International Journal of Electrical and Electronics Engineering Studies
Vol.6, No.1, pp. 1-12, 2020
Published by ECRTD-UK
ISSN 2056-581X(Print), ISSN 2056-5828(Online)

TRANSIENT STABILITY ANALYSIS OF THE MULTIMACHINE POWER SYSTEM USING ETAP-SOFTWARE

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ABSTRACT: *This paper proposes a transient stability analysis of interconnected multi-machine power system using ETAP (Electrical Transient Analysis Program)-software. During the operation of existing power systems, the network is gradually approaching their transmission limits, and these raise many stability problems that might cause severe consequences. Once the system is stressed, many undesirable phenomena arise, and these can cause damage to different parts of the system. The mathematical models developed and tested in this paper describe the dynamics of the multi-machine power system, including the interaction between aggregates and components. The study involved analyzes an IEEE 39-bus system that has 10-generators connected. This was done by applying different contingency scenarios and configurations. The ETAP software was used to carry out Transient Stability Analysis, Load Flow Analysis, and Optimal Power Flow Analysis. The results have shown that, during contingency analysis, the generators connected to the grid experienced changes in power input, and those which were closer to the fault location had a more significant power deviation. Numerical simulation has been compiled with all the components such as generators, transmission lines, transformers, and devices to achieve these studies. The stability of the system has been observed base on the simulation graphs.*

KEYWORDS: Transient Stability Analysis, interconnected multimachine power system, ETAP-Software

INTRODUCTION

Network nodal and interconnection are increasing consistently; therefore, the studying of the behavior and limits of the network becomes very decisive to supply power to the consumers and to achieve development scale. Power system stability problem has been and continues to receive a great deal of attention over the years [1] [2]. Transient stability refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to a disturbance. Hence, it becomes more challenging to assure the security of power systems. Transient stability analysis deals with the study of the system after a large disturbance. Due to a large disturbance, the synchronous alternator of the machine and power angle changes because of sudden acceleration of the rotor shaft. The major goal of transient stability is to determine the values of the angle that can return to steady-state after clearance of disturbance. Steadily maintaining the system and supply power continuously such that specified number of different scenarios do not lead to failure of the system is of paramount importance. It classifies rotor angle stability into small disturbance angle stability and large disturbance angle stability. Also, it classifies transient stability methods into two significant categories: numerical methods and direct methods, as shown in Fig.1.

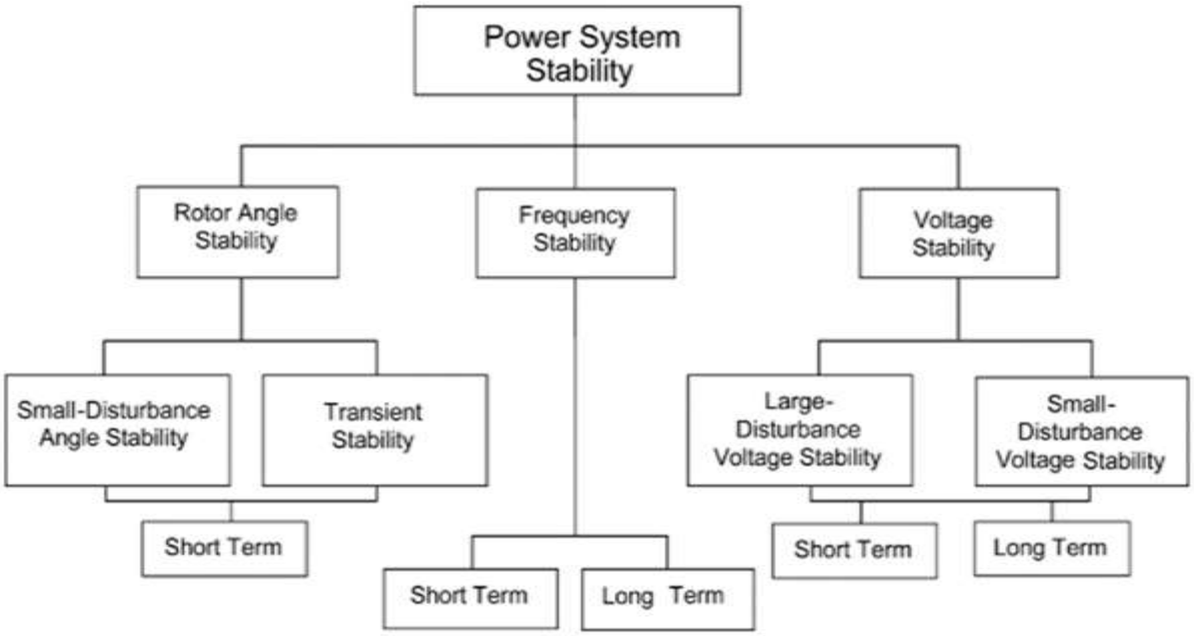

Figure 1.Classification of power System stability [1]

Transient stability is a dynamical analysis of power system subjected to severe disturbance, during different kinds of scenarios that can be identified as weakness or collapsing within the normal operating limits to return to normal limits as fast as possible [1]. The main cause of widespread blackouts is large rotor angle deviations. If the generator balance between electromagnetic and mechanical torque is disturbed, due to disturbances in the system, then this will lead to oscillations in the rotor angle. Therefore, it is required to develop a computational model of the simulation experiment run by the IEEE, CIGRE (International Council on Large Electric System) and compare the calculation with the experimental data [2] [1]. Transient Stability depends on several factors: type, duration of the fault, and the power level of each machine at the time of the fault.

The mathematical models developed and tested in this paper are based on Ordinary Differential Equations that can describe the dynamics underlying the machine including the interaction between aggregates and components. This achieved using ETAP (Electrical Transient Analysis Program and operation) software; a full-spectrum analytical engineering software company specializing in the analysis, simulation, monitoring, control, optimization, and automation of electrical power systems. ETAP software offers the most comprehensive and integrated suite of a powerful system enterprise solution that spans from modelling to operate. After that stage, many activities are done such as transient stability analysis, load flow analysis and optimal power flow analysis [3] [4].

Demetriou et al. Proposed a dynamic of the IEEE test system for a multimachine power system. It assessed and perform a transient stability analysis after a severe contingency [6]. Kavitha presented a transient stability analysis of the IEEE 30-bus system based on the ETAP-Software. It proposed and performing the stability of the power system under various disturbance [7]. Nitin and Arvind proposed transient stability of the 30-bus multimachine power system using a power system stabilizer and increasing inertia. It enhanced by implementing a power system stabilizer on increasing the inertia of the machine by keeping within a certain limit [5]. Eseosa and Ike proposed transient stability of the integrated Nigerian power system. A large disturbance occurs between generation and buses in the network [4].

Hashim et al. proposed a transient stability analysis of the IEEE 14-bus test system based on dynamic computation for power system [8]. Bosetti and Khan presented a transient oscillating multimachine system based on Lyapunov vector. Numerical accuracy of these Lyapunov vectors is validated by comparison with Floquet exponents obtained from the Jacobian matrix [9]. Werbeston et al. proposed an assessment for multiple contingencies using the multiway decision tree. Brazilian interconnected power system tested with real data from the one-day operation, demonstrated good performance [10]. Hijazi et al. presented restoration with transient stability after a significant blackout. Based on the optimal solution consist of a sequence of grid repairs and corresponding steady-states [11].

El-Shimy proposed stability-based minimization of load shedding in weakly interconnected systems for real-time applications. It improved from extended equal area criteria based on the availability of wide-area monitoring devices in modern power systems [12]. Bing et al. presented enhancing synchronization stability in a multi-area power grid. Based on the interlink between spatially distant nodes to improve synchronization stability [13].
This paper proposed a transient stability analysis of the interconnected multimachine power systems based on fault analysis studies and observed.

Problem Formulation

Network nodal and interconnection increasing every time, the studying of behavior and parameters of the electrical power system becomes very crucial to supply power to consumers and achieving development. Recently, due to several blackouts caused by transient instability, short circuit, shed loads, dynamic constraints are added into optimal power generation to guarantee the transient stability of multimachine against possible contingencies. In the operation of the existing power systems, the network is gradually approaching their transmission limits, and these raise many stability problems that could potentially result in severe consequences. Once the system is stressed, many undesirable phenomena arise, and these can cause damage to different parts of the system. The complexity of the multimachine power system comes from its high dimensionality (if there are many generators), strong nonlinearity, (each motor behaves nonlinearly) and strong interconnection between the subsystems. Interconnected multimachine power systems of many synchronous generators having different inertia constants, connected heavily loaded and weakly connected with a large transmission line are vast and highly complex system to control. The IEEE 39-bus system analyzed in this paper is commonly known as the 10-machines New England power system [6]. Mathematically, for each synchronous generator in a power system, the rotor angle $\delta_i = (i = 1, 2, ..., n)$ is determined by the swing equation.

$$\frac{H_i}{\pi f}\frac{d^2\delta_i}{dt^2} + D_i\frac{d\delta_i}{dt} = P_{mi} - P_{gi} \quad (1)$$

Where H_i is the inertia constant $D_i$is the damping P_{mi} is the mechanical input $P_{gi}$is the electrical input δ_i is the Rotor angle of the machine to the asynchronously rotating reference frame. In transient stability studies, the trajectory of the rotor angle δ_i is one technique that can investigate the transient stability. It is convenient to use the center of inertia (COI) to be the reference [7]. It uses the machine angles to the COI to test the stability of the system

$$\bar{\delta}_i = \delta_i - \frac{\sum_{k=1}^{ng} H_k\delta_k}{\sum_{k=1}^{ng} H_k} \le 100^\circ \quad (2)$$

$$\delta_{COI} = \frac{\sum_{k=1}^{ng} H_k\delta_k}{\sum_{k=1}^{ng} H_k} \quad (3)$$

$$TRASI = \frac{360^\circ - \max\left(\delta_{\max\_d}^{post}\right)}{360 - \delta_{\max\_d}^{pre}} \quad (4)$$

$$M_i = \frac{H_i}{\pi * f} \quad (5)$$

Where:

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δ_{COI} : Inertia center of the angle.

M_i : Machine moment of inertia.

f : System frequency.

The Rotor Trajectory Index is determined and calculated for each machine in the system individually using the machine's inertias values. It uses each machine relative rotor angle concerning the inertia center to determine the transient stability [8].

$$\Delta\delta_{i,COI} = \left\|\delta_i - \delta_{COI}\right\| \le \delta_{\max} \quad (6)$$

For $i = 1, 2, ..., NG$

Where:

$\Delta\delta_{i,COI}$: The difference between rotor angle and inertia center angle.

$\delta_{\max}$: Maximum angle difference for safe operation.

The transient stability status of a given operating point can be deducted as follows:

$$\Delta\delta_{i,COI} = Transiently \begin{cases} Stable, if\ \Delta\delta_{i,COI} \le \delta_{\max} \\ Unstable, \text{if } \Delta\delta_{i,COI} > \delta_{\max} \end{cases} \quad (7)$$

$$\lim_{t\to\infty}\left|\delta_i(t) - \delta_j(t)\right| < \varepsilon \quad (8)$$

Where: $\delta_i(t)$ and $\delta_j(t)$ are respectively the rotor angles of a machine i and j. It means that the angular difference of any two generators is approximately constant over some time. As a limit case of the previous definition, two machines are perfectly coherent if $\varepsilon = 0$. The coherent area will depend strongly on many factors, including:

1. The machine size and power output level
2. The admittance of the lines connecting the machine terminal buses to the boundary buses
3. The exciter models and parameters
4. The disturbances if the angle of these generators undergoes precisely or approximately the same transients in response to the disturbances.

Figure 2 shows the online diagram of the IEEE -39 Bus. It consists of 39 buses, 10 generators, 12 transformers, 20 loads and 34 transmission lines are connected in between the buses.

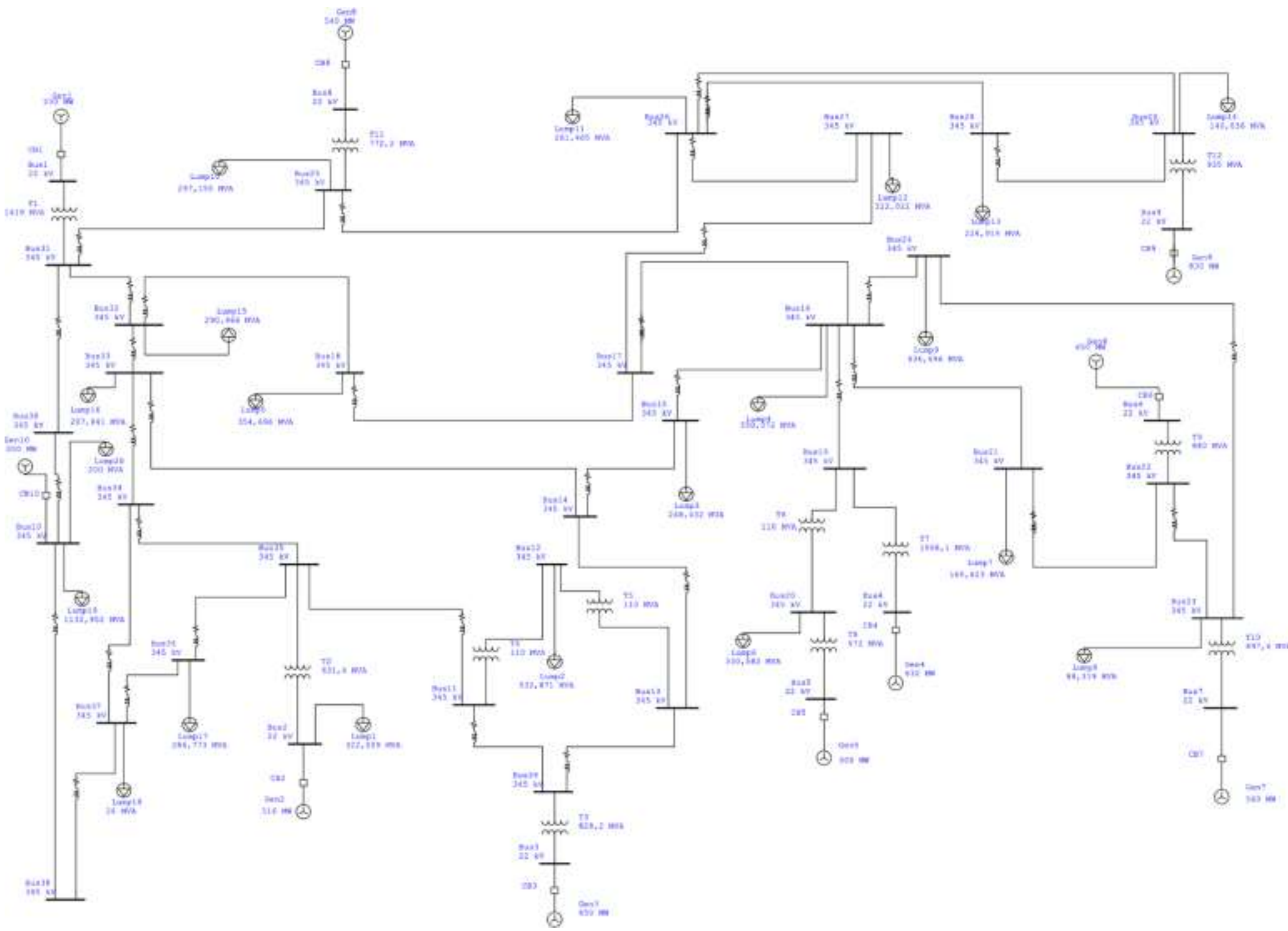

Figure 2. 39-IEEE Bus Test System

METHODOLOGY

The power system comprises many multimachine that accommodate nonlinearities in the interconnections among neighbouring synchronous machines. Here, all the synchronous machines run in parallel and at synchronous speed used under normal operating conditions. A large 10-machines, power system is investigated and analyzed. The goal is to enhance methods using fast computation and accurate outcome to test different scenarios of system behaviour. This observation and analysis of the entire IEEE-39 bus system test before, during, and post-fault. The stability for the multi- inputs and multi-outputs is carried out to allow this approach to optimize and robust control design. Numerical simulation has been compiled with all the components such as generators, transmission lines, transformers, and devices to achieve these studies. With the use of NS based on ETAP software sets, simulation is done for different contingency. It performs a stability analysis for various cases based on controllers, as given in table 1 below.

Table 1 System condition for various cases.

Case	System conditions
Case-1	Without exciter and governor and PSS A2
Case-2	With Type 1 exciter
Case-3	With ST governor
Case-4	With Type 1 exciter and ST governor
Case-5	With ST governor Type 1 exciter and PSS A2

The cases in Table 4.1 represent the different contingency analyses between the components of the machines. This observation and examination of the entire IEEE 39 bus may lead to the stability of the interconnected multimachine power system. As seen by observing the rotor angle, the rotor speed, and the excitation voltage, it can test the stability of the system.

I. Results and Discussion

The simulation results are discussed and compared in the numerical procedure for the interconnected multimachine power systems. Transient stability [9] [3] analysis has been done for different generators. The numerical simulation of the ten generators power system showed the results.

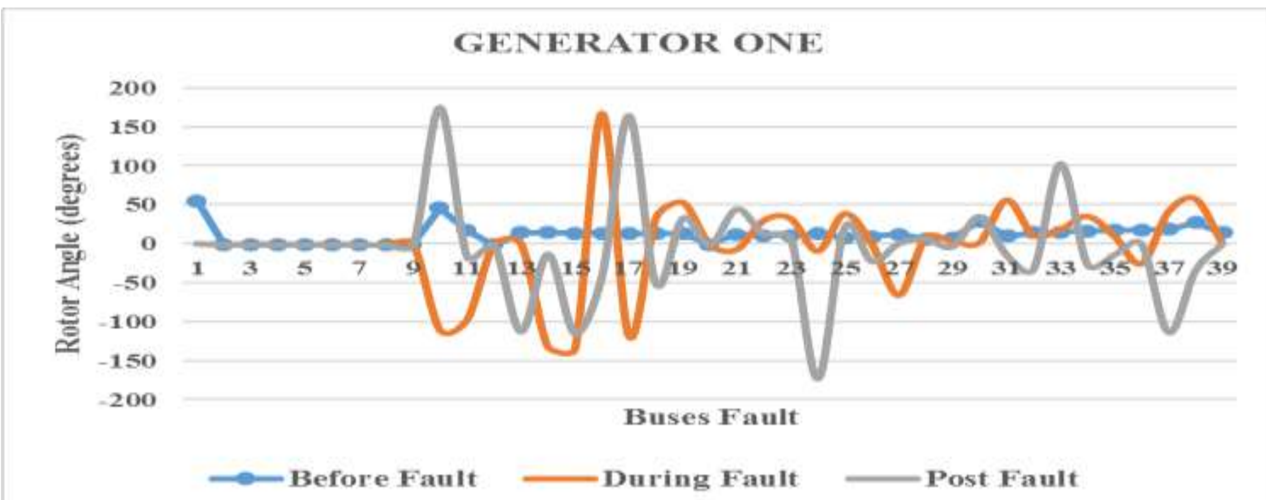

Figure 3 Rotor angle of generator #1.

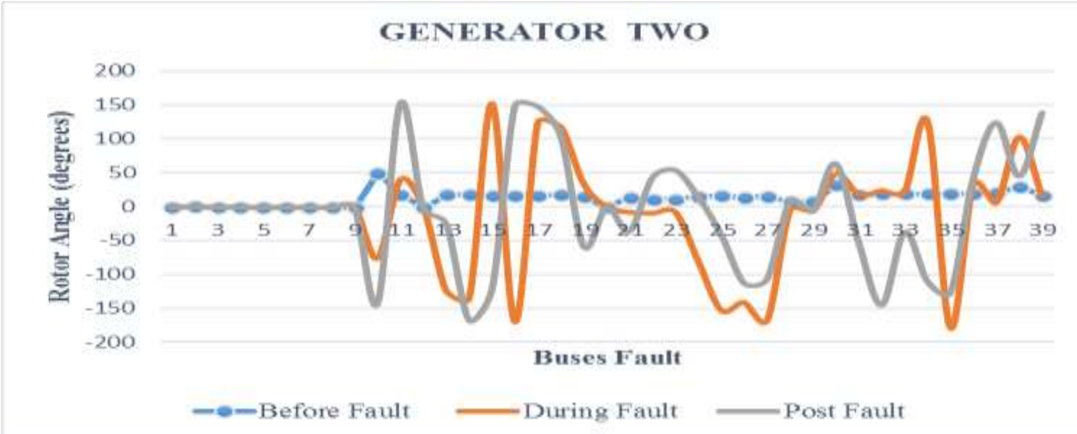

Figure 4 Rotor angle of generator #2.

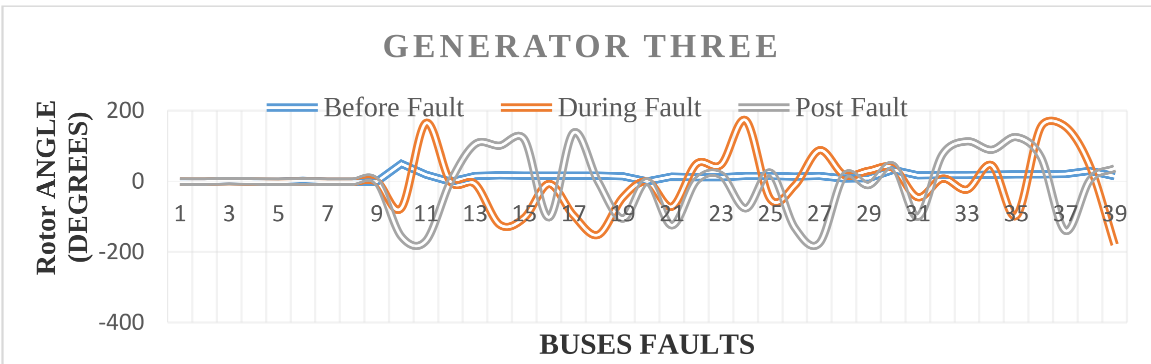

Figure 5 Rotor angle of generator #3.

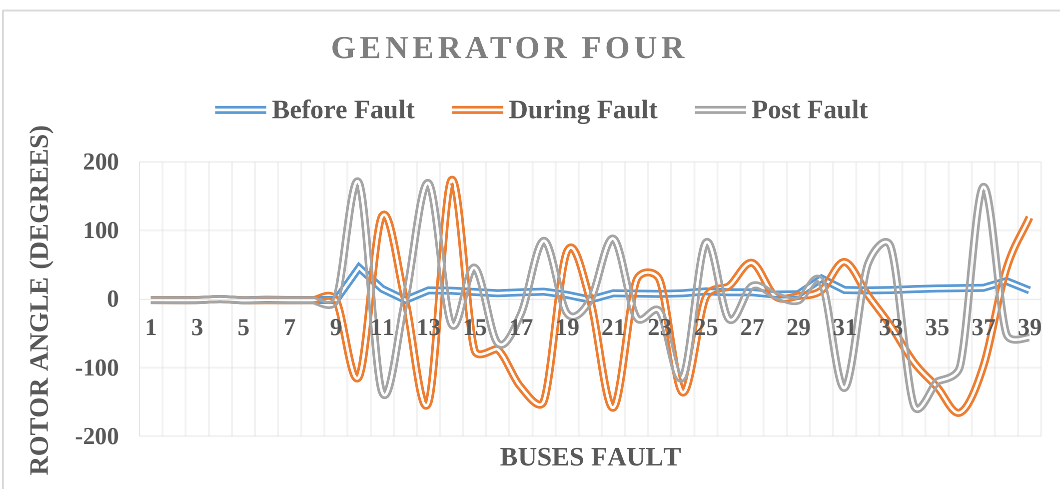

Figure 6 Rotor angle of generator #4.

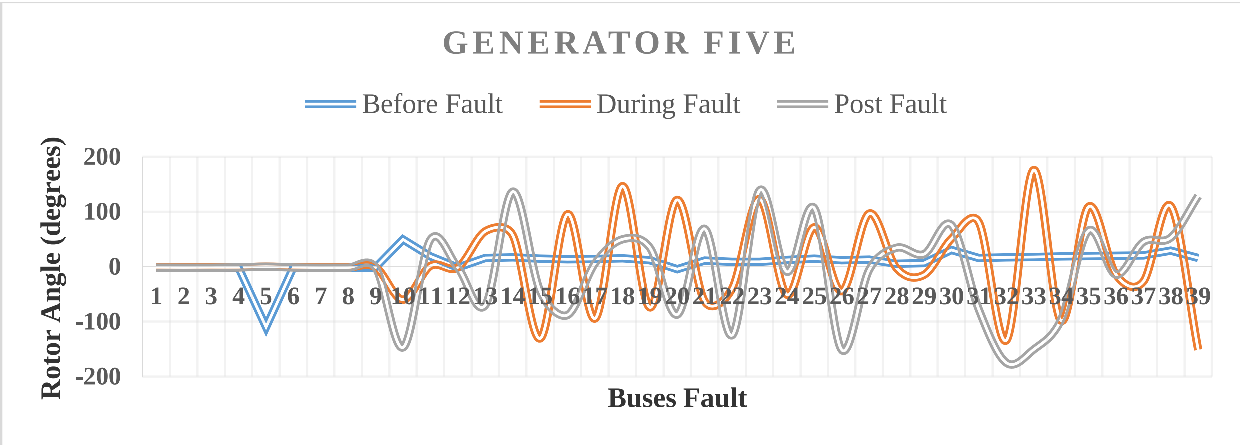

Figure 7 Rotor angle of generator #5.

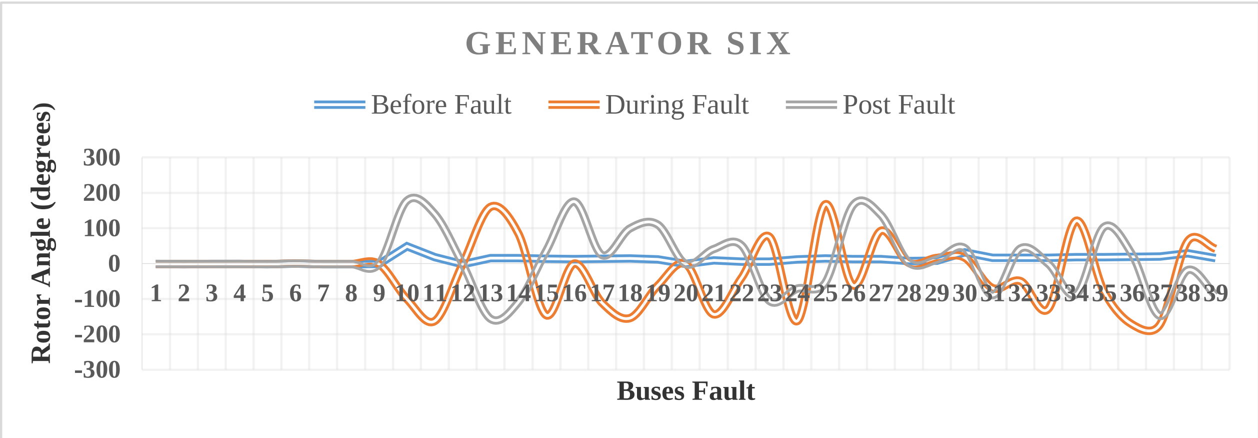

Figure 8 Rotor angle of generator #6.

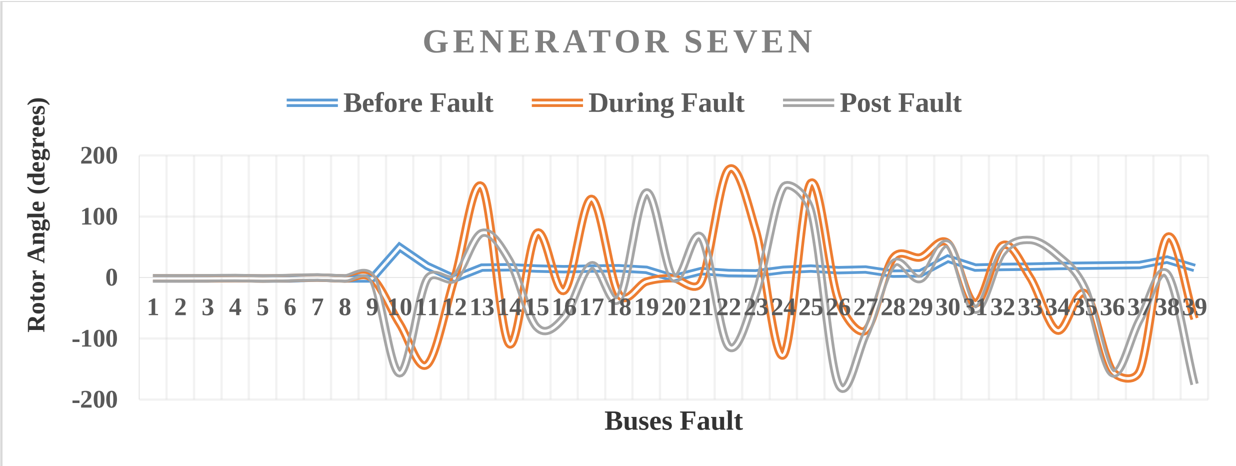

Figure 9 Rotor angle generator #7.

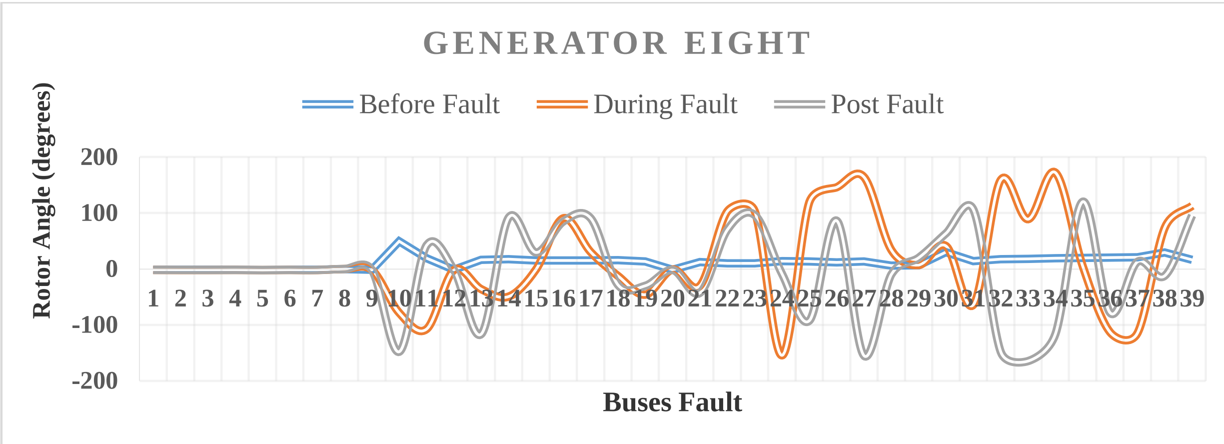

Figure 10 Rotor angle of generator #8.

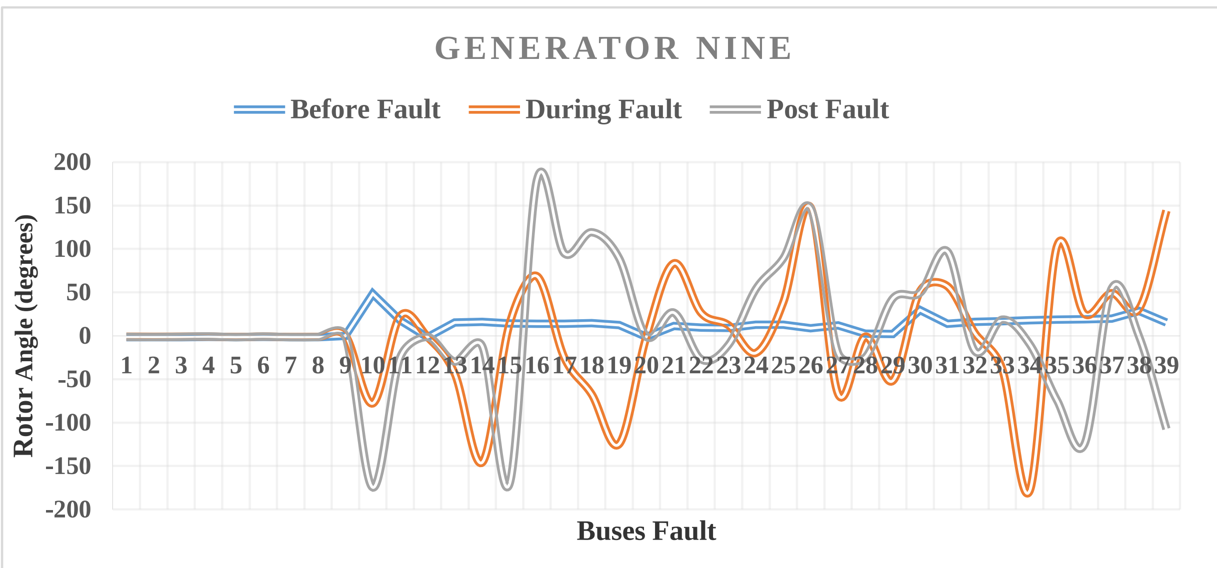

Figure 11 Rotor angle of generator #9.

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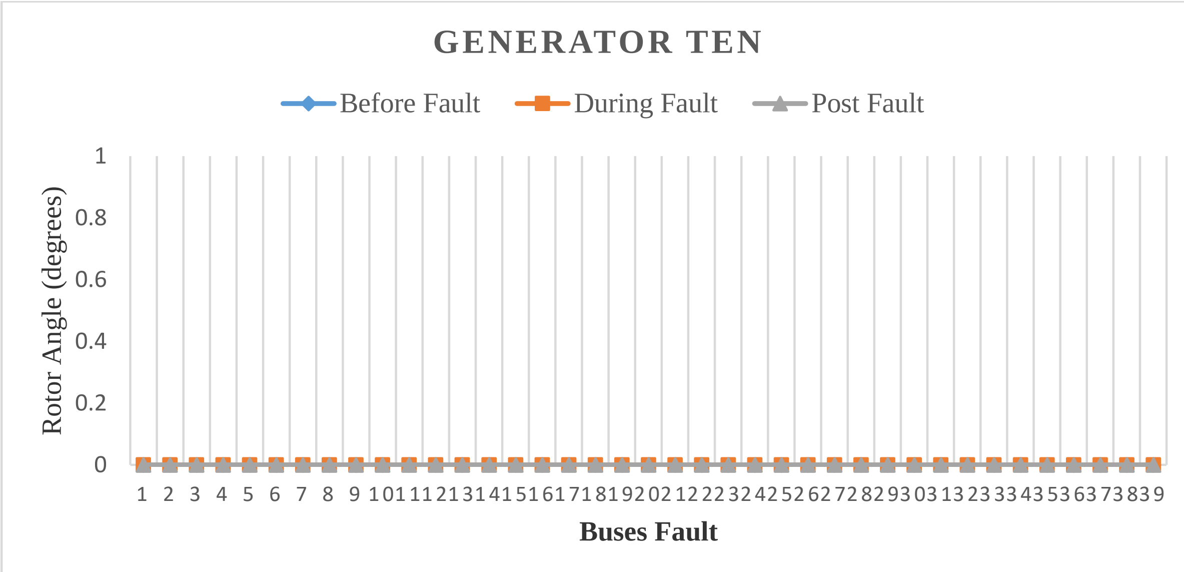

Figure 12 Rotor angle of generator #10.

Figure 3 shows that the variation of the rotor angle mentioned for each generator observed between bus #1 up to bus #39, a three-phase fault occurred at all buses, and different observation has been recorded before fault, during the fault, and post fault for the generator in the figures. All generators are behaving well except that the generator #10 which is swinging and is the most loaded in the system. It is shown in Figure 12 with all the events. Figure 4 presents the variation of the rotor angle for different contingency analysis between buses as shown in blue line before fault, the red line during a fault, and the grey line for post fault occurring at any bus in the system. While Figure 5 shows that the different varieties of the rotor angle during contingencies analysis with the fault depicted and following the observation mentioned. Figure 6 shows the different varieties of the rotor angle during contingencies analysis where generator #3 is unstable in a different bus, but the remaining generators it remains stable.

Figure 7 presents those different varieties of the rotor angle during contingencies analysis between bus in the system. Additionally, Figure 8 shows the different varieties of the rotor angle between bus during a fault occur for different scenarios observed to regain stability. The generator switched during fault and post-fault between the bus, but it remains stable at the end of events. Figure 9 shows the different varieties of the rotor angle during contingencies analysis observed from a different bus after a fault occurs. The generator fluctuates during fault at bus #9 to bus #39 to remain stable at a reasonable point of the bus. Furthermore, for the system post fault also depicted from bus #10 to bus #39 instead perturbed at the same point nearest to the last bus preserved.

Figure 10 shows the different varieties of the rotor angle during different scenarios observed after a fault occurred into the entire bus. The generator oscillated during fault between bus #9 to bus #39 steadily than after post fault events. Furthermore, figure 11 shows that the different positions of the rotor angle during a fault occurs along the bus. The generator swinging during the contingency's analysis between buses to remain stable for an extended period during fault and shortly during post fault.

Finally, Figure 12 shows the different varieties of the rotor angle during contingencies analysis. It represents the aggregation of a large number of generators and is considered not to have governor and exciter. After the fault occurs after 380 milliseconds, the rotor angle decreased, and the system becomes unstable at 560 milliseconds. The generator #10 behaviour over the dynamics interested during the events (before fault, during fault and post-fault), loses the rotor speed and frequency that is become more vulnerable that cannot run into the system and it switches off. It is because the generator #10 does not have an exciter.

Modelling is one of the most commonly used tools in engineering and applied sciences. At this stage of modelling, it can be used many devices to approximate the real solution. They used data from the IEEE test power system modelling and validation. All these analyses attempt to locate and so-called transient stability region in the system state-space. Once this is done, it can estimate the critical clearing time with a single simulation. Once a circuit breaker is ordered to open a line, shed load, or trip a generator, it can sometimes fail to operate. One problem that can occur in electric power systems is actuation failure.

CONCLUSION

This paper proposes a transient stability analysis of the interconnected multimachine power system using ETAP-software is proposed. The main contribution and simulation results based on the analysis using different scenarios and contingencies to enhance an interconnected multimachine power system. It assesses the transient stability analysis based on a subjected disturbance. The transient stability responses of the standard IEEE-39 bus test for the above cases mentioned in the results have also been analyzed, and the results have been validated. It equips all the generators with an IEEE type-1 exciter and simple turbine governor, except the generator #10 on bus #39, which is an aggregation of many generators and is considered not to have a governor. It also requires the limits of power transfer to keep the rotor angle stable if the system becomes unstable, then the security of the resupplying power may compromise. The steady-state stability is usually tested by computing the eigenvalues of the dynamic system. The state-space of the Jacobian matrix that linearized the dynamical equation. Exhibiting the analysis of different scenarios observed lengthwise in the multimachine power systems interconnected illustrated the rotor speed of the generators is:

1. The generator (or generators) near to the fault may lose synchronism exhibiting no synchronous swings; other generators affected by the fault occur for a period of synchronous oscillation until they eventually return to synchronism operations.
2. The generator (or generators) near to the fault occurred lose synchronous after showing the synchronous operations.
3. The generator (or generators) near to the fault bolted is the first to lose the synchronism and then followed by other generators in the system.
4. The generator (or generators) near to the fault exhibit the synchronism swings without losing the stability, but one, or more, of the generators remote from the fault, lose synchronism with the system.

A real demand to interconnected multimachine power systems is used to show the effectiveness of the transient stability.

References

[1] J. Machowski, W. B. Janusz and R. B. James, Power System Dynamics:Stability and Control, John Wiley and Sons , 1997.

[2] G.Anderson, "Modelling and Analysis of Electric Power Systems," in *Lecture 227-0526-00*, Zurich, 2008, p. 180.

[3] K. Brown, A. Herminio, S. Farookh and D. Gary, "Interactive Simulation of Power Systems: ETAP Applications and Techniques," *IEEE,* pp. 1930-1941, 90.

[4] O. Esoosa and I. Samuel, "Stability Studies of the Nigerian 330 KV Integrated Power System," *Electrical and Electronic Systems,* vol. 4, no. 1, p. 11, 2015.

[5] P. Demetriou, A. Markos, Q.-T. Jairo and K. Elias, "Dynamic IEEE Test Systems for Transient Analysis," *IEEE Systems Journal,* p. 10, 2015.

[6] K. R, "Transient Stability of IEEE-30 bus system using E-TAP Software," *International Journal for Scientific and Engineering,* vol. 3, no. 12, p. 7, 2012.

[7] N. M. Lal and K. S. Arvind, "Transient Stability enhancement of the 30 bus multimachine systems by using PSS and increasing inertia," *American Journal of Electrical Power and Energy Systems,* vol. 3, no. 2, pp. 21-26, 2014.

[8] N.Hashim, H. N, F. A. L. M and A. S. A "Transient Stability Analysis of the IEEE 14-Bus Test System Using Dynamic Computation for Power Systems," in *2012 Third International Conference on Intelligent Systems Modelling and Simulation*, Selangor, 2012.

[9] H. Bosetti and K. Sohail, "Transient Stability on Oscillating Multi-Machine Systems using Lyapunov Vectors," *IEEE,* p. 10, 2017.

[10] W. D.Oliveira, A. V. Joao P, H. B. Ubiratan and A. M. Daniel, "Power system security assessment for multiple contingencies using a multiway decision tree," *Electric Power System Research, Elsevier,* pp. 264-272, 2017.

[11] H. Hijazi, W. M. Terrence and V. H. Pascal, "Power System Restoration with Transient Stability," in *29th AAAI*, Canberra, 2015.

[12] M.El-Shimy, "Stability-based minimization of load shedding in weakly interconnected systems for real-time applications," *Electrical Power Energy Systems, Elsevier,* pp. 99-107, 2015.

[13] B. Wang, S. Hideyuki and A. Kazuyuki, "Enhancing synchronization stability in a multi-area power grid," *Scientific Reports, Nature,* p. 9, 2016.

[14] M.Oluic, G. Mehrdad and B. Bertil, "On the Parameterization of Rotor Angle Transient Stability Region," *IEEE,* p. 6, 2015.

[15] K.Verma, "Rotor Trajectory Index for Transient Security Assessment using Radial basis function Neural Network," in *IEEE PES General Meeting*, Washington DC, 2014.

[16] V.Guruprasada, Y. H. Rai and D. M, Coherent Generators, Allied Publishers Pvt, 1998.

[17] Y.Lin and Z. B, Study of the Resilience of the Integrated Energy System, Maldive: REM2016, 2016.

[18] E. Elghadi, M. M and R. A. K, "Risk of Transient using Rotor Trajectory Index as Severity Function," *International Journal of Electrical, Electronics and Computer Systems,* vol. 6, no. 3, pp. 591-601, 2017.

[19] S. K. Nallagalva, K. K. Mukesh and G. A. Dr, "Transient Stability Analysis of the IEEE 9-bus Electric Power System," *International Journal of Scientific Engineering and Technology,* vol. 1, no. 3, pp. 161-166, 2012.

[20] A. P. Khiyavi and Z. Farhad, "The Study and Analysis New Method for Improving Transient Stability IEEE 9-Bus System," in *ICEEE2015*, Gonadad, 2015.

[21] G. M. Girishbhai and S. S. Jigar, "Transient Stability Analysis on a Multi-MACHINE SYSTEM IN PSAT," *International Journal of Research in Engineering Technology,* vol. 4, no. 3, pp. 604-612, 2015.

[22] R. Patel, S. B. T and P. K. D, "Study of Power SystemTransient Stability with Simulink," in *National Power Systems Conference NPSC*, Delhi, 2002.

[23] G. C. Zweigle and V. Vaithianathan, "Wide-Area Optimal Control of Electric Power Systems with Application to Transient Stability for Higher-order contingencies," *IEEE TRANSACTIONS ON POWER SYSTEMS,* p. 8, 2012.

[24] M. A.El-Kady, A. A. Yasir and S. A.-S. Mamdooh, "Evaluation of Operating Domains in Power Systems," *Energy and Power Engineering,* pp. 274-282, 2012.

[25] H. M. Shertukde, Power Systems Analysis: Illustrated with Matlab and ETAP, Boca Raton: CRC, 2019.