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Overview of Single Line to Ground Fault Analysis

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Abstract— **A fault in power systems can be defined as an abnormal condition interrupting normal flow of current due to a failure of power system equipment. The fault condition usually involves a flow of excessive current and voltage disturbance which may lead to damaging electrical system equipment, affecting system stability and introducing hazards to humans. Single line to ground fault is the most common type of faults in power systems. In this paper, an overview is presented for this type of fault including its nature, causes, fault location techniques and fault analysis method.**

Keywords— power system; unsymmetrical faults; SLG fault analysis.

I. INTRODUCTION

The electrical power system is a huge network of different types of electrical equipment such as generators, transformers and transmission lines connected together to generate, transport and distribute electrical power to consumers. The power system can be exposed to several types of faults due to weather conditions, falling trees, disasters, human errors, ..etc. These faults generally result in the flow of excessive current, network instability, equipment damage, extended outages, hazards to humans, ..etc. Therefore, faults analysis is required to properly select the protection devices to overcome faults condition in order to ensure power system reliability and integrity in addition to protecting people and assets. [1]

In this paper, an overview of single line to ground fault is presented. The paper is organized as follows. The next section is a brief description of a power system. In the third section, faults types in power systems are discussed. The fourth section presents the methods used to locate single line to ground faults. Then, fault analysis using symmetrical components method is detailed in the fifth section. The sixth section sheds light on modern approaches used in power system faults analysis. In the last section, the conclusion is presented.

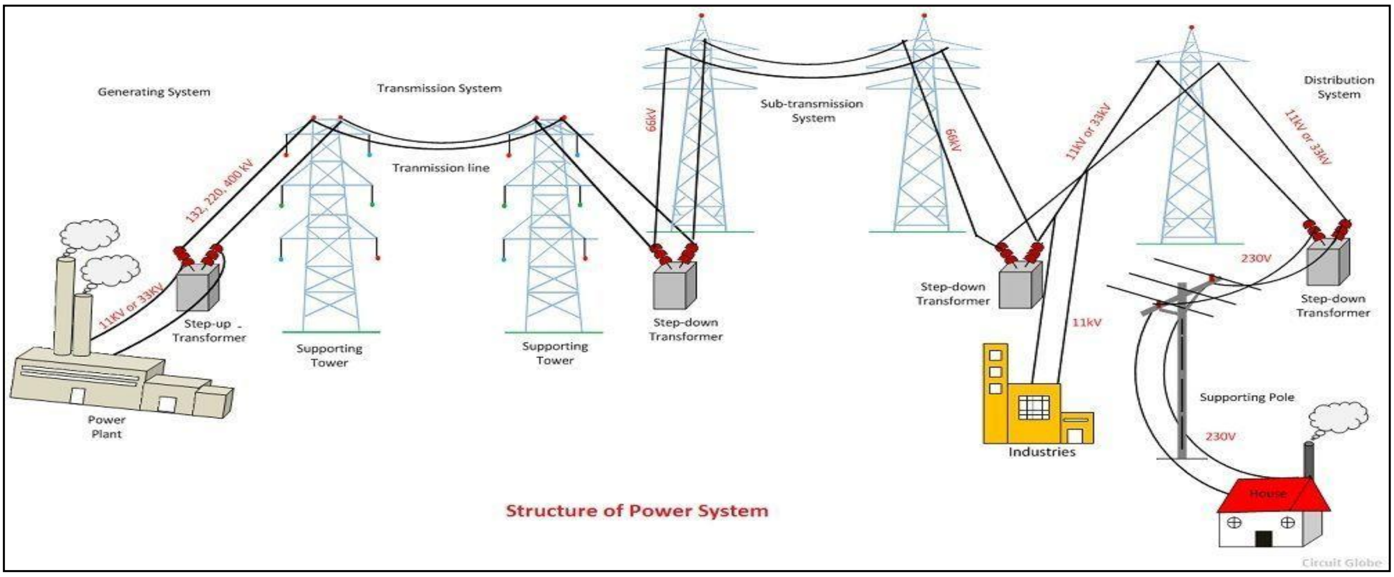

Figure 1: Structure of Power System [2]

II. POWER SYSTEM

A power system can be defined as a huge network of different types of electrical equipment such as generators, transformers and transmission lines connected together to generate, transport and distribute electrical power to consumers. The main purpose

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for a power system is to supply customers with electricity to run their loads economically and reliably. The power system network can be divided into three major subsystems which are generation, transmission and distribution as shown in Fig1. [2]

III. FAULTS TYPES IN POWER SYSTEMS

A fault in power systems can be defined as an abnormal condition interrupting normal flow of current due to a failure of power system equipment. The fault condition usually involves a flow of excessive current and voltage disturbance. Accordingly, it may lead to damaging electrical system equipment such as generators, transformers and transmission lines. It will also affect system stability and have adverse impact on consumers. Additionally, it results in hazards to humans, environment and facilities.[1]

Faults in a power system may have several causes such as electrical equipment insulation failure, heavy winds, falling trees, animals coming in contact with life electrical equipment, human errors, ..etc. [1]

Faults can be classified into shunt faults (short circuit faults) and series faults (open circuit faults). Shunt faults have two main categories which are:

1. *Symmetrical faults*

   Symmetrical faults occur due to a short circuit in all three phases and considered the most severe type of faults. However, this is the most uncommon type of faults which contribute to about 5% of all faults. [1][11]

2. *Unsymmetrical faults*

   Unlike symmetrical faults, unsymmetrical faults are unbalanced. The three phases are affected differently by the fault condition. Three main types of unsymmetrical faults exist:

   2.1 Single line to ground fault

   This is the most common type of faults in power systems. It contributes to about 70% of all faults. It takes place generally due to lightning or if a conductor made contact with a grounded structure.[1][11]

   2.2 Line to line fault

   This is the second common type of faults and contribute to 15% of all faults. It occurs when one phase touches another phase and is generally caused by heavy winds. [1][11]

   2.3 Double line to ground fault

   This type of faults contribute to about 10% of all faults. It happens when two phases come in contact with earth. It is usually caused by falling trees. [1][11]

IV. SINGLE LINE TO GROUND FAULT LOCALIZATION

In order to maintain reliability of the power system and achieve high level of customer satisfaction, faults in the system must be located promptly to restore any interrupted loads. A number of fault detection techniques are used in industry. Some of those are listed below:

1. *Fault Passage Indicator*

   In this technique, one fault passage indicator is installed on each phase of the circuit. These indicators allow supplier to monitor faults in each phase. The indicators are installed at regular distances along the line. Faults downstream of the indicators can be identified by monitoring the electromagnetic field surrounding the conductor. In case of a fault, the electromagnetic field around the faulted conductor increases dramatically due to the excessive current flowing in the conductor. This will happen for short time and then the current will go to zero once the circuit breaker trips and clear the fault. Such condition is sensed by the fault passage indicator and gives local alarm on-site and remote alarms to the control center. [7]

2. *Traveling wave-based method*

   Traveling wave fault location method is used to locate faults on overhead or underground cables. At the fault location, a traveling wave is generated by the power arc and the resulting voltage step change. This wave propagates along the line

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in the two directions to the line ends where fault locators are positioned. The fault locators capture the arrival time of the waves. The collected data is sent to a central station to calculate the distance from fault locators to fault location taking into consideration the line length and the propagation velocity. This method is called double-ended traveling wave approach. Another traditional approach exists which is the single-ended method but it is less effective in identifying accurate location of the fault. [7]

3. *Impedance-based method*

This method is used to estimate the fault location through measuring voltage and current signals and sequence impedance. These parameters are used to calculate the distance to the fault location. Measurements can be obtained from the microprocessor relays in the substation. [7]

Figure 2: A fault in transmission lines [3]

V. SINGLE LINE TO GROUND FAULT ANALYSIS

In order to overcome fault conditions in electrical power systems, protection devices must be designed properly. Before designing the protection devices, fault analysis must be conducted to be the basis for the protection design. Short circuit analysis exploring several scenarios is carried out to calculate the fault current at different locations of the power system. This analysis will enable the designer to select the proper size of protection devices such as circuit breakers, fuses, current and voltage transformers,.. etc. [8][10]

Unlike symmetrical three phase faults where the conventional equivalent single phase circuit can be used in fault analysis, unsymmetrical faults are analyzed in a different technique called symmetrical components method due to the unbalance condition. Symmetrical components method is used to represent the three phase system which is unbalanced during unsymmetrical fault condition by three balanced systems called the symmetrical components. These components are the positive sequence, negative sequence and zero sequence components. Accordingly, each phasor (voltage or current) can be represented by the sum of its three components. [4][6]

For example Ia=Ia1+Ia2+Ia0

Where Ia is the phasor current 'a' and Ia1,Ia2, Ia0 are its positive, negative and zero sequence components. Other phasors (voltage or current) can be calculated in the same way.

On the other hand, the symmetrical components can be calculated as follows:

Ia0 =1/3(Ia + Ib + Ic)
Ia1=1/3(Ia+ a Ib+ a2 Ic)
Ia2=1/3(Ia + a2 Ib + a Ic)
Where a=1<1200

Figure 3 below demonstrates the case of single line to ground fault at bus A.

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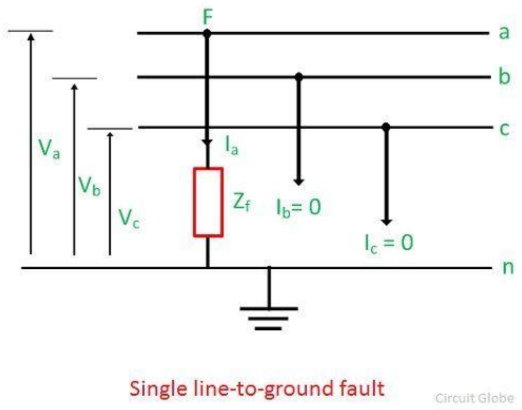

Figure 3: Single line to ground fault [2]

In this case, Ib=Ic=0
Va = Zf* Ia (fault through impedance)
Va=0 (solid ground fault)

Figure 4 below shows the three sequence networks used to calculate the fault current. It can be easily concluded that:

Ia1=Ia2=Ia0
Accordingly, If=Ia=3Ia0

For a fault through impedance:

$$If = Ia = \frac{3Ea1}{Z1+Z2+Z0+3Zf}$$

For a solid fault:

$$If = Ia = \frac{3Ea1}{Z1+Z2+Z0}$$

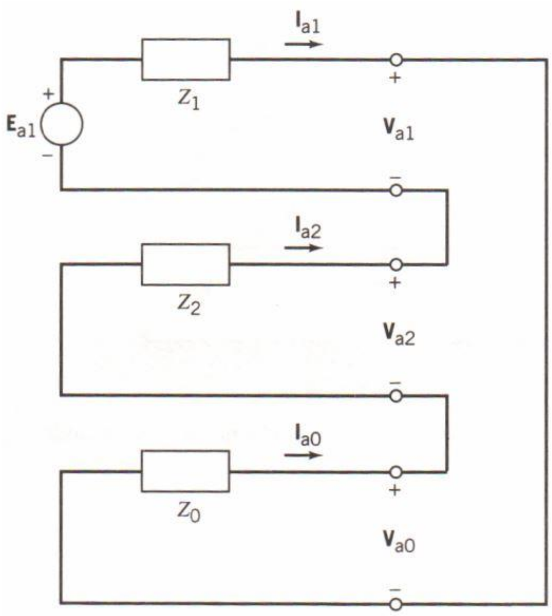

Figure 4: Interconnection of sequence networks of the single line to ground fault [5]

VI. MODERN TECHNIQUES USED IN FAULTS ANALYSIS

Nowadays, several modern approaches are used for power system faults analysis. These approaches were introduced to perform different faults analysis tasks including faults detection, type identification and localization to replace the conventional techniques discussed earlier in order to overcome accuracy issues and accelerate the whole process of detection, identification and localization. Succeeding to reduce the time of post-fault analysis enables prompt restoration of the affected line, minimizes maintenance and outage costs, and improve the resiliency and availability of the power system. [12]

Artificial intelligence-based techniques are among the most effective modern tools utilized for faults analysis. One of these powerful AI-based tools is the neural networks which have been used for a long time in several applications involving spanning patterns, recognition, feature extraction and classification. Artificial neural network ANN is a set of statistical models and learning algorithms designed to imitate the behavior of interconnected neurons in the human neural system. An ANN is usually trained with many input examples in a supervised manner where each set of inputs corresponds to certain desired outputs. When the network is trained sufficiently, it will be able to solve test scenarios and generalize the learning to produce solutions for other scenarios which were not part of the training phase. Figure 5 shows a simple one-layer perceptron neural network consisting of inputs, weights, activation functions and output. [12]

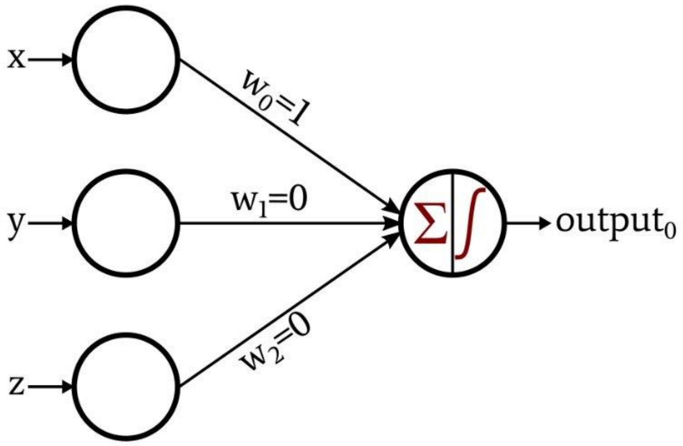

Figure 5: One-layer perceptron neural network [9]

Two types of neural networks have been used for power system faults analysis which are shallow learning and deep learning. While shallow learning neural networks utilize supervised learning, deep learning networks make use of supervised and unsupervised learning together to optimize data pre-processing and enhance features extraction. A shallow learning approach was used in [13] to detect and locate single line to ground faults in a medium voltage distribution network. A 20kV electrical system with many branches was modeled in Electromagnetic Transient Program EMTP. Faults in different locations and various fault resistances were simulated to train the neural network. The data was further processed in Matlab to estimate faults location. Then, the artificial neural network was built, trained and tested. The results showed 97% accuracy in faults localization.

In [14], a deep learning method was proposed for fault type identification and localization based on convolutional neural network. The proposed classifier works for substations with multi-transmission lines. For the training purpose, a 500kV power system simulation model was developed to generate the fault event data which include line impedance data, bus voltage, fault resistance and fault location (distance from substation). Then, the data was pre-processed to produce images for each type of fault to train the network on fault type identification. Ten types of faults in each transmission line were considered which are single line to ground fault on each phase (three scenarios), double line to ground fault (three scenarios), line to line Faults (three scenarios) and finally three line to ground fault (one scenarios). After that, the convolutional neural network was modeled and tested to classy different fault types and line locations. The results showed that the modeled CNN classifier is able to categorize the fault types and locations for various cases. When the network was trained on sufficient data, the type identification accuracy reached 99.9%.

Other AI-based techniques used for power system faults analysis are summarized in [12] including evolutionary computation and probabilistic methods for uncertain reasoning. The authors of [12] also shed light on other modern approaches different from AI-based tools such as communication network and control theory.

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VII. CONCLUSIONS

The concept of power system faults has been introduced. Among the different type of faults, single line to ground fault is the most common type contributing to 70% of all faults. Fault location techniques and fault analysis using symmetrical components method for this type of fault were discussed in this review paper. Finally, modern approaches for faults detection, type identification and localization were presented with more focus on AI-based tools.

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