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Transient Analysis of 9-Bus System using ETAP

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Abstract

This research paper presents a transient analysis of a 9-bus power system using ETAP software. The simulation results obtained from ETAP are analyzed in terms of voltage and current waveforms, fault current magnitudes. However, the system experiences voltage and current fluctuations during fault conditions, which can lead to instability if not properly addressed.

Keywords: *ETAP, Frequency Stability, Harmonic Analysis, IEEE-9 Bus Test System, Load Flow Study, Transient Stability.*

1.Introduction

The usage of transient analysis utilizing ETAP software can be used to address the serious power quality issues Nepal is now experiencing. A modeling approach called transient analysis is used to examine how the power system responds to various transient situations, such as voltage sags, swells, and other disturbances.

The power system in Nepal could be modeled using the ETAP scheme, and other factors including load flow, fault analysis, and protection coordination can be incorporated. Analysis of the voltage and current waveforms, fault current magnitudes, and relay coordination of the simulation results from ETAP is possible.

The main reason for significant power system problems is undervoltage. Due to the fact that voltage variations cause reactive power (VARs) to flow(Anwar et al., 2020) . VARs must be produced close to the location of consumption. For each potential disruption, the stability state of the power system is assessed using stability studies. For the IEEE-9 Bus test system that is simulated using ETAP, the Load Flow study and Transient Stability study are described and carried out.

1.1. Swing equation

The swing equation governs the motion of the machine rotor relating the inertia torque to the resultant of the mechanical and electrical torques on the rotor.

$$M_i \frac{d^2\delta_i}{dt^2} = P_{m_i} - P_{e_i} \text{ , i=1,2,3, 4......n} \qquad \text{---(1)}$$

With:
δ_i= rotor angle of the i-th machine;
M_i= inertia coefficient of the i-th machine;
P_{m_i}, P_{e_i}= mechanical and electrical power of the i-th machine;
E_i = voltage behind the direct axis transient reactance;
G_{ij}, B_{ij}= real and imaginary part of the ij-th element of the nodal admittance matrix reduced at the nodes which are connected to generators

1.2. Transient stability

When building an electric power system, it's crucial to consider the study of transient stability. It evaluates the power system's ability to withstand or sustain substantial disturbances as well as to make it through the changeover to a regular operational condition(*Power System Stability And Control by Prabha Kundur*, n.d.)Transmission line short circuits, generator loss, drop in load, rotor angle excursions, bus voltages, power flows, and other system variables can lead to disruptions. Power quality is a variety of electromagnetic phenomena that specify voltage and current at a certain time and location.

1.3. Power system stability

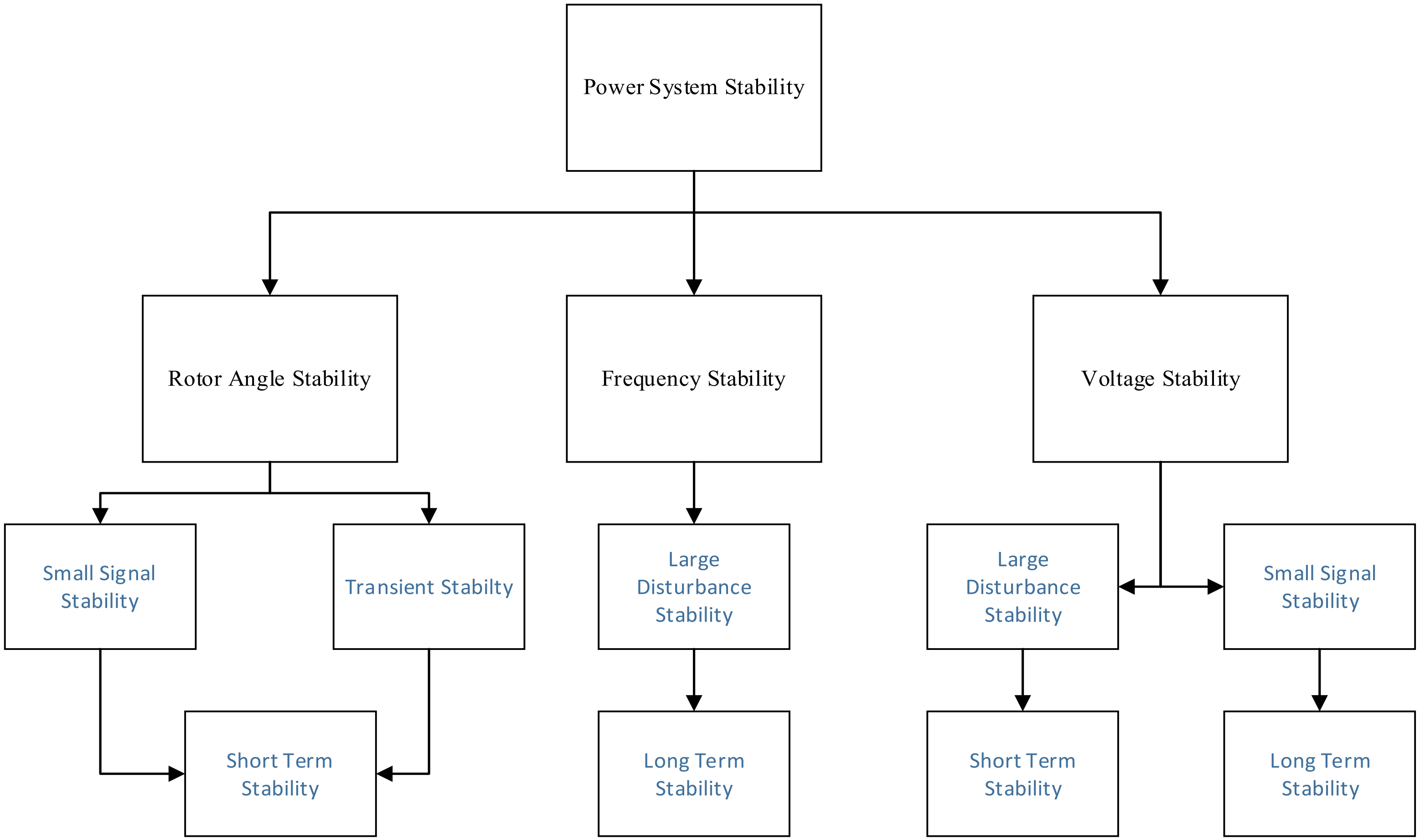

Figure 1: Classification of Power System Stability

1.4. Load flow

Bus classification:

BUS refers to a node where one or more lines, one or more loads, and one or more generators are linked. The magnitude of the voltage, the phage angle of the voltage, the active and reactive power in the load flow are the four quantities assigned to each node or bus. Depending on the stipulated quantity, the buses are divided into 3 groups: Load Bus, Voltage-controlled Bus, and Swing Bus / Slack Bus.

1. Load Bus: There is no generator attached to this bus.
2. Voltage-controlled Bus or Generator Bus: This bus provides the actual power Pg that matches its rating as well as the voltage magnitude that matches the generator voltage.
3. Swing Bus / Slack Bus: In the case of the Slack Bus, real and reactive powers Pg and Qg are obtained using the load flow solution.

Knowledge of pre-fault voltage magnitudes and transient stability is required. Real and reactive powers on transmission lines, bus voltage magnitudes and phase angles, real and reactive powers at generator buses, as well as other required variables, make up the crucial information gleaned from the power flow analysis. By using the Newton-Raphson (N-R) iteration approach, the findings of load flow studies may be used to determine the prior fault (pre-fault) conditions.

1.5. Harmonic analysis

Harmonics may cause devastation on the reliability of an electric power supply. They are caused by nonlinear loads on electronic equipment drawing incurrent in sharp, brief pulses, which recirculate distorted current waveforms into other components of the power system. Harmonics can lead to a variety of issues, such as overloading neutral conductors, overheating transformers, annoying breaker trips, overloading capacitor banks, and skin effect. Total Harmonic Distortion (THD) is the proportion of the total power of all harmonic components to the fundamental frequency.

1.6. IEEE 9 BUS SYSTEM

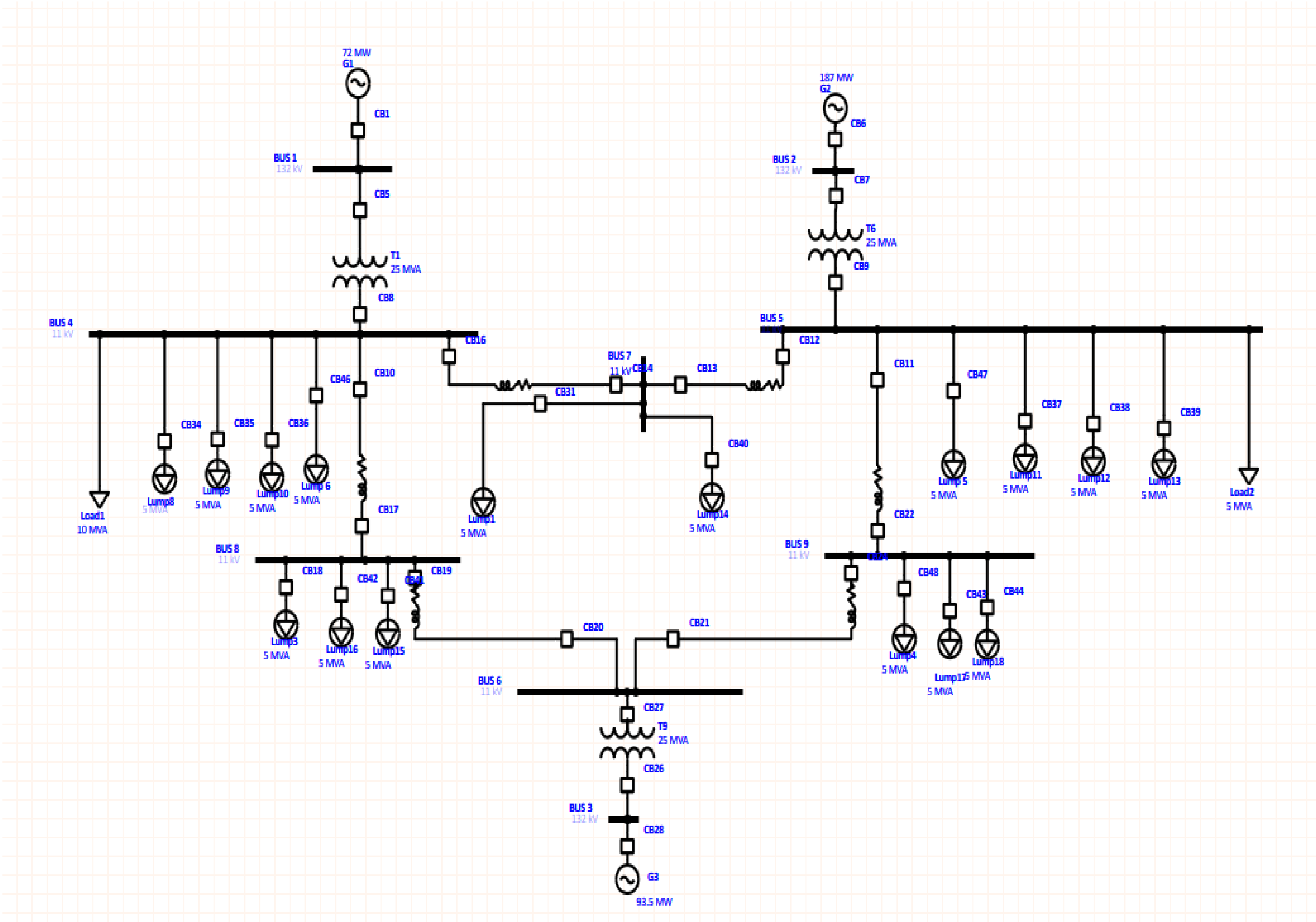

Figure 2: Single Line Diagram of IEEE 9 Bus test system

(Above single line diagram shows an IEEE 9- Bus System.)

Three generators, three transformers, and three loads make up this paper. In this system, generators, transformers, and loads are listed in the appendix. Generators G2 and G3 are linked to PV-bus, whereas generator G1 is connected to slack bus 1. Bus bars 5, 6, and 8 are used to link loads A, B, and C, correspondingly. There are 313MW of total generation and 347.5MW of total load. We have looked at two cases. The first instance was thought of without a three-phase defect, while the second case was thought of with a three-phase.

2. Methodology

The steps required for utilizing ETAP to do a transient study of a 9-bus system are the most important details in this work. This involves choosing the "Transient Stability" option when building a new project in ETAP. Create a one-line diagram, provide system parameters, specify fault circumstances, set up simulation settings, run the simulation, and examine the outcomes to define the system topology. Verifying the data used in the simulation, using suitable models for the generators, transformers, transmission lines, and loads, and doing sensitivity analysis are all advised in order to increase the accuracy of the simulation findings. With the help of ETAP, which is a potent instrument for transient analysis of power systems, precise and trustworthy findings may be acquired by adhering to the above-described technique.

3. System simulation and load flow analysis

In this paper IEEE 9 bus system is used as the test system, which is simulated on ETAP 19.0.1. Fig. 3 shows the single line diagram (SLD) of the simulated test system on ETAP. The load parameters and system generator for this test are listed in the appendix. The total generation is 313MW and total load is 347.5MW. It is good practice to have periodic and updated load flow study for every installation.

Many load flow solution techniques, including Gauss-Seidel, Newton-Raphson, and current injection, are employed in industry(Das, n.d.). For all load flow solution methods, the network must include at least one swing bus.

The Load Flow Analysis was done and the Bus voltages, Generation, Load and Losses were tabulated:

Bus No.	Bus KV	Voltage (Magnitude)	Voltage (Angle)	Generation (MW)	Generation (Mvar)	Total Bus Load		
						MVA Amp		%PF
1	132	132.00	0.0	-39.839	69.392	80.015	49.8	350.0
2	132	132.00	61.3	40.00	0.813	40.008	100.0	175.0
3	132	132.00	61.3	40.00	0.808	40.008	100.0	175.0
4	11	9.215	7.3	0	0	67.030	60.4	4199.7
5	11	10.986	55.6	0	0	39.958	99.7	2099.9
6	11	10.986	55.6	0	0	39.963	99.7	2100.1
7	11	9.226	33.7	0	0	33.551	89.5	2099.6
8	11	9.226	33.7	0	0	33.560	89.5	2100.1
9	11	10.986	55.6	0	0	0.006	70.7	0.3

4. Results and Discussion

For Transient Analysis, Bus 1, Bus 2 and Bus 3 were faulted.

At T = 1.0 sec Line to Ground Fault occurred at bus 1 and fault cleared at 1.2 sec , the Circuit Breaker 1 and 5 are operated

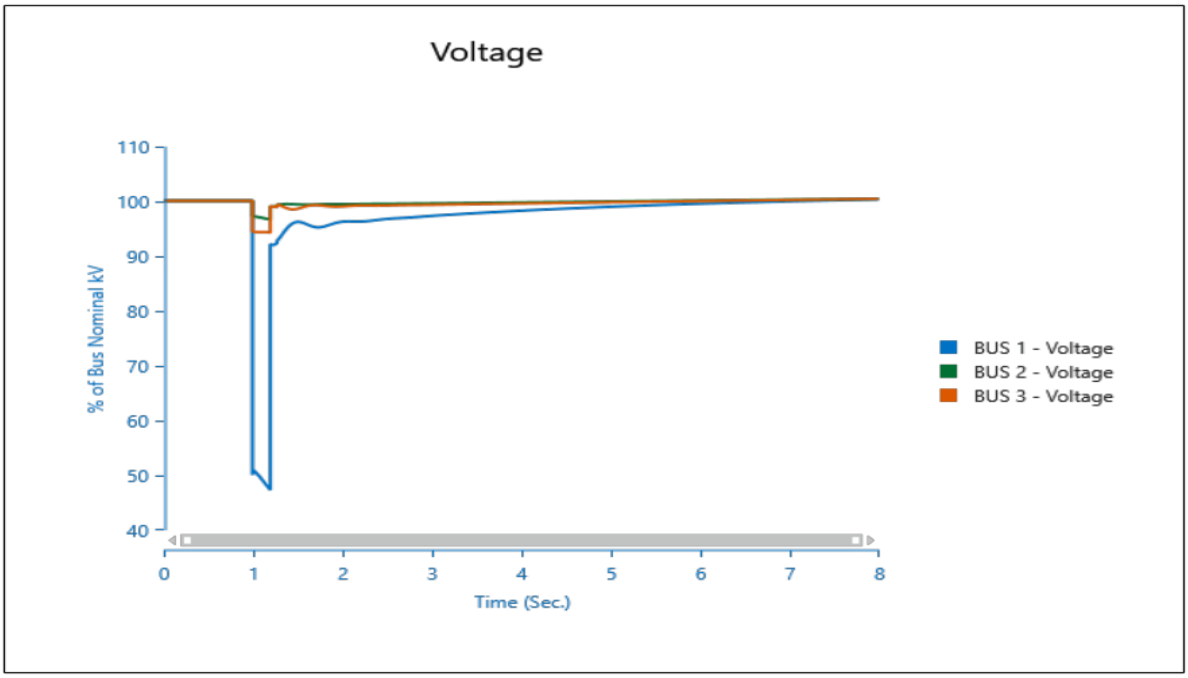

Figure 3: Bus Voltages when fault occurred at bus 1

At T = 1.0 sec Line to Ground Fault occurred at bus 2, the Circuit Breaker 6 and 7 are operated.

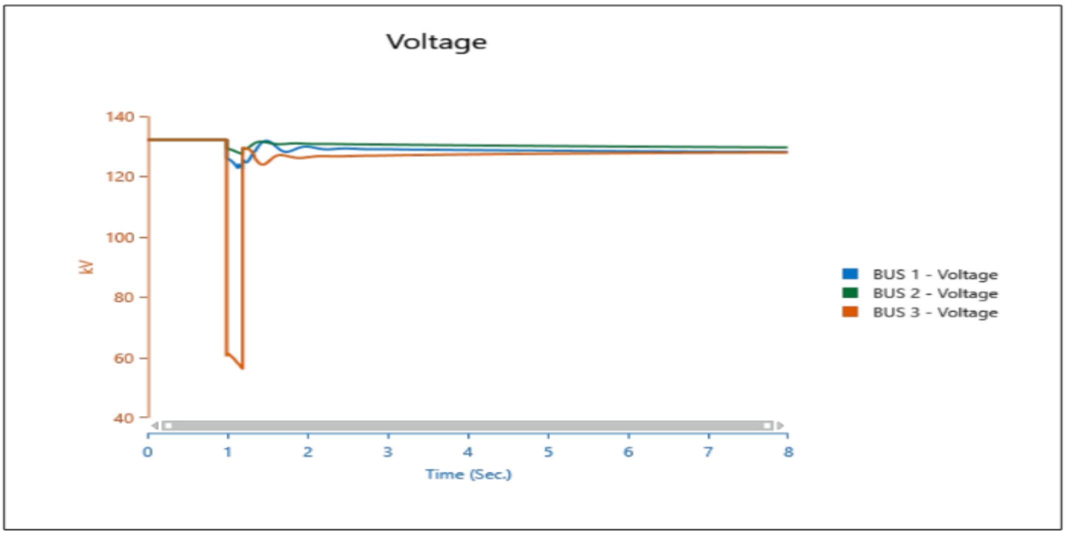

Figure 4: Bus Voltages when fault occurred at bus 2

Again, At T = 1.0 sec Line to Ground Fault occurred at bus 3, the Circuit Breaker 26 and 28 are operated.

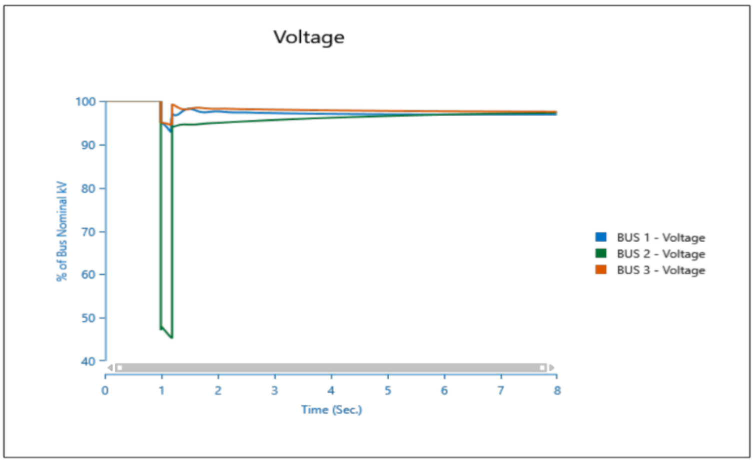

Figure 5 : Bus Voltages when fault occurred at bus 3

Similarly,When Line to Ground Fault occured at Bus 1,Bus 2 and Bus 3, the relative power angle for Gen 1, Gen 2, Gen 3 were simulated through plot manager.

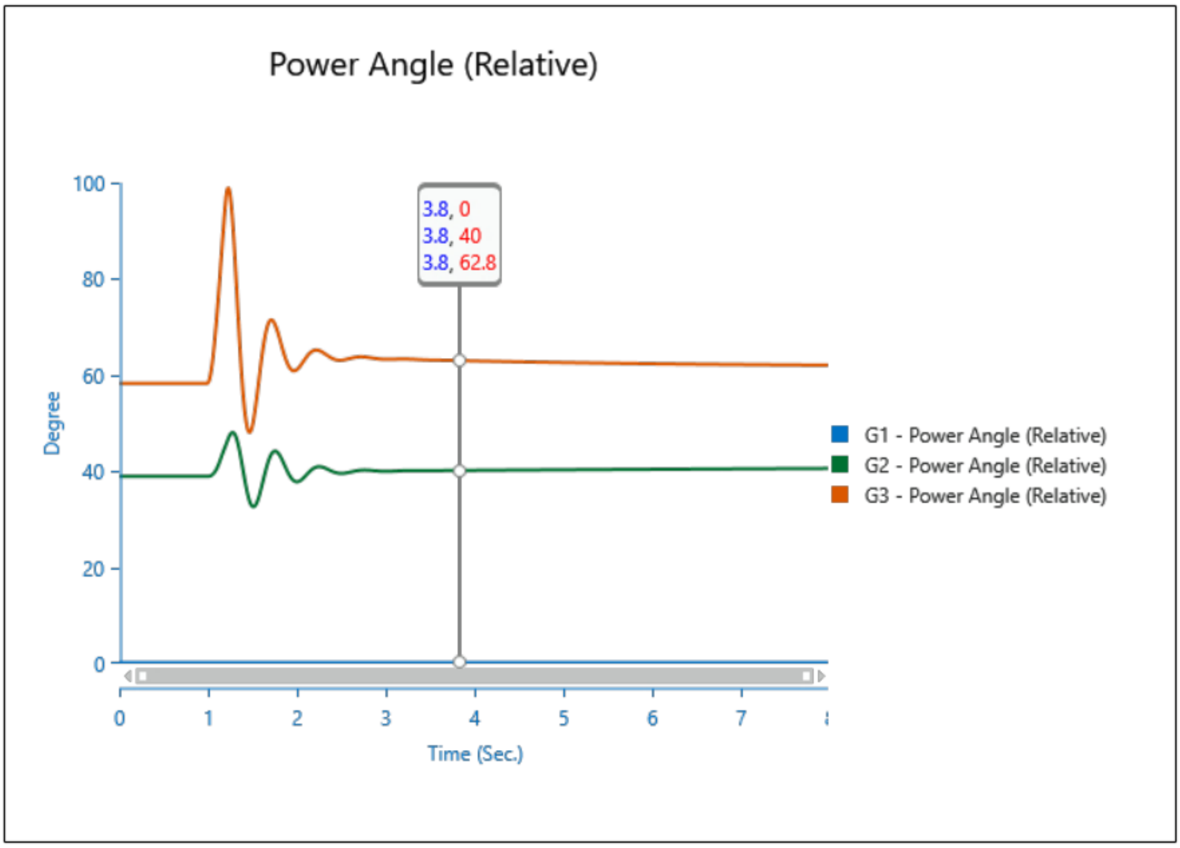

Figure 6: Relative power angles when fault occurred at bus 1

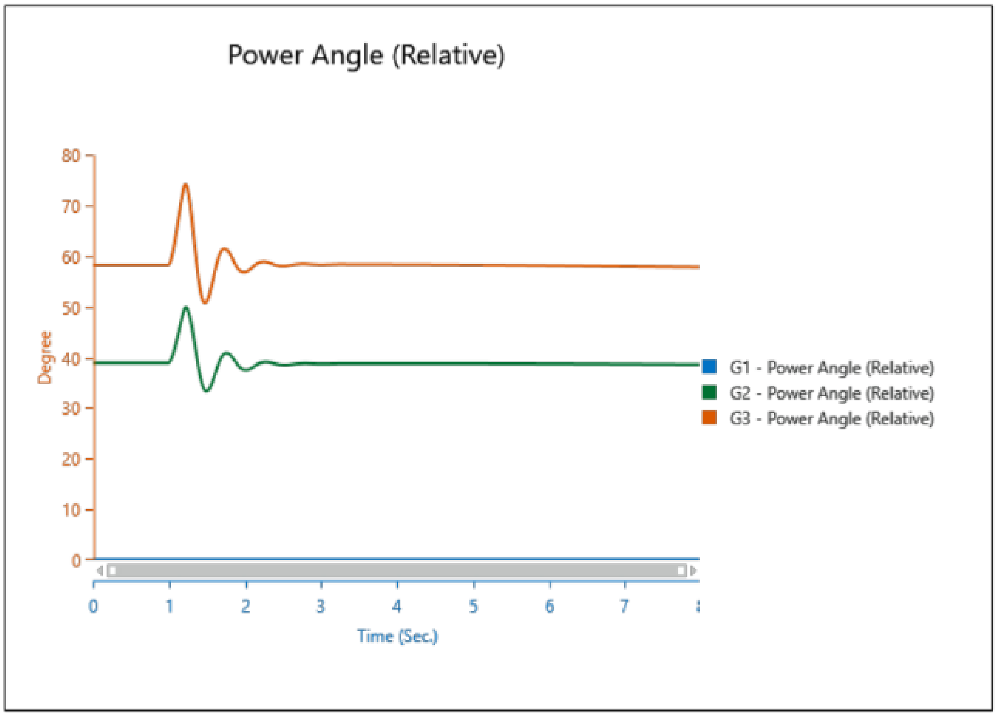

Figure 7: Relative power angles when fault occurred at bus 2

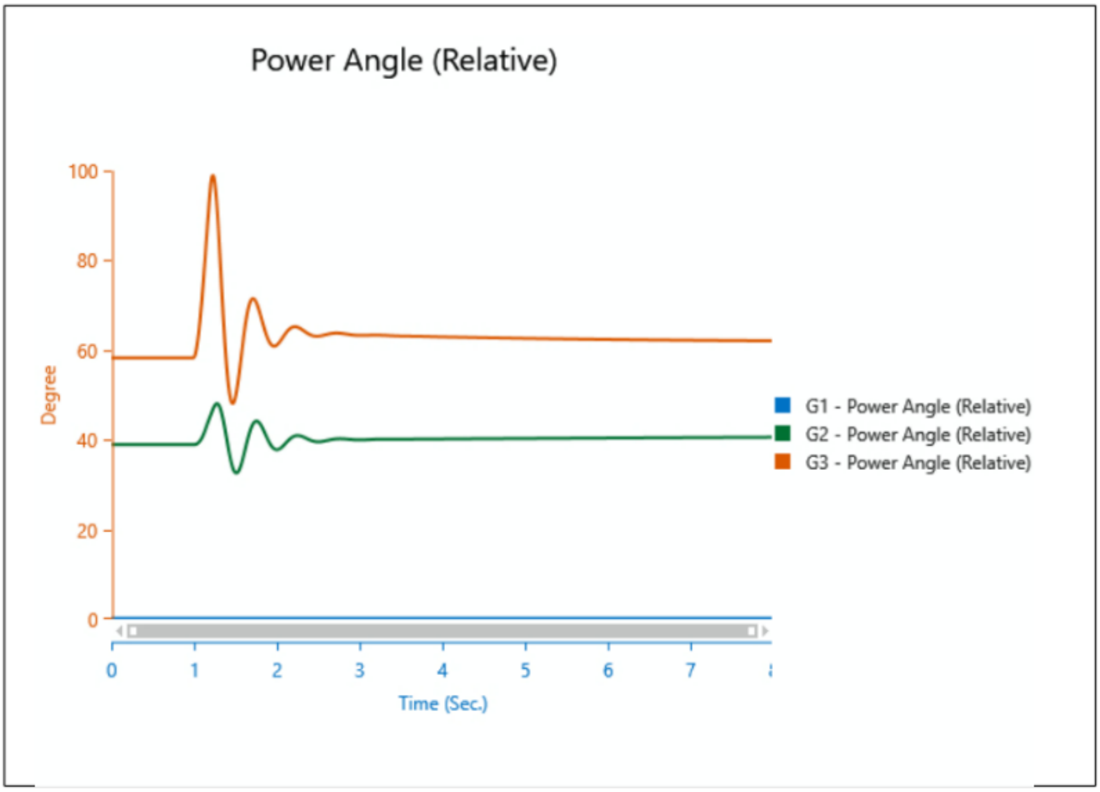

Figure 8: Relative power angles when fault occurred at bus 3

Now moving towards Harmonic Analysis,

We need to connect a static load at Bus 4 and Bus 5.

So Two static loads of 10 MVA and 5 MVA were connected to Bus 4 and Bus 5. The Harmonic Report is attached with Appendix.

The Simulation of waveform and spectrum of Bus 4 and Bus 5 is listed below: -

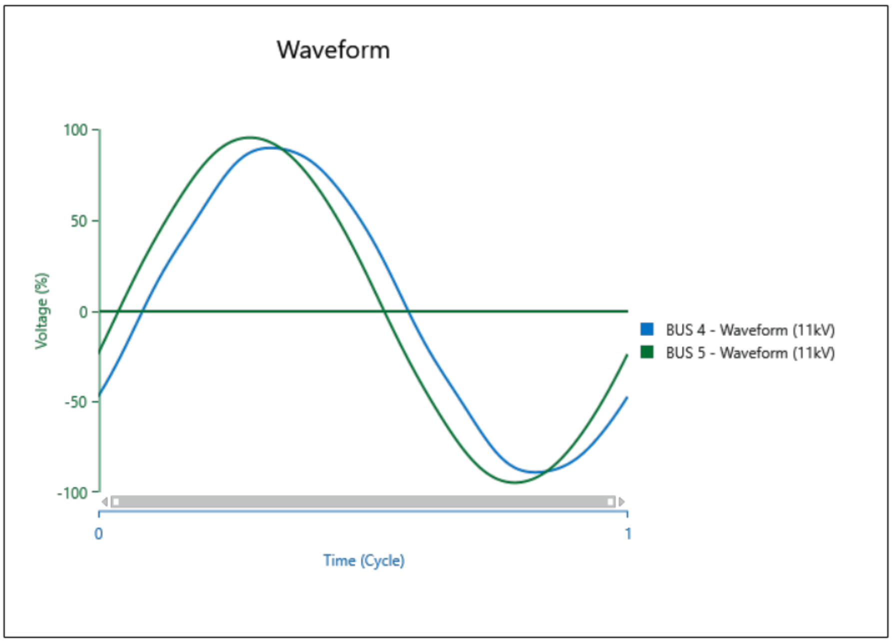

Figure 9: Waveform of Bus 4 and Bus 5 after Harmonic Analysis

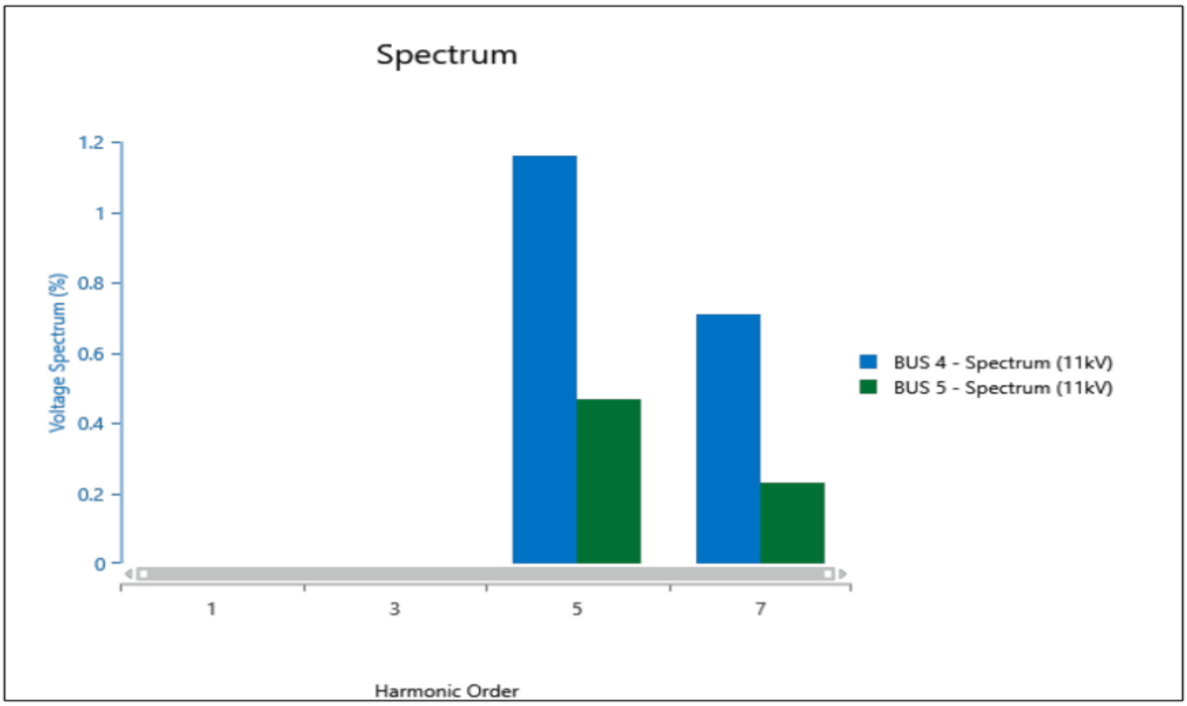

Figure 10: Spectrum of Bus 4 and Bus 5 after Harmonic Analysis

Again after running frequency scan, we obtained Z magnitude and Z angle towards Harmonic Order.

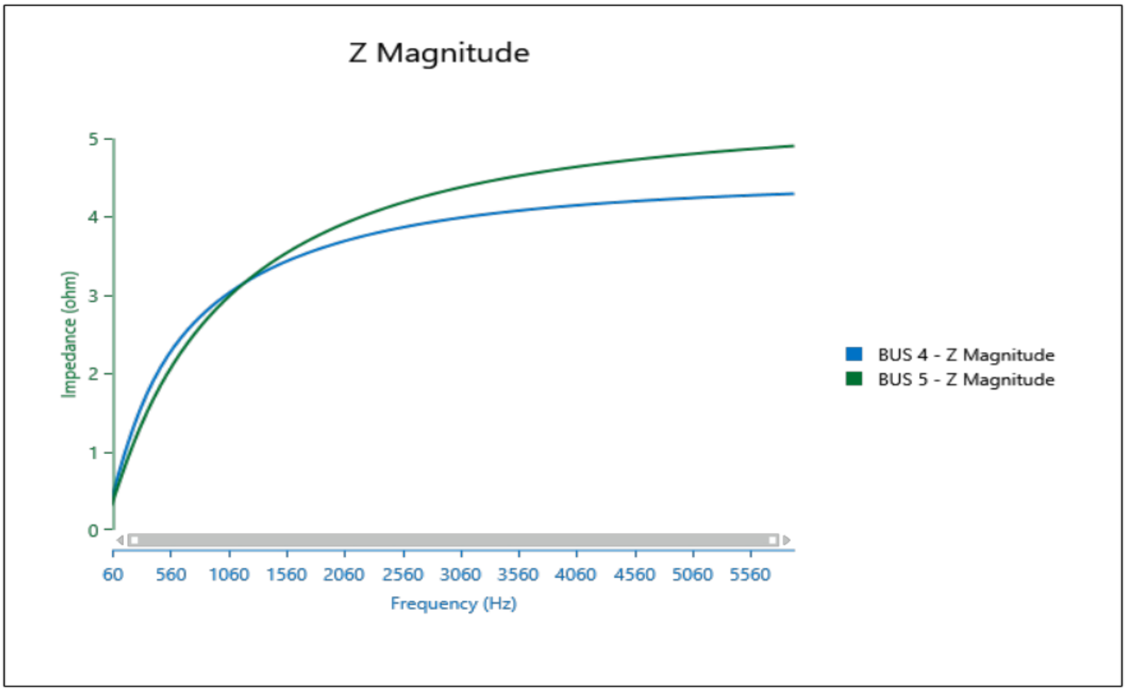

Figure 11: Magnitude plot of Impedance after Frequency Analysis

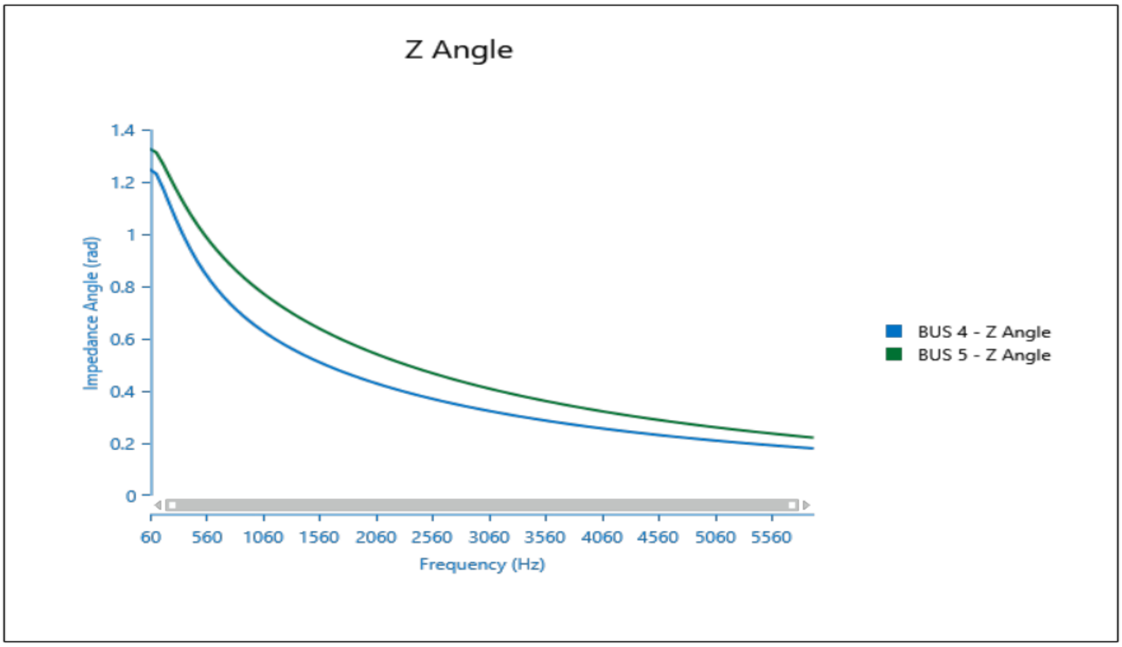

Figure 12: Angle plot of Impedance after Frequency Analysis

4. Conclusions

The IEEE 9-Bus Electrical Power System's stability has been investigated in this study. Transient stability analysis has been performed on ETAP software. System frequency and voltage is analyzed for different loading conditions and faults on buses. And Harmonic Analysis is done attaching two static loads. We observed that before to the fault, the system took a few seconds to stabilize, implying that any system prior to the breakdown first climbs to its peak or maximum value and then remains constant. Similarly, following a malfunction, the system needs significantly longer time to stabilize, and even rapid changes in the system are seen.

References

Anwar, N., Farhaj Khan, H., Hanif, A., & Farhan Ullah, M. (2020). Transient Stability Analysis of the IEEE-9 Bus System under Multiple Contingencies. In Technology & Applied Science Research (Vol. 10, Issue 4). Retrieved from www.etasr.com

Das, S. (n.d.). *E4 234 Aug 3:0 Advanced Power Systems Analysis Instructor Teaching Assistant*. Retrieved from http://www.ee.iisc.ac.in/academics-courseprograms-details.php

APPENDIX

Electrical Transient Analyzer Program

Load Flow Analysis

Loading: Operating P, Q

Generation: Operating P, Q, V

	Swing	V-Control	Load	Total
Number of Buses:	1	2	6	9

	XFMR2	XFMR3	Reactor	Line/Cable/ Busway	Impedance	Tie PD	Total
Number of Branches:	3	0	0	6	0	0	9

LOAD FLOW REPORT

Bus ID	Bus kV	Voltage kV	Voltage Ang.	Generation MW	Generation Mvar	Load MW	Load Mvar	Load Flow ID	Load Flow MW	Load Flow Mvar	Load Flow Amp	Load Flow %PF	XFMR %Tap
*BUS 1	132.000	132.000	0.0	-39.839	69.392	0.000	0.000	BUS 4	-39.839	69.392	350.0	-49.8	
*BUS 2	132.000	132.000	61.3	40.000	0.813	0.000	0.000	BUS 5	40.000	0.813	175.0	100.0	
*BUS 3	132.000	132.000	61.3	40.000	0.808	0.000	0.000	BUS 6	40.000	0.808	175.0	100.0	
BUS 4	11.000	9.215	7.3	0.000	0.000	0.000	0.000	BUS 7	-20.257	26.695	2099.6	-60.4	
								BUS 8	-20.257	26.705	2100.1	-60.4	
								BUS 1	40.514	-53.400	4199.7	-60.4	
BUS 5	11.000	10.986	55.6	0.000	0.000	0.000	0.000	BUS 7	39.827	-3.180	2099.6	-99.7	
								BUS 9	0.004	-0.005	0.3	-65.6	
								BUS 2	-39.831	3.185	2099.9	-99.7	
BUS 6	11.000	10.986	55.6	0.000	0.000	0.000	0.000	BUS 8	39.836	-3.193	2100.1	-99.7	
								BUS 9	-0.004	0.004	0.3	-76.2	
								BUS 3	-39.831	3.190	2099.9	-99.7	
BUS 7	11.000	9.226	33.7	0.000	0.000	0.000	0.000	BUS 4	30.042	-14.938	2099.6	-89.5	
								BUS 5	-30.042	14.938	2099.6	-89.5	
BUS 8	11.000	9.226	33.7	0.000	0.000	0.000	0.000	BUS 4	30.046	-14.949	2100.1	-89.5	
								BUS 6	-30.046	14.949	2100.1	-89.5	
BUS 9	11.000	10.986	55.6	0.000	0.000	0.000	0.000	BUS 5	-0.004	0.004	0.3	-70.7	
								BUS 6	0.004	-0.004	0.3	-70.7	

Synchronous Generator Input Data

Synchronous Generator ID	Type	Connected Bus ID	Rating MVA	Rating kV	Rating RPM	X/R Ratio X"/R	X/R Ratio X'/R	% Impedance in Machine Base R	Xd" Adj.	Xd" Tol.	Xd'
G1	Hydro	BUS 1	80.000	132.000	1800	19.00	19.00	1.000	19.00	0.0	28.00
G2	Steam Turbo	BUS 2	220.000	132.000	1800	19.00	19.00	1.000	19.00	0.0	28.00
G3	Steam Turbo	BUS 3	110.000	132.000	1800	19.00	19.00	1.000	19.00	0.0	28.00

Total Connected Synchronous Generators (= 3): 410.000 MVA

System Harmonics Bus Information

Bus ID	Bus kV	Fund. %	RMS %	ASUM %	THD %	TIF	TIHD %	TSHD %	THDG %	THDS %
BUS 1	132.000	100.00	100.00	100.93	0.67	2.68	0.00	0.00	0.67	0.67
BUS 2	132.000	100.00	100.00	100.18	0.13	0.69	0.00	0.00	0.14	0.14
BUS 3	132.000	100.00	100.00	100.14	0.11	0.62	0.00	0.00	0.11	0.11
BUS 4	11.000	89.76	89.77	91.66	1.54	6.03	0.00	0.00	1.54	1.54
BUS 5	11.000	95.02	95.02	95.72	0.55	2.01	0.00	0.00	0.55	0.55
BUS 6	11.000	98.68	98.68	99.03	0.27	1.03	0.00	0.00	0.27	0.27
BUS 7	11.000	86.58	86.59	87.58	0.87	2.99	0.00	0.00	0.87	0.87
BUS 8	11.000	84.77	84.77	85.79	0.88	3.37	0.00	0.00	0.88	0.88
BUS 9	11.000	89.59	89.59	89.98	0.34	1.13	0.00	0.00	0.34	0.34