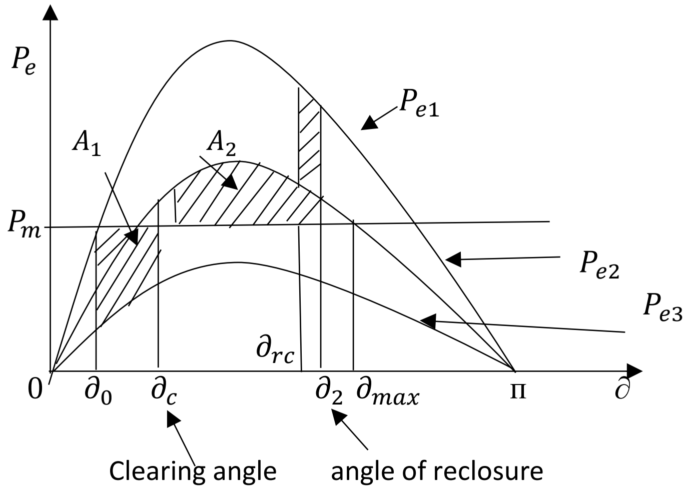


Figure 8 Generator connected to infinite bus and power angle curve

-Suppose that the system is operating under steady state condition at a power angle δ_0 and delivering a power $P_e = P_{e0}$ with mechanical power input $P_{m0} = P_{e0}$.

If the mechanical power input is suddenly increased by a large amount of ΔP, then new mechanical power will be $P_{m(new)}$. In fact this is equivalent to electrical load decreased by ΔP.

Here, Mechanical Input Power ($P_{m(new)}$ becomes > Electrical Output power (P_{e0}) by an amount of ΔP, Therefore, the rotor angle (δ) accelerates and electrical power output increases.

When rotor angle reaches to δ_1 (at t_1),

Input Power ($P_{m(new)}$) becomes = Elect power output again.

In order to make the energy balance during the acceleration period, the excess of energy input during the time interval of t_0 to t_1 will be absorbed by the inertia of the rotor.

The energy stored by the rotor during this period is proportional to the area 'A_1' shown in Fig.2.18.

At δ_1 (at t_1) the accelerating power ΔP becomes zero, but the rotor will not stop accelerating here due to its heavy inertia. The rotor will further swing beyond δ_1.

When the rotor crosses δ_1, Input Power < Output power and rotor starts to retard. During this period, the kinetic energy stored by the rotor will be released to supply the deficit power.

The rotor angle stops to increase at δ_2 and swings back to a lower value of power angle and oscillates around δ_1 and becomes stable at δ_1 after some time. Fig. below shows the swing curve of oscillation of δ with respect to time:
The rotor starts swinging back when all the K.E. stored by the rotor during acceleration period is released during retardation period. Therefore, the rotor starts to swing back from $\delta 2$ when $A2 = A1$. Where $A2$ = area proportional to energy released by the rotor during retardation.

By equating these two areas $A_2 = A_1$, the maximum swing angle δ_2 can be calculated as follows and stability can be checked. This is the **equal area criterion.**

CHAPTER FOUR:METHODOLOGY

4.1.Modelling of IEEE 9 bus system on Etap software

The following assumptions are made in the stability research for the IEEE 9-bus system under consideration: A steady-state network solution is used to calculate synchronous power. Each machine is represented in the network by a constant reactance (direct-axis transient reactance) in series with the constant electromotive force (the internal voltage); (iv) the mechanical angle X(i) of each machine; and (v) the input remains constant throughout the entire period of a swing curve. In the system, there are three states:

1. The initial condition for angles X(i), where i=1, 2, and 3 (equals the number of synchronous machines in the system), is determined by the prefault state.
2. The fault condition that is present at time t=0 and endures until time t=tcr, when the fault is cleared;
3. The critical clearing time (tcr[s]) and fault clearing time (t[s]) are the same.

4.2. Basic Swing Equation for the power system

When performing a stability study, the necessary starting point is to determine the description of the differential equations for the system. For a typical generator system, the mechanical input torque is given by :

$$T_m = J_{am} + T_D + T_e \ldots\ldots..(4.1)$$

where Tm [Nm] is the mechanical energy input at the rotor shaft . J [kg m2] is the combined polar moment of the inertia of the rotor masses , α m [rad/sec2] is the acceleration of the rotor masses, TD [Nm] is the damping torque of the generator squirrel cage winding and Te [Nm] is the torque equivalent of the generator electrical output power. The damping term TD in equation (1) is a very small percentage of Te and thus equation (3.1) is sometimes approximated by

$$T_m = J_{am} + T_e \ldots\ldots\ldots\ldots..(4.2)$$

This equation can be represented in terms of electrical power as

$$\frac{d^2x}{dt^2} = \frac{\text{п}.f}{H(P_m - P_e)} \quad ……….(4.3)$$

Where X is the rotor angle of the machine with respect to the synchronously rotating reference frame in radians and

H=stored kinetic energy at synchronous speed(MJ)/generator rating in MVA 10

f is the system frequency, Pm is the mechanical input power and Pe is the electrical output power which depends on the terminal voltage V, the generator excitation voltage E and the between the two buses. Equation (4.3) can also be written as [4.5]

$$M\frac{d^2x}{dt^2} = (P_m - P_e)…..(4.5)$$

Where M=$\frac{\text{п}.f}{H}$…………(4.6)

Equation (5), sometimes known as "the swing equation," controls the generator voltage angles. It is assumed in this work that the generator's damping is inversely proportional to the generator's own relative speed or slip. It is frequently preferable to incorporate an amount dampening that is not taken into consideration when Pe is calculated individually. In the foregoing equation, a term proportional to the speed deviation is added as shown in [4.7], where dxdt D is the damping constant. Using the equations above, the initial equation (4.1) may be

P_d=D …….(4.7)

written as follows;

$$M\frac{d^2x}{dt^2} = (P_m - P_e - P_d)…..(4.8)$$

The inertia constant (M) for each of the generators in the bus system from the given data in T is evaluated at the synchronous speed and is considered to remain constant and it be calculated as follows [4.8]:

M= $\frac{GH}{S_{base}}$*180f…….. (4.9)

Where M is the inertia constant in p.u, G is the generating station rating, Sbase is the base rating MVA and f is the frequency which is 50Hz.

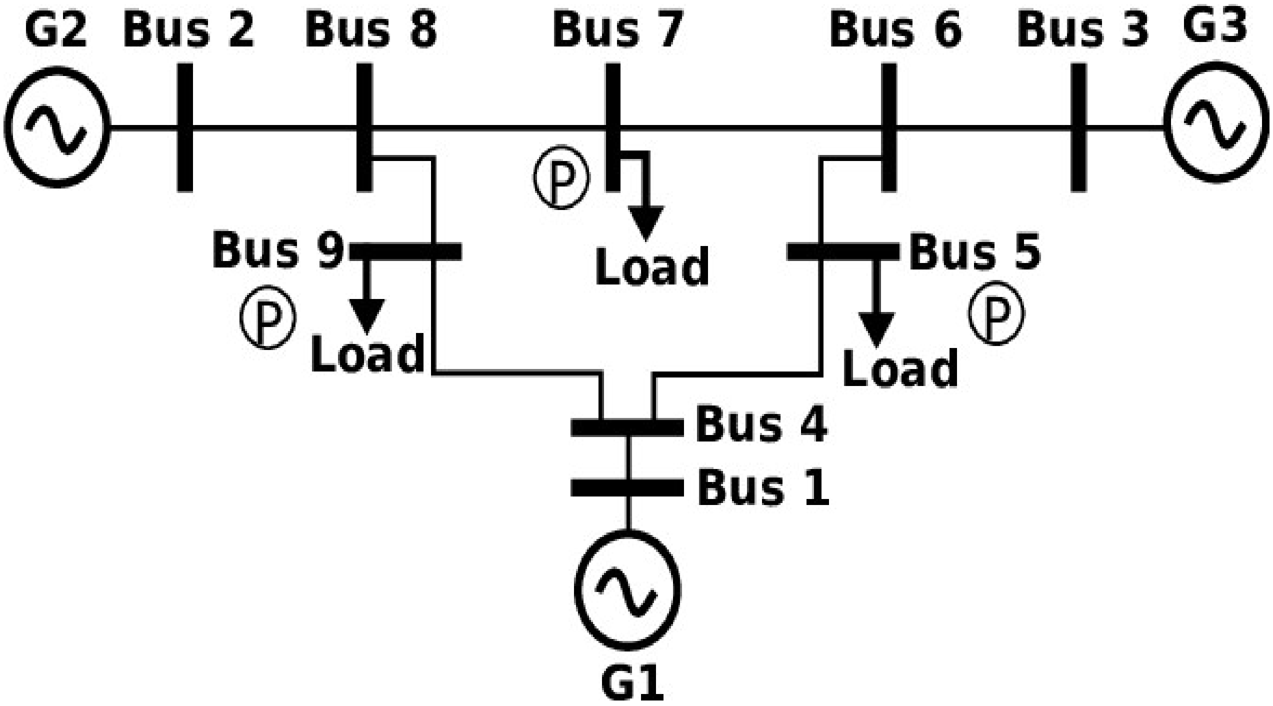


Figure 9: IEEE 9 bus interconnected system

The IEEE 9-bus network is the system under investigation (Figure 9). The transmission of power from one group of synchronous machines to another is the source of this power system's stability issue. The machines in each group swing roughly in unison during disturbances, maintaining their relative angular positions even though they are very different from those of the other group's devices. For analysis, one equivalent machine can be used in place of each group's machine.

Using the Newton-Raphson approach, the system is simplified to get the equivalent bus admittance in order to undertake a stability study on the power system. The connections among the buses, such as those of the shunt, load, and transmission lines, are represented as admittances by the elements of the admittance matrix Y. In the connection matrix Y, the non-diagonal elements are the admittances that, after being multiplied by -1, connect the corresponding buses, and the diagonal elements are the sum of the equivalent load admittances that correspond to the buses and the admittances, as well as the shunt admittances of the lines that are connected to the corresponding buses. Applying the reduction approach as stated below [4.10] yields the internal bus admittance:

Ynn is an n × n matrix where n is the number of generators. Ymm is the m × m matrix where m is the number of buses that are connected to any generator.

$$\begin{bmatrix} \mathrm{Ynn} & \mathrm{Ynm} \\ \mathrm{Ymn} & \mathrm{Ymm} \end{bmatrix} \begin{bmatrix} V \\ E \end{bmatrix} = \begin{bmatrix} 0 \\ I \end{bmatrix} \quad \ldots\ldots.\ \ldots\ldots.. \quad (4.10)$$

$$Y = \begin{bmatrix} \mathrm{Ynn} & \mathrm{Ynm} \\ \mathrm{Ymn} & \mathrm{Ymm} \end{bmatrix} \quad \ldots\ldots\ldots \quad (4.11)$$

I=[I1……..Im] ………. (4.12)

I is the m vector of machine current

V=[V1……….Vm]……………………. (4.13)
V is the n vector of bus currents

E=[E1……….Em]……………………….. (4.14)

Computing synchronous-machines angles and frequency changes trajectories require the solution of the swing equations which may be written as follows:

Mi d2X/dt2 = Pm - Ei2Cii ∑j=nj=1,j≠i Cij Cos[X(i)-X(j)-θij]- DidX(i)\dt… (4.15) where
i = 1, 2,3,4,5 is the number of synchronous machine in the IEEE 14 bus system

Cij=|Ei||Ej||Yij| is the power transferred at bus ij Ei=|Ei|∠|X^e(i)| is the voltage at bus i.

X^e(i) is the transfer reactance angle at bus i.

Yij=|Yij|∠θij are the internal elements of matrix Y. Rii are the real values of the diagonal elements of Y.

According to how they affect the stability of the system, power system faults can be divided into four categories: single line to ground, line to line, double line to ground, and balanced three-phase. The first three categories represent extremely imbalanced situations. In terms of transitory stability, the fourth type of switching action is the most severe, hence this paper will focus on it. Thus, two locations in Fig. 1 are taken into consideration for a three phase fault. As a result, the impact of the distance between the location of the fault and the generating stations as well as the impact of the fault clearing time are both examined.

The steps that being followed when doing the investigation are as follows:

- Following network modeling, initial machine input, initial bus voltages, and initial power output were calculated.
- The internal bus voltage should be computed.
- Compute the prefault system admittance matrix (Yprefault)
- Compute the faulted system admittance matrix (Yfault)
- The line on which the fault occurred should be isolated.
- The post fault system admittance matrix (Ypostfault) should be computed.
- Plot the angular deviation for machines 1-3 for three phase fault at different locations abefore and after the penetration of PV.

CHAPTER FIVE:RESULTS AND DISCUSSION

5.1Simulation on bus 2 system with and without integration of photovoltaic cell

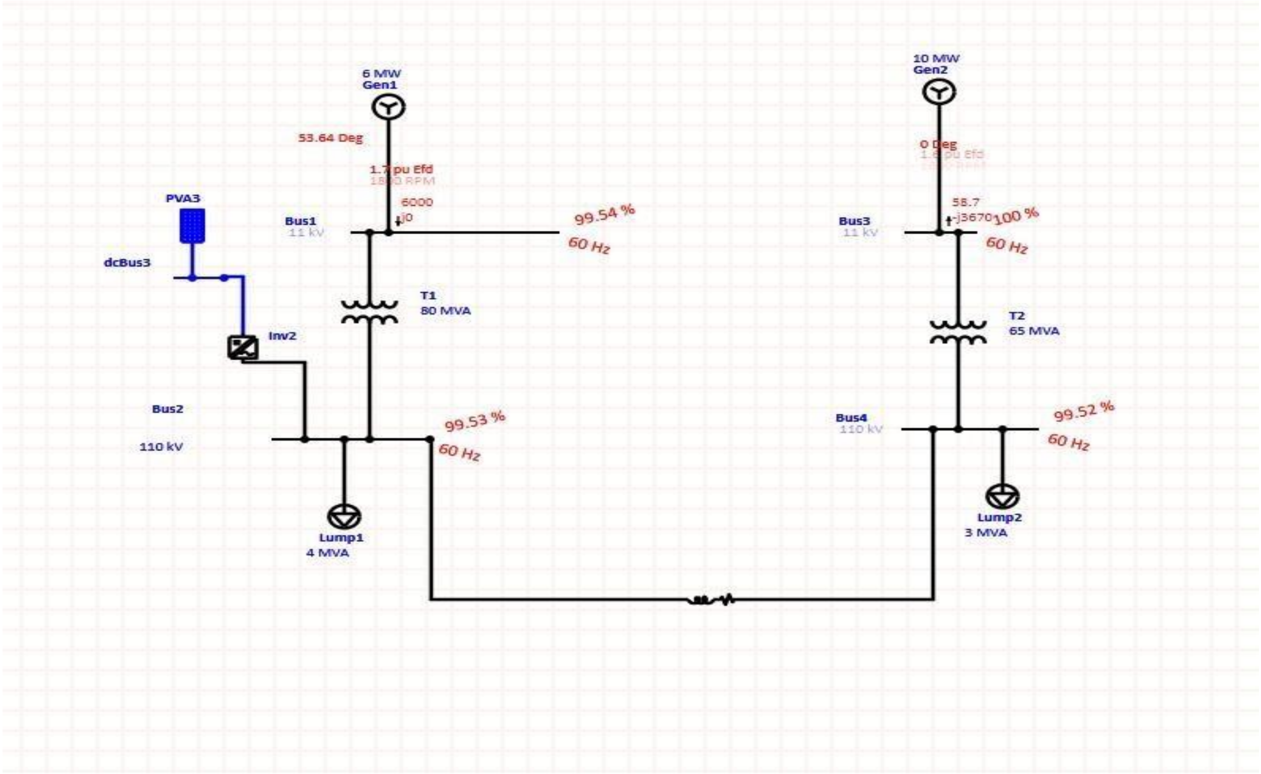


Figure 10. Two bus system

Generator 2 is a slack bus where gen1 is voltage controlled bus .At first study on bus system is done using simulation software Etap .3 phase fault is created at bus 1 and cleared after 0.11 sec and the after certain oscillations of rotor angle it seems to be stable as shown in fig 5.2. When the fault is cleared after 0.12 sec then the system seems to be unstable .It leads to the loss of synchronism as shown in fig 13.Here the critical clearing time is found to be 0.11 sec.

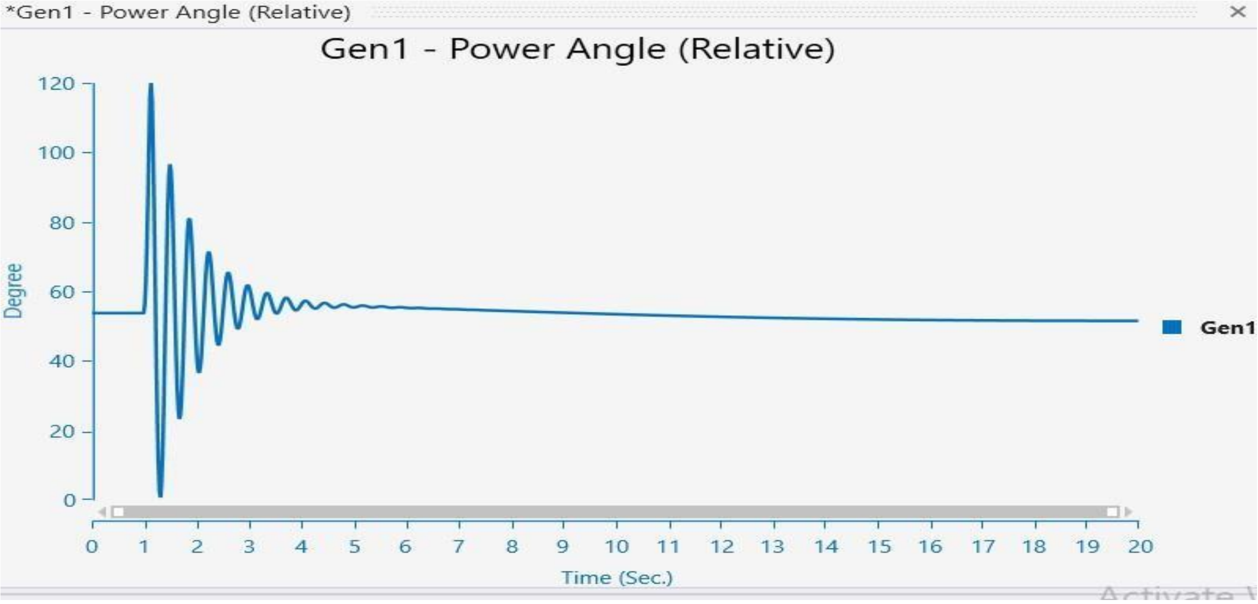


Figure 11 Plot of relative rotor angle vs time when 3 phase fault cleared at bus 2 after 0.11sec

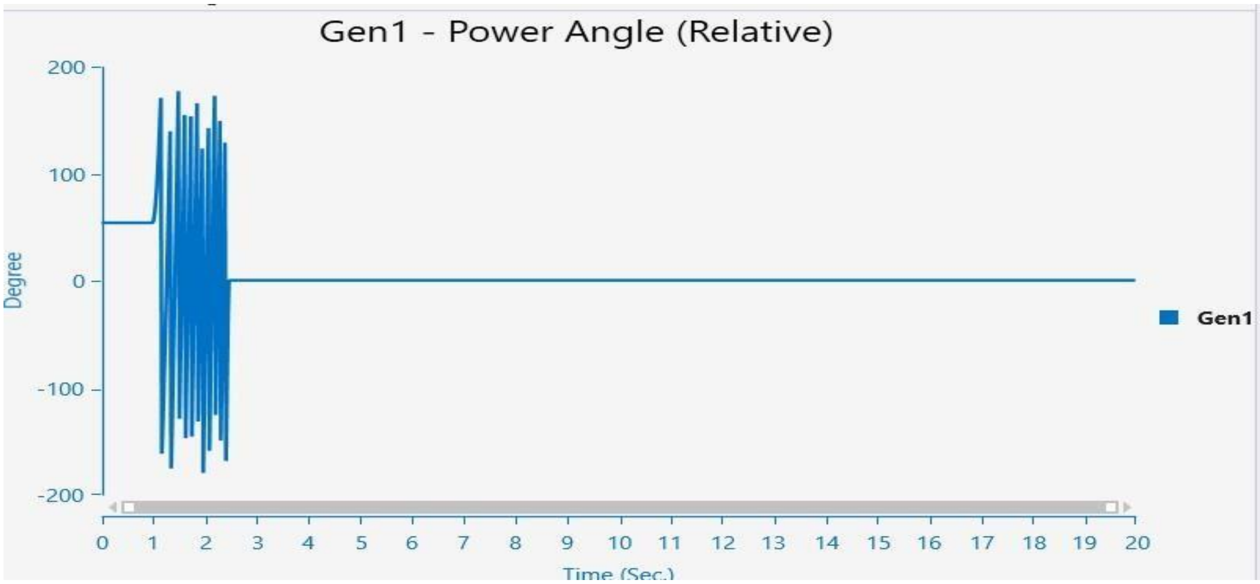


Figure 12 Plot when fault at bus 2 cleared after 0.12 sec

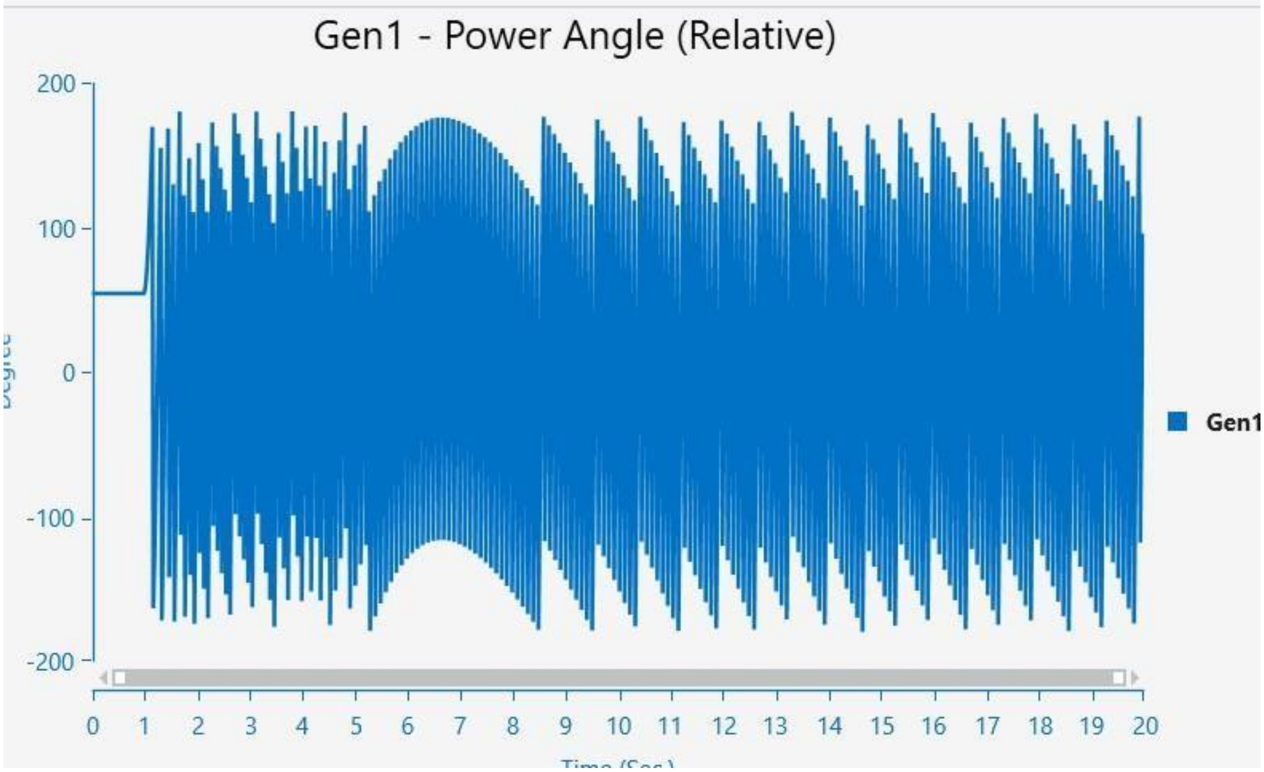


Figure 13 Fault cleared after 0.11 sec when pv of 3 mw is integrated at bus 2

When pv is integrated at bus producing power of 3 mw ,the system looses synchronism even the fault is cleared at 0.11 sec .But with out integration of pv ,the system remains stable even after the fault is cleared at 0.4 sec .We can conclude that after integration of pv to the system ,it makes existing system unstable .

When PV systems are integrated into the grid, they can change the characteristics of the power system, which can affect the CCT. One significant effect is that PV systems can reduce the inertia of the system, which can result in a faster decay of the fault-induced oscillations. As a result, the critical clearing time can be reduced.

5.2Simulation on IEEE 9 bus system on ETAP software

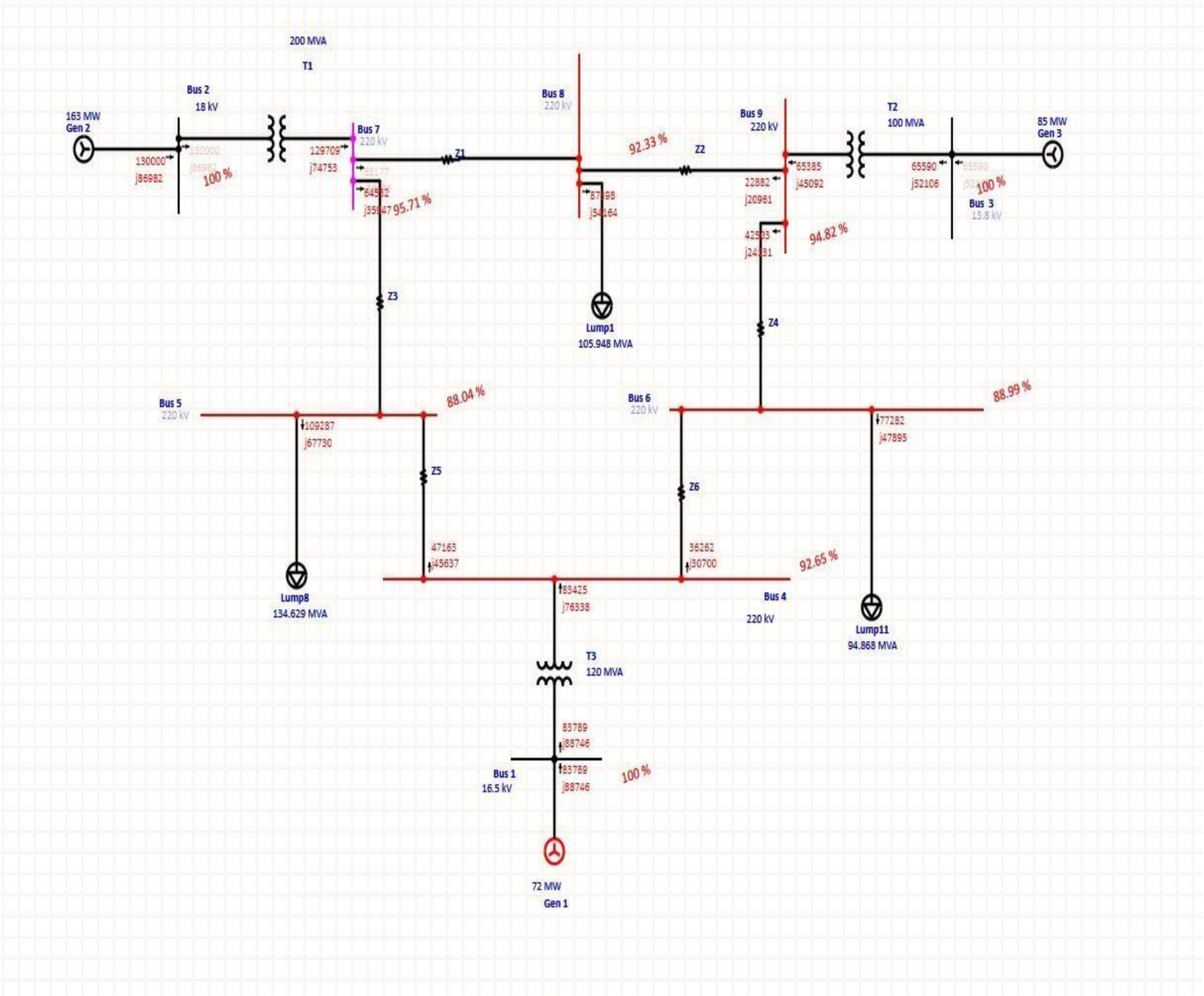
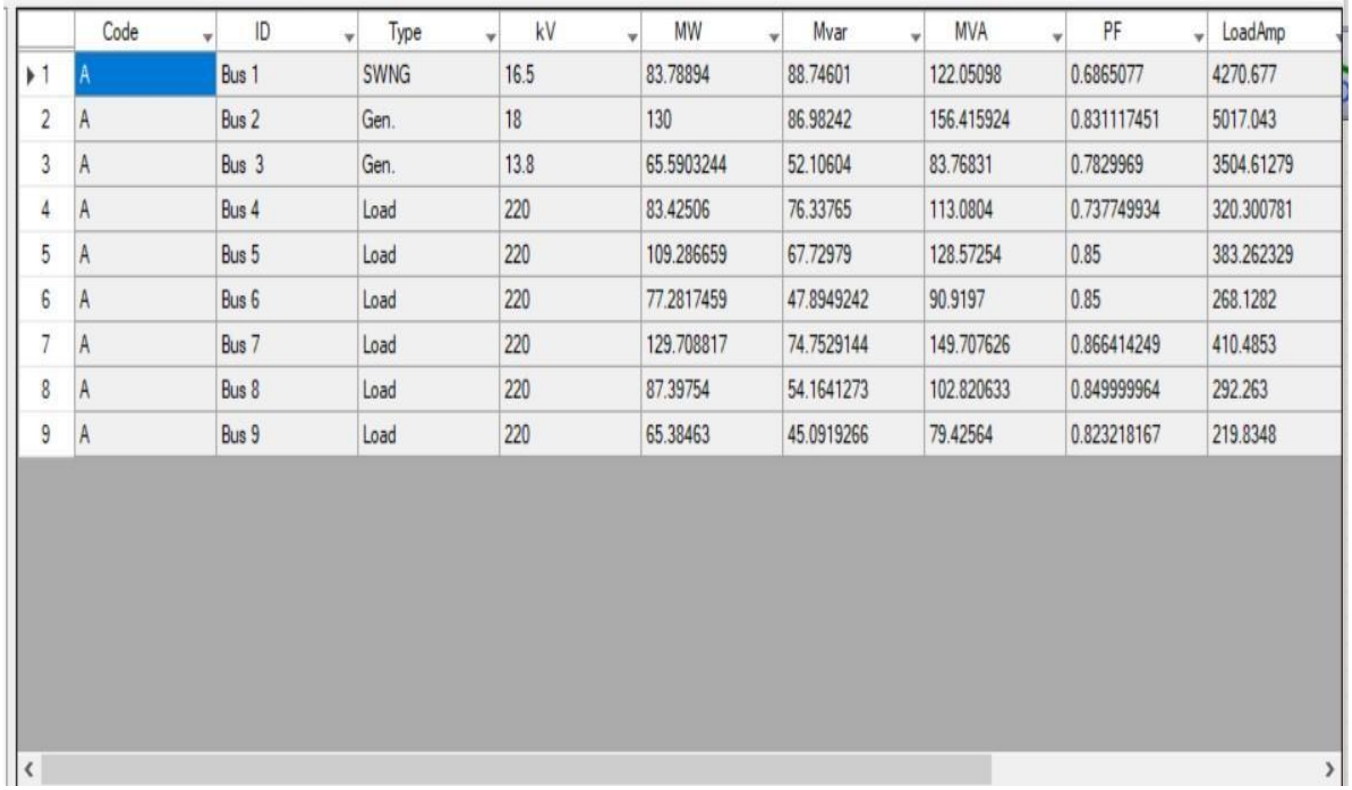


Figure 14 IEEE 9 bus system after load flow on Etap Software



	Code	ID	Type	kV	MW	Mvar	MVA	PF	LoadAmp
1	A	Bus 1	SWNG	16.5	83.78894	88.74601	122.05098	0.6865077	4270.677
2	A	Bus 2	Gen.	18	130	86.98242	156.415924	0.831117451	5017.043
3	A	Bus 3	Gen.	13.8	65.5903244	52.10604	83.76831	0.7829969	3504.61279
4	A	Bus 4	Load	220	83.42506	76.33765	113.0804	0.737749934	320.300781
5	A	Bus 5	Load	220	109.286659	67.72979	128.57254	0.85	383.262329
6	A	Bus 6	Load	220	77.2817459	47.8949242	90.9197	0.85	268.1282
7	A	Bus 7	Load	220	129.708817	74.7529144	149.707626	0.866414249	410.4853
8	A	Bus 8	Load	220	87.39754	54.1641273	102.820633	0.849999964	292.263
9	A	Bus 9	Load	220	65.38463	45.0919266	79.42564	0.823218167	219.8348

Figure 15 Load flow studies

Load flow studies are carried out to study the system .Load flow studies provide a detailed analysis of the steady-state performance of a power system, and can provide valuable insights into the design and operation of the system. The results of load flow studies can be used to identify areas of inefficiency or instability, inform decisions about equipment placement and sizing, and optimize the performance of the system for maximum reliability and efficiency.

5.3 Effect of fault location and fault clearing time on rotor angle stability

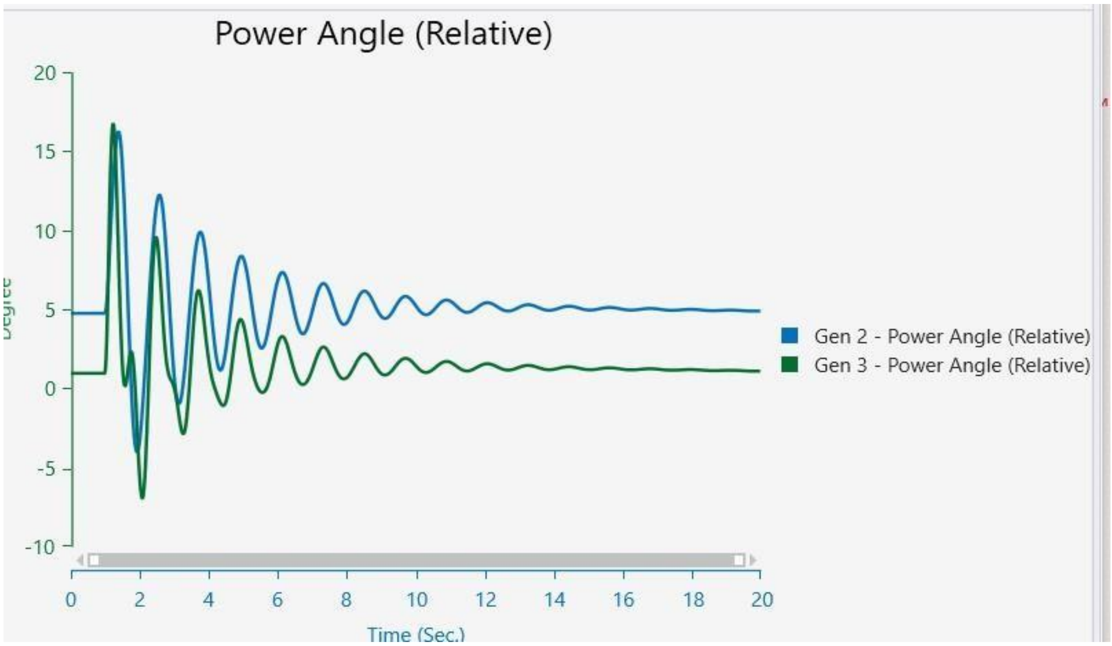


Figure 16 Plot of rotor angle vs time when fault at bus cleared after 0.6 sec

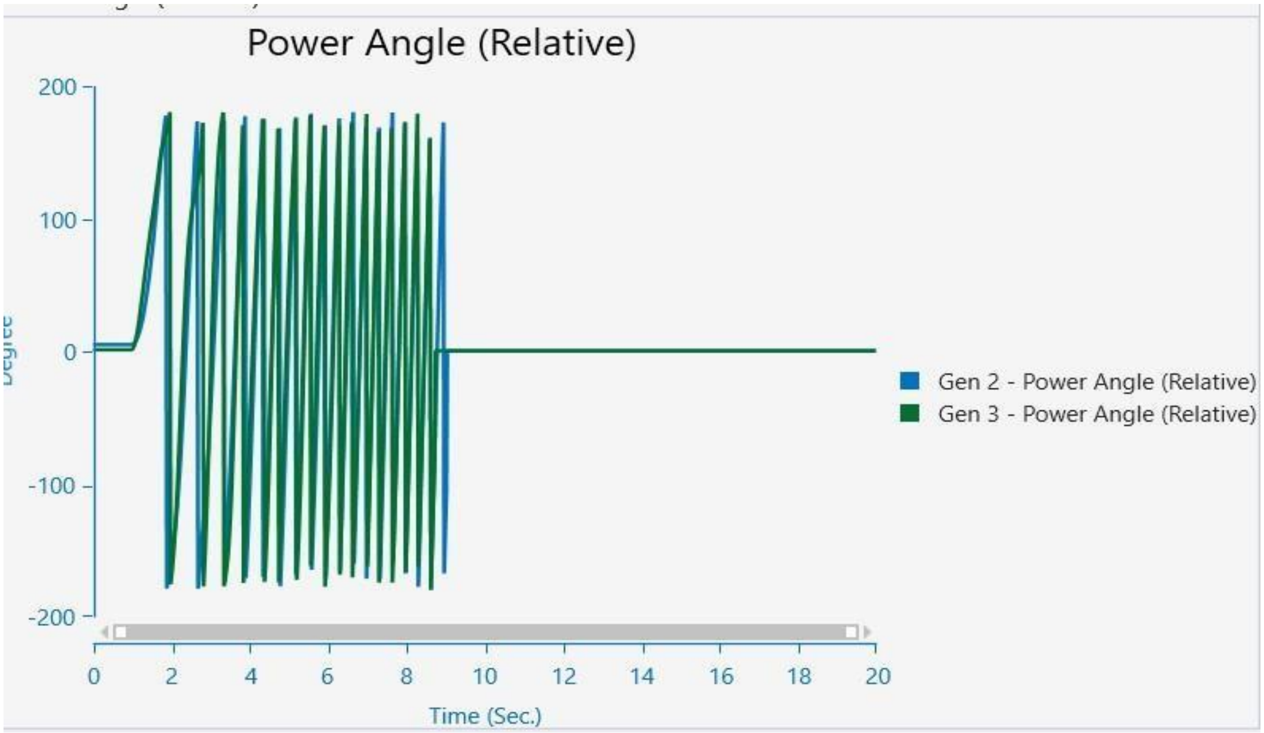


Figure 17 Fault at bus 6 cleared after 0.8 sec

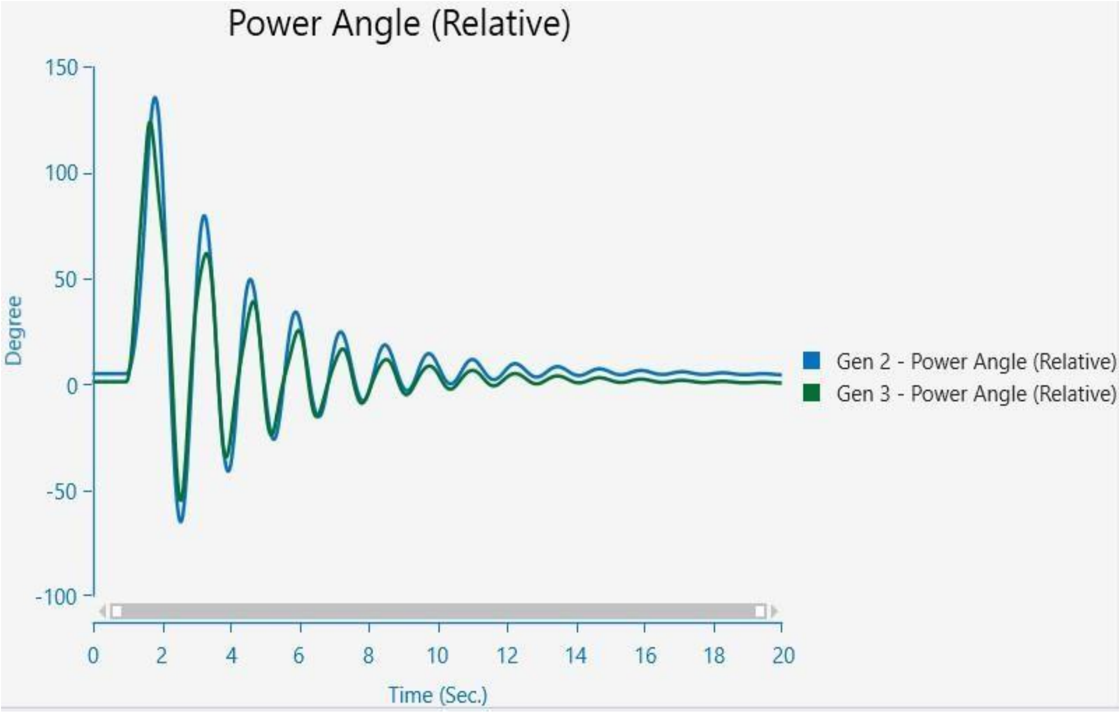


Figure 18 Fault cleared at bus 5 after 0.6 sec

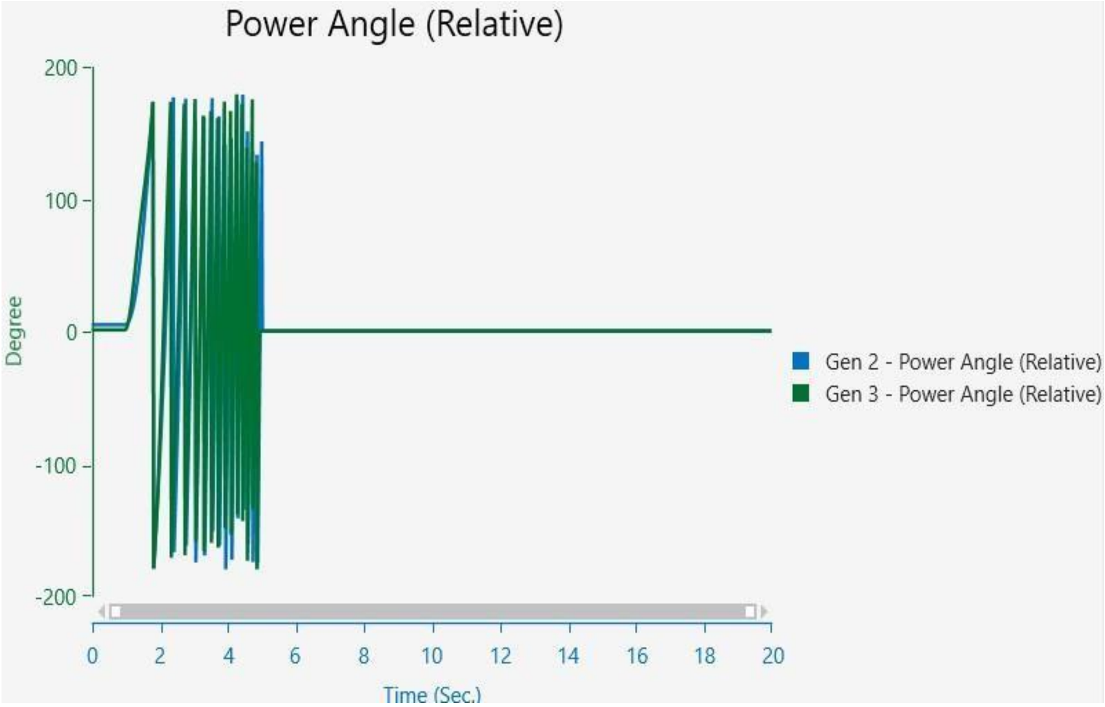


Figure 19 Fault at bus 5 cleared after 0.7 sec

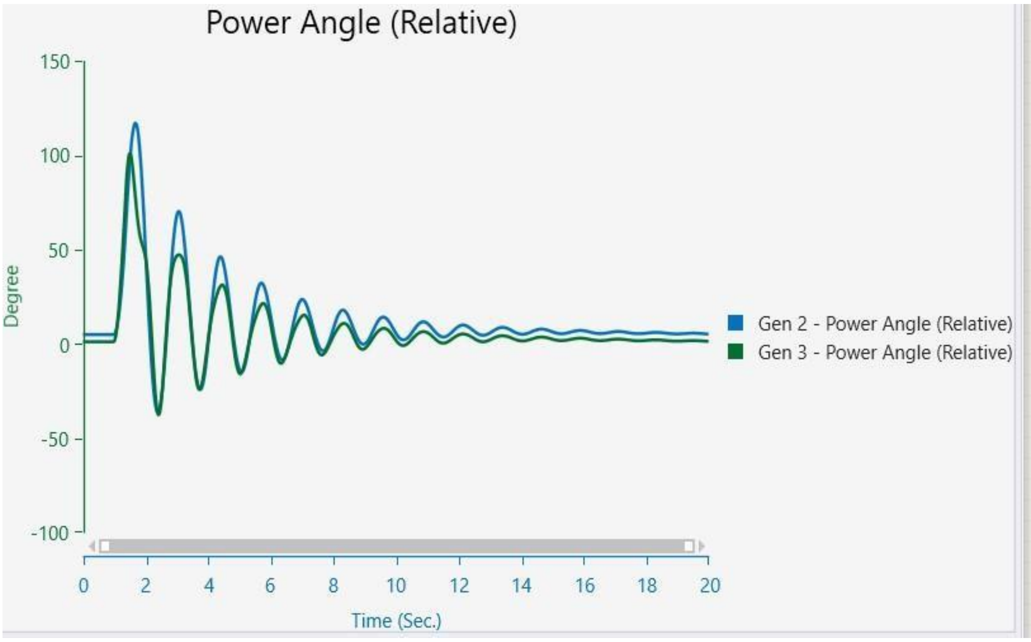


Figure 20 Plot when 3 phase fault at bus 2 which nearer to the generating station cleared after 0.4 sec

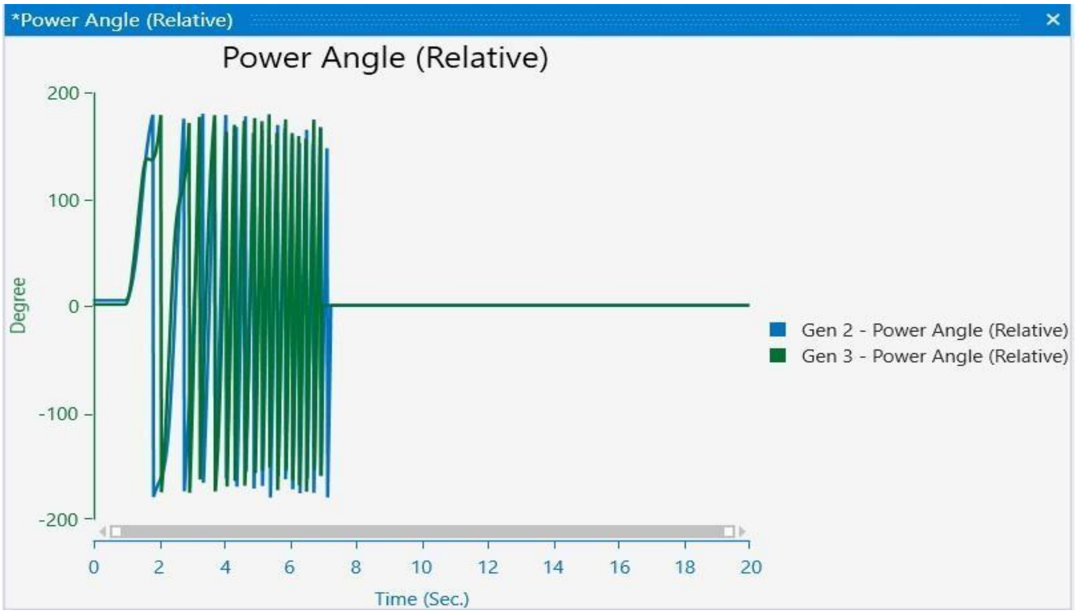


Figure 21 Fault at bus 2 when cleared at 0.5 sec

5.4.Simulation on pv integrated 9 bus system

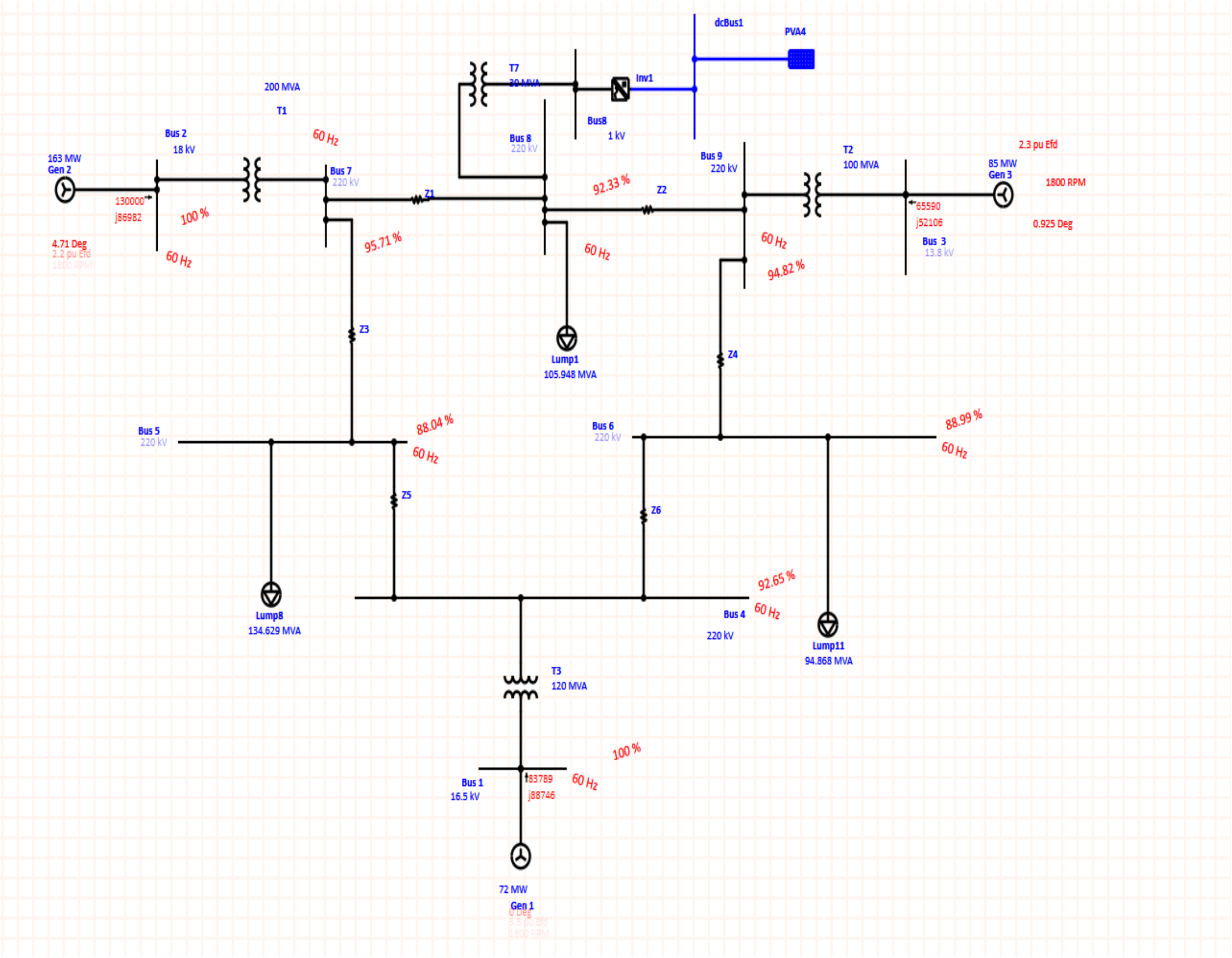


Figure22:IEEE 9 bus system where pv is integrated at bus 8

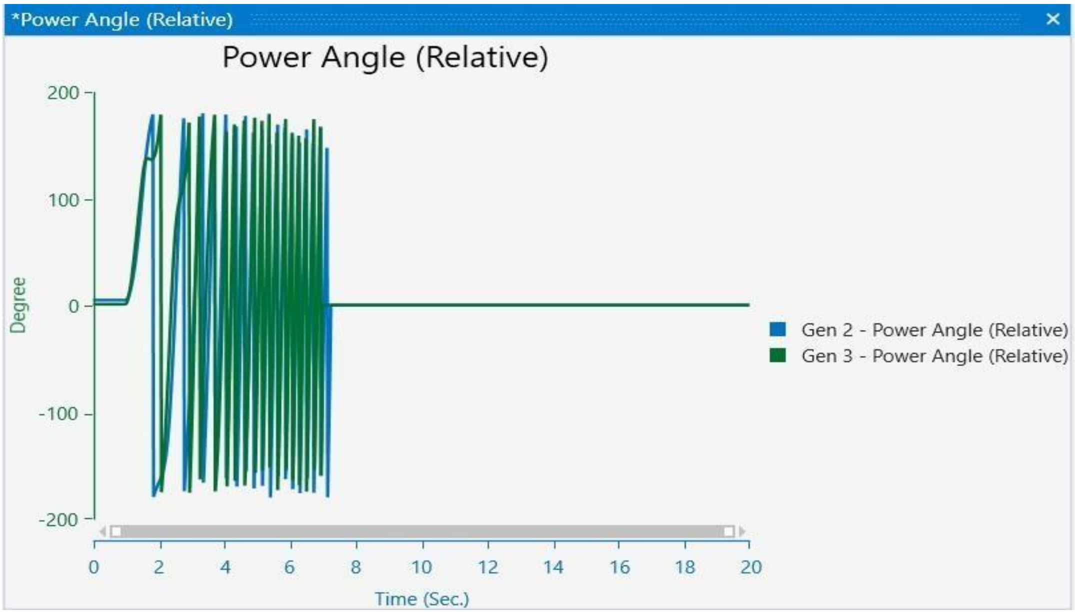


Figure 23.:plot of relative rotor angle vs time when fault at bus 2 is cleared at 0.4 sec

3 phase fault is created at bus 6 and its critical clearing time is found to be 0.7 sec and when fault is cleared at just after critical time ie 0.8 second ,the system loses synchronism and collapses .The critical clearing time of 3 phase fault at bus 5 is found to be 0.6 second and just above the critical clearing time ,the system collapses as shown in fig above.
When the fault at bus 2 occurs which is nearer at the generating station is found to be more severe ,the critical clearing time is only 0.4 sec at the instant of fault occurrence on bus 2 .

The location of the fault can affect rotor angle stability because it determines which generators are affected by the fault and to what extent. For example, if the fault occurs on a transmission line between two generators, those generators may experience different levels of disturbance to their rotor angles depending on their proximity to the fault. Generators closer to the fault may experience larger disturbances due to the sudden reduction in power supply, while those farther away may be less affected.

The fault clearing time is also critical in maintaining rotor angle stability. The faster the fault is cleared, the less time there is for the system frequency and voltage to be impacted. If the fault clearing time is too slow, the system may reach a critical point where the rotor angle instability becomes irreversible, leading to a blackout.

In summary, the location of a fault and the fault clearing time can have a significant impact on rotor angle stability in power systems. It is essential to have proper protective relaying schemes in place to detect and clear faults quickly to maintain the stability of the power system.

CHAPTER SIX :CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

Transient stability analysis has been carried out in this study using a typical IEEE 9 bus test system in the ETAP software. A power system's transient stability is influenced by a number of variables, including the location of the fault, the length of the fault, and the type of generators. The CCT value is influenced by the electricity available there as well as how far the problem is from the generator. The transient stability of the faults at crucial places has decreased with the replacement of traditional synchronous generators with 26.6% of PV penetration level, whereas the transient stability has increased, at least at critical locations.

6.2 RECOMMENDATION

1.Therefore, further research is needed to address these limitations and challenges to improve the accuracy and effectiveness of transient stability analysis.

2. Future research directions in this field may include the development of new models for simulating the dynamic behavior of power systems, the integration of renewable energy sources and other new technologies, and the development of advanced control strategies to prevent power system instability during transient events.

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