Pakistan Journal of Engineering and Technology, PakJET
ISSN (p): 2664-2042, ISSN (e): 2664-2050
Volume: 5, Number: 2, Pages: 23- 27, Year: 2022

Transient Stability Analysis of an HPR-1000 Power Plant using ETAP Software

Muhammad Awais[1], Walid Irfan[2], Naila Zareen[2], and Iftikhar Ahmed[1]

[1]Safety Analysis Centre, Pakistan Nuclear Regulatory Authority, Pakistan
[2] Karachi Institute of Power Engineering, Pakistan (Affiliated with PIEAS)

Corresponding author: Muhammad Awais (e-mail: muhammadawais1990@gmail.com)

Received: 5/02/2022, Revised: 01/03/2022, Accepted: 15/05/2022

Abstract- **Transient stability analysis has become an important subject, as the world's demand for electricity is increasing enormously. Power systems are facing different challenges like degradation of equipment, sudden load changes, switching operations and installation of new power plants to fulfill the demand and supply mismatch. Transient stability analysis is used to analyze whether the system will remain in synchronism or not following a disturbance. In this paper, this analysis is performed for an HPR-1000 nuclear power plant connected to the 500kV network of NTDC (National Transmission & Dispatch Company) Grid. Different external 3-phase fault scenarios are considered on the 500kV network and simulated using ETAP (Electric Transient Analyzer Program) software. To analyze the system stability behavior during and after the fault, generator speed, rotor angle, frequency and bus voltages are monitored. It was observed that the HPR-1000 power plant-maintained synchronism and remained stable.**

Index Terms-- **Grid, Transient Stability, ETAP, Power System, Modeling, Simulation**

I. INTRODUCTION

Power system transient stability is the capability of generators to operate synchronously when the system is disturbed [1]. The most common disturbances that produce instability in power systems include short circuits, loss of tie circuit to a public utility, loss of a portion of on-site generation, switching operations, impact loading on motors and abrupt decrease in electrical load on generators [2]. In power system, the demand for electricity is increasing all over the world. In Pakistan, the power system is facing challenges as line losses are significant, much equipment has completed its design life but is still in operation and there is gap in planning of demand and generation. Because of all these problems, the grid is not much reliable and there are frequent outages and blackouts. So, it is necessary to perform transient stability studies before adding any new plant to the system.

The advent of simulation softwares have made many problems easier to solve, which were previously considered as a major hurdle in achieving the desired objective. In power system, an ideal network never exists. There are always certain problems, such as demand and supply mismatch, sudden application or removal of loads, short circuits, etc. which make the system deviate from ideal conditions. To compensate for these changes, it was a common practice in the early days to install excess generating capacity thus providing much more cushion than the network would need thereby increasing electricity generation cost per unit. But now planning and analysis is highly emphasized and use of simulation softwares has increased with a rapid pace as it helps to evaluate network performance, optimize multiple designs, analyze grid responses and compare alternatives. In addition, it also allows planning for changes and foreseeing probable causes of failures. Therefore, transient stability analysis is paramount whenever there is going to be any addition of a power plant, or a big load or any other significant change in the network.

Pakistan is generating power through various sources and the installed capacity has doubled in the last decade with thermal having the largest share of 59.42%, hydel with a share of 30.52%, nuclear power plants having a share of 7.82% and other renewables with 2.23% as can be seen from Fig. 1 [3]. The compound annual growth rate of nuclear power plant contribution is highest among all with 17.9% and expected to increase further owing to the increasing energy demands and having less carbon footprint than thermal power plants as well [4].

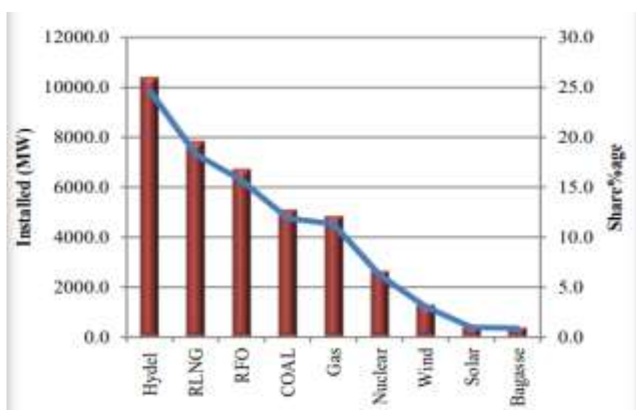

FIGURE 1. Fuel-wise Installed Capacity Breakdown

It has been observed from last two decades that stability analysis is being focused and performed before finalizing the system configurations. It is also evident from the literature that researchers are focused in this area and have used different simulation tools to comprehend and solve this problem. Tahir *et al.* evaluated IEEE 9 bus system for transient conditions using ETAP software [5]. DS Reddy *et al.* modelled a combined cycle power plant and performed transient stability analysis to ensure optimization of different operating scenarios of the power plant for a suitable economic operation [6]. Bind *et al.* performed transient stability analysis of a 9-bus system under different fault conditions, using MATLAB [7]. P. Maniraj performed the transient stability analysis of an IEEE 6 bus system in which three phase fault situation is simulated using ETAP software [8]. Kavitha R performed transient stability analysis of IEEE 30 bus system using ETAP software [9].

In this research work, HPR-1000 power plant which produces 1145 MW electric power is considered for stability analysis in NTDCs 500kV Network. Since inclusion of such large plants can cause significant stability issues to the Grid, therefore, transient analysis is performed by considering different possible fault scenarios.

II. MODELLING OF POWER SYSTEM NETWORK

The network understudy is a 500kV network consisting of an HPR-1000 Power Plant having a generation capacity of 1145 MegaWatt(MW), few thermal, hydel, and Combined Cycle Power Plant (CCPP) connected to the network.All the major grid stations of NTDC have been modelled using data of certain components such as bus voltage ratings, bus types, transformers MVA ratings, primary and secondary voltages of transformers, total connected loads etc. which are used in model development and is given in Table I, II, and III. Different reactors, capacitor and Lump loads (80% motor load and 20% static load) are also connected in the network at various buses.

TABLE I

GENERATION BUSSES RATINGS

Generation Bus ID	Type	kV	MW	MVAR
BALOKI-PP	Voltage Control	20	1053.7	175.0
BHIKKI-PP	Voltage Control	20	1026	230.5
HPR-1000-	Voltage Control	24	1145	182.3
ENGRO U1	Voltage Control	20.2	330	50.8
ENGRO U2	Voltage Control	20.2	330	50.8
G.BAROTHA-U1	Swing	20	33.95	105.6
G.BAROTHA-U2	Voltage Control	20	106.2	82.6
GUDDU-NEW-PP	Voltage Control	22	690	131.7
GUDDU-PP	Voltage Control	20	205.4	27.8
HB.SHAH-PP	Voltage Control	20	1056.6	313.5
HUB-CH U1	Voltage Control	22	660	92.7
HUB-CH U2	Voltage Control	22	660	92.7
LAHORE-CS-1	Voltage Control	20	791.5	143.3
LAHORE-CS-2	Voltage Control	20	791.5	143.3
P-QASIM U1	Voltage Control	22.1	660	65.9
P-QASIM U2	Voltage Control	22.1	660	65.9
ROUSCH-PP	Voltage Control	20	350.1	37.8
SAHIWAL-Gen	Voltage Control	20	1300	250.1

TABLE II

TRANSFORMER RATINGS

ID	Phase	MVA Rating	Prim. kV	Sec. kV	%Z
T1	3-Phase	800	22	525	15
T3	3-Phase	800	22	525	15
T5	3-Phase	425	20	525	14.5
T6	3-Phase	800	22.1	525	15
T7	3-Phase	800	22.1	525	15
T9	3-Phase	800	22	525	15
T11	3-Phase	425	20.2	525	14.5
T12	3-Phase	500	20	525	14.5
T13	3-Phase	425	20.2	525	14.5
T14	3-Phase	1350	24	525	16
T16	3-Phase	425	20	525	14.5
T18	3-Phase	425	20	525	14.5
T20	3-Phase	1350	20	525	16
T22	3-Phase	1350	20	525	16
T23	3-Phase	1350	20	525	16
T24	3-Phase	1350	20	525	16
T26	3-Phase	800	20	525	15
T27	3-Phase	800	20	525	15

TABLE III

TOTAL CONNECTED LOAD

Constant kVA		Constant Z	
MW	MVAR	MW	MVAR
9349.6001	3738.635	2531.385	-1068.29

A. ABBREVIATIONS AND ACRONYMS

HPR	Hualong one pressurized water reactor
ETAP	Electric transient analyzer program
NTDC	National transmission and dispatch company
kV	Kilo volts
MW	Mega watts
MVAR	Mega volts ampere reactive
MVA	Mega volts ampere
T	Transformer
PP	Power plant
U	Unit
CS	Converting station

RPM	Revolutions per minute
AVR	Automatic voltage regulator

III. LOAD FLOW ANALYSIS AND ITS RESULT

In ETAP, there are various methods available for load flow analysis, such as Accelerated Gauss-Seidel, Fast-Decoupled, Adaptive Newton Raphson, and Newton Raphson. In this work, Newton Raphson method is used for load flow analysis of the network with 99 maximum iterations and 0.0001 solution precision.

For load flow analysis Newton Raphson method solves the following equations iteratively,

$$I_i = \sum_{j=1}^{n} |Y_{ij}||V_j| \angle\theta_{ij} + \delta_j \tag{1}$$

$$P_i - jQ_i = |V_j| \angle{-\delta_j} \sum_{j=1}^{n} |Y_{ij}||V_j| \angle\theta_{ij} + \delta_j \tag{2}$$

On separating real and imaginary parts,

$$P_i = \sum_{j=1}^{n} |Y_{ij}||V_I||V_j| \cos(\theta_{ij} + \delta_i + \delta_j) \tag{3}$$

$$Q_i = -\sum_{j=1}^{n} |Y_{ij}||V_I||V_j| \sin(\theta_{ij} + \delta_i + \delta_j) \tag{4}$$

When equation 3 and 4 are expanded using Taylor's series about the initial estimate and by neglecting all the higher order terms, following set of linear equations is obtained,

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{ccc|ccc} \frac{\partial P_2}{\partial \delta_2}^{(k)} & \cdots & \frac{\partial P_2}{\partial \delta_n}^{(k)} & \frac{\partial P_2}{\partial |V_2|}^{(k)} & \cdots & \frac{\partial P_2}{\partial |V_n|}^{(k)} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_n}{\partial \delta_2}^{(k)} & \cdots & \frac{\partial P_n}{\partial \delta_n}^{(k)} & \frac{\partial P_n}{\partial |V_2|}^{(k)} & \cdots & \frac{\partial P_n}{\partial |V_n|}^{(k)} \\ \hline \frac{\partial Q_2}{\partial \delta_2}^{(k)} & \cdots & \frac{\partial Q_2}{\partial \delta_n}^{(k)} & \frac{\partial Q_2}{\partial |V_2|}^{(k)} & \cdots & \frac{\partial Q_2}{\partial |V_n|}^{(k)} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Q_n}{\partial \delta_2}^{(k)} & \cdots & \frac{\partial Q_n}{\partial \delta_n}^{(k)} & \frac{\partial Q_n}{\partial |V_2|}^{(k)} & \cdots & \frac{\partial Q_n}{\partial |V_n|}^{(k)} \end{array}\right] \begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ \Delta |V_2^{(k)}| \\ \vdots \\ \Delta |V_n^{(k)}| \end{bmatrix} \tag{5}$$

Or, in short form,

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \tag{6}$$

Where,

ΔP and ΔQ represents the difference between specified and calculated values or real and reactive powers respectively.

J1, J2, J3, and J4 are the Jacobian matrix elements.

Δδ and Δ|V| are the bus angle vectors and voltage magnitude. After running simulation for load flow analysis, following is the summary of load flow analysis as shown in Table IV, V, and VI.

TABLE IV
SUMMARY OF TOTAL GENERATION

	MW	MVAR	MVA	%PF
Source (Swing Buses)	1296.4	18.1	1296.5	99.9
Source (Non-Swing Buses)	10623.1	892.5	10660.5	99.6

TABLE V
SUMMARY OF TOTAL LOADING

	MW	MVAR	MVA	%PF
Total Motor Load	9349.6	3738.6	10069.3	92.8
Total Static Load	2502.2	-1070.4	2721.5	91.9

TABLE VI
SUMMARY OF TOTAL DEMAND AND LOSSES

	MW	MVAR	MVA	%PF
Total Demand	11919.4	910.7	11954.2	99.7
Apparent Losses	171.2	-1757.5		

IV. TRANSIENT STABILITY ANALYSIS

Stability or power system stability is defined as the ability of a system to return to steady state without losing synchronism. Power system stability can be classified into following types as shown in Fig. 2.

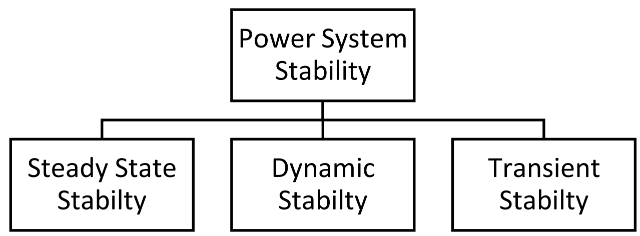

FIGURE 2. Types of stability

Steady state stability can be defined as the ability of a system to return to its initial state after small disturbance in the network and it usually involves load variations in power system.

Dynamic stability which usually takes Automatic Voltage Regulator (AVR) and governor system responses into account and is defined as the ability of a system to return to steady state following a significant disturbance.

Transient stability can be defined as the ability of a power system to return to steady state after experiencing a sudden change in generation, load or system characteristics.

For operation of power plants, stability is important as it may cause unplanned outage causing significant revenue loss. Transient stability analysis is used to evaluate the system performance as well as the power transfer capability of transmission lines when subjected to a fault by observing certain parameters such as rotor angle, frequency, speed, and bus voltage.

In the present study, two fault cases are considered. In each case, a three-phase fault is inserted each time with a different bus location in the network. The simulation is run initially for 1 second for pre-fault steady state values. The fault is inserted at selected locations for duration of 100 milli seconds (5 cycles) at 1 second. The fault is cleared at 1.1 second along with the tripping of a transmission line as shown in Table VII. The simulation is run for a total time of 20 seconds subsequently. For each case, certain parameters such as bus frequency, bus voltage, generator speed, generator relative rotor angle etc. are monitored and the graphs are plotted for a total time of 20 seconds.

TABLE VII
FAULT SCENARIOS

Case No.	3-Phase Fault Location	Transmission Line Outage
1.	HPR-1000 500kV bus	HPR-1000 - JAMSHORO 500kV S/C out
2.	JAMSHORO 500kV bus	HPR-1000 - JAMSHORO 500kV S/C out

V. RESULTS OF ANALYSIS

A. Case 1

For case 1, a 3-phase fault was inserted on the 500kV bus of HPR-1000. This is a near end fault and its severity is much more than a far end fault. For this scenario, the observed parameters of HPR-1000 power plant include generator rotor angle, frequency and bus voltage. It can be seen from Fig. 3 that, when the 3-phase fault occurred at the 500kV bus of HPR-1000 power plant, the frequency increases by 0.6% at the time of fault and there is a spike in frequency for a short interval of time. As the fault is cleared, the frequency reaches its steady value after some damping oscillations thus maintaining stability.

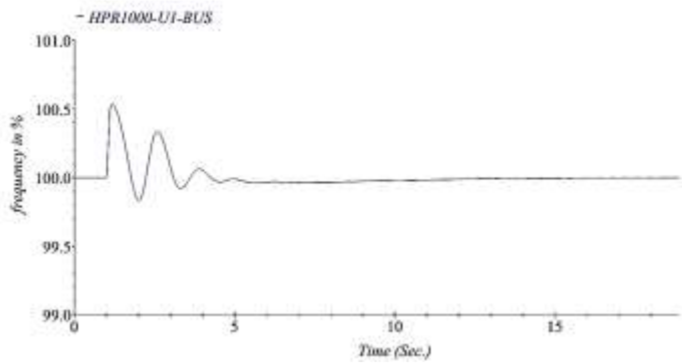

FIGURE 3. Bus Frequency

Similarly, from Fig. 4, it can be seen that the generator rotor angle deviated from its initial value and reached 70 degrees within short interval of time. As the fault is cleared at 1.1 s the rotor angle reaches a steady state value at 6 s after some oscillations.

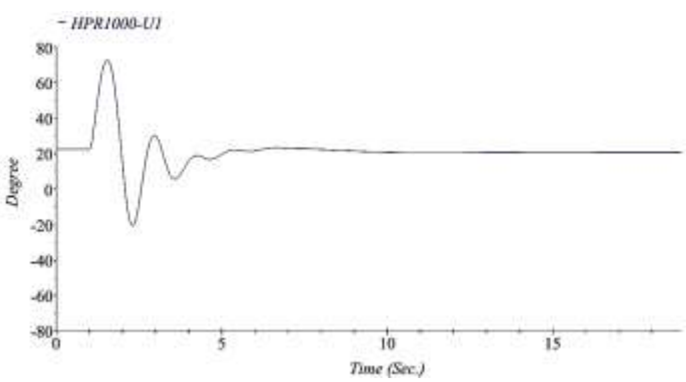

FIGURE 4. Generator Rotor Angle

From Fig. 5, it can be seen that the bus voltage dropped to zero as the fault was on the HPR-1000 500kV bus which is a near end fault and has a huge impact on the generators. As the fault is cleared at 1.1 s the voltage reaches a steady state to its initial value after some oscillations at around 6 s.

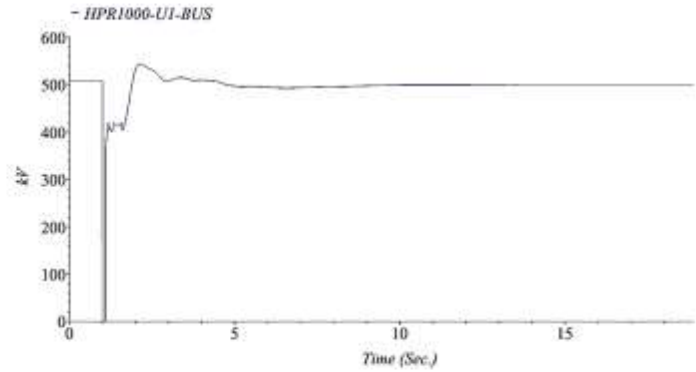

FIGURE 5. Bus Voltage

B. Case 2

For case 2, the observed parameters of HPR-1000 power plant include generator speed, rotor angle and bus voltage. It can be seen from Fig. 6 that when the 3-phase fault occurred at JAMSHORO bus, the speed of generator increases to 1512.50 RPM from its initial value of 1500 RPM at the time of fault which is indicated by the spike in the plot at 1.1 s. As the fault is cleared, the speed reaches its initial value after some oscillations at 7 s and stability is maintained.

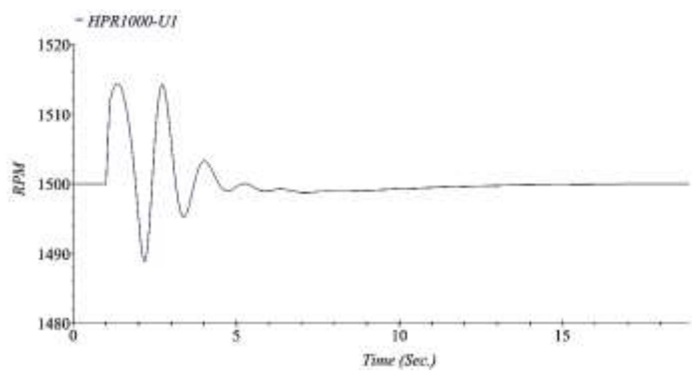

FIGURE 6. Generator Speed

Similarly, from Fig. 7, it can be seen that the generator rotor angle deviated from its initial value and reached 88 degrees within short interval of time. As the fault is cleared at 1.1 s the rotor angle reaches a steady state value at 7 s after some oscillations.

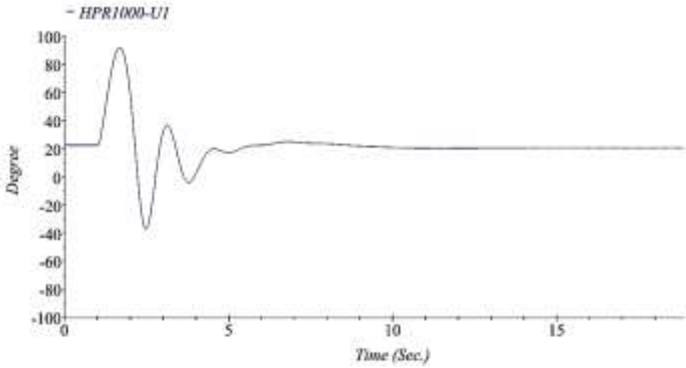

FIGURE 7. Generator Rotor Angle

From Fig. 8, it can be seen that in this case as the fault was away from the 500kV bus of HPR-1000, so the bus voltage did not drop to zero as was seen in the previous case. As the fault is cleared at 1.1s, the voltage increases to its initial value after some oscillations returns to normal voltage at around 7s.

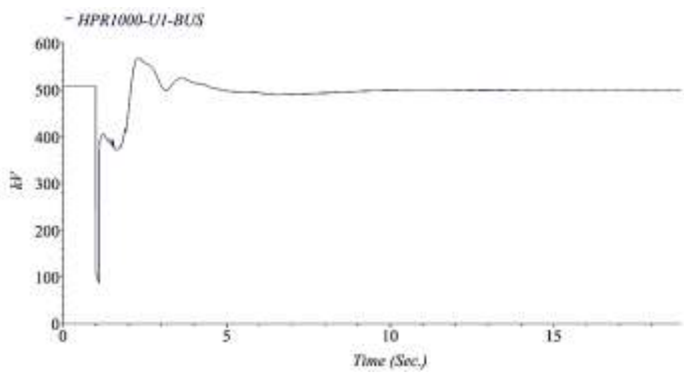

FIGURE 8. Bus Voltage

The summary for the above monitored parameters for both the above discussed scenarios is shown in Table VIII. It was observed that the system remained stable and the observed parameters also returned to a steady state value which can be seen from their respective plots, and the oscillations die out with in 7 secs which is in line with the stability criteria as discussed by P. Kundur *et al.* in [10].

TABLE VIII

SUMMARY OF RESULTS

Case No	Fault Location	Circuit Outage	Figure	Monitored Parameter	Result
1	HPR-1000 500kV Bus	HPR-1000 to JAMSHORO S/C	3	Bus Frequency	Stable
			4	Generator Angle	Stable
			5	Bus Voltage	Stable
2	JAMSHORO 500kV Bus	HPR-1000 to JAMSHORO S/C	6	Generator Speed	Stable
			7	Generator Angle	Stable
			8	Bus Voltage	Stable

VI. CONCLUSION

In present study, NTDC 500kV network is modelled with HPR-1000 in ETAP software which is really helpful in analyzing the transient stability of system. The load flow analysis is performed afterwards using Newton Raphson method to obtain the initial conditions as it serves as the basis for transient stability analysis. The transient stability analysis performed in different scenarios demonstrates that the system remains in synchronism after the occurrence of a fault. Parameters of HPR-1000 such as speed, frequency, voltage and rotor angle for different fault scenarios show that HPR-1000 will remain stable and maintain synchronism under different fault scenarios.

VII. REFERENCES

[1] P. Kundur, N. J. Balu, and M. G. Lauby, Power system stability and control, New York: McGraw-hill, 1994. pp.30-46

[2] IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis, IEEE Standard 399, 1997.

[3] Chapter 14, Economic Survey of Pakistan 2020-21, pp. 285–296, July 2021.

[4] “Pakistan 2020,”Available: https://pub.iaea.org/MTCD/Publications/PDF/cnpp2020/countryprofiles/Pakistan/Pakistan.htm. [Accessed: 24-Nov-2021][Online].

[5] J. S. M. S. Mazliham, Md parves Alam Muhammad Junaid Tahir, “Transient stability analysis: evaluation of IEEE 9 bus system under line fault conditions,” *Journal of Engineering Technology*, vol. 5, pp. 54–58, Dec. 2017.

[6] D. S. Reddy and C. S. Kumari, "Transient Stability Analysis of a Combined Cycle Power Plant Using Etap Software," in *IEEE 7th International Advance Computing Conference (IACC)*, Hyderabad, India, 2017, pp. 510-515.

[7] D. Prakash, E. Vinay, and K. Tripathi, “Enhancing Stability of Multi-Machine IEEE 9 Bus Power System Network Using PSS,” *Int. J. Adv. Res. Electr. Electron. Instrum. Eng.*, vol. 4, no. 5, pp. 4483–4490, May 2015, 10.15662/ijareeie.2015.0405082.

[8] P. Maniraj and M. Yuvaraj, “Transient Stability Analysis for 6 Bus System Using E-Tap,” *Int. Journal of Pure and Applied Mathematics*, vol. 118, no. 20, pp. 2277–2285, 2018.

[9] Kavitha R, “Transient Stability of IEEE-30 bus system using E-TAP Software,” *International Journal for Scientific and Engineering Research*, Vol. 3, Issue 12.

[10] P. Kundur et al., "Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions," in IEEE Transactions on Power Systems, vol. 19, no. 3, pp. 1387-1401, Aug. 2004, 10.1109/TPWRS.2004.825981.