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An Analytical Study of Power System under the Foult Conditons using different Methods of Fault Analysis

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Abstract—*Faults can be defined as the flow of a massive current through an improper path which could cause enormous equipment damage which will lead to interruption of power, personal injury, or death. In addition, the voltage level will alternate which can affect the equipment insulation in case of an increase or could cause a failure of equipment start-up if the voltage is below a minimum level. As a result, the electrical potential difference of the system neutral will increase. During normal operating conditions, current will flow through all elements of the electrical power system within pre-designed values which are appropriate to these elements' ratings. Any power system can be analysed by calculating the system voltages & currents under normal & abnormal scenarios.*

1. INTRODUCTION

During normal operating conditions, current will flow through all elements of the electrical power system within pre-designed values which are appropriate to these elements' ratings. Any power system can be analyzed by calculating the system voltages & currents under normal & abnormal scenarios. Unfortunately, faults could happen as a result of natural events or accidents where the phase will establish a connection with another phase, the ground or both in some cases. A falling tree on a transmission lines could cause a three-phase fault where all phases share a point of contact called fault location. In different occasions, fault could be a result of insulation deterioration, wind damage or human vandalism [4].

Faults can be defined as the flow of a massive current through an improper path which could cause enormous equipment damage which will lead to interruption of power, personal injury, or death. In addition, the voltage level will alternate which can affect the equipment insulation in case of an increase or could cause a failure of equipment start-up if the voltage is below a minimum level. As a result, the electrical potential difference of the system neutral will increase. Hence, People and equipment will be exposed to the danger of electricity which is not accepted [2].In order to prevent such an event, power system fault analysis was introduced. The process of evaluating the system voltages and currents under various types of short circuits is called fault analysis which can determine the necessary safety measures & the required protection system. It is essential to guarantee the safety of public [10].The analysis of faults leads to appropriate protection settings which can be computed in order to select suitable fuse, circuit breaker size and type of relay. The severity of the fault depends on the short-circuit location, the path taken by fault current, the system impedance and its voltage level. In order to maintain the continuation of power supply to all customers which is the core purpose of the power system existence, all faulted parts must be isolated from the system temporary by the protection schemes. When a fault exists within the relay protection zone at any transmission line, a signal will trip or open the circuit breaker isolating the faulted line.

To complete this task successfully, fault analysis has to be conducted in every location assuming several fault conditions. The goal is to determine the optimum protection scheme by determining the fault currents &voltages [2]. In reality, power system can consist of thousands of buses which complicate the task of calculating these parameters without the use of computer software such as Matlab. In 1956, L.W. Coombe and D. G. Lewis proposed the first fault analysis program [4].There are two types of faults which can occur on any transmission lines; balanced faults & unbalanced faults. In addition, unbalanced faults can be classified into single line-to-ground faults, double line faults and double line-to-ground faults. The most common types taking place in reality are Single line-to-ground fault, Line-to-line fault, Double line-to-ground and three phase fault [11].In order to analyze any unbalanced power system, C.L. Fortescue introduced a method called symmetrical components in 1918 to solve such system using a balanced representation This method is considered the base of all traditional fault analysis approaches of solving unbalanced power systems [4].

The theory suggests that any unbalanced system can be represented by a number of balanced systems equal to the number of its phasors. The balanced systems representations are called symmetrical components. In three-phase system, there are three sets of balanced symmetrical components can be obtain; the positive, negative and zero sequence components. The positive sequence consists of set of phasors which has the same original system sequence. The second set of phasors has an opposite sequence which is called the negative sequence. The zero sequence has three components in phase with each other. The symmetrical components theory will be discuss into more detail in chapter 3 of this project. Then, a description of the symmetrical components methods will be discussed in detail.

2. ELECTRICAL POWER SYSTEM

Energy in electrical form, apart from being clean, can be generated (converted from other natural forms) centrally in bulk; can be easily controlled; transmitted efficiently; and it is easily and efficiently adaptable to other forms of energy for various industrial and domestic applications. It is therefore a coveted form of energy and is an essential ingredient for the industrial and all-round development of any country.

The generation of electrical energy (by converting other naturally available forms of energy), controlling of electrical energy, and transmission of energy over long distances to different load centers, and distribution and utilization of electrical energy together is called an **electrical power system.**

The subsystem that generates electrical energy is called generation subsystem or generating plants (stations). It consists of generating units (consisting of turbine and alternator sets) including the necessary accessories. Speed governors for the prime movers (turbines; exciters and voltage regulators for generators, and step-up transformers also form part of the generating plants. The subsystem that transmits the electrical energy over long distances (from generating plants to main load centres) is called transmission subsystem. It consists of transmission lines, regulating transformers and static/rotating VAR units (which are used to control active/reactive powers).The sub system that distributes of energy from load centres to individual consumer points along with end energy converting devices such as motors, resistances etc., is called distribution subsystems. It consists of feeders, step-down transformers, and individual consumer connections along with the terminal energy converting electrical equipment such as motors, resistors etc.

Electrical energy cannot be stored economically and the electric utility can exercise little control over the load demand (power) at any time. The power system must, therefore, be capable of matching the output from the generators to demand at any time at specified voltage and frequency. With the constant increase in the electrical energy demand, more and more generating units, the transmission lines and distribution network along with the necessary controlling and protective circuits make the power system a large complex system. It is considered as one of the largest man-made systems. Hence highly trained engineers are needed to develop and implement the advances of technology for planning, operation and control of power systems.

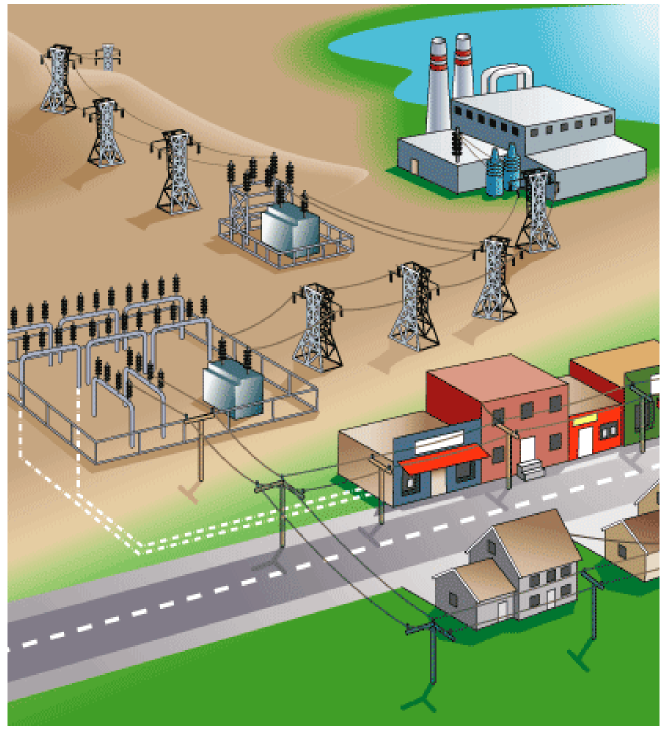


Fig. 2: Typical power system

3. ELECTRICAL FAULT METHODOLOGY

Faults can be defined as the flow of a massive current through an improper path which could cause enormous equipment damage which will lead to interruption of power, personal injury, or death. In addition, the voltage level will alternate which can affect the equipment insulation in case of an increase or could cause a failure of equipment start-up if the voltage is below a minimum level. As a result, the electrical potential difference of the system neutral will increase. Hence, People and equipment will be exposed to the danger of electricity which is not accepted.

Faults usually occur in a power system due to insulation failure, flashover, physical damage or human error. These faults may either be three phases in nature involving all three phases in a symmetrical manner, or may be asymmetrical where usually only one or two phases may be involved. Faults may also be caused by either short-circuits to earth or between live conductors, or may be caused by broken conductors in one or more phases. Sometimes simultaneous faults may occur involving both short-circuit and broken-conductor faults (also known as open-circuit faults).

3.1 Cusses of Fault:

- Weather conditions
- Equipment failures
- Human errors
- Smoke of fires

3.1.1Weather conditions: It includes lighting strikes, heavy rains, heavy winds, salt deposition on overhead lines and conductors, snow and ice accumulation on transmission lines, etc. These environmental conditions interrupt the power supply and also damage electrical installations.s

3.1.2Equipment failures: Various electrical equipment like generators, motors, transformers, reactors, switching devices, etc. causes short circuit faults due to malfunctioning, ageing, insulation failure of cables and winding. These failures result in high current to flow through the devices or equipment which further damages it.

3.1.3 Human errors: Electrical faults are also caused due to human errors such as selecting improper rating of equipment or devices, forgetting metallic or electrical conducting parts after servicing or maintenance, switching the circuit while it is under servicing, etc.

3.1.4 Smoke of fires: Ionization of air, due to smoke particles, surrounding the overhead lines results in spark between the lines or between conductors to insulator. This flashover causes insulators to lose their insulting capacity due to high voltages.

3.2 Types of fault

There are two types of faults which can occur on any transmission lines:

- Balanced faults or symmetrical faults
- Unbalanced faults or Asymmetrical faults

Most of the faults that occur on power systems are not the balanced three-phase faults, but the unbalances faults.In addition, Fault can be categorized as:

- Series fault
- Shunt fault
- Simultaneous fault

In the analysis of power system under fault condition, it is necessary to make a distinction between the types of fault to ensure the best results possible in analysis. However, for this analysis only shunt faults are to be analyzed.

3.2.1 Series faults

Series faults represent open conductor and take place when unbalanced series impedance conditions of the lines are present. Two examples of series fault are when the system holds one or two broken lines, or impedance inserted in one or two lines. In the real world a series faults takes place, for example, when circuit breakers controls the lines and do not open all three phases, in this case, one or two phases of the line may be open while the other/s is closed. Series faults are characterized by increase of voltage and frequency and fall in current in the faulted phases.

3.2.2 Shunt faults

Shunt faults are the most common type of fault taking place in the field. They involve power conductors or conductor-to-ground or short circuits between conductors. One of the most important characteristics of shunt faults is the increment the current suffers and fall in voltage and frequency. Shunt faults cab be classified into four categories:

- Line-to-ground fault
- Line-to-line fault
- Double line-to-ground
- Three phase fault

3.3.3simultaneous faults: Sometimes, more than one type of fault may occur simultaneously, these may all be short circuit fault, such as single-line-to-ground fault on one phase, and a line-to-line fault between other two phases. They may also be short-circuiting faults coupled with open conductor faults.

3.3.4 Line-to-ground fault: this type of fault exists when one phase of any transmission lines establishes a connection with the ground either by ice, wind, falling tree or any other incident. 70% of all transmission lines faults are classified under this category.

3.3.5 Line-to-line fault: as a result of high winds, one phase could touch anther phase & line-to-line fault takes place. 15% of all transmission lines faults are considered line-to-line faults

3.3.6 Double line-to-ground: falling tree where two phases become in contact with the ground could lead to this type of fault. In addition, two phases will be involved instead of one at the line-to-ground faults scenarios. 10% of all transmission lines faults are under this type of faults

3.3.7 Three phase fault: in this case, falling tower, failure of equipment or even a line breaking and touching the remaining phases can cause three phase faults. In reality, this type of fault not often exists which can be seen from its share of 5% of all transmission lines faults

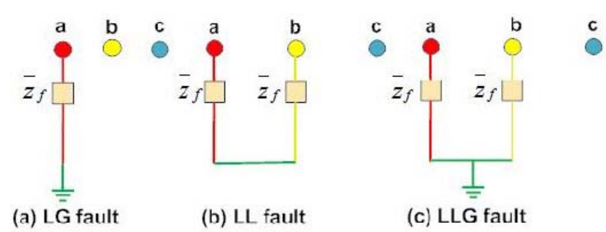


Fig. 3.1: Unsymmetrical fault

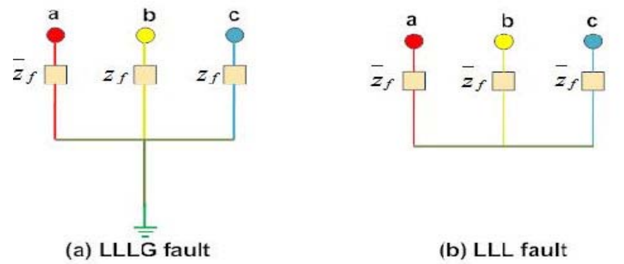


Fig. 3.2: Symmetrical Fault

3.4 Effects of Faults

There are a lots of effect of faults, below are some of the them:

- Over current flow
- Danger to operating personnel
- Loss of equipment
- Disturbs interconnected active circuits
- Electrical fires

3.4.1 Over current flow: When fault occurs it creates a very low impedance path for the current flow. This results in a very high current being drawn from the supply, causing tripping of relays, damaging insulation and components of the equipment.

3.4.2 Danger to operating personnel: Fault occurrence can also cause shocks to individuals. Severity of the shock depends on the current and voltage at fault location and even may lead to death.

3.4.3 Loss of equipment: Heavy current due to short circuit faults result in the components being burnt completely which leads to improper working of equipment or device. Sometimes heavy fire causes complete burnout of the equipment.

3.4.4 Disturbs interconnected active circuits: Faults not only affect the location at which they occur but also disturbs the active interconnected circuits to the faulted line.

3.4.5 Electrical fires: Short circuit causes flashovers and sparks due to the ionization of air between two conducting paths which further leads to fire as we often observe in news such as building and shopping complex fires.

4. FAULT ANALYSIS AND DISCURSION

Fault analysis of a power system is required in order to provide information for the selection of switchgear, setting of relays and stability of system operation. A power system is not static but changes during operation (switching on or off of generators and transmission lines) and during planning (addition of generators and transmission lines). Thus fault studies need to be routinely performed by utility engineers.

Fault analysis is usually carried out in per-unit quantities (similar to percentage quantities) as they give solutions which are somewhat consistent over different voltage and power ratings, and operate on values of the order of unity. In the ensuing sections, we will derive expressions that may be used in computer simulations by the utility engineers.

Any power system can be analyzed by calculating the system voltages and currents under normal & abnormal scenarios. The fault currents caused by short circuits may be several orders of magnitude larger than the normal operating currents and are determined by the system impedance between the generator voltages and the fault, under the worst scenario if the fault persists, it may lead to long-term power loss, blackouts and permanently damage to the equipment.

To prevent such an undesirable situation, the temporary isolation of the fault from the whole system it is necessary as soon as possible. This is accomplished by the protective relaying system [4]. The process of evaluating the system voltages and currents under various types of short-circuits is called fault analysis which can determine the necessary safety measures & the required protection system to guarantee the safety of public. The analysis of faults leads to appropriate protection settings which can be computed in order to select suitable fuse, circuit breaker size and type of relay.

The severity of the fault depends on the short-circuit location, the path taken by fault current, the system impedance and its voltage level. In order to maintain the continuation of power supply to all customers which is the core purpose of the power system existence, all faulted parts must be isolated from the system temporary by the protection schemes. When a fault exists within the relay protection zone at any transmission line, a signal will trip or open the circuit breaker isolating the faulted line.

To complete this task successfully, fault analysis has to be conducted in every location assuming several fault conditions. The goal is to determine the optimum protection scheme by determining the fault currents & voltages, and this can be achieved using computer software such as MATLAB.

4.1 The Goals of fault analysis is to determine

- The magnitudes of the currents present during the fault.
- The maximum current to ensure devices can survive the fault.
- The maximum current the circuit breakers (CBs) need to interrupt to correctly size the CBs.

4.2. Why do we need to analyze the faults?

- To adjust and set the protective devices so we can detect any fault and isolate the faulty portion of the system.
- To protect the human being and the equipment during the abnormal operating conditions.

- To determine the maximum current to insure devices can survive the fault.

4.3 Method of Fault Analysis

Balanced three phase faults may be analyzed using an equivalent single phase circuit while unbalanced faults can be analyzed using method called symmetrical components. In order to analyze any unbalanced power system; we use the method called symmetrical components to solve such system using a balanced representation. This method is considered the base of all traditional fault analysis approaches of solving unbalanced power systems.

The theory suggests that any unbalanced system can be represented by a number of balanced systems equal to the number of its phasors. The balanced systems representations are called symmetrical components. In three-phase system, there are three sets of balanced symmetrical components can be obtain; the positive, negative and zero sequence components.

The positive sequence consists of set of phasors which has the same original system sequence. The second set of phasors has an opposite sequence which is called the negative sequence. The zero sequence has three components in phase with each other.

5. SYMMETRICAL COMPONENT ANALYSIS

Symmetrical components are the name given to a methodology, which was discovered in 1913 by Charles LegeytFortescue who later presented a paper on his findings entitled, “Method of Symmetrical Co-ordinates Applied to the Solution of Polyphase Networks.” Fortescue demonstrated that any set of unbalanced three-phase quantities could be expressed as the sum of three symmetrical sets of balanced phasors. Using this tool, unbalanced system conditions, like those caused by common fault types may be visualized and analyzed. Additionally, most microprocessor based relays operate from symmetrical component quantities and so the importance of a good understanding of this tool is self-evident.

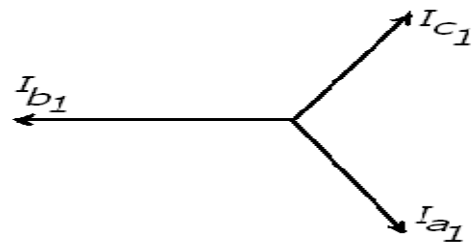
The theory suggests that any unbalanced system can be represented by a number of balanced systems equal to the number of its phasors. The balanced systems representations are called symmetrical components. In three-phase system, there are three sets of balanced symmetrical components that can be obtain; the positive, negative and zero sequence components.

Under a no fault condition, the power system is considered to be essentially a symmetrical system and therefore only positive sequence currents and voltages exist. At the time of a fault.

Positive, negative and possibly zero sequence currents and voltages exist. Using real world phase voltages and currents along with Fortescue’s formulas, all positive, negative and zero sequence currents can be calculated. Protective relays use these sequence components along with phase current and/or voltage data as the input to protective elements.

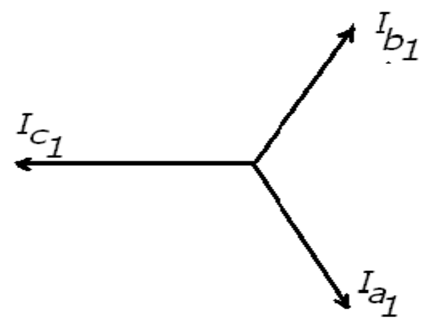
5.1 Positive Sequence Components

The positive sequence sets have three phase currents/voltages with equal magnitude, with phase b lagging phase a by 120°, and phase c lagging phase b by 120°. Positive sequence sets have zero neutral current.



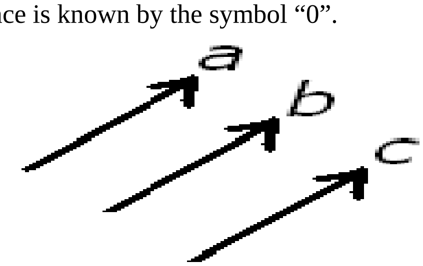
5.2 Negative Sequence Components

The negative sequence sets have three phase currents/voltages with equal magnitude, with phase b leading phase a by 120°, and phase c leading phase b by 120°. Negative sequence sets are similar to positive sequence; except the phase order is reversed .Negative sequence sets have zero neutral current



5.3 Zero Sequence Components

Zero sequence sets have three values with equal magnitude and angle. Zero sequence sets have neutral current. Under an asymmetrical fault condition, this sequence symbolizes the residual electricity in the system in terms of voltages and currents where a ground or a fourth wire exists. It happens when ground currents return to the power system through any grounding point in the electrical system. In this type of faults, the positive and the negative components are also present. This sequence is known by the symbol “0”.



5.4 Sequence Set Representation

Since each of the original unbalanced phasors is the sum of its components, the original phasors expressed in terms of their components are:

Va=Va1 + Va2 + Va0

Vb=Vb1 + Vb2 + Vb0

Vc=Vc1 + Vc2 + Vc0

To reduce the number of unknown quantities, let the symmetrical components of Vb and Vc can be expressed as product of some function of the operator a and component of Va. Thus,

$$V_{b1} = a^2 V_{a1} \qquad V_{b2} = a V_{a2} \qquad V_{b0} = V_{a0}$$
$$V_{c1} = a\, V_{a1} \qquad V_{c2} = a^2 V_{a2} \qquad V_{c0} = V_{a0}$$

$$a = 1\angle 120^0 = -0.5 + j\,0.866$$

Using these relations the unbalanced phasors can be written as

$$V_a = V_{a0} + V_{a1} + V_{a2}$$
$$V_b = V_{a0} + a^2 V_{a1} + a V_{a2}$$
$$V_c = V_{a0} + a V_{a1} + a^2 V_{a2}$$

In matrix form,

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} v_{a0} \\ v_{a1} \\ v_{a2} \end{bmatrix}$$

Let $Vp = \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}; \quad Vs = \begin{bmatrix} v_{a0} \\ v_{a1} \\ v_{a2} \end{bmatrix}; \quad A = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}$

The inverse of A matrix is

$$A^{-1} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}$$

With these definitions, the above relations can be written as

$$V_p = A\,V_s; \qquad V_s = A^{-1} V_p$$

Thus the symmetrical components of V_a, V_b and V_c are given by

$$V_{a0} = 1/3\,(V_a + V_b + V_c)$$
$$V_{a1} = 1/3\,(V_a + a\,V_b + a^2 V_c)$$
$$V_{a2} = 1/3\,(V_a + a^2 V_b + a\,V_c)$$

6. FAULT CURRENT FORMULA

Single Line to Ground Fault

Single Line To Ground Fault(SLG) :- The Positive Sequence, negetive Sequence and Zero Sequence Fault currents are given by

- $I_1 = I_2 = I_0 = \frac{V}{Z_1+Z_2+Z_0}$ *(Solid Fault)*
- $I_1 = I_2 = I_0 = \frac{V}{Z_1+Z_2+Z_0+3Z_f}$ *(Fault Through impendence Z_f)*
- $I_{aF} = I_1 + I_2 + I_0 = 3I_1 = 3I_2 = 3I_0$

Double Line to Ground Fault:

Line to Line Ground Fault (LLG) :-

1. solid Fault :-
   - $I_1 = \frac{V}{Z_1 + \frac{Z_2 Z_0}{Z_2+Z_0}}$
   - $I_2 = -I_1 \frac{Z_0}{Z_2+Z_0}$
   - $I_0 = -I_1 \frac{Z_2}{Z_2+Z_0}$

Line To Line Fault:

LL fault :- The Zero Sequence Data is not required for this fault.

- $I_1 = -I_2 = \frac{V}{Z_1+Z_2}$ *(solid Fault)*
- $I_1 = -I_2 = \frac{V}{Z_1+Z_2+Z_f}$ *(Fault Through impendenceZ_f)*

Three Phase Fault:

Three Phase Fault :- For a Three Phase fault only Positive Sequence Network is considered. The fault currents are given by the following equations.

- $I_1 = \frac{V}{Z_1}$ *(solid Fault)*
- $I_1 = \frac{V}{Z_1+Z_f}$ *(Fault Through impendenceZ_f)*

7. CONCLUSION

Analysis of power system has been conducted, symmetrical components where used to analyse various types of unsymmetrical faults in power system so as to ensure the stability and reliability of the system, and to prevent the system from any hazard. A fault in a circuit is any failure that interferes with the normal system operation, Lighting strokes cause most faults on high voltage transmission lines producing a very high transient that greatly exceeds the rated voltage of the line, This voltage usually causes flashover between the phases and/or the ground creating an arc, Since the impedance of this new path is usually low, an excessive current may flow. Faults involving ionized current paths are also called transient faults. They usually clear if power is removed from the line for a short time and then restored.

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