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POWER SYSTEM FAULTS ANALYSIS: A LEAD TO IMPROVEMENT AND RELIABILITY OF PUBLIC POWER SUPPLY

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ABSTRACT
Nigerian nation experiences epileptic public power supply. This is due to inadequate generation, faults, sabotage etc. This study, therefore, identifies some methods through which faults associated with power systems can be analyzed. Out of the approaches applied, it was found that the bus matrix method is the fastest. Also, a study was carried out to determine the more common of the two categories of faults and the result indicated unsymmetrical (unbalance) as against symmetrical (balance) and the most frequent type of fault revealed short-circuit. Recommendations were made based on the causes of these faults and other salient factors. The emerging result will be power delivery at improved level.

Key Words: Power system, short-circuit faults, unsymmetrical, Bus matrix, improved.

INTRODUCTION

Electricity has become a very essential ingredient for the economic development and domestic comfort globally. Many functions necessary to present day living will grind to a halt when the supply of electrical energy is stopped. According to Mehta and Mehta (2011), it is practically impossible to estimate the actual magnitude the part that electrical energy plays in the building up of present-day civilization. This is because there is no known sector existing on the earth surface today that has no direct or indirect bearing on electrical power and energy. According to Gupta (2008), the process of modernization, increase in productivity in industries and agriculture and improvement in the quality of life of the people depend so much upon the supply of electrical energy that the annual per capital consumption of electrical energy has emerged, these days, as an accepted yardstick to measure the prosperity of a nation. It is on this basis

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that every Nation, world over, tends to improve on the efficiency of her power sector to ensure that the effect of this all-important commodity is felt in all sectors of the economy. As a result, various formations were put in place viz: generation stations, sub-stations, Transmission lines and Distribution systems for final utilization. In Nigerian nation, it is very glaring that the power being generated is far below what is demanded (proof: shed-load, outages e.t.c); hence the need for improvement in the quantity and quality of electrical energy. It then becomes very vital to address the problems associated with failure of power systems. In order to appreciate the problems of the power sector, it will not be out of track to highlight the operation of power system.

ELECTRICAL POWER/ENERGY

Electrical energy occupies the top position in the energy hierarchy (Gupta, 2008). Normally, electrical energy, which is the conversion of energy available in different forms, from different natural sources, like kinetic energy of winds, pressure head of flowing water, chemical energy of fuels (in solid, liquid or gaseous form) and nuclear energy of radio-active substances into electrical energy, is carried out in remote areas far away from load centers (point of utilization). The choice of such remote sites is a function of availability of land area (and cheap too), natural energy source, cooling system, and cheap labour. Energy is usually generated at a certain voltage level (say 11KV), transformed to a higher energy level in a sub-station known as “sending-end or step-up sub-station”. It is then transmitted over a long distance either by overhead or underground cables, known as transmission lines. At the end of the transmission line it is brought down to a lower level by another sub-station called “receiving-end or step-down sub-station”.

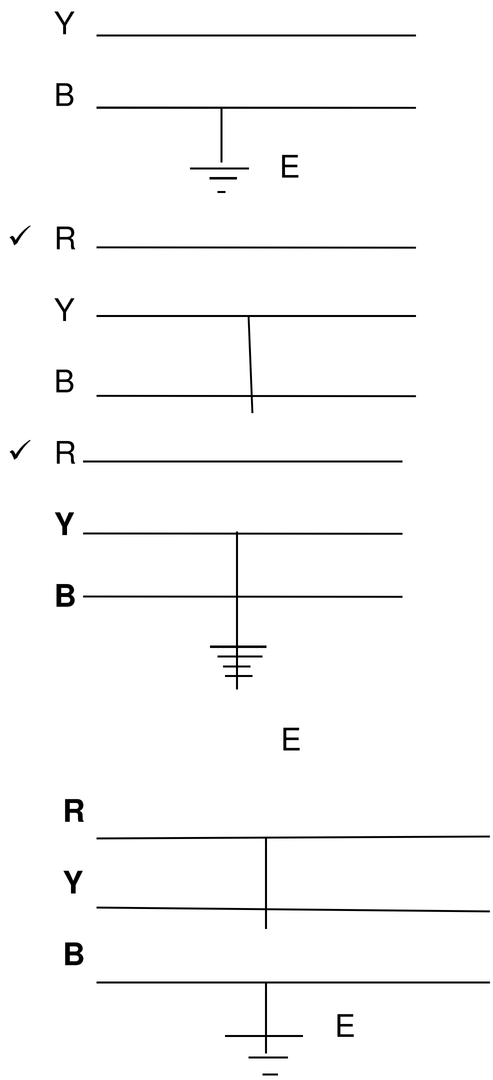
POWER SYSTEMS FAULTS

The steady state operating mode of power system is balanced 3-phase ac. However, due to sudden external or internal changes in the system, this condition is disrupted (Gupta 2010). Faults in power system can be defined as defects in the system which leads to current being diverted from the intended path or cease completely (PHCN, 2009). Faults give rise to failures of any system, resulting in their inability to perform its expected functions effectively and efficiently. It should be noted that failures are inevitable in every system. A fault occurs when two or more conductors that normally operate with a potential difference come in contact with each other. These faults may be caused by sudden failure of a piece of equipment, accidental damage, short-circuit to lines or by failure of insulation resulting from lightning surges. Irrespective of the causes, the faults in power system can be classified into two main categories viz.

(i) Unsymmetrical faults (ii) Symmetrical faults

Unsymmetrical faults: Another name for this kind of fault is “Unbalanced fault”. These are faults which give rise to unequal fault currents in the lines (phases) with unequal phase displacements. In the event of unsymmetrical fault, the currents in the three lines (RYB) become unequal and also are their phase displacements. Note that the term “unsymmetry” applies only to the fault and the resulting line currents but system impedances and source voltages are at symmetry (i.e. the red phase impedance does not differ from that of the yellow or the blue phases. Below are ways in which unsymmetrical faults may occur in a power system:

✓ R ____________________ (a) Single line-to –ground faults (L-G)



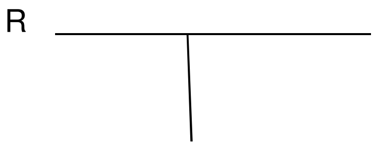
(b) Line-to-line fault (L-L)

(c) Double line-to-ground fault(L-L-G)

(d) Line-line and third line to ground (L-L & L-G)

Fig.1: Different forms of unbalanced faults.

Symmetrical faults: These faults are known as "Balanced faults". These are faults that give rise to equal fault-current in the phases and equal phase displacement of 120^{o}. In this case, the three lines are brought together into short- circuit condition Rao et al (2013) and Mehta et al (2011). See fig.2 (a & b) below.



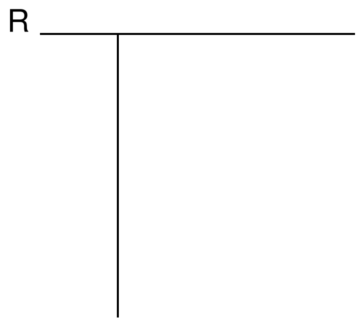


Fig.2: Different forms of balanced (symmetrical) faults: (a) All phase in short-circuit
(b) All phase to ground.

Because the fault is balanced, it is required that only one of the phases be considered in calculations since the other phases are similar. Symmetrical faults can occur, for example, when the three phases made safe for maintenance purpose, by clamping, are accidentally made alive or when, due to slow fault clearance, an earth fault spreads across to the other two phases or when a mechanical excavator cuts quickly through the three lines. In power systems generally, most of the faults are asymmetrical in nature and it is important to note also that balanced faults are more severe and impose more heavy duty to protective devices like circuit breakers.

Most of power systems faults result to short-circuit condition, which gives rise to a heavy current known as 'short-circuits current'. This fault-current, when allowed to flow through equipment, causes considerable damage to the equipment and interruption of service to consumers, a condition referred to as power outage.

The majority of faults in power systems are asymmetrical in nature. To analyze an unsymmetrical fault means solving the problem of unbalanced 3-phase circuit, which makes the direct solution to be is somehow difficult. Therefore, the solution is more easily obtained by using symmetrical components since it yields three (fictitious) single phase network, only one of which contains a driving e.m.f. Also, since the system reactances are balanced, the three fictitious networks have no mutual coupling between them; hence the method of analysis is quite simple (A method proposed by an American scientist, C.L. Fortescue in 1918) Rohit (2011), Gupter (2010). The general principle is that any set of three-phase current or voltage can be transformed into 3 balanced sets:

(i) A positive sequence set of three symmetrical currents (all numerically equal and all displaced from each other by 120^{o}) having the same phase sequence abc as the original set and denoted by $I_{a1,}$ $I_{b1,}$ I_{c1}

(ii) A negative sequence set of three symmetrical currents having the phase sequence opposite to that of the original set and denoted by $1_{a2,}$ 1_{b2} and $1_{c2.}$

(iii) A zero sequence set of three currents all equal in magnitude and in phase and denoted by $1_{a0,}$ 1_{b0} and 1_{c0}

The entire positive, negative and zero sequence sets are called symmetrical components. And adding them all gives the three–phase current (or voltage as the case may be). I.e.

$$\left.\begin{array}{ll} 1a = 1_{a1} + 1_{a2} + 1_{a0} & (a) \\ 1_{b} = 1_{b1} + 1_{b2} + 1_{b0} & (b) \\ 1_{c} = 1_{c1} + 1_{c2} + 1_{c0} & (c) \end{array}\right\} \text{-------------------------- (1)}$$

Note that the fault currents are much larger than that of the load, so the load current can be neglected during fault current calculations. However, in some situations it may be necessary to consider the effect of load current because knowing the pre-fault voltage can be used to determine the fault-current. The phasor sum of the fault current and load current gives the total current.

The calculation of fault current can be easily done by applying Thevenin's theorem. This theorem states that any linear network containing any number of voltage sources and impedances can be replaced by a single e.m.f and impedance. The e.m.f is the open circuit voltage as seen from the terminals under consideration and the impedance is the network impedance as seen from these terminals. This circuit thus formed (single e.m.f and impedance) is known as Thevenin's equivalent circuit Gupta (2010), Gupta (2008), Theraja (2006), Hughes (1995). For example, consider the simple circuit shown in fig.3:

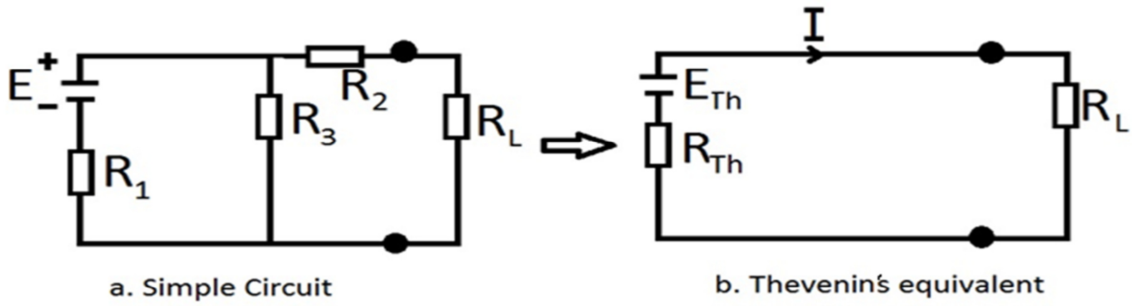


Fig.3: Thevenin's equivalent (b) of a simple circuit (a).

PROCEDURES FOR SYMMETRICAL FAULT CALCULATIONS

A 3-phase short-circuit fault leads to balanced (symmetrical) fault currents (fault currents in the three phases are equal in magnitude but displaced 120° to one another). Problems involving such faults are handled by considering only one of the phases since these are subjected to the same prevailing conditions. Given below are the steps to be taken in finding the solution of such fault:

- Draw a single line diagram of the network showing rating, voltage and percentage reactance of each element of the network.
- Choose a numerical convenient value of base KVA and convert all percentage reactances to this base KVA.
- Corresponding to the single line diagram of the network, draw the reactance diagram showing one phase of the system and the neutral. Indicating the percentage reactance on the base KVA in the diagram. Any transformer in the system should be represented with reactance in series.
- Find the total percentage reactance of the network up to the point of fault (say X%). This is to permit rapid short circuit calculations. The percentage reactance of a circuit can be defined as the percentage of the total phase-voltage drop in the circuit when full-load current is flowing, and is given by:

$$\%X = (^{IX}/_{V})100$$

Where I = full-load current, V = phase voltage

X = reactance in ohms per phase

- Find the full-load current corresponding to the base KVA and the normal system voltage at the fault point (say I).
- Then compute the various short-circuit values. Thus:

Short-circuit current, $I_{sc} = I(^{100}/_{\%X})$

Short-circuit KVA for 3 phase circuit = $3VI_{sc}/1000 = 3VI/1000 \times {}^{100}/_{\%X}$

CAUSES OF POWER SYSTEMS FAULTS

There are different causes of faults in power system. Viz:

Insulation Breakdown: Defects or errors in design, manufacturing defects or improper manufacturing methods, improper installation, ageing and deterioration, thermal and voltage overstressing, mechanical fracture, chemical decomposition etc.

Electrical: Lightning surges, switching surges, dynamic over-voltages etc.

Mechanical: wind, snow or ice, atmospheric pollution and contamination especially in industrial areas etc.

Thermal: Over-current, over-voltage

Others: Birds and other flying animals, sabotage, bush fires, vehicles crashing,

trees falling, under growth etc.

Table 1: Approximate Percentage of Various Causes of Faults Gupta (2008):

S/N	Courses	Percentage of Total
01	Lightning	12
02	Wind, mechanical etc	20
03	Apparatus failure	20
04	Switchig	20
05	Miscellaneous (trees falling, birds, sabotage, accidents etc)	28

KINDS OF POWER SYSTEMS FAULTS

There are three major kinds of faults in electric power systems. These are: short-circuit faults, earth faults, and open-circuit faults. The circuit below is a model of normal operating condition of power system.

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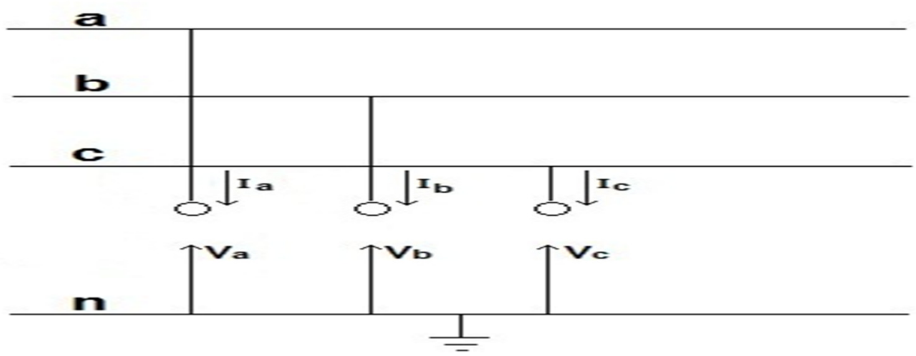


Fig.4: Normal operating condition of a power system.

SHORT-CIRCUIT OR SHUNT FAULTS

This is the most common fault in power systems. It occurs as a result of breakdown in insulation of current-carrying phase relative to earth or between phases. The event of short- circuit causes heavy current to flow in the system. As soon as the fault occurs, the fault current attains its peak (maximum) value and then decays to a steady-state value.

Short-circuit (fault) current model is as shown in fig 5 below.

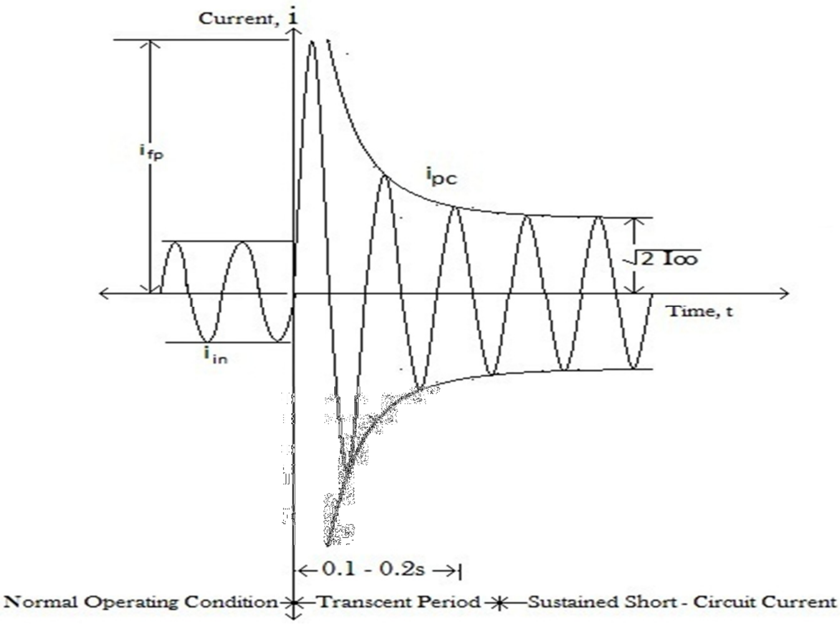


Fig.5: Changing process in a short – circuit current/time.
Source: Gupta (2008), PHCN (2009) and wikipedia/short circuit.

The graph can be explained thus:

(i) First Peak Short-circuit current (i_{fp}) is the maximum instantaneous value of the current attained during the first moment of the short-circuit fault. The value of the first peak short-circuit current is required in designing electrical equipment for dynamic stability.

$$i_{fp} = 1.8(\sqrt{2} i_{pc}) \quad \text{--} \quad (2)$$

Where i_{pc} = the root mean square (rms) value (0.707I) of the component of the short-circuit current 2-3 periods after the initiation of the short-circuit. (Period is the time taken for one complete cycle.)

Sustained current (∞) is the fault current that will flow in the circuit if it is allowed to persist after the transient process ends. It is the value used in designing electrical equipment for thermal stability. From the fig 5, it is observed that during the fault, the current undergoes a continuous change. This phenomenon is called 'Transient phenomenon'. Transient, means 'Temporary happening that last for a short duration of time'. The first zone in which the current is very high but falls very rapidly is called 'sub-transient state' and it is for a very few cycles. After this zone follows the transient state in which the decrease in current is less rapid. The transient state last for several cycles and after which the steady state is reached and the rms value of short-circuit current remains constant. Short-circuit faults in power systems are due to insulation breakdown which give rise to current flowing through an unintended path.

Effects Of Short-Circuit Faults

Various types of short-circuits may affect the power system and differently too. This depends on the system voltage, method of neutral connection, presence of regulating devices and the speed of isolation of the faulted section by protecting devices. Short-circuit may have one or more of these consequences:

(a) Excessive heating that could result in fire or explosion resulting from flow of heavy current.

(b) Arcing which may cause damage to elements of the power system. For example, arcing, if not quickly taken care of, can burn the conductor leading to breakage, which results to power interruption (outage).

(c) System stability which may lead to a complete short down of the system.

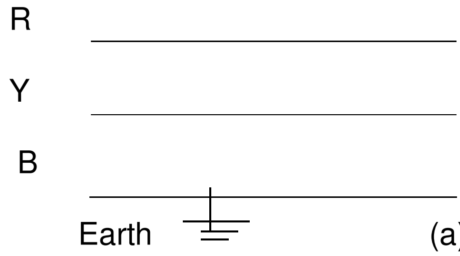
(d) Sometimes there is a marked reduction in the voltage or frequency such that relays having pressure coils tend to fail.

(e) When there is outage as a result of breakdown of element and apparatus in the system or abnormal currents being drawn by consumers (industries' motors), industrial production is lost and hence the economy is affected too.

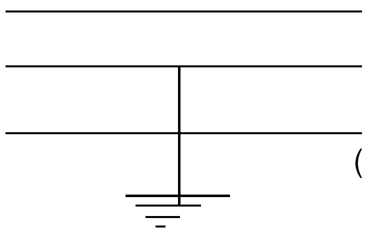
(f) Heavy currents due to short-circuit (power surge) can damage consumers' electrical equipment. Etc.

EARTH FAULTS

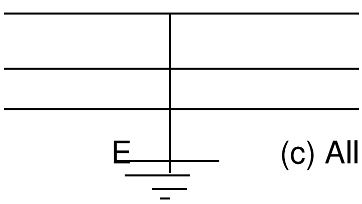
Earth fault is the most dangerous of the three kinds of fault in power system. It occurs when current is directed through the mother earth (ground) away from its intended rout. It is the most dangerous to personnel and person within the environment. When a live conductor comes in contact with ground and ground being at zero potential, current tendto flows. Most times, protective devices see it as normal current and so there will be no isolation, hence exposing persons and animals to hazards of electric shock leading to injuries and possibly death. The situation is worst on a wet soil or water pool. Examples:



(a) Single line to ground (L-G)



(b) Double line to ground (L – L – G)



(c) All lines to ground (L-L-L-G)

Fig.6: Various types of earth faults.

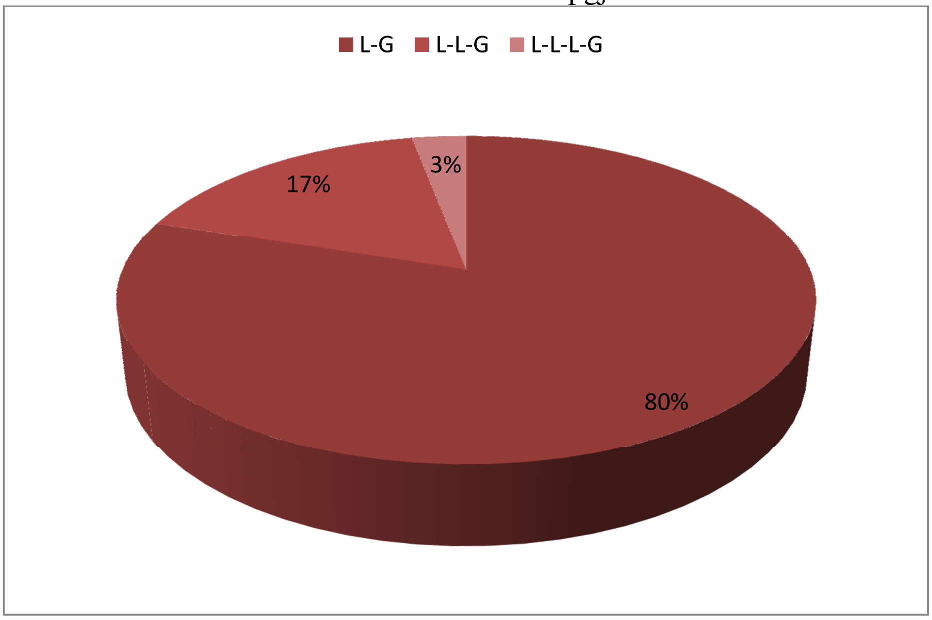


Fig.7: Chart showing the percentage occurrence of the various earth faults.

OPEN CIRCUIT FAULTS

Open-circuit faults in electrical power systems occur when there is discontinuity in the path of current. At that point, the resistance is very high (usually at infinity) hence current cannot pass through.

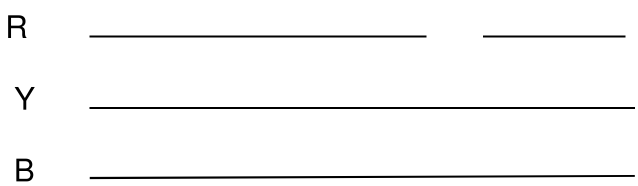


Fig.8: Showing an open-circuit at the Red phase.

Effects of Open-circuit Faults

The major effect of open-circuit fault is power outage. This is usually after the fault point from the supply end. Open-circuit could only prove dangerous when it leads to short-circuit or earth fault. Usually, the open-circuited line will register drop in load defined by the point of opening.

The explanation here is that only the loads before the opening point will be sensed at the control panel. This is because those loads after the point are isolated and this will initiate trouble-shooting and clearance by assigned personnel.

Table 2: The average percentage occurrence of the faults for 7 year period (2004-2010) PHCN.

FAULT	2004	2005	2006	2007	2008	2009	2010	AVG_2
S/C	53.75	54.58	53.67	54.83	53.00	54.10	51.17	53.60
E/F	24.67	25.83	22.91	21.42	24.50	22.50	23.92	23.70
O/C	21.58	20.42	23.42	23.75	22.50	23.40	24.92	22.90

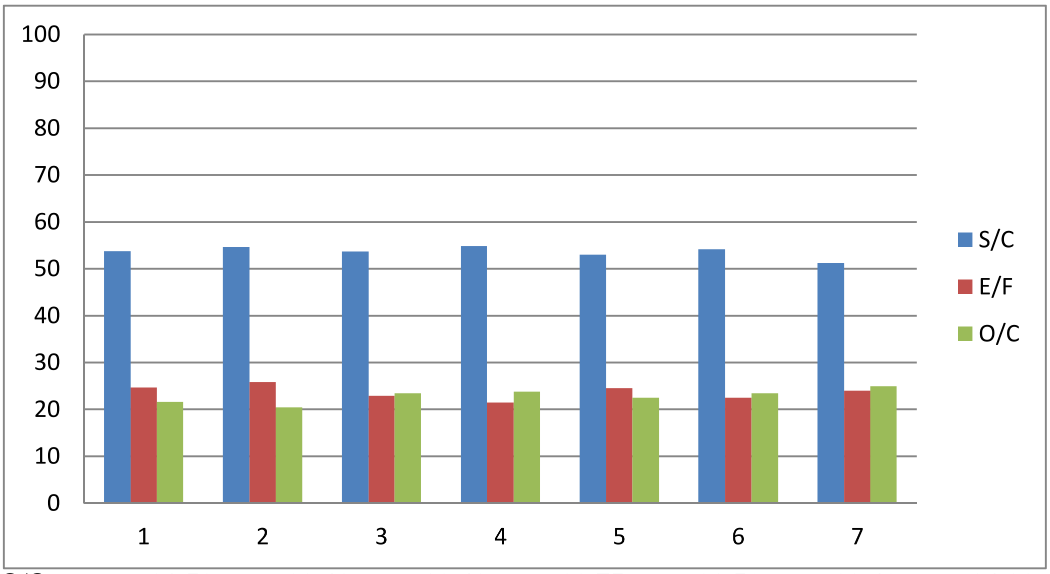


Fig 9: Bar chart showing the percentage occurrence of the faults within the period

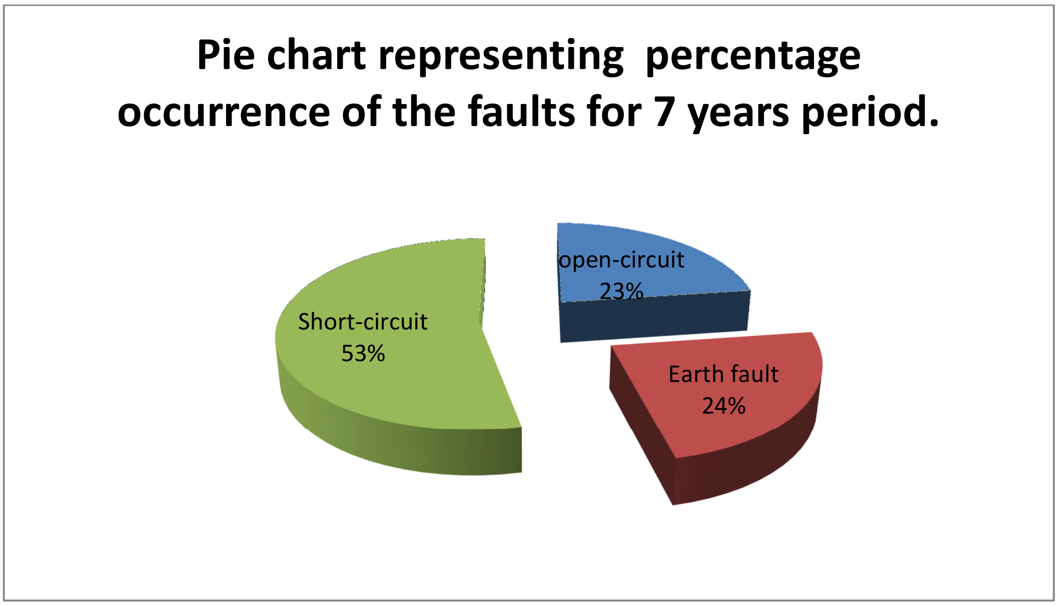


Fig.10: Pie chart showing the percentage occurrence of the various faults within the period.

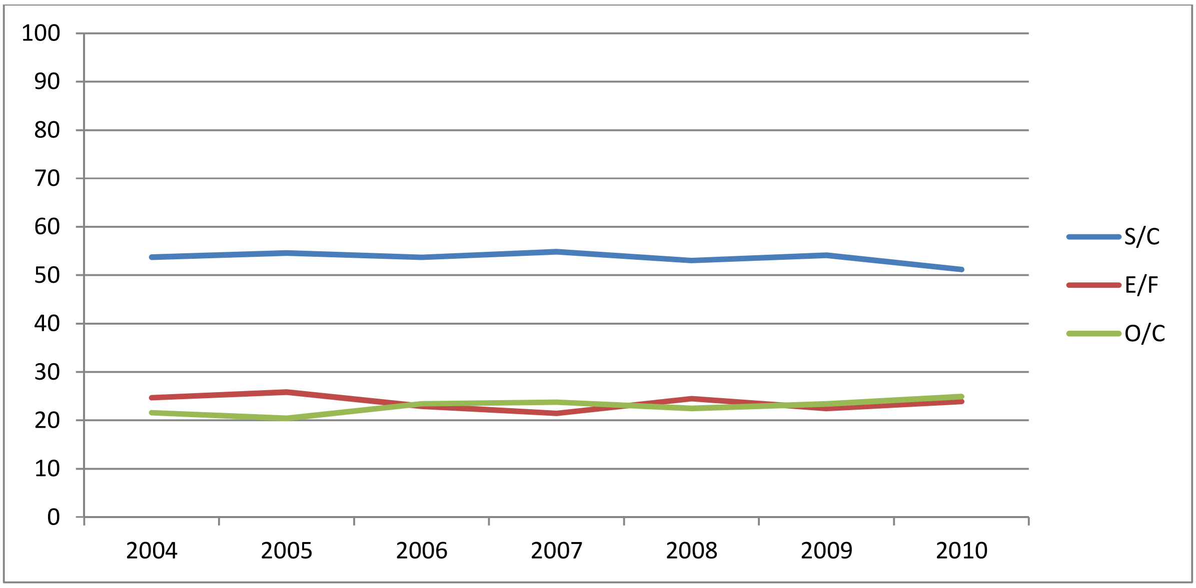


Fig.11: Graph showing the occurrence relationship amongst the three faults within the period.

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Table 3: Frequency of Fault Occurrence in Different Links of a Power System

S/N	Equipment	Percentage of Total
01	Overhead lines	50
02	Cables	10
03	Transformers	10
04	Switchgear	15
05	Control equipment	3
06	Instrument transformers (current and potential)	2
07	Miscellaneous	10

DISCUSSION:

From the study, it was made clear that open-circuit fault poses a very serious danger to electrical and electronic equipment and can even lead to explosion/fire. It is the peak value of the transient period, at short-circuit, that does this havoc. While earth fault is not much hazardous to electrical equipment, it is to personnel, other members of the public and animals. This is because they are hardly sensed as fault by protective devices but as normal current. Open circuit can only be of danger if it degenerates to either earth or short-circuit fault. From the analysis of data obtained from PHCN as presented in table 2, it is seen that shout-circuit faults occur the most in power systems while it alternates in the cases of earth and open-circuit faults. In power system equipment, more faults occur in overhead lines than any other component of the system.

CONCLUSION:

Because faults in any system are inevitable, with respect to this study, it is bestowed on all to fight towards the reduction of power outages so that various types of users will have maximum utility. This could be achieved by the application of the best methods in analyzing and clearance of these faults. The adoption of new concepts and advanced sub-station automation one of which is by using intelligent electronic devices for monitoring and reporting disturbances will be of great achievement in the nation's power system. The end result is power delivery at its best.

RECOMMENDATIONS:

Electricity is one of the most important infrastructures worldwide. With its immeasurable benefits to mankind, it bestowed on all to synergize efforts for its improvement. Premised on this, I wish to advice every Government, and other stake holders to imbibe the spirit of maintenance culture, do things right and shone indiscipline. Power system automation, using intelligent electronic devices (IEDs) for monitoring and reporting of disturbances should be put in place. Pre-paid energy metering system should be introduced to curb power wastage. Acts of vandalism, embezzlement and other unholy acts should be condemned in totality. No doubt these will give room to reliability in power systems.

Having seen some of the causes of faults in power systems, effort should then be geared towards eliminating those bottle-necks. For example, it is on record that Insulation breakdown can lead to short-circuit or earth fault, and this breakdown is as a result of ageing and climatic/atmospheric influence (though climatic/atmospheric effect is natural and cannot be checkmated by man). It is advised that periodic inspection and replacement when due should be carried out by the authorities. It is necessary to carry out regular inspection on conductors to correct for partial contacts, arcing points and the replacement of aged ones to avoid open-circuit. Proper and effective earthing system should be maintained always. Overloading should be avoided to prevent overheating. The government and power authorities should always employ the use of standard and approved equipment/materials and methods and appropriate protective devices should be incorporated e.g. reactors (limit the short-circuit current and thus protect equipment from over-heating, localization of troubles and hence increase chances of continuity of power supply), circuit breakers, fuses etc. This will enable the system to serve (under normal operating conditions and outside the influence of nature) for a good number of years before aging will set in (not without the normal periodic maintenance/servicing). Trees around systems should be cut and bushes cleared to avoid the former falling on installations and bush fires. Security personnel and Strong/firm perimeter fencing of some power systems facilities (e.g. sub-stations environments) should be carried out to take care of sabotage and vehicles crashing into premises.

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