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Critical clearing time evaluation of Nigerian 330kV transmission system

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Abstract: Critical Clearing Time (CCT) is the largest possible time for which a power system is allowed to remain in fault condition without losing stability. Appropriate CCTs settings of protective equipments on power system greatly determine the reliability of power supply. This paper determines the CCTs for all the transmission lines in the Nigerian 24-bus, 39-lines 330kV transmission system. The Transient Stability Analysis (TSA) program adopted used the method of partitioned approach with explicit integration method. The result of TSA was considered satisfactory since about 87% of the values obtained fall within acceptable international range. It was concluded that the determination of appropriate CCTs for the Nigerian power system will enhance the operation of the power system by limiting effects of faults on the power system.

Keywords: Power System, Transient Stability Analysis, Critical Clearing Time

1. Introduction

The Nigerian 330kV transmission network links the generating stations and distribution system. Interruptions in this network hinder the flow of power to the load. The cost of losing synchronism through transient instability is extremely high [1]. The quality of electricity supply is measured, amongst other factors, by the ability of the power system to clear faults before they cause damage to the power system equipments. The time at which fault is cleared before it causes damage on the power system is known as Critical Clearing Time (CCT). CCT is the largest possible time for which a power system can remain in fault condition without losing stability once the fault is cleared [2, 3, 4]. Constant faults on Nigerian power system have had adverse effects on the Nigerian economy and its citizenry. The yearnings and aspirations of the Nigerians for constant supply of electricity can partly be met if Nigerian 330kV National Grid is operated to clear faults before damages are caused by the faults given adequate generation, transmission and distribution facilities. Hence, the need to determine appropriate CCT for the circuit breakers on the power system. CCT is determined through the performance of Transient Stability Analysis (TSA) of the power system.

TSA is the evaluation of the stability of a power system when there is large and sudden disturbance on the power system. This disturbance can be a fault which includes; transmission line short-circuit, loss of generator, load or a part of the transmission network and gain of load [5]. The generators in the power system respond to the occurrence of these disturbances with large swinging of their rotor angles. Initial operating conditions and the severity of the disturbance determine the stability of a power system [6].

Transient stability problems are concerned mainly with the behaviors of synchronous machines in power system after they have been perturbed. When a fault occurs on the power system, an imbalance is created between the generator output and the load. The rotor angle of the machine accelerates beyond the synchronous speed which is the reference speed, for a time greater than zero. When this happens, the machine is said to be ‘’swinging” and two possibilities are identified when the rotor angle is plotted as a function of time [7].

i. The rotor angle swings and eventually settles at a new angle. The system is said to be stable i.e. in synchronism.
ii. The rotor angle swings and the relative rotor angle diverge as time increases. This condition is considered unstable i.e. losing synchronism.

The single line diagram of the Nigerian 24-bus, 330kV transmission system considered is shown in Figure 1 [8].

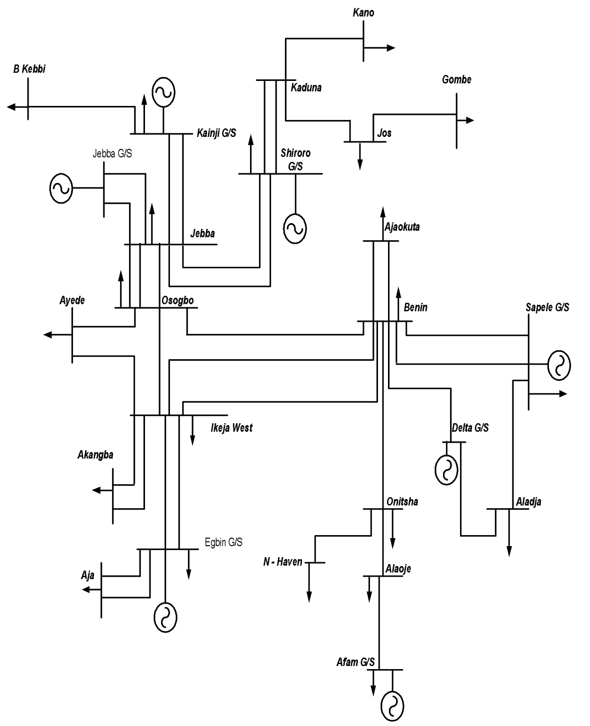

Figure 1. *Nigerian 24 Bus 330kV National Grid [8].*

2. Methodology

The initiation of fault and its removal by circuit breakers in a power system is considered that the system is going through a change in system configuration in three stages: pre-fault, fault and post-fault stages. The dynamics of the power system during fault and post-fault periods are nonlinear and the exact solution is too complex. In order to reduce the complexity of the transient stability analysis, the following simplified assumptions are made [7];

i. Every synchronous machine in the power system is modeled by a constant voltage source at the back of direct axis transient reactance.
ii. The governor's actions for the automatic control generation are neglected and the input powers are assumed to remain constant.
iii. Using the pre-fault bus voltages, all loads are converted to equivalent admittances to ground and are assumed to remain constant.
iv. Damping or asynchronous powers are ignored.
v. The mechanical rotor angle of each machine coincides with the angle of the voltage behind the machine reactance.
vi. Machines belonging to the same station swing together and are said to be coherent. A group of coherent machines is represented by one equivalent machine.

In transient stability studies, particularly those involving short periods of analysis in the order of a second or less, a synchronous machine can be represented by a voltage source behind transient reactance that is constant in magnitude but changes its angular position [9]. This representation neglects the effects of saliency and assumes a constant flux linkages and a small change in speed. The voltage behind the transient reactance is determined from the following equation (1) [7, 9, 10].

$$E_i^{'} = V_i + jX_d^{'} I_i \quad (1)$$

Where
$E_i^{'}$ = Voltage behind transient reactance.
$V_{i,}$ = Machine terminal voltage
X_d = direct axis transient reactance.
I_i = Machine terminal current

The rotor mechanical dynamics are represented by the following equations [3, 11]..

$$2H \frac{d\omega}{dt} = T_m - T_e - D\omega \quad (2)$$

$$\frac{d\delta}{dt} = \omega \quad (3)$$

Where H = per unit Inertial Constant
D = Damping coefficient
ω = rotor angle of the generator
δ = angular speed of the generator
T_m = Mechanical Torque Input
T_e = Electrical Torque output

Numerical integration techniques are used to solve the swing equation for multimachine stability problems. The Modified Euler's method is used to compute machine power angles and speeds in this research work. The real electrical power output of each machine is computed by the following equations.

$$P_e = Real[E_n I_n^*], \; n = 1, 2, \dots, m \quad (4)$$

$$P_e = \sum_{j=1}^{n} |E_i^{'}||E_j^{'}||Y_{ij}| \cos(\theta_{ij} - \delta_i - \delta_j) \quad (5)$$

The above equations (1) to (5) are very crucial to transient stability studies because they are used to calculate the output power of each machine in the power system.

The individual models of the generators and the system load given by the differential and algebraic equations have been stated. Together, these equations form a complete mathematical model of the system, which are solved numerically to simulate system behaviors. To develop a power system dynamic simulation, the equations used to model the different elements are collected together to form: [6, 10, 12].

(i) A set of differential equations

$$\dot{x} = F(x, y) \quad (6)$$

That describes the system dynamics, primarily contributed by the generating units and the dynamic loads.

(ii) A set of algebraic equations

$$0 = g(x, y) \quad (7)$$

That describes the network, static loads and the algebraic equations of generators.

The solutions of these two sets of equations define the electromechanical state of the power system at any instant in time. Equations (6) and (7) can be solved using either a Partition Solution method or a Simultaneous Solution method. In the partitioned solution method, the differential equations are solved using a standard explicit numerical integration method with algebraic equation (7) being solved separately at each time step. The simultaneous solution uses implicit integration methods to convert the differential equations of (6) into a set of algebraic equations which are combined with the algebraic network equations of (7) to be solved as one set of simultaneous algebraic equations [6, 11, 12].

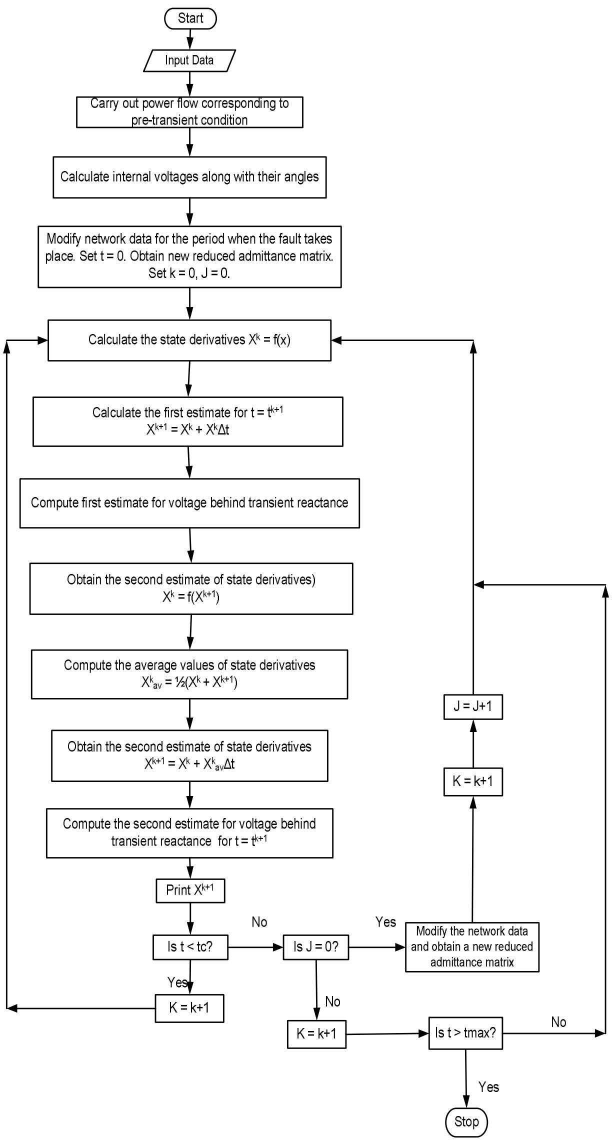

Figure 2. Modified Euler's Method Applied to Transient Stability sstability Problems [13]

The partitioned approach with explicit integration method is the traditional approach used widely in production grade stability program [6]. The transient stability program adopted in this research work uses the method of partitioned approach with explicit integration method. The advantages of the method include programming flexibility and simplicity, reliability and robustness. Figure 2 shows the flowchart for the transient stability solution using the Modified Euler's method [13].

3. Results and Discussion

The Nigerian power system considered is a 24 bus system which has seven (7) generators and thirty-nine (39) transmission lines. Three phase fault was simulated on each bus and different lines removed to determine the stability or otherwise of the power system. The critical clearing time, which is a measure of the stability, was determined by varying the fault clearing times. At any time greater than the critical clearing time, the system becomes unstable. The stability and instability of the power system at a given fault is determined by the behavior of the generators. If the rotor

Angles of the generators diverge, the system is unstable and if otherwise, the system is stable.

Figures 3, and 4 show the behaviors of the generators, with generator 7 (Egbin) as reference, on the power system when three-phase faults occur on Buses 3 (AJA) and 9 (AYEDE) and lines L1 (AJA to EGBIN) and L20 (AYEDE to OSOGBO) are removed respectively for faults cleared at the critical clearing times. The generators swing together to show stable equilibrium. Figures 5, and 6 show the behaviors of the generators, with generator 7 as reference, on the power system when faults occur on Buses 3 (AJA) and

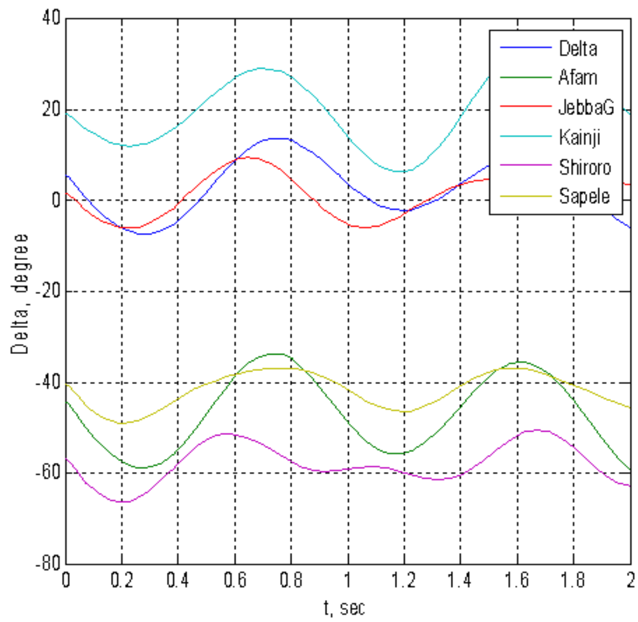

Figure 3. Generator rotor angle behaviour for fault at bus3 and line L1 removed at 0.01s critical clearing time (stable condition)

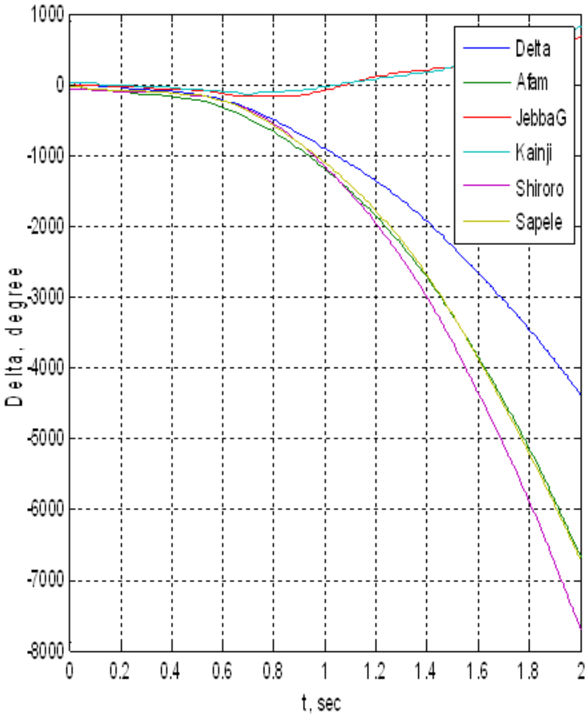

Figure 4. *Generator rotor angle behaviour for fault at bus 3 and line L1 removed at 0.05s critical clearing time (unstable condition)*

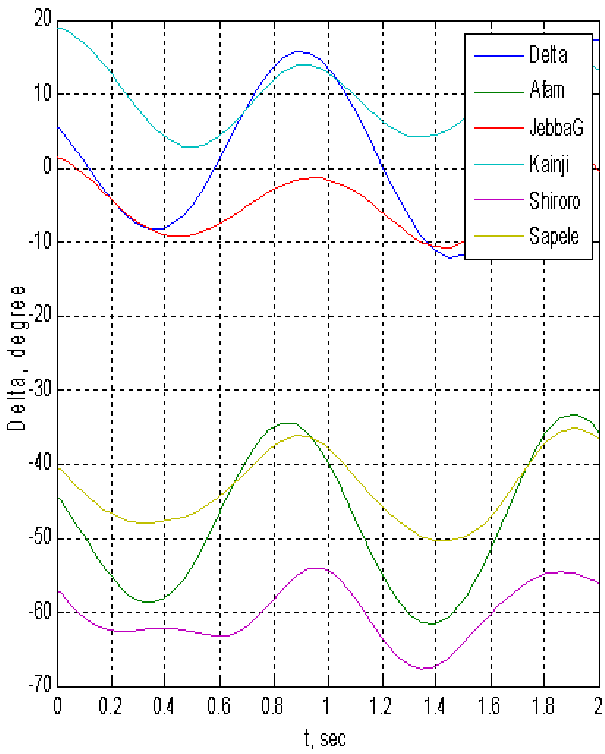

Figure 5. *Generator rotor angle behaviour for fault at bus 3 and line L1 removed at 0.01s critical clearing time (stable condition)*

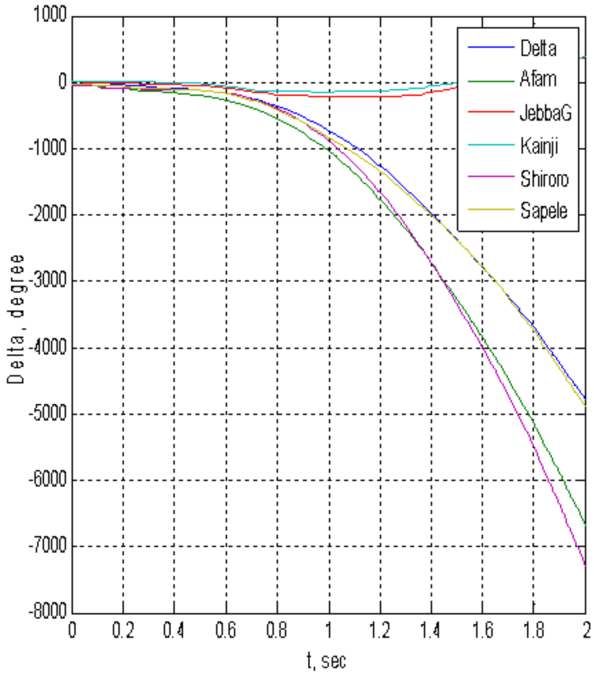

Figure 6. *Generator rotor angle behaviour for fault at bus 3 and line L1 removed at 0.08s critical clearing time (unstable condition)*

9 (AYEDE) and lines L1 (AJA to EGBIN) and L20 (AYEDE to OSOGBO) are removed respectively for faults cleared at times greater than the critical clearing times. It was observed that the rotor angle diverges and hence the system is unstable.

Figures 3 and 4 show that the generators on the Nigerian 330kV Transmission Grid System are grouped into two. Buses 2 (Delta), 18 (JebbaG) and 21 (Kainji) formed the first group while buses 11 (Afam), 23 (Shiroro) and 24 (Sapele) are in the second group. Machines in each group swing together with respect to the reference machine (Bus 1). The system is stable from these figures. Figures 5 and 6 show the angular positions of machines for a clearing time greater than the critical clearing time. In these cases, the clearing times increase beyond the critical clearing times and the machines go out of steps as seen in the figures. It is found that the critical clearing time of the fault on Bus 18 (JebbaG) is lower than those of buses 3 (Aja) and 9 (Ayede). This can be interpreted in such a way that faults closer to generating stations must be cleared rapidly than faults on the lines far from the generating stations.

Table 1 shows the critical clearing times in milliseconds determined for all the thirty-nine lines on the Nigerian 330kV National Grid. Starting with a clearing time of 0.01seconds, transient stability analysis program is run and if the conditions proved stable, another run is made with a higher value; if the second run showed the system to be unstable, then the clearing time of the first run gives the desired result. If the second run is still stable then more runs are made until the system becomes unstable. In some cases, a lower value of time is tested if 0.01 proved to be unstable. Comparing the results in Table 1 with Table 2 [14] which is a standard Range of typical EHV Relay-Breaker Clearing

Time, it was observed that all the relay breaker clearing times fall below the normal Critical Clearing Times but 87% fall below the total back-up clearing time as shown in Table 1.

4. Conclusion

The transient stability analysis was carried out to determine the critical clearing time for the circuit breakers on the power system. The partitioned solution method with explicit Modified Euler's integration method was used in solving the transient stability equations. The results of the transient analysis are considered satisfactory since the entire relay breaker clearing times fall below the normal Critical Clearing Times. The system is well protected in the first instant but the protection has to be improved upon so that 100% total back-up clearing will be achieved. It has been demonstrated in this research work that determination of appropriate CCTs for the Nigerian power system will enhance the operation of the system by limiting the effects of faults on the power system. The CCTs for three-phase faults of circuit breakers installed on the Nigerian 330kV Transmission Grid were established which serves as reference data for the use of power system experts and researchers.

Table 1. *Critical clearing time for faults on Nigerian 330kV transmission system*

Faulted bus	Removed lines	Critical clearing time, t_{cr} (milliseconds)
3	L1	20
	L2	20
4	L3	20
	L4	20
1	L5	20
	L6	20
5	L7	20
	L8	20
9	L9	60
10	L10	60
6	L11	40
	L12	40
2	L13	40
7	L14	20
24	L15	100
14	L16	60
8	L17	40
8	L18	20
	L19	20
9	L20	60
15	L21	20
17	L22	60
	L23	60
	L24	60
11	L25	60
	L26	60
12	L27	60
13	L28	100
16	L29	100
18	L30	20
	L31	20
23	L32	20
	L33	20
21	L34	20
	L35	20
20	L36	100
22	L37	100
20	L38	20
	L39	20

Table 2. *Range of typical EHV relay-breaker clearing time [14]*

Function	Time in cycles	Time (milliseconds)
Primary relay	0.85 – 1.25	17 – 25
Breaker clearing	2.5	50
Total normal clearing time	**3.35 – 3.75**	**67 – 75**
Breaker-failure detection	0.425 – 1.25	8.5 25
Coordination time	2.5 – 4.25	50 – 85
Auxiliary relay	0.425 – 0.85	8.5 – 17
Backup breaker clearing	1.75	35
Total backup clearing	**8.45 – 11.85**	**169 – 237**

References

[1] O. Anthony, and O. Ameze. "Transient stability assessment of the Nigerian 330kV network,". International Journal of Engineering, Vol. 4, Issue 5, pp 357 – 367, 2011.

[2] M.H. Haque, and A.H. Rahim. "Determination of first swing stability limit of multimachine power system through taylor series expansion," IEEE Proceedings on Power Application, Vol. 136, No. 6, November 1989, pp. 374 – 379.

[3] B. Boussahoua, and M. Boudour. "Critical clearing time evaluation of power system with UPFC by energetic method," Journal of Electrical Systems,Special Issue, No. 1, pp 85 – 88, 2009.

[4] Z. Eleschova, M. Smitkova, and A. Belan. "Evaluation of power system transient stability and definition of basic criterion," International Journal of Energy, Issue 1, Vol. 4, pp 9 – 16, 2019.

[5] P. Iyambo, and R. Tzenova. "Transient stability analysis of the IEEE 14 test bus electric power system," IEEE Transaction on Power Systems, Vol. 25, No. 3, pp 1 – 7, 2007.

[6] S. Ravi, and S. Siva. "Transient stability improvement using UPFC and SVC," ARPN Journal of Engineering and Applied Sciences, Vol. 2, No. 3, pp 28 – 45, 2007.

[7] H. Saadat. Power System Analysis. McGraw-Hill, New York, USA, 1999.

[8] G. Adepoju, O. Komolafe and A. Aborishade. ‘‘Power flow analysis of the Nigerian transmission system incorporating FACTS controller,’’ International Journal of Applied Science and Technology, Vol. 1, No. 5, pp 186 – 200, September 2011.

[9] G.W. Stagg, and H. El-Abiad. Computer Methods in Power System Analysis. McGraw-Hill, Kogakusha, Tokyo, 1968.

[10] X. Wang, S. Yonghua, and I. Malcolm. Modern Power System Analysis. Springer , New York, USA, 2008.

[11] K. Prabha. Power System Stability and Control. McGraw-Hill, New York, USA, 1994.

[12] J. Machowsky, J. Bialek, S. Robak, and J. Bumby. Power System Dynamics Stability and Control. John Willey & Sons Ltd, Wiltshire, Great Britain, 2008.

[13] C.L. Wadhwa. Electrical Power System. John Wiley and Sons, New Delhi, India, 1991.

[14] G. Adepoju. Transient stability: a case study of NEPA 330kV transmission grid system. M.Sc, University of Lagos, Akoka, Nigeria, 2000.