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ANALYSIS OF STEADY AND TRANSIENTS – STATE STABILITY OF TRANSMISSION NETWORK

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ABSTRACT

This paper proposed two scenario, the 1st scenario look at the analysis of transient stability study of 330KV super-grid voltage level of Nigerian power system network. Considering Alaoja (load-bus), Onitsha (load-bus) and Afam power station (generating-bus) referred as study case, from the Nigerian 330KV transmission grid (network) for purpose of investigation and findings. The analysis is based on swing-equation model approach and power transfer capability conditions. The activities of fault initiated were recorded as "sustained fault" classified with respect to time setting of the protective relay and circuit breaker operations from Afam power generating station (GS) to the 330KV network in order to measure the behaviour of the turbine rotor-angle with the clearing time setting of the relay. The collected data were simulated via Matlab platform, with the clearing time setting of (t = 0.0, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50) corresponding to the respective deviation of the rotor swinging angles of (rf1, rf2, rf3 and rf4). Where rf1 defined the deviation of the rotor-angle of the turbine power plant due to sustained fault condition with time, t. while rf2, rf3, and rf4; defined the restoration ability of the deviated rotor-angle (rf1) from instability to gradual progressive stability condition, with fault cleared at 2.5cycle (rf2), 6.5 cycle (rf3) and 8.25cycle (rf4) respectively. The 2nd scenario also look at the analysis of three (3) phase short-circuit faults including: (phase A, phase B; phase C respectively) in a Matlab coded environment. The results of the simulated fault condition shows that, there is strong need for short –circuit fault-clearing time which should be quick for relay and circuit breaker responses (sensitivity and selectivity- based). The revelation of the finding also shows that system instability will be restored for improvement at fault clearing time before 0.05s. Evidently, further work will look at the investigation of incremental loading condition of the turbine power plant.

Keywords: Transient stability, swing-equation, load/rotor angle, fault, power transfer, transmission grid, protective relaying and circuit breaker.

INTRODUCTION

The stable operation of a power requires a continuous match between energy input to the prime movers and the electrical load on the system. Continuous change is normal for an operating power system. Usually the changes are very small increment as customer load increases or decreases. Each load increase or decrease may be accompanied by a corresponding change in input to the prime mover of the generators on the system.

Changes in loads and generation results in relative change in the position of the generator rotor that must all operates in synchronism, if the power system is to remain "stable". Therefore, power system stability is primarily concerned with variations in rotor speeds, rotor-positions and generator loads. This means that "power system stability' is the ability to respond to disturbance from normal operation by reforming to a condition where the operation is again normal purpose of analysis there are three (3); Stability conditions that must be considered:

- steady-state stability
- transient stability
- dynamic stability

In the case of 'stead-state stability', the ability of an electric power system to maintain synchronism between machines within the system and external lines following a small slow disturbances; this includes: normal load fluctuation action of the automatic voltage regulators and turbine governors. If the maximum power transfer is exceeded under this condition, individual machines or group of machine will cease to operates in synchronism, thus violation fluctuations of voltage will occur and the steady-state stability limit for the system as a whole would have been reached. This means that steady-state stability limit is the maximum power which can be transferred through the system without loss of stability. In practice, load change may not be gradual, there may be sudden disturbance due to:

i. Sudden change to load
ii. Switching operation
iii. Loss of generation
iv. Fault.

Following such sudden disturbance in the power system, rotor angular differences, rotor speeds and power transfer undergo fast changes whose magnitudes are dependent upon the severity of disturbances. For a large disturbance changes in angular differences may be so large as to cause the machine to fall out of step. This type of instability is known as transient instability. Transient instability is a fast phenomenon, usually occurring within one second for a generator close to cause disturbance.

A sudden large disturbances includes: faults, clearing of faults, sudden load changes and continuous or uncontrollable tripping of lines and generators. The maximum power which can be transferred through the system without the loss of stability under sudden disturbance is the case of 'transient stability limit'. there are many factors that affects 'transient stability' of a system such as: the strength of the transmission network within the system in and the times to adjacent systems, the characteristics of the operating units, including inertia of the rotating parts, the electrical properties such as magnetic saturation characteristics of the stator and rotor.

Power system stability involves the study of the dynamics of the power system under disturbances. From the classical point of view, power system instabilities can be seen as loss of synchronism (i.e. some synchronous machines going out of step) when the system is subjected to a particular disturbance.

Evidently the steady-state stability of power system will always require the ability of the system to bring itself back to its stable configuration following a small disturbance in the network via normal load fluctuation or actions of automatic voltage regulators. This is considered only during a very gradual infinitesimally small power change. In the case the power flow through circuit exceeds the maximum power permissible, then there are chances that a particular machine or group of machines will ceases to operate in synchronism, resulting into more disturbances. In such a situation, the steady-state limit of the system is said to have been reached. Therefore any violation outside the maximum amount of power that is permissible through the system imposes loss of its steady-state stability".

Problem Statements

The declining state of transmission network 330KV and 132KV as super and grid voltage level in terms of efficient electricity power supply is becoming a major challenge due to inadequate power generation at the generating station, particularly to the study case: Afam power generation to the transmission network

This is also strongly associated to the power system machine deviations; including:

- Power system machine under overload conditions, that is if there is a strong deviation of the swing equation representing the solution of generators rotor angle which is a case of mis-match between the two power which is also a function of balance between machine power and electrical power which needs to be investigated.

Aim of Paper

The aim of this study will consider the analysis of 330KV and 132KV power transmission, stability in a developing economy.

Objectives of Paper

The increase in demand on the 330KV and 132KV transmission system has made the network to be over loaded beyond their design limits including the power transfer capacities and that have reduced the quality of power delivered particularly in the case study area.

Therefore, the objective of this study will consider the existing configuration of the network from Afam power generation station to 330KV and 132KV transmission network from Afam power station to the network for purpose of:

i). Developing the swing equation of the power system, in order to determine the operating condition whether stable or unstable.
ii). Implementing the collected data of the system into the swing equation for stability analysis.
iii). Simulating the swing equation model, using electrical transient analyzer tool (E-tap) Matlab in order to investigate system responses and stability limits before during and after the system disturbance.
iv). Validation test between the existing system configuration and improved compensation for deviation from normal operation.

Scope of the Paper

Considering the complexities of power system stability and the robust of engineering activities including protective relay and circuit breaker operations (switching device) Therefore, this research work will consider the investigation of machine (supplying power from Afam to 330KV and 132KV transmission network at Port Harcourt Mains (Z_2) for purpose of analysis and verification.

Justification of Paper

Engaging adequate provision of regular, affordable and efficient electricity supply will rapidly attract more industrialization, this mean the machine; need to be subjected to regular control to avoid overloading the transmission network beyond its thermal limits.

Review of Previous Paper

In recent time, the management of power systems has proven to be more difficult than in the past. This is due to recent increased competition (existing power systems are required to provide same service at lower cost), environmental constraints and other factors have conspired; thus limiting the expansion of the transmission network [16]. The deregulation and unbundling of the power sector has witnessed a sudden increase in the demand for electricity with economic consideration as a top priority. The modern deregulated electricity environment has driven utilities, around the world, so as to operate the power systems closer to the stability thresholds to ensure more efficient utilization of transmission networks [8]. This development has opened a new opportunity for power system operators, whereby at the same time, put the system under considerable pressure to strike a balance between more profit on one hand and fear of possible loss of the system on the other hand. Critical analysis of recent widespread occurrence of power outages (worldwide) showed that blackouts is recorded whenever the sequence of normal contingencies exceeds the acceptable security limits and reliability margins [6]. It can also be noted that large power system failure is a rare event that are difficult to predict; so also, much tedious to control. In order to maintain stability of power system, there are two very important parameters which are namely: the' fault clearing time (FCT) and critical clearing time (CCT). The FCT is defined as the time at which fault is cleared after the occurrence of the fault; always recorded in (seconds). Whereas, the CCT is the fault clearing time at which the system is critically stable, also measured in seconds [7].

In the case of Nigeria, the power network is constructed to generate and wheel power to load centers at specific voltage and frequency levels with statutory limits. The nominal frequency is 50Hz ±0.5%. Even though there are possibilities for system stress; the power system variation, statutorily, could be 50Hz+ 2.5%. (i.e. 48.75 Hz-51.25Hz). On the other hand, the nominal transmission system voltage levels are 330kV and 132kV; in the case of the latter, it has a statutory limit stated as 132kV ± 0.5%. However, when the power system is under stress or during system faults, voltages can deviate outside the limits by a further 5% except under transient and sub-transient disturbances.

Due to the inadequacy of the transmission network capacity, the power system could be stressed to such as an extent that relatively small disturbance can cause a great upset which may eventually result in a possible voltage collapse. In addition, the present architecture of power systems worldwide supports the idea that larger area of the systems be interconnected so as to maximize power generation/transmission efficiency as well as effective power transfer. This implies that a significant portion of the system will be affected whenever/wherever there is any noticeable system disturbance.

In this paper, the Ikeja West 330kV transmission subnetwork was investigated for transient stability. In which case, evaluating its response to sudden/large disturbance (fault conditions) on adjoining transmission lines connected to the station. The systems transition from a perturbed state to a normal operating state with respect to varying critical clearing time (CCT) was documented. Special attention was paid to the Egbin-Ikeja West line (since Egbin delivers the highest quantum of power to the station). The system under examination was modeled and simulated on the ETAP software. The ETAP is a real-time system simulator with special features that include the ability to perform studies both at on-load and off-load conditions. More importantly, it could be implemented for interconnected systems as well as isolated systems. The voltage and frequency deviation was thus plotted against the time. At the end of this study, security limit for faults occurring on the IKEJA-WEST bus was determined, thereby supplying relevant information on the weak points in the system. This made it easy to suggest ideas towards reinforcing network security.

Transient Stability Analysis

Transient faults are a usual occurrence in interconnected systems. They usually clear if power is removed from the line and then restored after a short while. Transient stability is the ability of a power system to regain its normal operating condition after sudden and severe disturbance in the system [19]. Power stability assessment plays an important role in determining the system operating limits and operating guidelines [15]. These analyses also aim to establish the power supply system's reliability and its ability to withstand various disturbances [23].

Transmission Line Performance

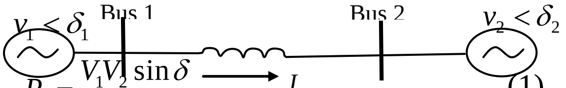
Line Parameters

All transmission lines in a power system are made to transport energy from power generating stations to distribution stations. Hence, they exhibit the electrical properties of resistance, inductance, capacitance, and conductance. Their value are given in per unit of the length of the transmission line and they are denoted by R. L. C. and G. respectively. These parameters are functions of the line geometry, construction materials and operational frequency. The resistance is due to the nature of the conductor while inductance and capacitance are due to the effects of magnetic and electric field around the conductor. The series resistance accounts for the Ohomic loss (I^2R) line loss. Series impedance including resistance and inductive reactance are due to the effects of voltage drop along the line, while inductance and capacitance are due to the effects of magnetic and electric field around the conductor. These parameters form the basis for the development of transmission line models used in power system studies. The shunt conductance accounts for leakage current which flows across insulators and ionized pathways in the air. The leakage currents are negligible compared to the current flowing in the transmission lines and may be neglected (Kr Ahuja & Chankaya, 2012). The line resistance and inductance form the series impedance of the line. The capacitance and the conductance form the shunt admittance of the line.

Power Flow through Lines

The aim of power lines is to effect power transmission from one bus to another or from one grid to another. Transmission lines are built either in single circuit or double circuit lines (for higher capacities). Power flow through a line is determined by the voltage magnitudes of the two buses connected by the line, the line impedance and the difference in angles of the voltages of the two buses. When double circuit (parallel line) is involved, the fact that current flows through the line of least impedance path can also bring about an imbalance in the flow of power and this can cause an overloading of one line of the circuit in some cases as the other line operates quite below its power rating [14].

For a simple 2-bus transmission system shown in Figure 1, the power flow through the line is represented by equations 1-2, where $\delta = \delta_1 - \delta_2$



$$P_2 = \frac{V_1 V_2 \sin\delta}{X_L} \quad (1)$$

$$Q_2 = \frac{V_2 (V_2 - V_1 \cos\delta)}{X_L} \quad (2)$$

$$V = f(P,Q) \quad (3)$$

Equations above indicate that the active and reactive power/current flow can be regulated by controlling the voltages, phase angles and line impedance of the transmission system. Real power transfer can be increased by increasing the line voltage, reducing the line reactance or by increasing from (2.1), the active power flow will reach the maximum when the difference in phase angles is 90° but in practice, a small angle difference, between 35^0 to 45^0, is used to keep the system stable from the transient and dynamic oscillations [21]. Also, from equation (2.2), reactive power at any bus is dependent on the voltage drop along the line, such that reactive power increases with increase in voltage difference between the two buses. As a result of (2.1) and (2.2), the voltage at the receiving-end of the line becomes a function of the active and reactive power flow through the line as given in (2.3). For effective operation of a transmission line, these transmission parameters are kept under control. Power flow balance is achieved in a parallel transmission line using series compensation or phase shifting transformers [13]).

Surge Impedance Loading

The surge impedance loading (SIL) of a transmission line is the MW loading of the transmission line at which a natural reactive power balance occurs. It is simply the MW loading at a unity power factor at which the lines MVar usage is equal the line's MVar production, causing reactive powers to cancel out. S1L is given in equation form as:

$$SIL = \frac{(VLrated)^2}{Z_c} \quad (4)$$

Where Z_c *is* the characteristic impedance or surge impedance of the line.

The concept of SIL is important in transmission line studies because it sets the theoretical limit for stable operation (power delivery) for very long lines and indicates where the reactive requirements of the line are small.

Line Loadability

There is always an inherent trade-off between increasing utilization of the grid and security of grid's operation. Loadability of a transmission, line is defined as the optimum power transfer capability of a transmission line under a specified set of operating criteria. Many research works have been carried out on the improvement of transmission transfer capability with a variety of operation constraints, such as stability, voltage security and thermal limits [17].gSt. Clair curve [23] provides a. simple means for estimating power transfer capabilities of transmission lines. It concerns three limiting factors: thermal limit, voltage drop limit and angular stability limit which usually affects short, medium and long transmission lines respectively. Voltage limit and stability limit fall below thermal limit. Compensation can be used to modify the natural parameters of transmission lines and to increase loadability of long lines toward their thermal limit.

Transmission Systems Enhancement Strategies

Several methods which could be used to enhance the performances of transmission lines have been reported in [18]which include:

i). **Installation of New Transmission Line:** This is usually the first option that comes to mind whenever a transmission line is limited in the amount of power it can transmit, so as to alleviate overloading by providing additional paths for power flow. It is beneficial by increasing the reliability of the transmission system. However, it has to pass through economic, political and environmental hurdles.

ii). **Reconductoring Transmission Line/Terminal Equipment Replacement:** A line can be reconductored with a larger conductor with more power-carrying capability if the original transmission line conductor is inadequate to carry expected power flows, provided that the transmission line towers do not need to be significantly altered to support the heavier conductor. In addition, some terminal equipment may need to be upgraded to match the desired rating.

iii). Conversion **from** single circuit to **double circuit:** This involves making necessary modifications to the existing transmission towers and adding a second transmission line.

MATERIAL AND METHODS

Materials

The power supply network from Afam power generating station through 132KV transmission line Port Harcourt to 33KV injection substation at Port Harcourt mains (Z_2), network data will be collected from the Port Harcourt Electricity Distribution Company (PHEDC) and transmission company of Nigeria (TCN) for purpose of analysis and investigation for the study case.

Method of Analysis

Considering the activities of power systems whether steady state, transient state and dynamic behaviour of the electrical network which will be determined for a given set of loading and operating condition of the system. This means that power flow problems will be formulated in order to monitor the existing state of the system. Evidently, it is a requirement to consider the efficiency of the power system at all time for purpose of planning, design, and reconfiguration of the power system. This work will strongly consider the application, using numerical techniques (Rungkutta equations, trapezium rule equation, etc.) Each techniques will be applied to the problem case where necessary. Electrical Transient Analyzing Tool (ETAP) will be used to draw and design the electrical network from the supply system to the study case while Matlab tool will be used for the simulation of the existing state of the system.

CASE 1:

Steady State Stability: variation of generator load angle with load.

When generator is loaded, the load angle is increased. The maintenance of the load angle depends upon the generator load current, the generator reactance and power factor. Since the internal reactance of the generator remaining underlisted, it will neglected as a variable.

i. Consider an equivalent current for a generator directly connected to a reactance with $(pf = 1)$ load.
ii. The production of the load currents I_a and the generator internal reactance, X_d produces the internal voltage drop, $I_a.X_d$.
iii. For a given load current, I_a and terminal voltage, $V_{T,}$ a load-angle of 8_g is produced in the generator.

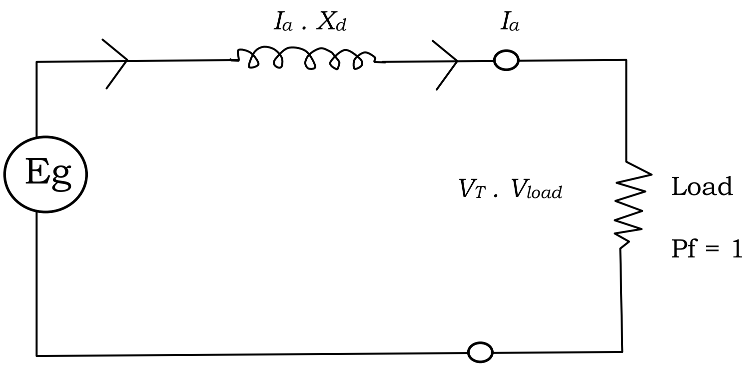


Fig. 1: The terminal voltage V_T and the load angle

- Consider the relationship between I_a X_d and the load angle.
- If the load current, I_a is increased, all other constraint, the I_a X_d product increases casing the load angle to increase.

CASES 2:
Steady-State Stability: variation of transmission line load angle with load.

i. When a transmission line is loaded, a load angle, δ_L is produced across the line. Consider an equivalent circuit for the line having a reactance of X_L and the load is operating with pf $(of \ \cos\theta)$ lagging.
ii. The resistance of the line is very small compared to its reactance.
iii. When the line is operating at 0.9 pf lagging.
iv. The supply voltage has to be considerably larger than the load voltage which is kept constant.
v. From the equivalent circuit diagram of figure 3.2 we can analyze the system behaviour.

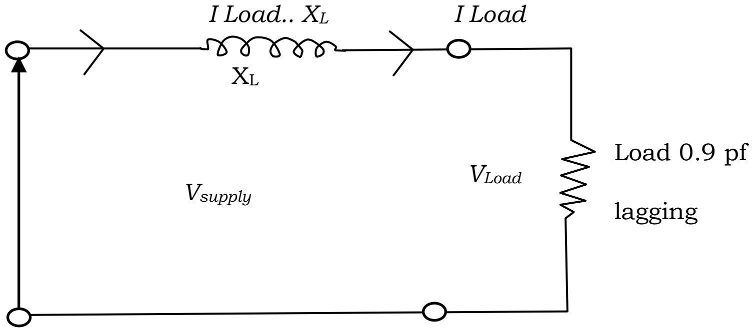


Fig. 2: The supply voltage and the load

i). With a given large load current, I_a on a line having a large value of X_L gives a large load angle.
ii). The result of changes in load angle caused by changes in load power factor, changes in θ.

iii). As θ becomes more lagging, it increases clockwise, thereby δ_L decreases.
iv). As θ becomes more leading, δ_L gets larger, if MW load remains constant.

CASES 3:
STEADY-STATE STABILITY: VARIATION OF GENERATOR AND LINE LOAD ANGLE WITH LOAD.

i). Consider an equivalent circuit of a generator feeding a load via a transmission line.
ii). When the generators operate with a load angle of δ_g and the line operates with a load angle of δ_L.
iii). The load is operating with a Pf of $\cos\theta$.
iv). The generator operates at a power factor angle of θ_{gm} which is greater than the θ load.
v). The generator and line operates together at an angel of δ_T, which is the sum of δ_g and δ_L.
i). Any change in load angle of the line or the generator will result in a change in the total load angle for the generator/line.

Consider the equivalent circuit of a generator with increasing load current.

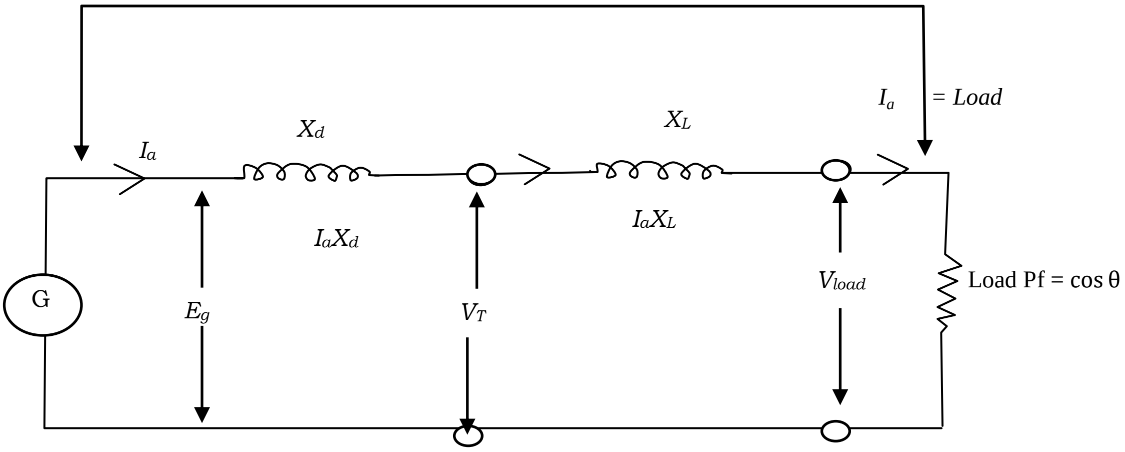


Fig 3: The load angle of the generator increase with increasing load current

i). The load angle in a given generator increases with increasing load circuits, I_L.
ii). The load angle in a given generator also increases with operating at a more leading power factor (*Pf*), if the MW load is held constant.
iii). The load angle decreases with decrease in load/or operation at a more lagging *Pf*, if the MW load remain constant.
iv). The load angle for a given transmission line increases as the load on the line increases.
v). As the load power factor (*Pf*) for a transmission lines becomes more leading, the load angle will increase.
vi). The load angle for a generator/lines is the sum of individual load angles.
vii). The changes in load angle for the individual components will directly affects the load angle of the grouped components.

Relationship between load-angle and active power (MW) transfer

i. In this analysis, the resistance of the generator and the line is neglected.

ii. The system can be taken to be loss free, that is there will be no active power loss between the generator terminals and the load.

iii. As losses are neglected

$$P_{gen} = P_{load} \qquad (5)$$

iv. If the line has reactance, X_L then we can initiate the power transfer equation as:

$$P = \frac{V_T V_{load} \, Sin\delta_L}{X_L} \qquad (6)$$

Where:

X_L: The reactance of the line

δ_L : Line load angle

For generator:

$$P = \frac{V_T E_g \, Sin\, \delta_g}{X_d} \qquad (7)$$

Where;

δ_g : generator load angle

X_d : the reactance of the generator.

- Hence, the power transfer equation for the generator and line together are given as:

$$P = \frac{V_{load} \, Eg \, Sin(\delta_g + \delta_{load})}{X_d + X_L} \qquad (8)$$

Equation (3.4), shows the maximum active power transfer, P can be analyzed.

- X_d and X_L should be kept as low as possible.
- A generator has a value of X_d which cannot be altered.
- X_L can be kept low by having 'short-transmission lines' or many lines in parallel.
- Eg and V_T or V_{load} should be kept at a constant value.
- If Eg is allowed to fall or if V_T or V_{load} falls due to fault condition, less power will be transferred.
- Then the composite load angle should not exceeds 90, that is (δ_g + δ_L) should not exceeds 90^0.

Steady-State Stability: Transmission Line Characteristics

- In the case of a loss free power line, the power at both ends of the line will be same as:

$$P_{in} = P_{out} \qquad (9)$$

From equation (3.2):

$$P_{in} = P_{out} = \frac{V_T V_{load} \, Sin\delta}{X_L} \qquad (10)$$

- When $Sin\delta = 1.0$
  Then,
  $$\left.\begin{array}{l} \\ \delta = Sin^{-1}(1.0) = 90^0 \end{array}\right\} \quad (11)$$
  Equation (8), is the conditions for maximum power transfer that is,
  $$P_{in} = P_{out} = P_{\max} \qquad (12)$$
- For condition other than maximum power transfer, the power transmitted or received is given as δ:
  $$P_{in} = P_{out} = P_{\max}\, Sin\,\delta \qquad (13)$$

Hence, the power transmitted or transferred from one end of the line to the other is a function of Sin δ and a power transfer curve can be drawn which has a sine wave – shape.

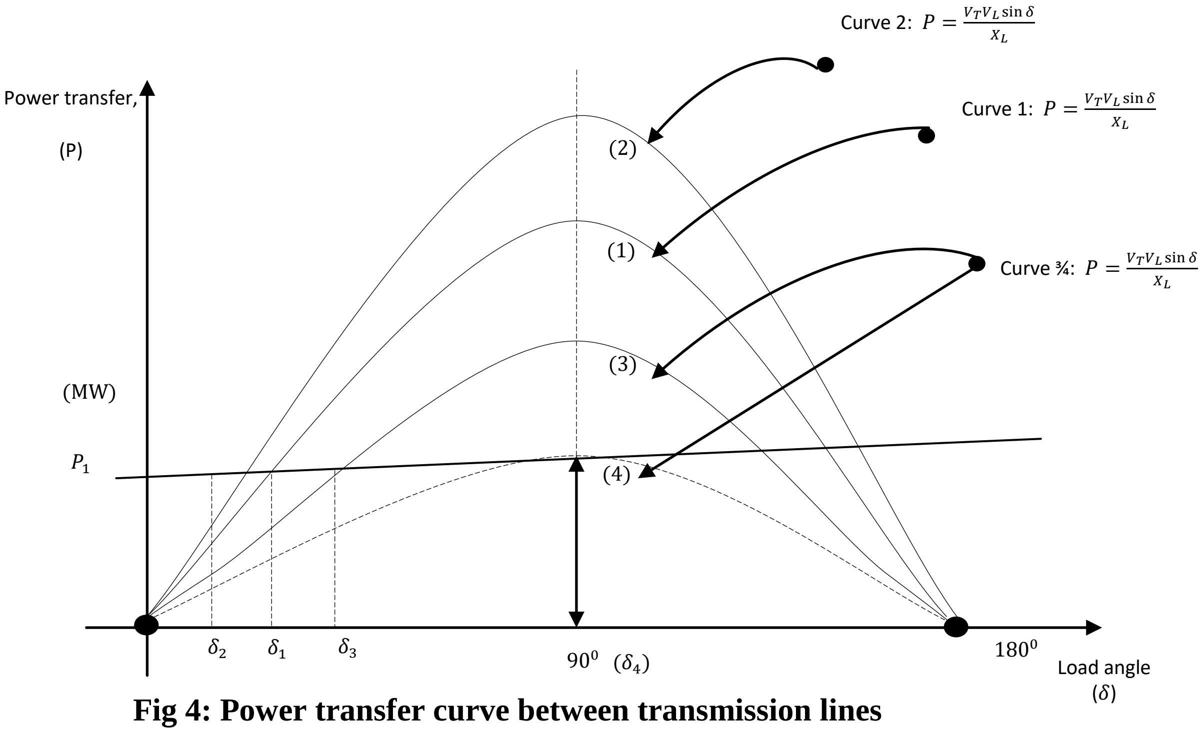


Fig 4: Power transfer curve between transmission lines

i. Consider the power transfer curve of fig 4, the power transmitted between two ends of a line having a reactance X_L, and a voltage V_T, at one end and V_L (V_{Load}) at the other end.
ii. This means that when power is transmitted at 100% capacity (MW) and the line is operating on curve 1, then the load angle of δ_I is obtained.
iii. If the sending – end voltage, V_T is increased then the power transfer capability (PTC) for the line will be increased.
iv. When this scenarios happens, we move to curve number 2, and the line will operates at an angle, δ_2; which is less than δ_1.

Analysis of Power Transfer – Curve Behaviour

i. Power curve 2, when V_T or V_L is increased or X_L is reduced.
ii. Power curve 1, when V_T, V_L and X_L are at 100% values.

iii. Power curve 3, 4 when V_T, V_L is reduced or X_L is increased.

iv. Steady – state stability analysis deals with slow averages in system considerations. This means that the movement between operating curve is a 'slow process' and the load – angle changes are small and slow.

v. The worst scenario for steady – state stability condition is when the operating point moves to the peak of an operating curve with $\delta = 90^0$, at load-angle δ_4 (curve number 4). Thus, instability will occur if condition changes.

vi. Instability can be prevented by operating with total load angles below stability limit.

vii. This means that maintaining a reasonable 'operating margin' of load angle, which will ensure unstable condition which are not reachable even when transmission lines are removed for service.

viii. The corrective measure or action to avoid steady state instability are:
  - Reduction in mechanical power input.
  - An increase in field current which will boost the flux and in order to cause the operating points to move to a higher curve.

ix. If the line voltage, V_L is decreased the power transfer capability (PTC) of the line will shift to curve number 3, and the line will operates at angle, δ_3.

x. If the line voltage, V_L is reduced further the line will operates on curve 4 with operation at load – angle, δ_4.

xi. When the load angle, δ_4 is reached the line is operating at a 90^0 load angle.

xii. Any further reduction of the height of the curve or any further increases in power to be transferred, will result in the power input exceeding the power that can be transferred.

xiii. If the mechanical power output from the turbine is constant and the line voltage decreases further.

xiv. Then the generator will not be able to convert the mechanical power into electrical power.

xv. This means that there will be excess of mechanical power produced over the electrical power being transferred which is the case of mix match.

xvi. This excess power will cause the whole turbine generator shift to accelerate.

xvii. This evidently, means that the net result of the two ends of the line will no longer large remain in synchronism, making the system to experience instability.

xviii. In applying these curves to the generators consideration, as soon and the load-angle exceed 90^0, the power input to the generator will be greater than the power it can convert or transfer into electrical active power.

xix. Therefore, the generator will start to speed up, unless corrective measure are taken immediately, the generator will pole-ship.

xx. This pole-shipping is as a result of excessive mechanical – input power causing the magnetic flux- link between the generator and electrical power system to be stretch excessively; causing synchronism to be broken.

xxi. The stronger the magnetic link between the generator and the electrical system, the more difficult pole shipping to be experienced.

TRANSIENT STABILITY IN POWER SYSTEM

More often than not, the power generation systems are subjected to faults of different kind, and it is extremely important for power engineers to be well-versed with the stability conditions of the system behavior.

In general practice studies related to *Transient Stability in Power System* are done over a very small period of time equal to the time required for one swing, which approximates to around 1 sec or even less. If the system is found to be stable during this first swing, its assumed that the disturbance will reduce in the subsequent swings, and the system will be stable thereafter as is generally the case. Now in order to mathematically determine whether a system is stable or not we need to formulate the swing equation of power system.

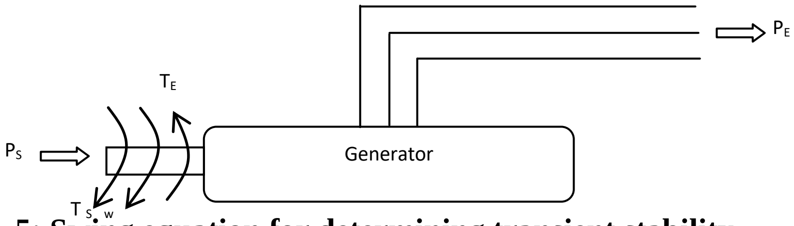


Fig. 5: Swing equation for determining transient stability

When the synchronous generator is fed with supply from one end and a constant load is applied to the other, there is some relative angular displacement between the rotor axis and the stator magnetic field, known as the load angle δ which is directly proportional to the loading of the machine. The machine at this instance is considered to be running under stable condition.

Now if we suddenly add or remove load from the machine the rotor decelerates or accelerates accordingly with respect to the stator magnetic field. The operating condition of the machine now becomes unstable and the rotor is now said to be swinging with respect to the stator field. The equation (that gives) the relative motion of the load angle δ with respect to the stator magnetic field is known as the In order to determine the transient stability of a power system using swing equation, let us consider a synchronous generator supplied with input shaft power P_s producing mechanical torque to T_s as shown. This makes the machine rotate at a speed of ω rad/sec and the output electromagnetic torque and power generated on the receiving end are expressed as T_e and P_e respectively.

Swing equation for transient stability of power system

Here for the sake of understanding we consider the case where a synchronous generator is suddenly applied with an increased amount of electromagnetic load, which leads to instability by making P_E less, then rotor undergoes deceleration. Now the increased amount of generating power required to bring the machine back to stability is given as:

Accelerating power, $P_{AG} = P_S - P_E$ (14)

Similarly, the accelerating torque is given by:

$$T_{AG} = T_S - T_E \qquad (15)$$

Now we know that

$$P_{AG} = T_{AG}\omega = 1 \propto \omega \qquad (16)$$

(Since T = current x angular acceleration)
Furthermore, angular momentum, M = 1ω

$$P_{AG} = m \qquad (17)$$

But on loading the angular displacement θ varies continuously with time, as shown in the figure below, we can write.

$$\theta = \omega_s + \frac{d\delta}{dt} \qquad (18)$$

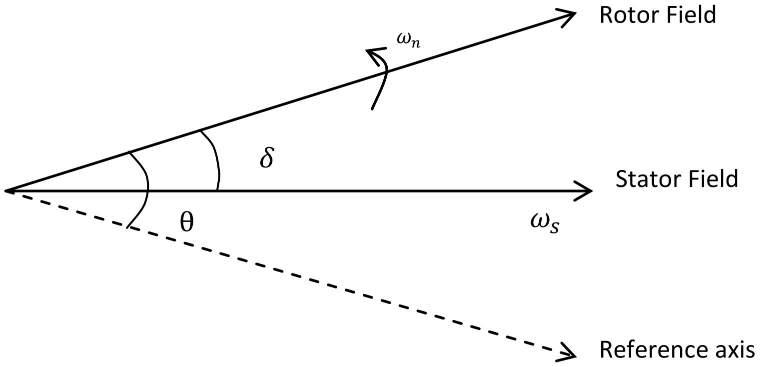


Fig. 6: The angular displacement with loading condition

Double differentiating the equation with respect to the time, we have,

$$\frac{d^2\theta}{dt^2} = \frac{d^2\delta}{dt^2} \qquad (19)$$

Where the angular acceleration

$$\propto = \frac{d^2\theta}{dt^2} = \frac{d^2\delta}{dt^2} \qquad (20)$$

Thus we can write,

$$\left.\begin{array}{c} P_{AG} = M\frac{d^2\delta}{dt^2} \\ or \\ M\frac{d^2\delta}{dt^2} = P_S - P_E \end{array}\right\} \qquad (21)$$

Now the electromagnetic power transmitted is given by,

$$P_E = \frac{V_G.V_M}{X}\sin\delta = P_{max}\sin\delta$$

When $\delta = 0$,

$$\text{maximum amplitude} = \frac{V_G.V_M}{X} \qquad (22)$$

Thus we can write,

$$M\frac{d^2\delta}{dt^2} = P_S - P_{max}\sin\delta$$

This is known as the swing equation for transient stability in power system.
The stability of an interconnected power system is its ability to return to normal or stable operation after having been subjected to some form of disturbance. With interconnected systems continually growing in size and extending over vast geographical regions, it is becoming increasing more difficult to maintain synchronism between various parts of the power system.

- The various studied behavior includes: Stability – steady state stability, transient state stability and the swing equation and its solution using numerical methods and MatLab/Simulink are used in the analysis of system behavior investigation. The solution of swing for transient stability analysis using the three different methods – Point-by-Point method, Modified Eulier method and Runge-Kutta method are normally used.

- Modern power systems have many interconnected generating stations, each with several generators and many loads. The study may consider one-machine system or multi-machine stability analysis.
- For small-signal performance of a machine connected to a large system through transmission lines. While gradually increase the load and monitoring effects of the dynamics of the field circuit. This small-signal performance are measured using the eigen value analysis.
- Detailed transient stability analysis is carried out using classical model which can slightly improved the effect of damping towards transient stability response. The characteristics of the various components of a power system during normal operating conditions, during disturbances can be determined, and the effects on the overall system performance can now be investigated.

The successful operating of a power system depends largely on the engineer's ability to provide reliable and uninterrupted service to the loads. The reliability of the power supply implies much more than merely being available. Ideally, the loads must be fed at constant voltage and frequency at all times. The first requirement of reliable service is to keep the synchronous generators running in parallel and with adequate capacity to meet the load demand. Synchronous machines do not easily fall out of step under normal conditions. If a machine tends to speed up or slow down, synchronizing forces tend to keep it in step. Conditions do rise, however, such as a fault on the network, failure in a piece of equipment, sudden operation of a major load such as a stem mill, or loss of a line or generating unit, in which operation is such that the synchronizing forces for one or more machines may not be adequate, and small impacts in the system may cause these machines to lose synchronism.

A second requirement of reliable electrical service is to maintain the integrity of the power network. The high-voltage transmission system connects the generating stations and the load centres. Interruptions in this network may hinder the flow of power of the load. This usually requires a study of large geographical areas since almost all power systems are interconnected with neighboring systems.

Random changes in load are taking place at all times, with subsequent adjustments of generation. Provided the change from one equilibrium state to another is considered synchronism frequently may be lost in that transition period, or growing oscillations may occur over a transmission line, eventually leading to its tripping. These problems must be looked at by the power system engineer for purpose of *'power system stability'.*

The tendency of a power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium is known as 'stability'.

The problem of interest is one where a power system operating under a steady load condition is perturbed, causing the readjustment of the voltage angles of the synchronous machines. If such an occurrence creates an unbalance between the system generation and load, it results in the establishment of a new steady-state operating condition, with the subsequent adjustment of the voltage angles. The perturbation could be a major disturbance such as the loss of a generator, a fault or the loss of a line, or a combination of such events. It could also be a small load or random load changes occurring under normal operating conditions. Adjustment to the new operating condition is called the transient period. The system behaviour during this time is called the dynamic system performance, which is a major concern in defining system stability. The main criterion for stability is that the synchronous machines maintain synchronism at the end of the transient period.

That is if the oscillatory response of a power system during the transient period following a disturbance is damped and the system settles in a finite time to a new steady operating condition, then the system is stable. If the system is not stable, it is considered unstable. This primitive definition of stability requires that the system oscillations be damped. This condition is sometimes called 'asymptotic stability' This means that the system contains inherent forces that tend to reduce oscillations. This is a desirable feature in many systems and is considered necessary for power systems. The definition also excludes continuous oscillation from the family of stable systems, although oscillators are stable in a mathematical sense. The reason is practical since a continually oscillating system would be undesirable for both the supplier and the user of electric power. Hence the definition describes a practical specification for an acceptable operating condition. The stability problem is concerned with the behaviour of the synchronous machines after a disturbance. For convenience of analysis, stability problems are generally divided into two major categories-steady state stability and transient state stability.

Swing Equation

Under normal operating conditions, the relative position of the rotor axis and the resultant magnetic field axis is fixed. The angle between the two is known as the power angle or torque angle. During any disturbance, rotor will decelerate or accelerate with respect to the synchronously rotating air gap (mmf), a relative motion begins. The equation describing the relative motion is known as the swing equation.

Synchronous Machine Operation

- Consider a synchronous generator with electromagnetic torque Te running synchronous speed ω_{sm}
- During the normal operation, the mechanical torque Tm = Te.
- A disturbance will result in accelerating/decelerating torque Ta = Tm-Te, when (Ta>0 if accelerating, Ta<0 if decelerating).
- By the law of rotation, we have:

$$J\frac{d^2\theta_m}{dt^2} = T_a = T_m - T_e \qquad (23)$$

Where J is the combined moment of inertia of prime mover and generator

- θ_m is the angular displacement of rotor with respect to the stationery reference frame on the stator
- $\theta_m = \omega_{sm} + \delta_m, \omega_{sm}$ is the constant angular velocity
- Taking the derivative of θ_m, we obtain-

$$\frac{d\theta_m}{dt} = \omega_{sm} + \frac{d\delta_m}{dt} \qquad (24)$$

Steady State Stability

This is the ability of power system to maintain synchronism and return to its original state when subjected to small disturbances. Such stability is not affected by any control efforts such as voltage regulators or governor.

Analysis of Steady-state Stability by Swing Equation

- Starting from swing equation

$$\frac{H}{\pi f_o}\frac{d^2\delta}{dt^2} = P_{m(\rho u)} - P_{e(\rho u)} = P_m - P_{max}\sin\delta \qquad (25)$$

$$P_s = \frac{dP}{d\delta}|_{\delta_o} = P_{max}\cos\delta_o \qquad (26)$$

- Introduce a small disturbance $\Delta\delta$
- Deviation is from $\delta = \delta_0 + \Delta\delta$
- Simplify the nonlinear function of power angle δ
- Analysis of steady-state stability by swing equation
- Swing equation in terms of $\Delta\delta$

$$\frac{H}{\pi f_o}\frac{d^2\Delta\delta}{dt^2} + P_m\cos\delta_0\Delta\delta = 0 \qquad (27)$$

- $PS = P_{max}\ \cos\delta 0$: the slope of the power-angle curve at $\delta 0, PS$ is positive when $0^0 < \delta < 90^0$
- The second order differential equation

$$\frac{H}{\pi f_o}\frac{d^2\Delta\delta}{dt^2} + P_s\Delta\delta = 0 \qquad (28)$$

- The characteristic equation becomes;

$$d^2 = \frac{\pi f_o}{H}P_s$$

Rule 1: If P_s is negative, one root of the system is unstable

Rule 2: If P_s is positive, two roots of the system in the $j\omega$ axis and motion is oscillatory and undamped, system is marginally stable

The oscillatory frequency of the undamped system

Damping Torque

- Phenomena: when there is a different angular velocity between rotor and air gap field, an induction torque will be set up on rotor tending to minimize the difference of velocities.
- Introduce a damping power by damping torque

$$P_d = D\frac{d\delta}{dt} \qquad (29)$$

- Introduce a damping power by damping torque
- Characteristic equation:

$$\left.\begin{aligned}\frac{H}{\pi f_o}\frac{d^2\Delta\delta}{dt^2} + D\frac{d\Delta\delta}{dt} + D\frac{d\Delta\delta}{dt} + P_s\Delta\delta = 0\\ \frac{d^2\Delta\delta}{dt^2} + 2\varsigma\omega_n\frac{d\Delta\delta}{dt} + \omega_n^2\Delta\delta = 0\end{aligned}\right\} \qquad (30)$$

- Analysis of characteristic equation;

$$S^2 + 2\varsigma\omega_n s + \omega_n^2 = 0 \qquad (31)$$

- For damping coefficient is given as;

$$\zeta = \frac{\mathrm{D}}{2}\sqrt{\frac{\pi f_o}{\mathrm{H}P_s}} < 1 \qquad (32)$$

- Roots of characteristic equation is given as;

$$S_1, S_2 = -\zeta\omega_n \pm j\omega_n\sqrt{1-\zeta^2} \qquad (33)$$

- Damped frequency of oscillation is given as;
  $$\omega_d = \omega_n\sqrt{1-\zeta^2} \qquad (34)$$
- Positive damping ($1 > \zeta > 0$): S_1, S_2 have negative real part if $P_S$is positive, this implies that the response is bounded and the system is stable.
- Solution of the swing equation
  $$\frac{d^2\Delta\delta}{dt^2} + 2\varsigma\omega_n\frac{d\Delta\delta}{dt} + \omega_n^2\Delta\delta = 0 \qquad (35)$$
- Roots of swing equation
  $$\Delta\delta = \frac{\omega_n\Delta\delta_o}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}(\omega_d t + \theta),$$
  $$\delta = \delta_o + \frac{\omega_n\Delta\delta_o}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\ \sin(\omega_d t + \theta) \qquad (36)$$
- Rotor angular frequency
  $$\Delta\omega = -\frac{\omega_n\Delta\delta_o}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin(\omega_d t),$$
  $$\omega = \omega_o + \frac{\omega_n\Delta\delta_o}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin(\omega_d t) \quad (37)$$
- Response time constant
  $$\left.\begin{array}{l} \tau = \frac{1}{\zeta\omega_n} = \frac{2H}{\pi f_o D} \\ setting\ time; \\ \quad t_s \cong 4\tau \end{array}\right\} \qquad (38)$$
- Relations between settling time and inertia constant H: increase H will result in longer t_s, decrease ω_n and ζ

The analysis of the swing equation, Ibe & Odia (2017) used the Runge Kuta method to establish the clearing time (tcl) needed to restore generator synchronization and regain system equilibrium but this study deviated from such known approach and rather implemented the swing equation using example MATLAP Simulink. The governing equation is stated below as well as the basic assumptions made in the circumstance to establish the equation while the generation and transmission parameters needed to compute the equation were obtained appropriately.

Schematic Overview of the 330KV Transmission Grid in Nigeria

The 330KV Transmission grid is a non linear network of power system infrastructure linking various generators and their associated sub stations to the national grid as shown in Fig, 12. Some of the sub networks can be classified as long transmission lines like Shiroro GS to Jebba TS which is about 244KM; medium lines like Kanji GS to Jebba TS which is about 81 KM or short transmission lines like Afam GS to Alaoji TS which is about 25KM. Depending on the line of interest, the shunt capacitance and linkage reactance may be neglected for short lines in computing the line parameters but this is not the same case when computing the line parameters for long lines.

In the event of fault or overload on the transmission line, the power system responds through the breakers to clear the perturbation within the set time but such perturbation depending on the duration, may lead to loss of generator synchronization. There are other associated power system phenomenons like reactive power but this paper will also focused on the swing equation model to determine the critical clearing time of a fault or system overload necessary to maintain generator synchronization.

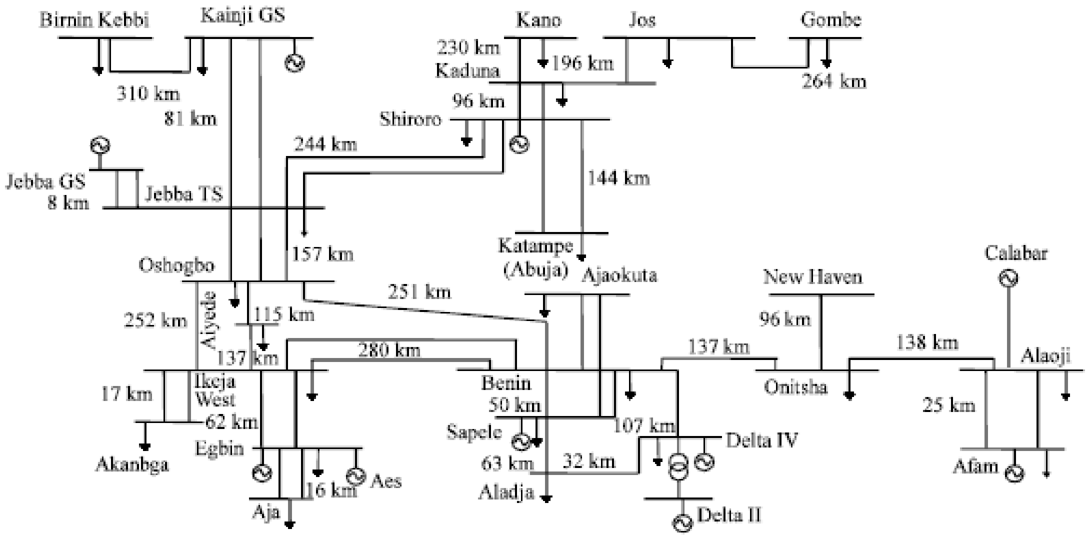


Figure 13: Two Line Overview of the 330KV Transmission Network

Swing Model Equation

Basic assumptions were made in the swing equation which include:

- Constant mechanical power input during the period of the transients
- Negligible damping or asynchronous power
- Representation of synchronous machine by constant voltage source behind a transient reactance. Though this assumption is rarely applicable
- The most important assumption is that synchronous power may be calculated from a steady state solution of the network, to which the machines are connected; hence, P_e, the electrical power output is obtained from the machine

The procedure for achieving transient stability in a multi-machine power system must take into account the conditions for continuous synchronization or swing operation of the generators. This approach often restores loss of synchronization but the determination of the swing process under normal operating conditions focuses on the relative position of the rotor axis and the normal resultant magnetic field axis which are normally fixed. The power angle or torque angle which is the angle between the rotor axis and the magnetic field axis is equal when considering the conditions for swing operation.

When there is a disturbance either due to fault or overloading of lines, the rotor usually decelerates or accelerates with respect to the synchronously rotating air gap and a relative motion being initiated. The basic considerations therefore is to initiate this action including:

- A synchronous generator with electromagnetic torque T_e, running at synchronous speed ω_m
- A mechanical torque T_m-T_e at normal operation
- Decelerating torque $T_a=T_m-T_e$ ($T_a > 0$ for accelerating torque; $T_a < 0$ for decelerating torque) in the event of an induced disturbance.

Invoking the basic principles of rotation, the swing equation which governs the inertia and the equilibrium of energy transfer in accordance to Newton's Second Law is given as:

$$J\frac{\partial \omega_m}{\partial t} = T_m - T_e \qquad (39)$$

where,

J = the cumulative moment of inertia of the prime mover and generator,

ω_m = is the angular displacement of rotor with respect to fixed frame of reference on the stator.

$\frac{\partial \omega_m}{\partial t}$ ω_m = is the change of ω_m with respect to time, t.

T_m = is the mechanical torque

T_e = is the electrical torque

However, its often convenient in electrical power systems to describe eqn(63) in terms of their electrical powers instead of torque as:

$$\frac{2H}{\omega_{e,s}}\frac{\partial \omega_e}{\partial t} = P_m - P_e \qquad (40)$$

where;

H = the generator inertia constant,

$\omega_{e,s}$ = is the angular speed with respect to fixed frame of reference on the stator.

P_m = is the mechanical power

P_e = is the electrical power

The inertia constant, H, is further computed as:

$$H = \frac{\frac{1}{2}J\omega_m^2}{S_{base}} \qquad (41)$$

where,

S_{base} = the generator MVA rating.

The numerator in eqn. (65) represents the Kinetic Energy of the rotating masses.

For a multi-machines system, it is expected however to yield several swing equations probably equal to the number of machines so that the behavior of each machine can be investigated with respect to a 3-phase fault or any other fault but it is desirable to minimize the number of swing equations by combining the machines into one single equivalent machine.

Classical Dynamic Model for Transient Stability Analysis

In order to gain insight into the behavior of a power system network, appropriate modeling tools are required. This can be in the form of simulation program or model via Model View Controllers (MVCs) with convenient user interfaces. The swing program developed takes into account the swing equations described in the previous section. First the topology of the network under investigation is described figuratively and the parameters numerically defined, then the swing model equations are applied to the network of equations to determine the rotor angle (or angular frequency) response of the generated electrical power.

The sub-transmission power system network study considered the activities of the system. It consists of a generation bus (Afam G.S.), the Alaoji Bus under and the

Onitsha Bus, as a single-machine infinite bus system. For this analysis, we shall assign the Afam G.S, Alaoji and Onitsha buses with labels 1, 2, 3 respectively.
The equivalent (pre-fault) reactance between the generator internal voltage and the infinite bus voltage may be computed as:

$$X_{eq} = \frac{(X_d^{\prime} + X_{tsc} + X_{12}) * X_{23}}{(X_{12} + X_{23})} \qquad (42)$$

where,

$X_d^{\prime}$ = the transient reactance of the generator

X_{tsc} = short-circuit reactance of the transformer

X_{12} = series reactance of lines 1-2

X_{23} = series reactance of line 2-3

For the computation of line parameters
the maximum pre-fault active power deliverable by the system is computed as:

$$\begin{aligned} P_m = P_e &= \frac{E_q^{'} V}{X_{eq}} \sin\delta \qquad (43) \\ &= P_{\max} \sin\delta \end{aligned}$$

where,

$E_q^{'}$ = the generator internal voltage.

V = the infinite bus voltage.

δ = the machine (generator) rotor angle.

The initial machine angle δ may be obtained from a two-point solution as:

$$\delta = \begin{cases} \delta_o = \arcsin\left(\frac{P_m}{P_{\max}}\right) \\ 180 - \delta_o \end{cases} \qquad (44)$$

where,

δ_o = the initial machine angle.

For any change in electrical power with respect to machine angle greater than zero and less than 90 degrees, the system is stable; otherwise it is unstable.

RESULTS

Real-Time Dynamic Simulations for Transient Stability Analysis (TSA)

The results using a real-time implementation model is presented. The model system is particularly developed to allow dynamic transient loading (intermittent and abrupt MW/MVAR peaks) to be made in real or near-real-time. The results are interpreted in terms of the Root-Mean-Square (RMS) value of the generation voltage; under normal (fault free) conditions the generation voltages are assumed to be relatively stable considering the fact that all bus loading are at permissible ranges the circuit breakers are connected to each phase which are also assumed to be switching. Based on the analysis of results, the peak-to-peak values considering the breaker current flow, generator sending end voltage and generated power obtained during simulations were also taken into account.

Results of short-circuit fault simulations – Phase-A only

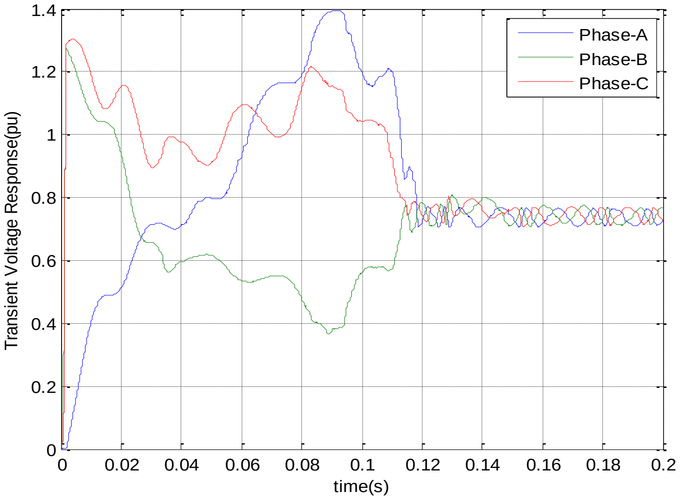


Figure 14: Transient Voltage Response of the Alaoji Sub-Transmission Network with a Fault at Phase A-Terminal

The results of single short circuit fault for Phase-A by activating only Phase-A using the Fault simulator block while considering the generator voltage responses at all phases. From the voltage response below, Phase A experienced an abnormally high voltage while Phase B collapsed; Phase C voltage also increased but not in the same magnitude with the faulted phase. The fault was active for a duration of 0.08s before being cleared by the breakers but if it had persisted and the voltages on Phase A and C continues to increase as seen from the plot, then the system would have been beyond its stability limit. This means that this such fault is cleared at tcl=0.07s.

From the observation, quick response harmonic resistance breakers are needed for this kind of fault clearance as the breakers staggered for about 0.02s before finally clearing the fault and the system restored to equilibrium

Results of short-circuit fault simulations – Phase-B only

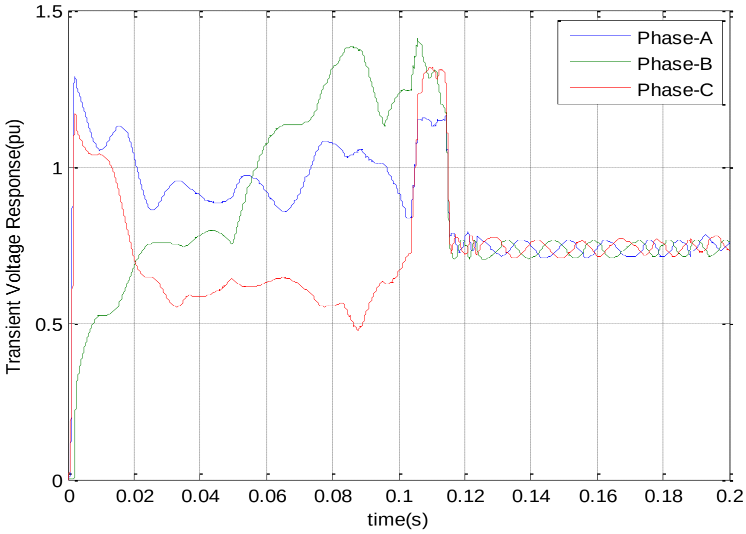


Figure 15: Transient Voltage Response of the Alaoji Sub-Transmission Network with a Fault at Phase B-Terminal

The results of single short circuit fault by activating only Phase-B using the Fault simulator block is as shown in Figures 15 considering the generator voltage responses at all phases. From the result shown Phase A and B experienced high voltage with Phase A attaining very high value while Phase C collapsed. The fault duration was about 0.08s before the breakers cleared the fault. This is almost consistent with the analysis made in Fig. 14 in terms of the breaker requirements.

Results of short-circuit fault simulations – Phase-C only

The results of single short circuit fault by activating only Phase-C using the Fault simulator block is as shown in Figures 16 considering the generator voltage responses at all phases.

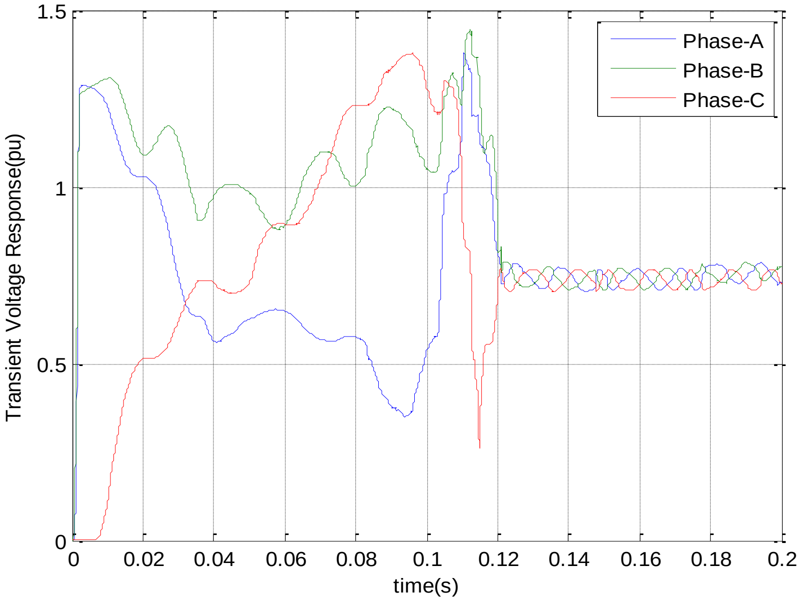


Figure 16: Transient Voltage Response of the Alaoji Sub-Transmission Network with a Fault at Phase C-Terminal

Phase C experienced an abnormal high voltage before finally collapsing while phase A collapsed at the instance of the fault. Phase B also experienced an increased voltage before the breakers cleared the fault. The fault duration was about 0.08s. This situation must be avoided by ensuring faster breaker operation.

Results of transient loading experiments

The results of transient overloading tests at the Alaoji Bus is studied at the peak loading (MW/MVAR ratings) for a short duration before simulation time step, t_s = 0.1s and for a time duration of t = 0.2s. This transient overloading is increased gradually above the maximum loading in increments of 200MW from a set value of 467MW and 178MVAR up to a value of 1067MW and 878MVAR. The results for the incremental transient loading experiments are as shown in Figures 14, 15, 16, 17 and 18.

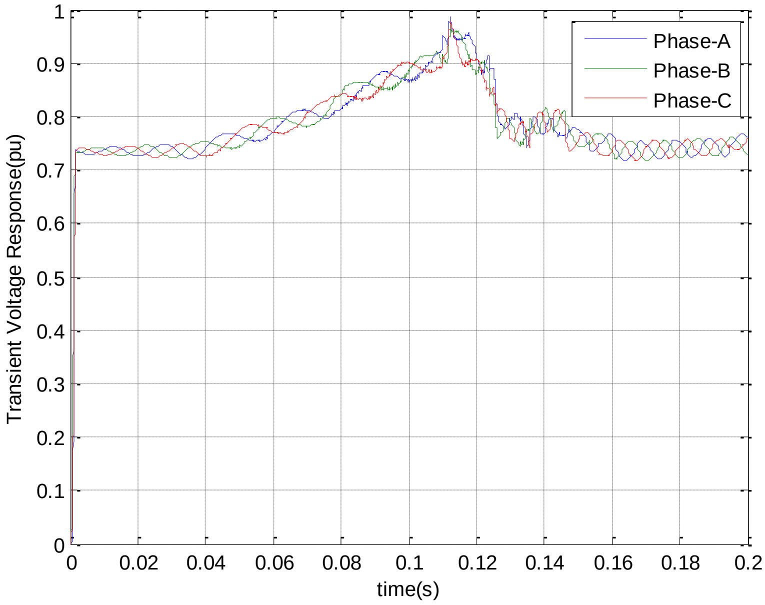


Figure 17: Transient Voltage Response of the Alaoji Sub-Transmission Network with a Peak Transient Loading of 467MW and 178MVAR

At 467MW and 178MVR loading, Phase A, B and C experienced a steady minimal increase in voltage for about 0.08s before breaker action and the system was restored. This simulation shown in Fig. 17 clearly demonstrates the behaviour of the Alaoji Sub-Transmission Network when subjected to incremental transient loading. It effect is that a steady increase in load to a value large enough can cause loss of synchronization hence initiating transient instability.

The load is increased as specified and simulated for 667MW and 378MVAR and the system response shows that all three phases experienced abnormal voltage increase as well as resistance to breaker operation. This is indicative that system overload must be avoided if equilibrium must be maintained for the whole period of operation.

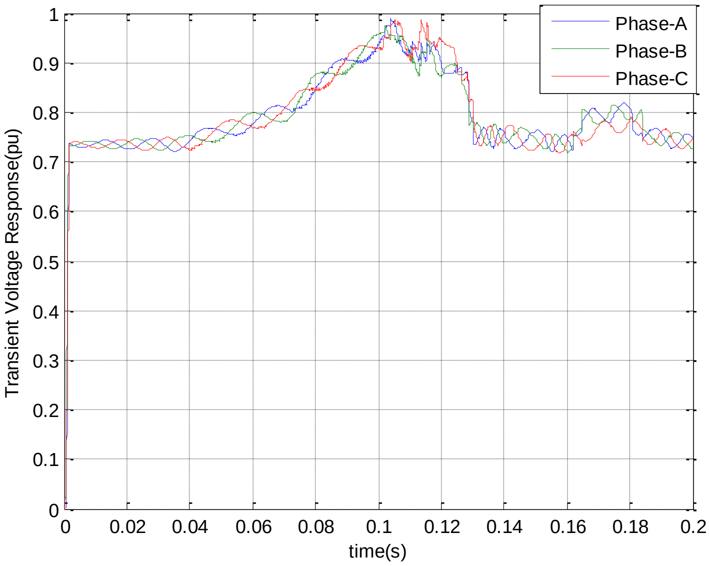


Figure 18: Transient Voltage Response of the Alaoji Sub-Transmission Network with a Peak Transient Loading of 667MW and 378MVAR

The result for transient loading of 867MW and 578MVAR is presented in Fig. 19 and it shows that the Phase voltage for all three phases rose steadily to an abnormal value before breaker operation. Fault lasted for about 0.08s but was eventually cleared and the system regained synchronization. This result affirms the simulations carried outwith clearing time (tcl) was set at 0.07s for allowable machine angle.

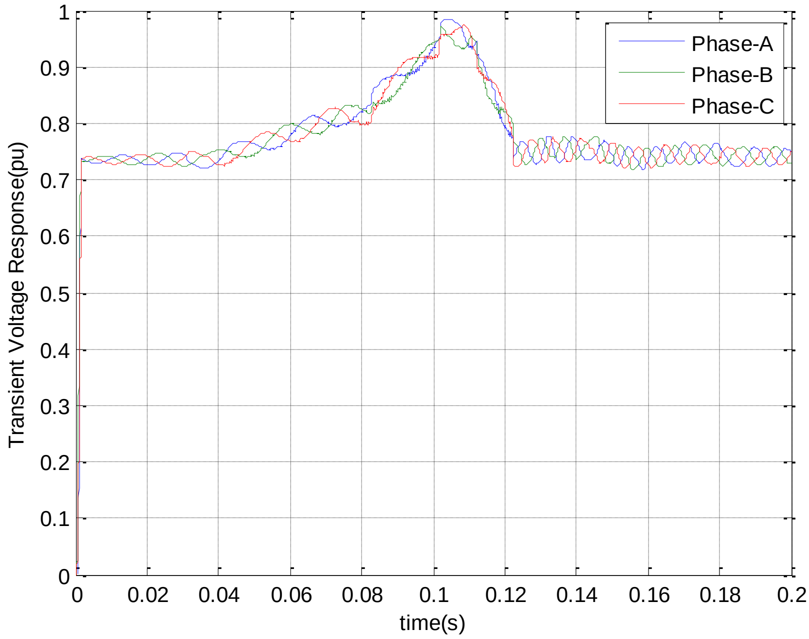


Figure 19: Transient Voltage Response of the Alaoji Sub-Transmission Network with a Peak Transient Loading of 867MW and 578MVAR

To ensure equilibrium to be maintained, transient loading on the Alaoji Sun-Transmission Network must not exceed 0.08s set clearing time, (tcl) otherwise the system would gradually lose synchronization.

This investigation was carried out for peak loading of 1067MW and 878MVAR and the result presented in Fig. 19 shows similar trend of steady voltage increase for all three phases. The result also confirm that achieving effective system synchronization may be a difficult task when the loading condition is at peak value hence load shedding becomes inevitable.

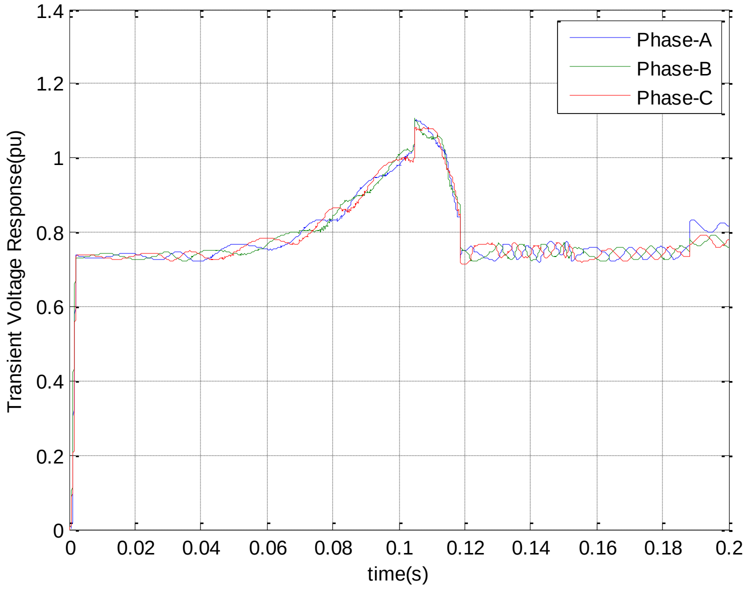


Figure 20: Transient Voltage Response of the Alaoji Sub-Transmission Network with a Peak Loading of 1067MW and 878MVAR

Table 1: Afam, power generating station (rotor angle deviation and time)

Data were collected from Afam power generating station to observe the behaviour of the rotor-angle with respect to time, and the ability to the circuit-breaker via relaying operating time action to clear the fault is a precondition for effective operation of power system while monitoring the operating time and gradual swinging into instability of the turbine in order to avoid system collapse.

Time (seconds)	Sustained fault and rotor angle (rf1)	Fault cleared at 2.5yers (rf2)	Fault cleared at 6.5years (rf3)	Fault cleared of 8.25cycle (rf4)
0.00	21.64	24.21	21.64	20.64
0.05	24.21	24.21	24.21	23.22
0.10	31.59	29.54	31.59	30.34
0.15	42.89	34.10	42.89	40.56
0.20	56.87	36.70	50.09	45.08
0.25	72.30	37.72	51.63	48.88
0.30	88.28	34.16	47.28	42.12
0.35	104.44	29.64	37.85	35.45
0.40	121.02	24.33	25.50	22.22
0.45	138.90	19.73	13.50	14.55
0.50	159.65	17.73	5.37	4.28

Table 2: Data for analysis

The bus loading, that is the maximum and minimum load from PHCN data

Table 2: Bus loading condition tansmith network (Alaoji)

Bus	MW (max)	MW (min)	MVar (mix)	MvAr (min)
Onitsha	162 - 644	102 - 105	76 - 80	48 - 60
Alaoji	266 - 280	167 - 170	124 - 130	78 - 85

Table3: Network parameter for transmission at Alaoji

S/N	From	To	Lenght, L (km)	Resistance, R (Rpu)	Inductance (Xpu)
1.	Onitsha	Aloji	138 - 140	0.0049425	0.041945
2.	Alaoji	Afam, Station	25 - 30	0.0004523	0.003478

Table 4: generator parameters (station)

S/N	Parameter	Value-assign
1.	H- constant	280.05
2.	MW	200.05
3.	MVAR	140.08
4.	Frequency, f	50Hz

Table 5: Study case designation

S/N	Bus	Designation	Description
1.	Onitsha	280.05	3
2.	Alaoji	200.05	2
3.	Afam (Station)	PV - Bus	1

The results of simulations are indicative of the possible behavior of a real power system as such lowering the fault clearing time a little, translates to very small range of rotor angle and angular frequency. It is imperative therefore for the breakers to open early during the fault condition but in the event that the breaker does not open, the system may risk total collapse.

To solve this problem, a backup sequential protection is proposed, such that the breakers are programmed to operate in sequence but at the same calibrated time. This procedure allows for the second breaker to pick up the fault at real time in the event that the first breaker fails to open.

```
%program......;
% file name ... mtec,celestine
%clear all previousley used memory variables i matlab
workspace
%clc : clear all display screen
% d1,d2,d3:turbines rotor angles
% Computation of swing equation of themal power plant
stability analysis
rf1=[21.64,24.21,31.59,42.89,56.87,72.30,88.28,104.44,121.
02,138.90,159.65];
rf2=[24.21,24.21,29.54,34.10,36.70,37.72,34.16,29.64,24.33
,19.73,17.73,];
rf3=[21.64,24.21,31.59,42.89,50.09,51.63,47.28,37.85,25.50
,13.50,5.37];
rf4=[20.64,23.22,30.34,40.56,45.08,48.88,42.12,35.45,22.22
,14.55,4.28];
```

```
t=[0.00,0.05,0.10,0.15,0.20,0.25,0.30,0.35,0.40,0.45,0.50]
;
figure
plot(t,rf1,'-dk',t,rf2,'-xr',t,rf3,'-ob',t,rf4,'-
g','linewidth',3);
xlabel('t,time');
ylabel('rf1(sustained turbine rotor angle),rf2(turbine
rotor angle),rf3(turbine rotor angle),rf4(fault cleard at
8.25cycle');
legend('sustained fault turbine rotor angle rf1','fault
cleared at 2.5cycle rf2','fault cleared at 6.5cycle
rf3','fault cleared at 8.25cyclerf4');
```

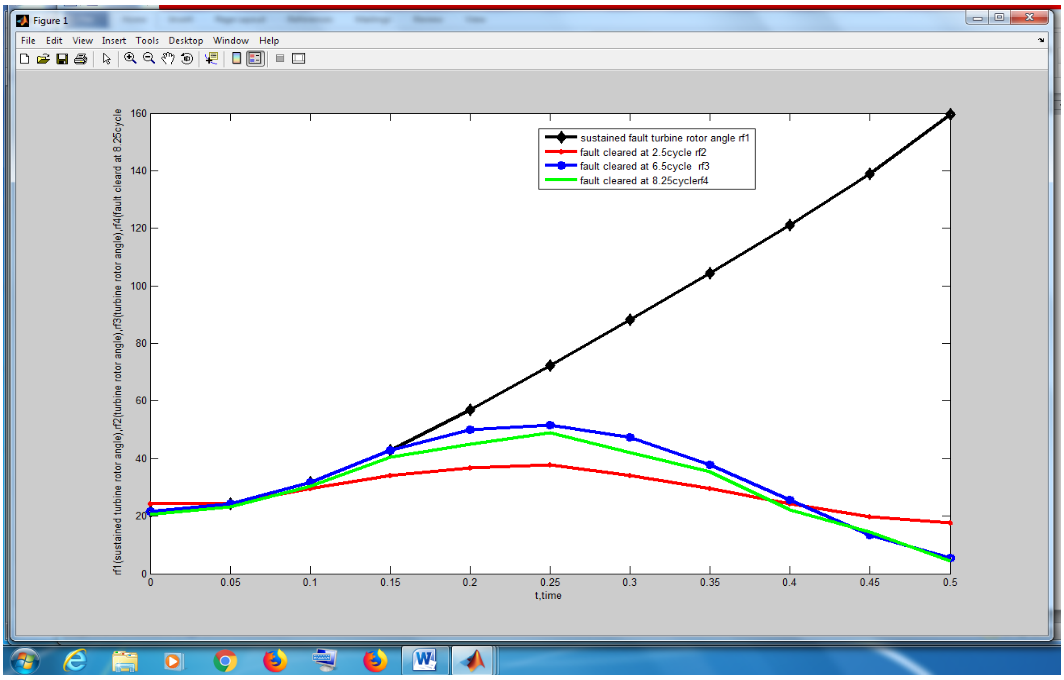


Figure 21: showing sustained fault condition and fault being cleared at different cycle with respect to time setting.

CONCLUSIONS AND RECOMMENDATION

Conclusions

The Transient analysis model using Swing equation and power transfer capability techniques are presented. The activities of the power systems are implemented in matrix-laboratory (Mat lab) environment; in order to investigate and justify whether the 330KV and 132KV network from Afam power generating station are responding to quick selectivity relay action for fast discrimination of the circuit breaker before, during and after the initiation of faults occurrence in the form of overload or perturbation, lighting initiation including faults due to phases etc which may not be healthy for power system operation and performance. The analysis and investigation shows that fault protection scheme should have lower clearing time for an effective operating performance. It is also evident that a programmed time setting of the protective relay within 0.05 second will clear the fault immediately, that is when system swing to sustain faults instability state due to fault condition (making the turbine-rotor angle deviated from normal with time) to stability condition state with the programmed fault clearing cycle of: 2.5cycle (rf2), 6.5 cycle (rf3) and 8.25 cycle (rf4) respectively for purpose of avoiding black-out which may result into load-shielding in most cases.

Recommendation

The effective and reliable operation of protective relay coordination are strongly recommended in the generating station which should be based on ‘selectivity’ and ‘sensitivity’ for fast discrimination of the circuit breaker action in the case of fault reoccurrence, which may seriously cause damage to power system equipment, facilities and most cases times and properties if not cleared immediately.

Evidently, Automated and efficiently programmed protective relay scheme on real-time basis should be integrated to monitor and scan the power system network, particularly to the generating station-power plant, on the view to enhance sequential operation of the relay action to enhance effective performance at all time. Most importantly the application of artificial intelligence (Artificial neutral network etc) may also be considered for quick-sensitivity action.

REFERENCES

[1] Abdelmalik A. A. (2011) "Power transformer life management: Relevance to Nigerian power industry" Department of Physics Ahmadu, Bello University, Zaria, Nigeria.

[2] Ezim W. (2016) "Nigerian Power Grid has Collapsed 21 times in" http://www.nigerladaUynews.news/news/319356~mgerian-power-grid-has-collapsed-2 l-times-in-2016,

[3] Abiola A. and Adekilekun T. (2013) "Critical clearing time evaluation of Nigerian 330kV transmission system", American Journal of Electrical Power and Energy Systems;2(6): October 20, pp. 123-128.

[4] Ghorbari A., Khedezadeh M. and Mozafari B. (2 012) "Impact of SVC on transmission lines", Electric Power and Energy System 42 pp. 702-709.

[5] DeMarco C.u, Baone C. , Lesieutre B., Han Y., Bose A., Kansal P., Kezunovic M. and Matic-Cuka B, (2012) "Control and protection paradigms of the future". Power Systems Engineering Research Center Publication May, pp. 12-10.

[6] Haidar A., Mustafab M., Ibrahim F. and Ahmed I., (2011) "Transient stability evaluation of electrical power system using generalized regression neural networks" Int.). Applied Soft Computing 11, pp. 3S58-3570.

[7] Hossain M. and AH M. (2015) "Transient stability augmentation of PV/DF1GSG-hased hybrid power system by parallel-resonance bridge fault current Hmiter", Int.], Electric Power Systems Research 130, pp. 89-102.

[8] Abdul Wahab N., Mohamed A. and Aini H. (2011) "Fast transient, stability assessment of large power system using probabilistic neural network with feature reduction techniques", Int. I. Expert Systems with Applications 38, pp. 11112-11119.

[9] Kauri T. and Kakran S. (2012) "Transient Stability Improvement of Long Transmission Line System by Using SVC", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 1, Issue 4.

[10] Navid G, Haniyeh M., and Iman S. (2013) "Improvement voltage stability and load ability enhancement by continuation power flow and bifurcation theory". Technical Journal of Engineering and Applied Sciences, pp. 2712-2720.

[11] Kumar A. and Dubey S. B. (2013) "Enhancement of Transient Stability in Transmission Line Using SVC Facts Controller", International Journal of Recent Technology and Engineering (IJRTE), Volume-2, Issue-2.

[12] Khani D., Yazdankhah A, and Kojabadi H. (2012) "Impacts of distributed generations on power system transient and voltage stability", Int. J. Electrical Power and Energy Systems p. 488-500.

[13] Kr Ahuja R. and Chankaya M. (2012) "Transient Stability Analysis of Power System with UPFC Using PSAT" International Journal of Emerging Technology and Advanced Engineering Volume 2, Issue 12.

[14] Mahdad B. and Srairi K. (2013) "Application of a combined, superconductor fault current Hmiter and STATCOM to enhancement of power transient stability". Int. J. Physica C 495 September 2013, pp. 160-168.

[15] Robak S. and Gryszpanowicz K. (2015) "Rotor angle small signal stability assessment in transmission network expansion planning", Int. I. Electric Power Systems Research 128 August 2016 pp. 144-150.

[16] Mukherjee A., Kumar Roy P. and Mukherjee V. (2016) "Transient stability constrained optimal power flow using oppositional krill herd algorithm" International Journal Electrical Power and Energy Systems83, March pp 283-297, 2016.

[17] Onohaebi O. (2009) "Power outages in the Nigerian transmission grid", journal of Applied Sciences 4(1) pp. 1-9.

[18] Samuel L, Katende J. and Ibi'cunle F. (2012) "Voltage collapse and the Nigerian National Grid", E1E 2nd International Conference on Computer, Energy, Networking, Robotics and Telecom.

[19] You D., Wang K., Ye L., Wu J. and Huang R. (2012) "Transient stability assessment of power sys-tem using support vector machine with generator combinatorial trajectories inputs", Int. /. Electrical Power and Energy Systems 44, September, pp. 318-325.

[20] Panda S. and Patel R. N. (2006) "Improving Power System Transient Stability with an Off-Centre Location of Shunt Facts Devices", Journal of Electrical Engineering, Vol. 57, No. 6, pp. 365-368.

[21] Zadkhast S., Jatskevich J., Vaahedi E. and Alitnardani A. (2014) "A new adaptive dynamic reduction method for power system transient stability problems, Int. J, Electric Power Systems Research 115, April, pp. 102-110.

[22] Porate K., Thakre K. and Bodhe G. (2012) "Voltage stability enhancement of low voltage distribution feeder using Static Var Compensator: a case study", Advanced Applications of Electrical Engineering.

[23] Su W. and Wang J., (2012) "Energy Management Systems in Micro-grid Operations", The Electricity Journal' Vol. 25, October Issue 8.

[24] Szuegbunam F., Ubah C. and Akwukwaegbu I. (2012) "Dynamic security assessment of 330kv Nigerian power system", Academic Research International, Vol. 3, No l.

APPENDIX A

Appendix 1: Matlab Code for Power-Swing Fault Analysis

```
% This script defines the parameters of the Alaoji-Sub
Transmision power network,
% which is modeled by the Simulink file sm.mdl.
% The simulated event is a three-phase short-circuit at
time=tf=0.
% During the fault a Thevenin equivalent models double line
and infinite bus
% The fault is cleared at time=tcl.
%
%            Xtr  1                           2
%  __ Xdp    ><   |_o_______________________o_|\
% /  \___|___><___|      X12    3             |\
% \__/   |   ><   |_o___________|___________o_|\
%            ><   |      X13    |      X23    |\
%
%

wnom=2*50*pi;
H=28.050;

Xdp  = 0.0610;  % Transient reactance of the generator
Xtr  = 0.10;  % Short-circuit reactance of the transformer
X12  = abs(0.000452 + 0.003478j);  % Series reactance of line
1-2
%X13  = 0.15;  % Series reactance of line 1-3
X23  = abs(0.004942 + 0.041945j);  % Series reactance of line
2-3

E=1.2812;     % Generator internal voltage
Vinf=1;       % Inifinite bus voltage
Pm=0.8;       % Turbine power

% Fault at bus 1 at t=tf=0
% Fault self-extinguishes at t=tcl without line tripping

%X1=Xdp+Xtr+X12*(X13+X23)/(X12+X13+X23); % Prefault reactance
between E and Vinf
X1=Xdp+Xtr+X12*(X23)/(X12+X23); % Prefault reactance between E
and Vinf
%X2=          % Reactance between E and Vinf during fault
%X3=          % Postfault reactance between E and Vinf

P1max=E*Vinf/X1;% Prefault maximum active power deliverable by
the generator
P2max=0;        % Maximum active power deliverable by the
generator during the fault
P3max=P1max;  % Postfault maximum active power deliverable by
the generator
```

```
tf=0;
tcl=0.07; %default is 0.1% Redefine (vary up-down) tcl in the
command window to find the maximum value.
PD=0;

dinit=asin(Pm/P1max);    % Initial value of machine angle
delta in RADIANS

TRANSIENT_MODEL_ALAOJI_v1a
```

Appendix B: Code for Computing the Generation and Line Parameters:

```
%Generation constant computation:
f = 50;
w = 2*pi*f;
H = 28.050;
Pbase = 200e6; % 200MW
Qbase = 140e6; % 140MVAR
Sbase = sqrt((Pbase^2) +  (Qbase)^2);
Sbase = 244.13e6 %244.13MVA

J = (2*H*Sbase)./w.^2
Ra = 0.0010 %ohms
Xprimed = 0.0610; % ohms
L = Xprimed/(2*pi*f)

%Line computation:
Rbase = (((330e3)^2)/200e6) % Approx = 1kohm
Rbase = 1000;
Xbase = 1000;
Rlinepu = 0.0009825
Xlinepu = 0.0073898

Rline = Rlinepu*Rbase
Xline = Xlinepu*Xbase

%% Bus Labels Used:
%Afam - Bus 1 (PV)
%Alaoji - Bus 2 (Load)
%Onitsha - Bus3 (Load)
Rline_osha_alaoji = 0.00605225*Rbase
Xline_osha_alaoji = 0.0455212*Xbase;
Lline_osha_alaoji = Xline_osha_alaoji/(2*pi*f)
Xcline_osha_alaoji = (1/(0.02))*Xbase;
Cline_osha_alaoji = 1/(Xline_osha_alaoji*(2*pi*f))

Rline_afam_alaoji = 0.0009825*Rbase
Xline_afam_alaoji = 0.0073898*Xbase;
Lline_afam_alaoji = Xline_afam_alaoji/(2*pi*f)
Xcline_afam_alaoji = (1/(0.09))*Xbase;
Cline_afam_alaoji = 1/(Xline_afam_alaoji*(2*pi*f))
```