Available online at www.worldscientificnews.com

World Scientific News

An International Scientific Journal

WSN 158 (2021) 267-284 EISSN 2392-2192

Power System Transient Stability Case Study: A Power Sub-Station Plant in Sudan

Asma Abbas[1,2,a], Kamal Ramadan Doud[1,b], Elmustafa Sayed Ali Ahmed[2,c]

[1]Department of Electrical and Electronic Engineering, University of Khartoum, Khartoum, Sudan

[2]Department of Electrical and Electronic Engineering, Red Sea University, Port Sudan, Sudan

[a-c]E-mail address: asma_alki@yahoo.com , kamalramadan@uofk.edu , elmustafasayed@gmail.com

ABSTRACT

Power system stability is defined by the tendency of the energy system to develop recovery forces equal or greater than the disturbing forces to maintain a stable equilibrium state. In general, power system stability problems are usually divided into two parts, steady state and transient state. An extension of steady-state stability is dynamic stability. Transient stability deals with the effects of large disturbances such as malfunctions, sudden line interruptions, and sudden application or load removal. This research is presents load angle method to transient stability problem for multi-machine system. The ETAP program is used to simulate the above method to study transient stability. A sub-station plant in Khartoum (GARRI) with four generation sections (1, 2 and 4) has been taken as a case study. The simulation result shows that when a single line-ground fault occurs at main busbar and cleared at time t = 0.4 sec the system is stable, in case 2, when the same fault cleared at t = 3 sec the system become unstable.

***Keywords*:** Transient Stability, Dynamic Stability, GARRI power stations, synchronism, Swing Equation, power angle

(Received 25 May 2021; Accepted 15 June 2021; Date of Publication 16 June 2021)

1. INTRODUCTION

The concept of system stability expresses the ability of the system to return to the steady state in the event of any disturbance to the system, and it has a special effect on synchronous generators that operate in conjunction with the rest of the system [1]. The synchronization process between the generator and the bus takes place at the same frequency, voltage and phase sequence.

Therefore, we find that the stability of the power system depends on the ability of the system to return to its stable state without the occurrence of loss of synchronization [2]. Usually, power system stability is categorized into Steady State, Transient and Dynamic Stability. With the great expansion of electric power grids, power systems have become extremely complex and highly sensitive when electricity cuts even in short periods, which can lead to dire consequences. The stability of the power systems leads to the stability of the electrical supply, but when some disturbances occur, the supply is affected, especially when the synchronous machines are present. As the transient signals lead to instability [3].

Any sudden change in voltage or current in the power system leads to the occurrence of the transient state, which reduces the quality of performance. Power control Many problems can be solved by improving the quality of performance [4]. This research is developed to find the critical time clearing and power angle of a system for a given fault conditions. The rest of this paper is organized as follows; section 2 provides a background and concepts related to the electrical power system stability. In section 3, the theoretical concepts of transient stability are provided. Different methods for transient stability improvement are presented in section 4. In section 5, the simulation model of transient stability analysis for Garri station case study is reviewed. The simulation results and discussion are presented in section 6. Finally, in section 7, the paper conclusion and future direction are provided.

2. BACKGROUND

When faults occur in the power system, the electrical power from generators close to failure is greatly reduced. Also, the remote generators may be affected due to the malfunction. Sometimes the power system remains stable even when a continuous error occurs [5]. However, this often happens, as the fault needs to be repaired quickly enough to maintain the stability of the system. The stability of the system depends on the type of failure, its location, clearing time, and the method of filtering. There are three main types of power system stability [6] (see Figure 1). The transient stability limit depends on the type, location, and size of the disorder and is almost always below the steady-state limit. Steady-state stability is defined as the ability of a system to develop recovery forces equal or greater than the disturbing force and to remain in equilibrium or synchronization after small and slow disturbances [7]. These strikes may be sudden due to sudden change in pregnancy, switch operation, loss of generation, and fault. Dynamic stability defines the system's ability to maintain stability under continuous small disturbances, also known as small signal stability [8].

Transient stability represents the power system ability to maintain synchronization when subjected to severe transient disturbance such as a malfunction, sudden line disconnection and application or removal of loads [9]. The resulting system response includes large trips to the generator rotor angles and is affected by the nonlinear power angle relationship.

Transient stabilization is a rapid phenomenon, usually occurring within one second of a generator close to the disturbing cause. The aim of studying transient stability is to ascertain whether the loading angle returns to a steady value after the turbulence is removed. Faults in heavily loaded lines are more likely to cause instability than fault in lightly loaded lines [10]. This, because they tend to produce more acceleration during a fault.

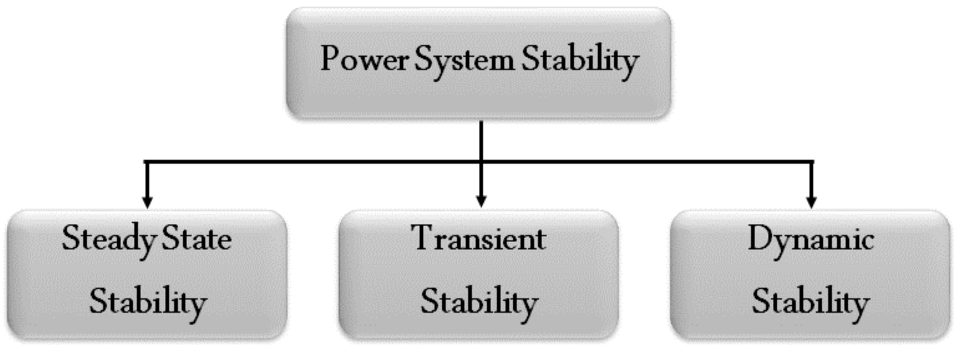

Figure 1. Types of Power System Stability.

Three phase faults produce accelerations greater than those involving single or two-phase conductors. Faults not cleared by an initial fault produce more angle deviations in nearby generators. The backup fault clearance is performed after a time delay and thus produces heavy fluctuations [11]. Large load loss or main generating station results in major system disturbance. In transient stability, various influence factors have to be taken into account, such as generator inertia, generator load, generator output. However, it depends on fault location and fault type, fault clearance time, transmission system reactance after fault, generator reactance, and generator internal voltage size [12]. This depends on the excitation of the field, i.e. the power factor of the transmitted power at the generator stations, and the magnitude of the infinite voltage of the bus [13].

3. THEORITICAL STUDY FOR TRANSIENT STABILITY

Transient stability is disturbances that occur for a very short time in electrical. In transient to occur, there has to be a cause like some of the most common causes related to atmospheric phenomena like lightning, solar flares, in addition leads switching, fault currents interruption, switching power lines, and capacitor bank switching [14]. The power system consists of a number of synchronous devices that operate simultaneously under all operating conditions. Under normal conditions, the relative position of the rotor axis and the axis of the resulting magnetic field are fixed.

The angle between the two is known as power angle or torque angle [15]. During any disturbance, the rotor decelerates or accelerates with respect to the synchronously rotating air gap mmf, creating relative motion. The power exchange between the mechanical rotor and the electrical network due to the rotor acceleration and deceleration is called an inertial response. The circuit is quickly restored to the original operation under the condition that no damage occur (see Figure 2).

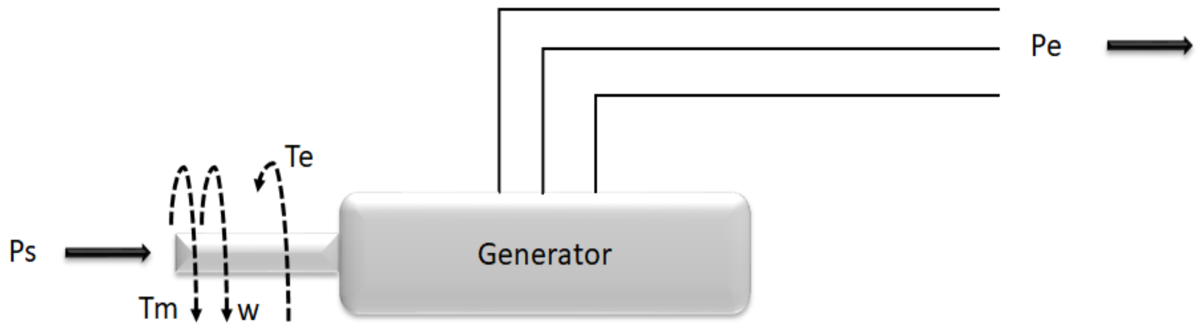

Figure 2. Generation Unit.

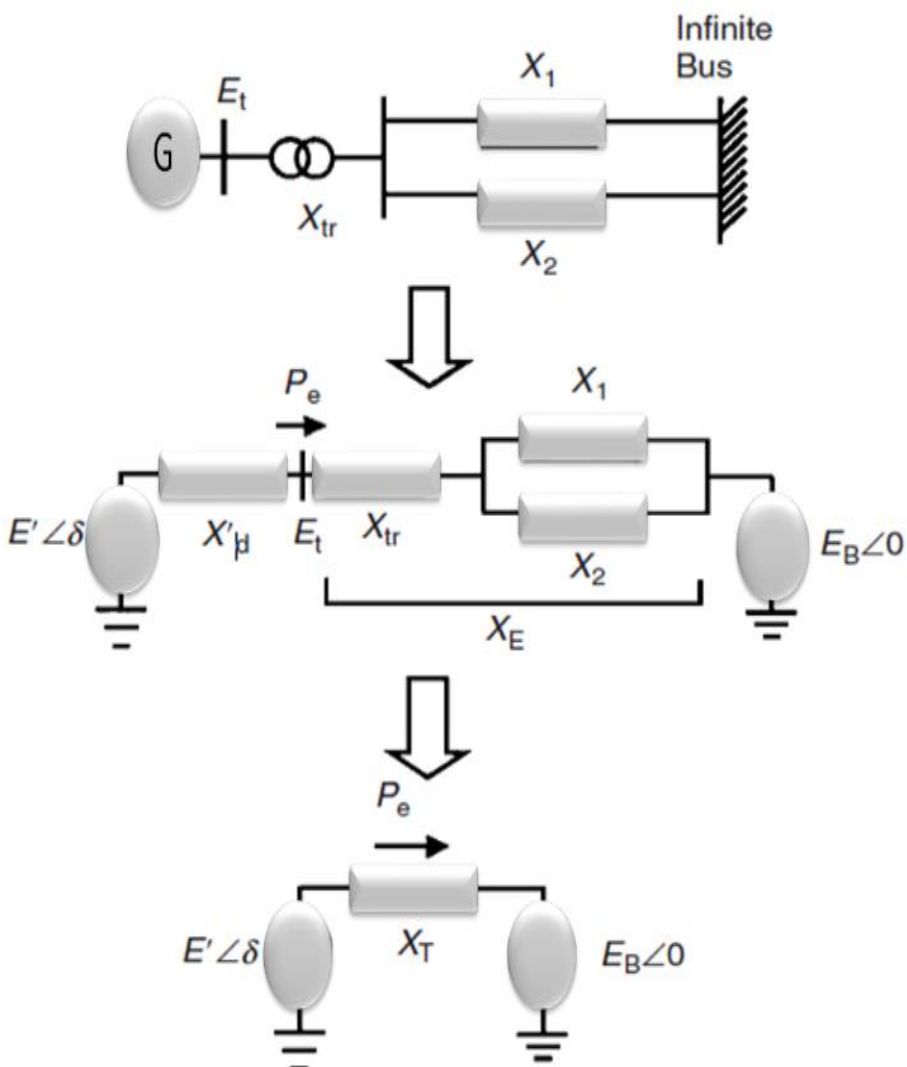

Figure 3. Simple Model of a Generator Connected to an Infinite Bus.

In a synchronous machine, the prime mover exerts a mechanical torque T_m on the shaft of the machine and the machine produces an electromagnetic torque T_e [16]. If, as a result of a disturbance, the mechanical torque is greater than the electromagnetic torque, an accelerating torque T_a exists and is given by equation 1:

$$T_a = T_m - T_e \quad (1)$$

By ignores the other torques caused by friction, core loss, and windage in the machine. T_a has the effect of accelerating the machine, which has an inertia J (kgm^2) made up of the inertia of the generator and the prime mover and therefore:

$$J\frac{dw_m}{dt} = T_a = T_m - T_e \quad (2)$$

where t represents the time in seconds and w_m is denoted for angular velocity of the machine rotor in mechanical rad/s [17]. It is common practice to express this equation in terms of the inertia constant H of the machine.

A simple model of a single generator connected to an infinite bus through a transmission system is shown in Figure 3. The model can be reduced as shown by replacing the generator with constant voltage behind a transient reactance (classical model). It is well known that there is a maximum power that can be transmitted to the infinite bus in such a network [18]. The relationship between the electrical power of the generator p_e and the rotor angle of the machine d is given by equation 3.

$$p_e = \frac{E`E_B}{X_T}\sin\delta = p_{max}\ \sin\delta \quad (3)$$

$$p_{max} = \frac{E`E_B}{X_T} \quad (4)$$

An increase in X_T leads to reduction in p_{max}. It observed that for the same mechanical input (Pm1), the situation with one line removed causes an increase in rotor angle to δ [19].

4. TRANSIENT STABILITY IMPROVEMENT METHOD

The transient stability is defined as the ability of a power system to maintain the generators in synchronism and reach acceptable steady-state operating conditions when subjected to large disturbances such as short circuits, loss of large generating units, loss of critical network branches, or large load variations [20]. The system data collected, includes generators' parameters, network impedances, loads, control parameters and settings, various constraints and limits, relay settings. All this information must be provided to the transient stability analysis software [21].

A. High Speed Fault Clearing

Since the amount of kinetic energy gained during a fault is directly proportional to the duration of the fault, the error elimination is faster in stability. Fast acting circuit breakers eliminate fault in two cycles through better contact and fast acting relays [22].

B. Dynamic Braking

While a fault occurs, the mechanical power input to the generator is greater than the output electrical power which will accelerate the generator rotor. Alternatively, the excess energy available due to the mismatch between the input and output forces can be absorbed by the resistors, which can be connected to the generator terminals during the fault [23]. These are called throttle resistors because they will reduce the rotor acceleration by absorbing the excess energy. The disadvantage is that energy is lost in the form of heat dissipation of the resistors.

C. Single switching

Instead of tripping all three phases and then re-closing each simultaneously, each phase can be tripped and re-closed from 0.5 to 1.5 seconds. So that another two phases are still operating in the event of a single line to ground fault because they are the most common faults [24]

D. Independent Operation of Circuit Breakers

Instead of switching out all the three phases for every fault only the faulted phase may be switched out. This will significantly improve the stability [25].

E. Fast valve operation

The steam valves operate in a specific manner to reduce the power of the generator accelerated or slow after receiving serious failure in the transmission system. This technology can be used on thermal modules to help maintain the stability of the power system [25].

5. CASE STUDY: GARRI POWER STATIONS PLANT SIMULATION MODEL

The main objective of this paper is to study the transient stability for GARRI power stations plant (1, 2 and 4), 11 kV and 220 kV bus bars using (ETAP 12.6) simulation program. Power system analysis program (ETAP12.6) is used to determine the fault levels network using parameters provided by GARRI power stations plant. The simulation model in ETAP for the study system is shown in Figure 4. In the simulation, we conduct the load flow analysis of the whole system. When running load flow using ETAP, it's found that all buses are regulated and no buses are under voltage or over voltage problems. Similarly, no generators are overloaded and also other protecting instruments. The minimum voltage occurred is only at 11kV buses that are about 92%.

The Load flow studies have been performed at various monitoring points using ETAP, in which Newton–Raphson (NR) method is used. Here number of iterations used is 99. Transient stability analysis is analyzing whether the system is stable under severe disturbances or it loses synchronism or not during faulty conditions.

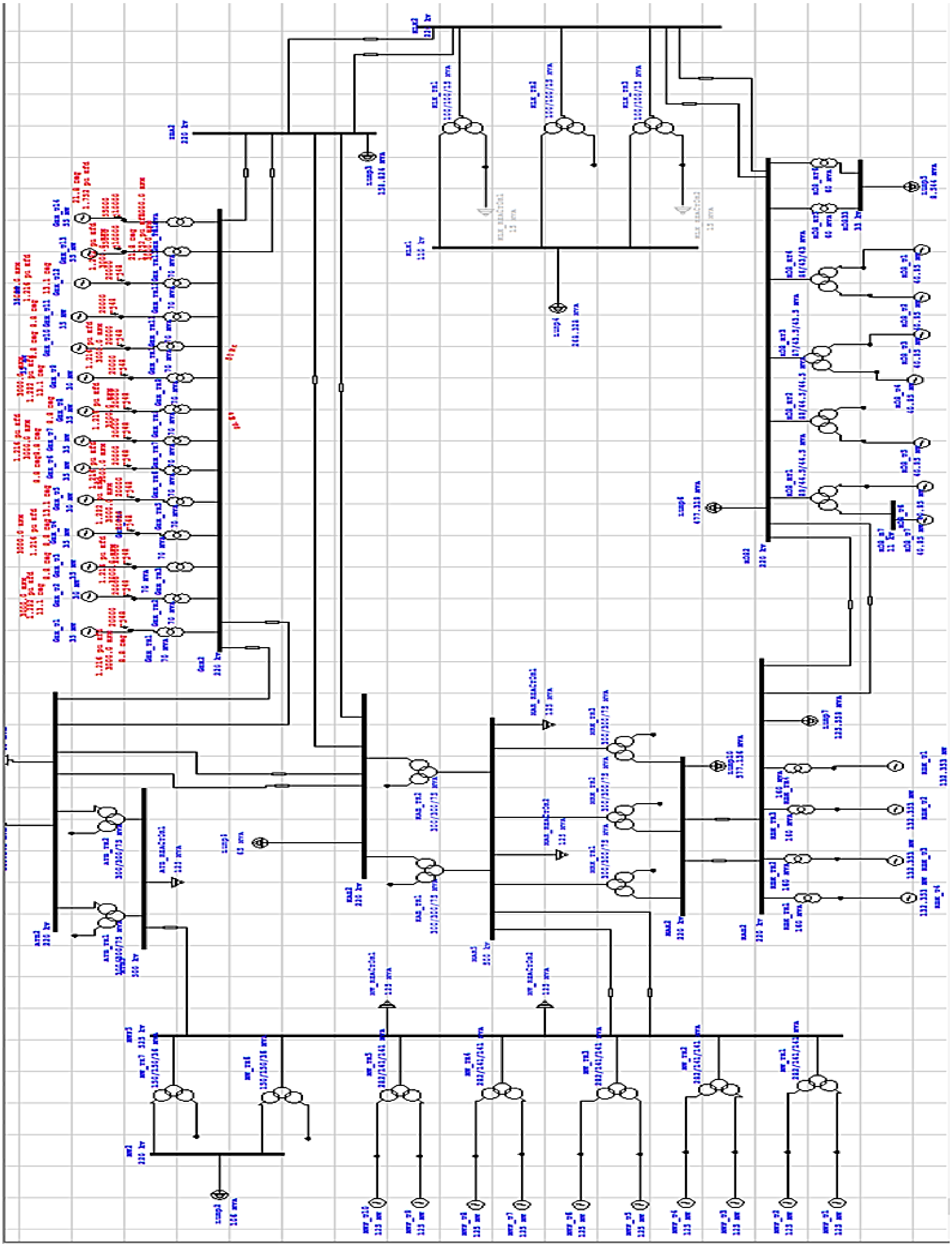

Figure 4. Simulation model in ETAP

First, we are applying a line to ground fault at main bus of GARRI at 0.02 sec and clearing the fault at 3 sec. This continuous till it becomes unstable. Second, we are applying a line to ground fault at main bus of GARRI at Creating an event in ETAP at t = 0.2 sec and clearing the fault at t = 0.4 sec using Newton-Raphson method with 99 iterations. This continuous till it becomes stable.

6. SIMULATION RESULTS AND DISCUSSION

In case 1, the fault is occurred at t = 0.2 sec and cleared at time t = 0.4 sec. The system is found to be stable. The second case 2, where the fault is occurred at t = 0.02 sec and cleared at time t = 3 sec, the system is unstable (Tables q = 1 and 2). These results are for all generation in the main bus-bar in GARRI power stations plant. The calculations are conducted in different units as follows.

In all units, these are: Gen 1, Gen 3, Gen 4, Gen 5, Gen 7, Gen 8, and Gen 10.

Table 1. Case 1 Fault Occurrence.

Fault	Cleared
t = 0.2 sec	t = 0.4 sec

Table 2. Case 2 Fault Occurrence.

Fault	Cleared
t = 0.02 sec	t = 3 sec

A. CASE 1: 35 MW Gas Units

The gas turbine installations are thermal machineries that convert the chemical energy, stored in the primary fuel, into mechanical energy. The working fluid used in this case is a gas (air, carbon dioxide, helium etc.) and change to electrical energy. Fault occur at t = 0.2 sec and clear the fault at t = 0.4 sec the fault is cleared by tripping the faulty element but without changing the equivalent network impedance but in the second (Figure 6), we find that the Fault occur at t = 0.02 sec and clear the fault at t = 3 sec the system is becoming unstable.

Table 3. 35 MW Gas Unit Stability.

Cleared time	System
$t \leq 0.4$ sec	stable
$t > 0.4$ sec	unstable

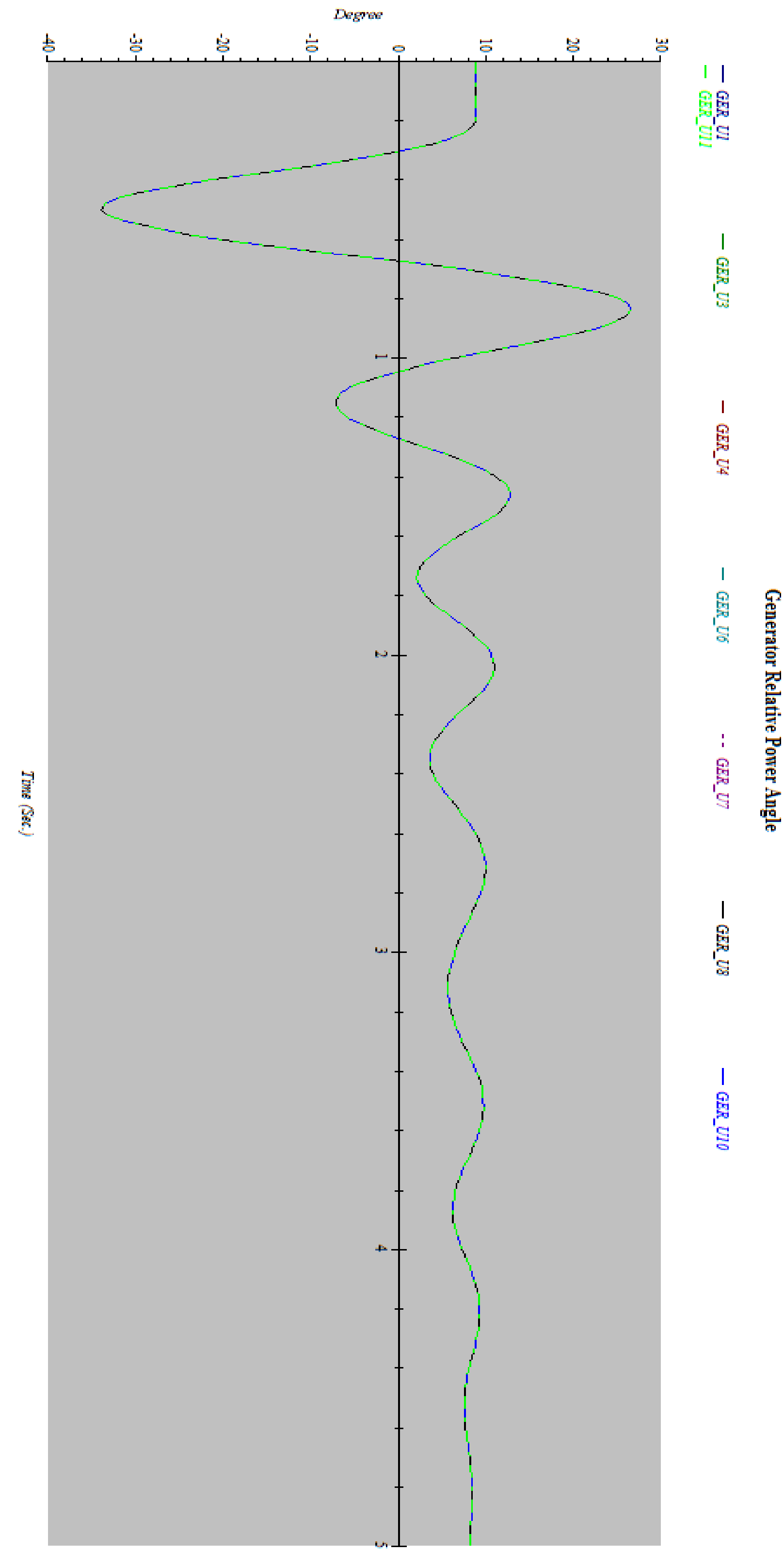

Figure 5. Load angles Vs Time for 35 MW Gas Unit Stable system.

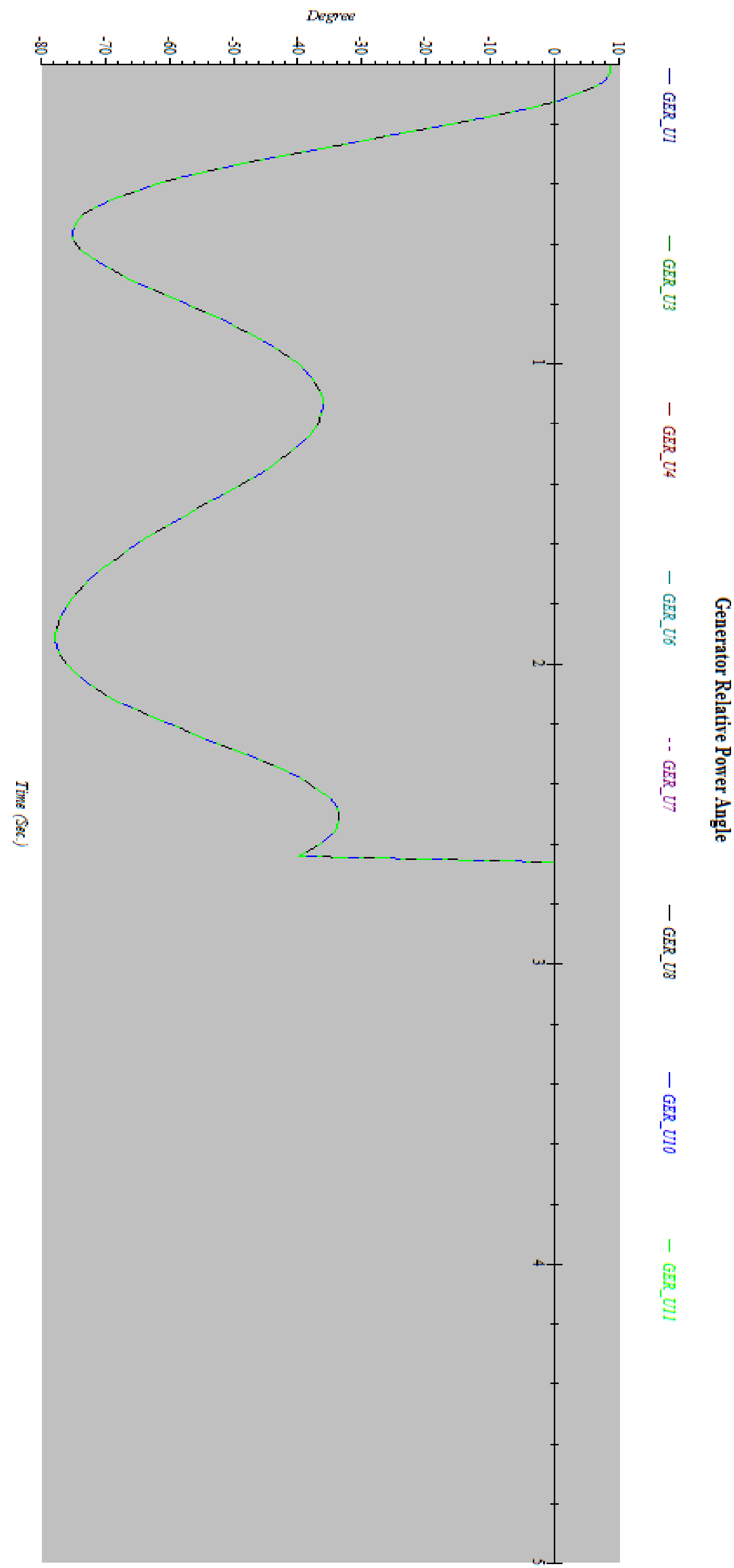

Figure 6. Load angles Vs Time for 35 MW Gas Unit Unstable system.

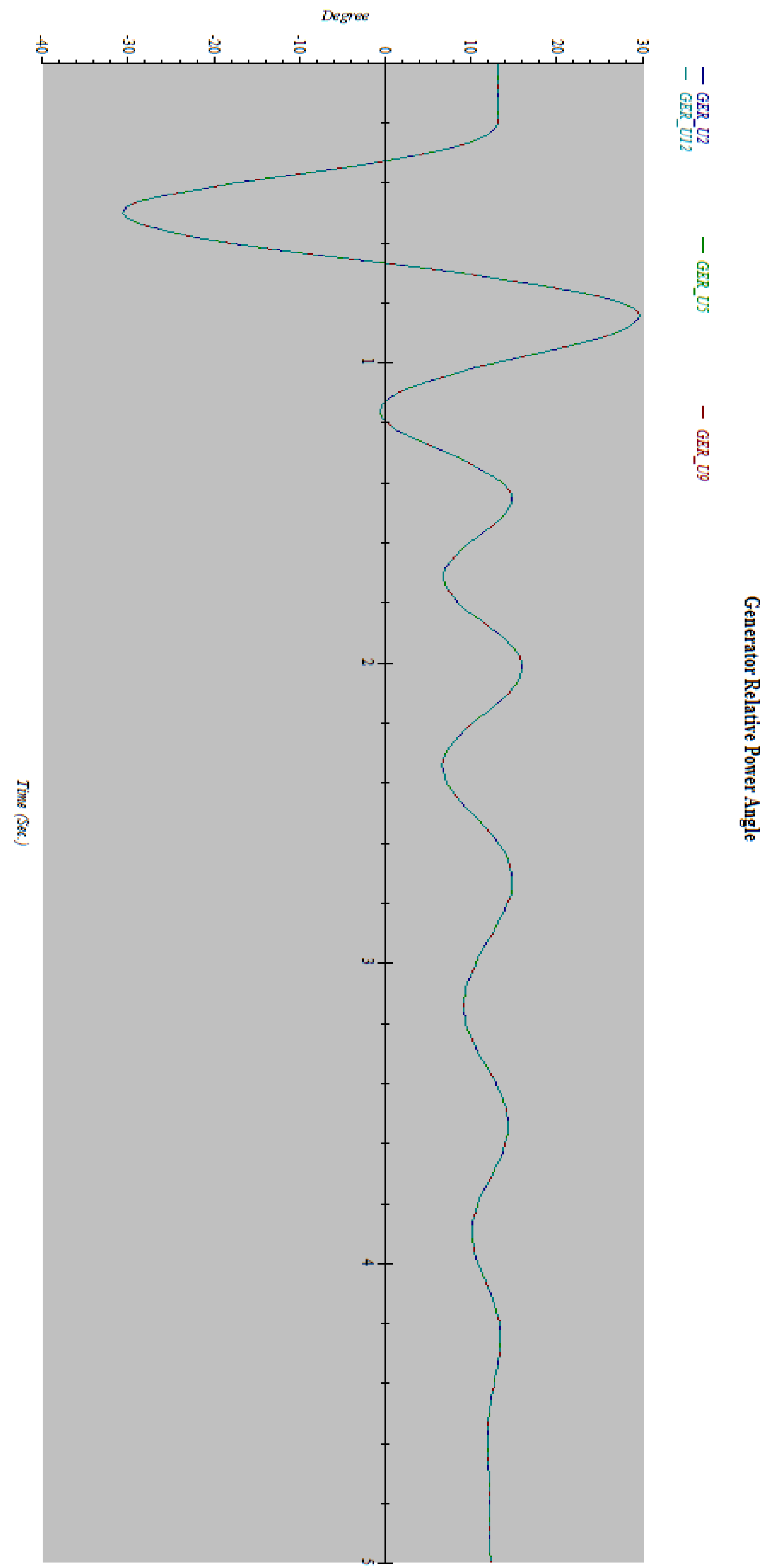

Figure 7. Load angles Vs Time for 30 MW Steam Unit Stable system

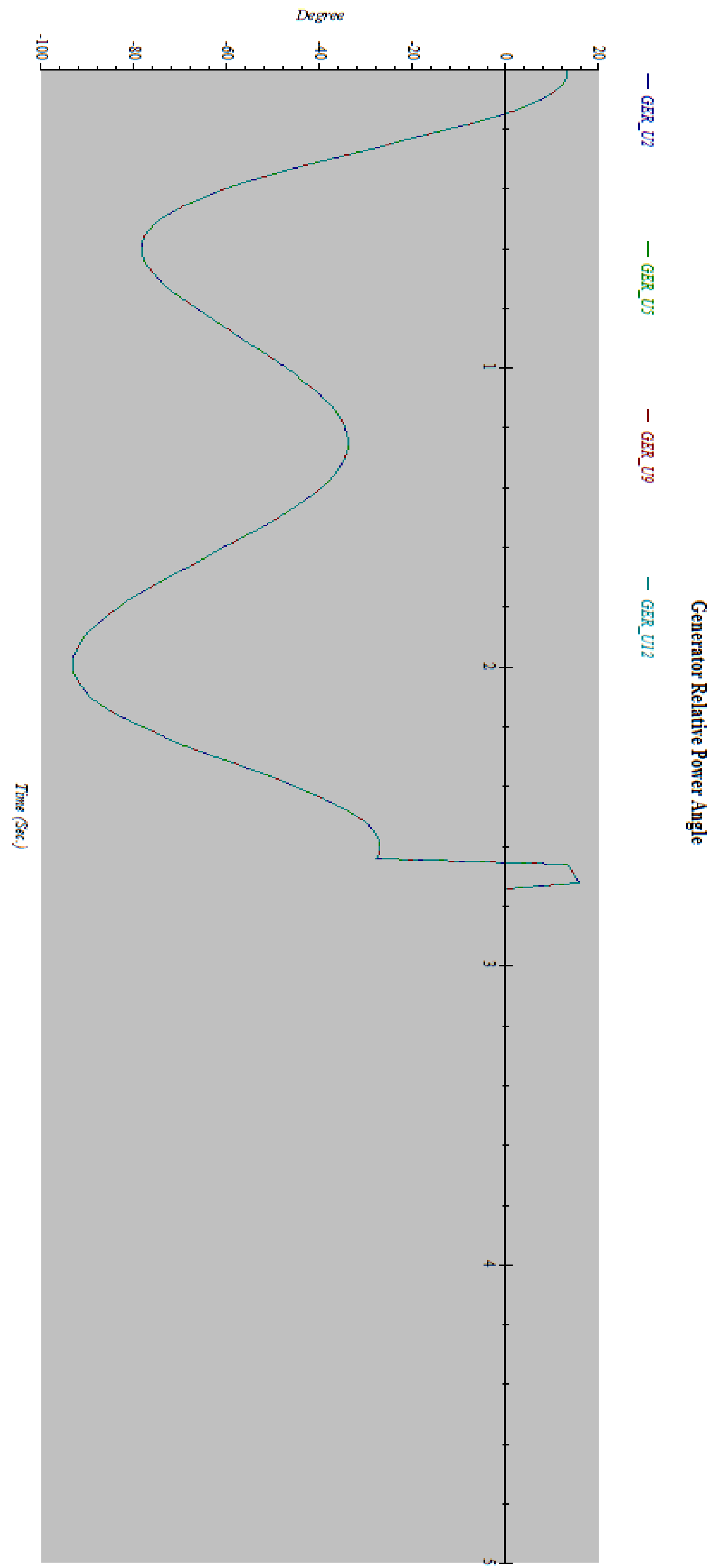

Figure 8. Load angles Vs Time for 30 MW Steam Unit Unstable system

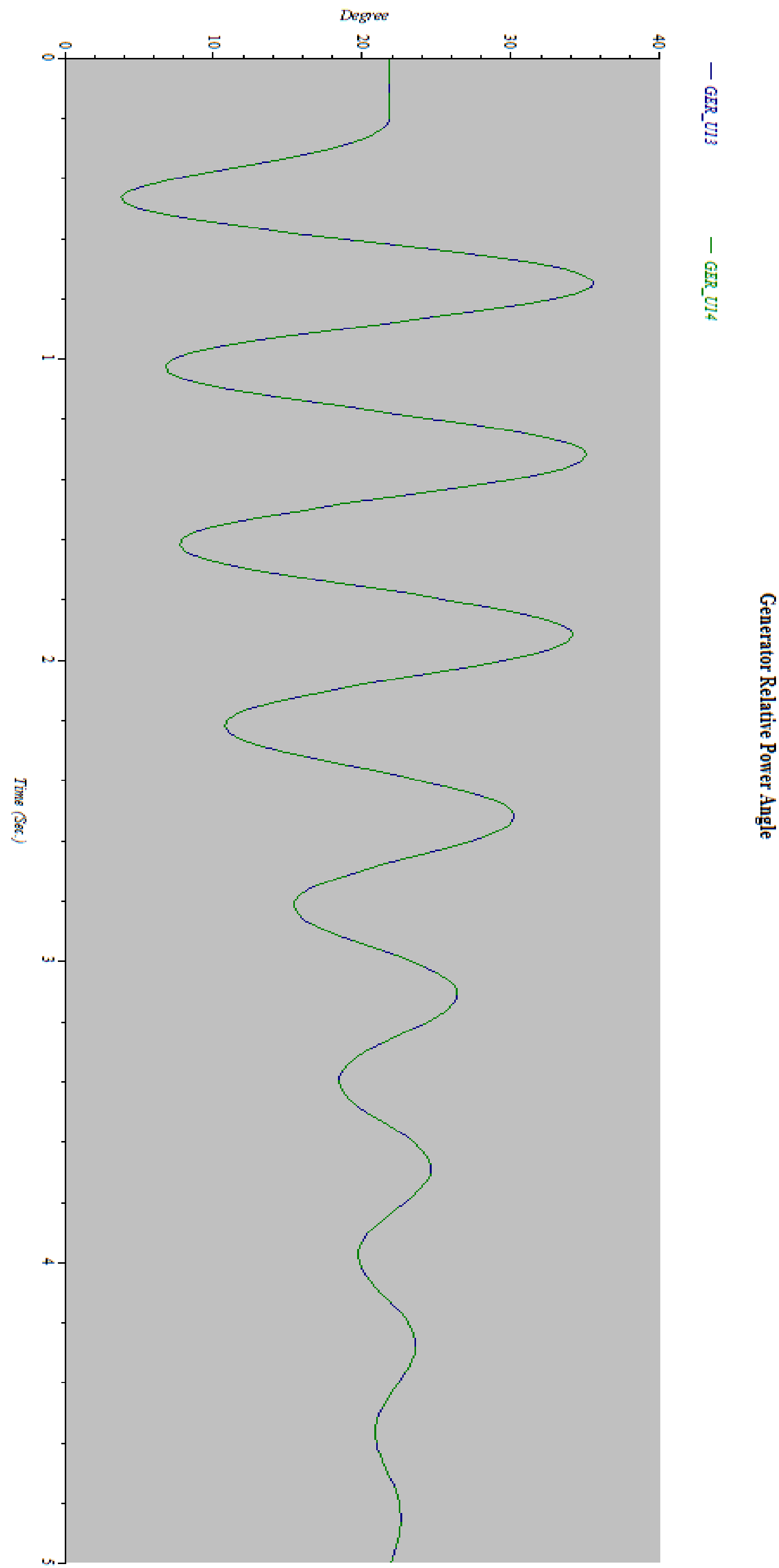

Figure 9. Load angles Vs Time for 55 MW Steam Unit Stable system

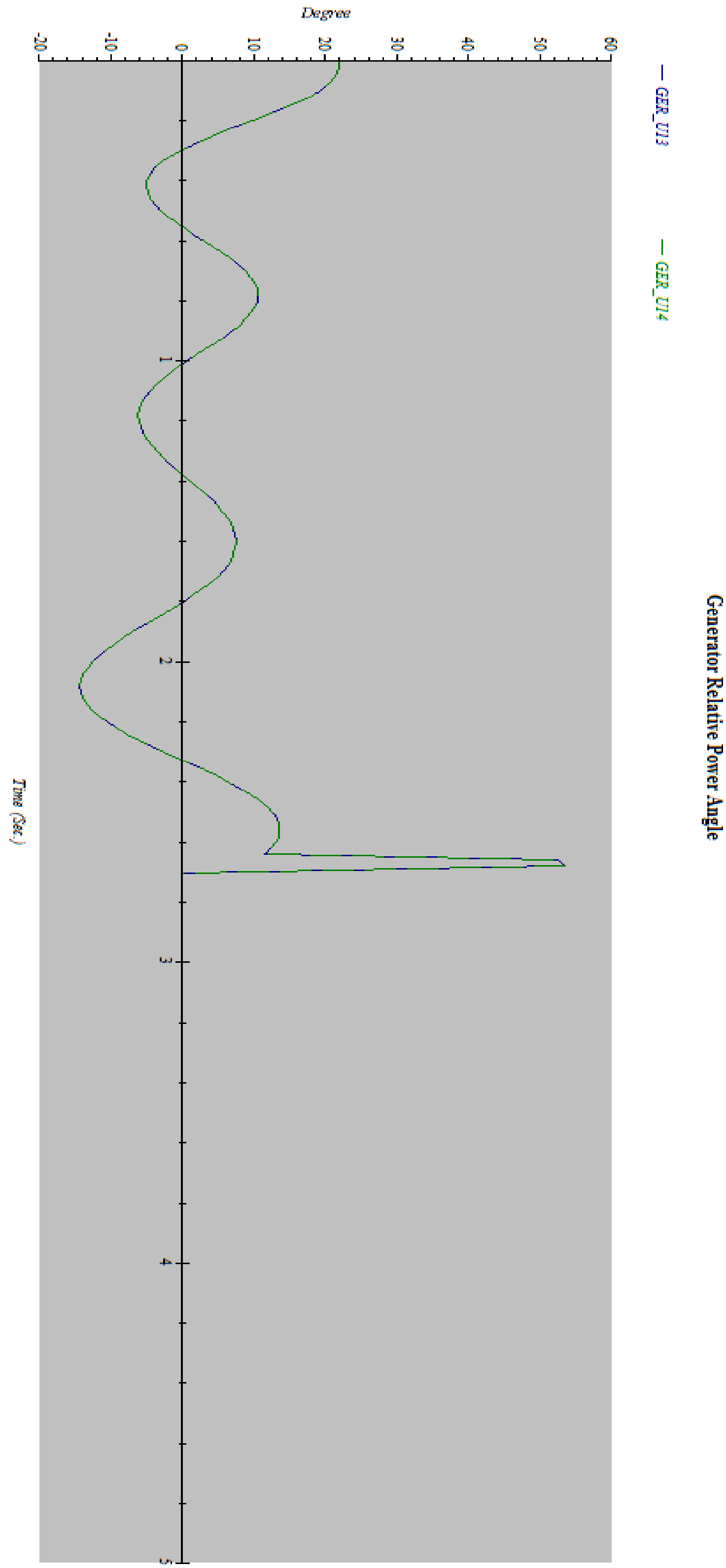

Figure 10. Load angles Vs Time for 55 MW Steam Unit Unstable system

B. CASE 2: 30 MW Steam Units

The steam turbine, converts stored energy of high pressure and high temperature steam into rotating energy, which is in turn converted into electrical energy by the generator. The heat source for the boiler supplying the steam is furnace fired by fossil fuel (coal, oil or gas). There are: Gen 2, Gen 5, Gen 9, and Gen 12. We can determine the fault clearing time corresponding to the load angle, when the Fault occur at t = 0.2 sec and clear this fault at t = 0.4 sec, we find that the system is stable. Otherwise when the fault is occurring at t = 0.02 sec, and clear this fault at t=3sec, the system is becoming unstable (see Figures 7 & 8).

Table 4. 30 MW Steam Unit Stability.

Cleared time	System
$t \leq 0.4$ sec	stable
$t > 0.4$ sec	unstable

C. CASE 3: 55 MW Steam Units

In this unite, we find the deferent figure shape not seem to the above unite. In this case, we notice that the load angle is in the positive vertical direction when malfunction occurs in time 0.2 sec and even when this malfunction is removed at time = 0.4 sec. Also, we notice that when the fault is happening in t = 0.02 sec, the load angle is approximately in positive direction until we remove fault at t = 3 sec.

Table 5. 55 MW Steam Unit Stability.

Cleared time	System
$t \leq 0.4$ sec	stable
$t > 0.4$ sec	unstable

From the about figures, we notice that in 35 MW Gas Units, the system is found to be stable when fault is cleared for time $t \leq 0.4$ sec and the system is unstable when fault is cleared in time $t > 0.4$. In 30 MW Steam Units, the system is found to be stable when fault is cleared for $t \leq 0.4$ sec for the first method and the system is unstable when fault is cleared in time $t > 0.4$ sec. In 55 MW Steam Units, the system is found to be stable when fault is cleared for $t \leq 0.4$ second for the first method and the system is unstable when fault is cleared in time $t > 0.4$ sec. From this case study, we find that for the stable operation the turbine must have a power-speed characteristic such that as the speed increases the mechanical input power reduces. Similarly, a decrease in speed should result in an increase in the mechanical Power. This will restore the balance between the electrical output power and mechanical input power (see Figures 9 & 10).

The output of this case study, the oscillations are damped out within < 0.4 Sec after the occurrence of the disturbance and the system is stable. We notice that the different between Gas unit and Steam unit is when the fault is cleared (damped the oscillation) t > 0.4 the unit is becoming unstable we find that in Gas unit we can't make restart to the unit until the speed is becoming zero, but the opposite is occurring in the steam unit, we can repair the damped when the speed between (1700-2000 rpm) before reach zero speed. This shows that in damping oscillations for the fault in the steam unit, we can control by the governor also control the boiling water. Finally, we can decrease all of this problem by increasing the cooling and decreasing the loading. Table 6 Shows the comparison study between the three types of generation units and stability performance in use for GARRI Power Stations Plant (1, 2 and 4) in Sudan.

Table 6. System Units Stability Performance

Turbine	Fault time cleared (Sec)	System Stability	Speed
35 MW gas unit	$t \leq 0.4$	Stable	Increase
	$t > 0.4$	unstable	Decrease / can't restart until reach zero
30 MW steam unit	$t \leq 0.4$	Stable	Increase
	$t > 0.4$	unstable	Repair damping before reach zero
55 MW steam unit	$t \leq 0.4$	Stable	Increase
	$t > 0.4$	unstable	Repair damping before reach zero [1700-2000 rpm]

7. CONCLUSION AND FUTURE WORK

The study case is presents load angle method to transient stability problem for multi-machine system. The ETAP program is used to simulate the above method to study transient stability. Transient stability for GARRI power stations plant (1,2 and 4) using ETAP simulation program for 220 kv main bus-bar in GARRI founded that after case study, case 1 fault at t = 0.2 sec, and cleared the fault at t = 0.4 sec the system is stable, case 2 when the same fault cleared at t = 3 sec. The system is unstable. Finally, GARI power station plant, can use this study to develop protection system, make review for setting system and recover all the unit.

For future work, there are suggestions to consider the use of NE plan program software for simulation and result. Investigates on load current, speed and power vs time. Protection and control, operating strategy, control settings of equipment i.e. power system stabilizer, relay settings, load shedding schemes etc., based on various study cases are considered as one of the vital topics that must be taken into account in an analysis of power stations system stability.

In addition, as the manual and traditional numerical analysis methods for power system stability characteristics are inefficient and probable to results errors. And it is possible to avoid some intangible processes in the power system as shown during the study. Therefore, the future study also aims to use a Machine Learning (ML) mechanism to evaluate the transient stability of the proposed power system in order to analyze the simulation data and know the characteristics related to the stability of the power grid and improve the operating mode determinant.

References

[1] Jovi Atkinson and Ibrahim M. Albayati, Impact of the Generation System Parameters on the FrequencyResponse of the Power System: A UK Grid Case Study. *Electricity* 2021, vol 2, page 143-157

[2] Lavr Vetoshkin and Zdenek Müller, A Comparative Analysis of a Power System Stability withVirtual Inertia. *Energies* 2021, vol 14, page 1-20

[3] Khalid Mehmood Cheema, A comprehensive review of virtual synchronous generator. *International Journal of Electrical Power & Energy Systems*, Volume 120, 2020, page 1-10

[4] Warren J., Farmer, Arnold J., Optimizing power system frequcney stabiloty using virsual intertia from invertor based renewable energy generation, *IET Renew. Power Gener*, 2020, vol 14, pages 2820-2829

[5] A. Tayyebi, D. Groß, A. Anta, F. Kupzog and F. Dörfler, Frequency Stability of Synchronous Machines and Grid-Forming Power Converters. *IEEE Journal of Emerging and Selected Topics in Power Electronics*, 2020, vol. 8, no. 2, pp. 1004-1018

[6] Lingling Li et al, Renewable Energy System on Frequency StabilityControl Strategy Using VirtualSynchronous Generator. *Symmetry* 2020, vol 12, pages 1-22

[7] Magdy, G.; Bakeer, A.; Nour, M.; Petlenkov, E. A New Virtual Synchronous Generator Design Based on the SMES System for Frequency Stability of Low-Inertia Power Grids. *Energies* 2020, 13, pages 1-17

[8] Shuhuan Wang, Li Han and Kai Chen. Improved Control Strategy of Virtual Synchronous Generator in Response to Power Grid Harmonics. *Automation of Electric Power Systems*, 2020, pages 115-135

[9] Huiqiang Sun, Adjustment of Active and Reactive Power of Synchronous Generator in Grid-connected Operation. *IOP Conf. Series: Earth and Environmental Science* 440, 2020, pages 1-7

[10] Arcadio Perilla et al, Power-Angle Modulation Controller to SupportTransient Stability of Power Systems Dominated by Power Electronic Interfaced Wind Generation. *Energies* 2020, vol 13, pages 1-20

[11] Junji Tamura et al, Enhancement of Power System Transient Stability bythe Coordinated Control between an AdjustableSpeed Pumping Generator and Battery. *Appl. Sci.* 2020, vol 10, pages 1-16

[12] Amirhossein Sajadi, Richard Wallace Kenyon, and Bri-Mathias Hodge, Inherent Synchronization in Electric Power Systemswith High Levels of Inverter-based Generation, arXiv:2104.04066v1 [eess.SY] 8 Apr 2021, pages 1-17

[13] Abdoli, O, Gholipour, M, Hooshmand, R. Improving synchronization stability of grid connected converters by virtual impedance. *IET Gener Transm Distrib*. 2021, vol 15, pages 1136-1143

[14] Ivan Viši ́c, Strnad I, Marušić A. Synchronous Generator Out of Step Detection Using Real Time Load Angle Data. *Energies* 2020, vol 13, pages 1-21

[15] Elechi, P., Ahiakwo, C.O. and Okwu, U.N. Transient Stability Analysis of 33 KV Transmission Network of Egi Community, Nigeria. *Journal of Power and Energy Engineering*, 2020, vol 8, pages 18-35

[16] Viacheslav Zakharov and Tatiana Minav, nalysis of Field Oriented Control of PermanentMagnet Synchronous Motor for a Valveless Pump-Controlled Actuator. *Proceedings* 2020, 64, 19, pages 1-12

[17] Ren J, ZhaoW, Wang X, Xing Z. Torsional vibration analysis of the surface-mounted permanent magnet synchronous machine using analytical model considering flux harmonics. *IET Electr. Power Appl*. 2021, vol 15, pages 501-511

[18] Jing, C.; Yan, Y.; Lin, S.; Gao, L.; Wang, Z.; Shi, T. A Novel Momentof Inertia Identification Strategy for Permanent Magnet Motor SystemBased on Integral Chain Differentiator and Kalman Filter. *Energies* 2021, vol 14, pages 1-23

[19] Jun Liu et al, An Improved Power System Transient StabilityPrediction Model Based on mRMR Feature Selectionand WTA Ensemble Learning. *Appl. Sci*. 2020, vol 10, pages 1-17

[20] Anvari Ghulomzoda et al, Recloser-Based Decentralized Control of the Gridwith Distributed Generation in the Lahsh District ofthe Rasht Grid in Tajikistan, Central Asia. *Energies* 2020, vol 13, pages 1-18

[21] Hak Kyu Lim, Jong-hoon Park, Effects of house load operation on PSA based on operational experiences in Korea, *Nuclear Engineering and Technology*, Volume 52, Issue 12, 2020, Pages 2812-282

[22] Fan, GF., Wei, X., Li, YT. et al. Fault detection in switching process of a substation using the SARIMA–SPC model. *Sci Rep* 2020, vol 10, pages 1-17

[23] Meegahapola, L.; Sguarezi, A.; Bryant, J.S.; Gu, M.; Conde D., E.R.; Cunha, R.B.A. Power System Stability with Power-Electronic Converter Interfaced Renewable Power Generation: Present Issues and Future Trends. *Energies* 2020, vol 13, pages 1-35

[24] M. Katsivelakis, D. Bargiotas and A. Daskalopulu. Transient Stability Analysis in Power Systems Integrated with a Doubly-Fed Induction Generator Wind Farm. *2020 11th International Conference on Information, Intelligence, Systems and Applications (IISA)*, 2020, pgaes 1-7

[25] Geon Kim, Jin Sung Lee, Jin Hyo Park, Hyun Duck Choi and Myoung Jin Lee, Zero Crossing Hybrid Bidirectional DC Circuit Breaker forHVDC Transmission Systems. *Energies* 2021, vol 14, pages 1-12