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Fault Location Techniques in Electrical Power System: A Review

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Abstract

Electric fault is the main challenge in the process of providing continues electric supply. Fault can occur at anytime and anywhere. Due to the fault causes are mainly based on natural disaster or accident. Most fault occurrence hardly predicted nor avoided. Therefore, a quick response fault detection is necessary to ensure that the fault area is maintained to ensure a continuous power supply system. Hence, a system is required to detect and locate the position of the fault in the power system especially in the transmission line and distribution line. This paper will review the type of fault that possibly occurs in an electric power system, the type of fault detection and location technique that are available together with the protection device that can be utilized in the power system to protect the equipment from electric fault.

Keywords*: Transformers, Transmission line, Fault in transmission line, Fault location techniques, Traveling wave method*

1. Introduction

Many aspects need to be considered to provide high quality power systemy aspects need to be considered. There are various types of disturbance may occur especially in distribution line which increases the difficulty in identifying and locates the fault. Besides that, power quality also caught the attention of consumer whereby latest technologies and gadgets are highly sensitive to power source quality. A power system must have a protection system that can protect user equipment or devices. Hence, upgrade current power system and identify the type of potential disturbance is the priority task. Disturbance frequently occurs in a power system is a fault. About 80% fault causes due interruption in the power system are especially in the distribution area [1, 2]. To enhance the protection of the power system, the protection system should able to detect the fault location in order perform to isolate the zone which faults short duration. Fast response of protection system can prevent the damage caused by the fault to spread to the whole system or grid. Faults resultant disturbance on current to flow which could damage the equipment in use and cause interruption [3]. Another crucial aspect of improving the power protection system from a fault is the identification of the type of fault that occurs. As the electric fault could not be avoided in an electrical power system, some protection devices are needed to protect the expensive equipment in electric power systems such as transformers and switchgear. This paper will review protection devices such as fuse, relay, circuit breaker and lightning arrester.

2. Review of Electric Power System

Electrical power system consists of three main structures, which are generation system, transmission system, and distribution system [4]. Generation system consists of a mechanical machine that converts mechanical energy into electrical energy. Conventional generation systems in this current technology are the hydro power plant and thermal power plant. The

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transmission system consists of a transmission tower and an overhead cable that used to transmit electricity from one location to another location. The electric power from the generation system will be stepped up by using a transformer and then transmit to the other location by using the transmission line to reduce the losses while transmitting the electric power. In the distribution system, the electricity is distributed to the consumer by step down the voltage levels received from the transmission line. The consumer such as industry, commercial building and residential is connected to the distribution system. In the electrical system, many protections devices are required to be installed in the system to prevent interruption of power supply on the consumer side. There are various types of protection device can be used to protect the electrical power system such as relay, fuse and circuit breaker. These protective devices are usually embedded in the electrical power system.

2.1. Importance of Protection System in Electrical Power System

Protection system is a system that is used to protect or isolate a system or device from fault. A protection system is required to protect the overall system from having damage caused by fault or disturbance. This disturbance can interrupt the electrical power being transmitted to the consumer side. Disturbance or fault can be occurred due to many factors such as a lightning strike, overvoltage, power system components failure and human fault [5]. Protection system operates as to prevent the fault from flowing through the system by disconnecting the electrical system from the fault. However, the protection system cannot use to solve the fault, but it can be utilized to detect and partially separate the system from fault. Thus, it can prevent electrical system equipment from having damage and consumer does not require to spend more money on replacing the damaged equipment. Moreover, protection system also helps to protect user at fault. Sometimes short circuit can occur on electrical equipment. To protection system installed on the equipment, the short circuit can be avoided by giving electrical shock on the human body or the worst case may cause fatal. Beside of protective device, there are few methods can be used to detect a fault occurs in a power system. This method is known as fault location detection technique [6]. This method can be used to identify the location of the fault so that fast action can be taken to fix the fault.

2.2. Type of Fault in Electrical Power System

Fault can occur at any part of the electrical power system. These faults may cause by nature, electrical equipment or human. Fault also knew as an abnormal condition in a system, which causes failure in an electrical device. Power system fault is classified into four types which are shunt fault, series fault, symmetrical fault and unsymmetrical fault [7-9]. These faults commonly occur in the transmission system and distribution system.

2.3. Series Fault in Electrical Power System

Series fault knew as open circuit fault is a fault that occurs when there is a failure of one or more conductor cables [7, 8]. This fault can be due to the cable jointing failure, broken fuse or conductors. This fault is also known as unbalance fault which means there is a difference in impedance which is the impedance become very large value on each phase or conductors. There are three types of series fault can be occurring in the electrical power system which is single phase open circuit fault, two-phase open circuit fault and three phase open circuit fault. For single phase fault current, only one phase is in open circuit condition and can be occurring at any phase. For two-phase open circuit faults, open circuit occurs at any two-phase or conductor only. While for three-phase opens circuit faults, all the three phases are in open circuit condition. In a transmission line system, conductors can be in open circuit fault condition when there is broken or damage on the conductors.

2.4. Shunt Fault in Electrical Power System

Shunt fault also known as short circuit fault is a type of fault that occurs when there is an unwanted connection between phase and phase conductor or phase and ground conductor (short circuit connection) in an electrical power system [7]. This type of fault can cause damage to the electrical equipment due to the high current produced during a fault. There are few factors which lead to shunt faults such as broken insulation and falling tree. There are four fault categories of shunt fault which are single phase to ground fault (SPG), phase to phase fault (PP), double phase to ground fault (DPG) and three phases to ground fault (TPG). This type of

fault frequently occurs in the distribution system. The highest percentage fault is a single phase to ground fault with the percentage of 70% of total fault and follow by phase to phase fault with a percentage of 15% of total fault [10].

2.5. Symmetrical and Unsymmetrical Fault in Electrical Power System

Series faults and shunt fault can be categorized into symmetrical fault and unsymmetrical faults. The symmetrical fault is also known as balance fault and usually occur when all phases conductor is connected together (short circuit) with or without ground. Usually, this type of fault takes place in the three-phase system only [11, 12]. The unsymmetrical fault is the most common fault occurs in the electrical power system. This fault also known as unbalance fault. This fault occurs when there is unbalance current flow in the system due to high current flow in any phase conductor in the system[13]. Examples of unsymmetrical fault are single phase line to ground fault, double phase to ground fault and phase to phase fault [14].

2.6. Effect of Fault on Electrical Power System

Fault usually occurs in power generation, transmission, and distribution system. It may affect the performance of the overall system. For example, a short circuit fault or shunt fault may cause high current flow in the system. Thus it will cause damage to the electrical power system and the connected equipment [15]. Fault also can cause the overall operation to miss operation. Furthermore, high current or voltage produced by the fault may cause damage to the conductor insulation. Fault also can be harmful to human and may cause fatal. Spark or arc produce from fault may lead to an explosion or fire in electrical equipment [16]. For example, if a voltage is flowing through a transformer more than the transformer voltage rating, the transformer can be exploded and damage. As a result, the equipment is in maintenance status or even damage. Neither one possibility requires a high cost to fix the problem. Furthermore, the electrical power system equipment is very expensive, and the fault may cause financial loss. Moreover, a fault can cause an interruption in transmitting power supply to the consumer and may interrupt the production of an industry. Therefore, action should be taken to prevent faults from occurring and isolate the existing system from being affected by the fault. Applying a protection system such as relay, circuit breaker and fuse may help in preventing faults from damaging the connected equipment. Application of fault location detection method also can assist in finding the fault source location and fasten the troubleshooting process.

3. Conventional Fault Location Technique

Fault commonly occurs in the distribution part of the electrical power system. Most of them are caused by certain natural phenomena such as wind or thunderstorm which will cause incidence such as trees knocking down the transmission line after stroke by lightning [17]. Therefore, to maintain the continuity of power supply the zone affected by the fault should be isolated. Hence, identity fault location is the priority task. The conventional method that is available and applied today is traveling wave based method and impedance based method. The review of these methods is presented in the following section.

3.1. Traveling Wave Method

Fault location using traveling wave technology is applied in the transmission line system. It can be done by using the time taken for a pulse wave to travel to and from fault point to the fix reference point where the measurement is taken [18].

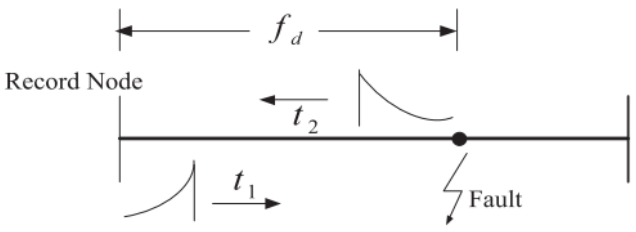

Figure 1. Wave traveling method [19]

Wave traveling method is as shown in Figure 1. Record nodes the point where the pulse wave is going to be transmitted. It is also the point where the pulse will be reflected too. Therefore, the sum of the period for the pulse wave to travel to the fault and reflect on the record node will be measured to identify the location of the fault occurrence of the transmission system.

The advantage of this method is that the load variance, series capacitor bank, and high grounding resistance will not affect the location technique. There are two types of traveling wave based fault locator method which is the single terminal locations as explained earlier and another type which is the double terminal location [20]. Unlike single terminal location technique, there are no needs of considering the follow-up signal. Both sides of the line end must be installed with the data acquisition which must be synchronized with the GPS clock to each other [21]. The disadvantage of wave traveling method is that the equipment and devices used in the technique are very expensive such as GPS and transient waveform capturing sensors.

3.2. Impedance Based Method

In an electrical power system, the appearance impedance is sensitive to small load variation. As the distribution generation varies, the impedance varies as well [22]. This method proposed by Motazavi in [23] for reverse power flow detection. A fault can be identified by observing the reduction in voltage within an operation and then applied in the calculation of impedance of the electric power system [24]. Figure 3 shows the simple circuit of impedance based method. The important measurement in finding the distance of the fault from the measurement node, f_d is the value of impedance per unit of the line of the distribution system.

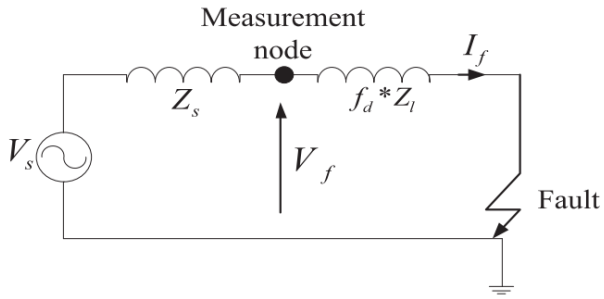

Figure 3. Impedance Based Method

Many other approaches can be used to calculate the distance such as in [25] uses the conversion of the estimated apparent reactance of line to the distance required for the location estimation. Another technique used Thevenin equivalent method to calculate the fault voltage and current to locate the fault. The advantage of impedance based method is that it is cheaper compared to traveling wave method as it only requires measurement data of the distribution line. As a result, the accuracy of the method is based on the data taken from the system. The data needs to be frequently recorded as a purpose of monitoring the electric power system. However, there are some disadvantages of using impedance based method. The first one is that the inaccuracy of the fault location detection might be due to the changes of the traction line structure. Besides that, accuracy is also influenced by the transition resistance and harmonic.

3.3. Artificial Fault Location Technique

To fulfill the demand of consumer, more advanced and accurate techniques are needed to adapt to the new complex distribution system. Artificial intelligence is applied to resolve complex type distribution system. In this paper, there will be two types of artificial intelligence that is reviewed which is the fuzzy logic and the neural network.

3.3.1. Fuzzy logic

In some electric power systems, the conventional algorithm is not suitable to produce the information and location for the maintenance operation. It will be more appropriate to implement the fuzzy-based approached as mention in [26, 27]. This method concept is to

produce numbers of fuzzy rules for each type of fault available. This not only enables the system to detect and locate the fault but also identifies the type of fault that occurred. The advantages of fuzzy-based approach are that it is flexible in the aspect of the input value and measurement accuracy. This is because the measurement accuracy depends on the rules determined in the designing process of the fuzzy logic system. The more solid the membership function of the fuzzy logic system, the more accurate the system. In the situation where the measurement is inaccurate, the fuzzy sets provide more information as a single input can use multiple membership degrees to be used in the calculation for a higher accuracy. One of an example of a fuzzy logic application with solid membership function was simulated in [28] where the system is capable of detecting and classifying all types of shunt faults accurately. Other than that, the system is immune to the variation in resistance of the fault, interception angle and location of the fault.

3.3.2. Neural network

System fault is the greatest threat to the electrical power system, especially in electrical supply. This is because faults consist of many types and are unavoidable. Therefore, a system that can detect and classified the fault occurrence is needed to protect the equipment in the electric power system. Due to an increasingly sophisticated electric power system, the procedure to deal with fault and the possibility of detecting a fault is the system becomes more complicated. Therefore, artificial neural network is one of the solutions to solve the protection issues as it can be trained especially with the ability to train with off-line data [29]. To detect fault location, the artificial neural network needs to be trained with parameters or input such as voltage phase (V) and the angle ($\emptyset$) from the measurement node. Similar to other fault detection and location method artificial neural network also use two approaches in finding the fault location in the transmission line which is the one-end measurement and two-end measurement. Other than detecting the fault location in the transmission line, the artificial neural network also applied in the location or detection of high impedance fault in the distribution system. The drawback of the application of artificial neural network in fault locating is that designing the system is time to consume as the system needed to be trained using large size of data to ensure an accurate output of the system. However, it is proven in [30] that the result of simulation of fault detection using the artificial neural network is reliable as the system's operating time is 13ms after fault occurrence.

3.4. Fault Protection Device in Electrical Power System

There are four conventional types of protection device used in the electrical power system which is fuse, circuit breaker, relay and lightning arrestor. This protective device is used to protect the electrical power system from fault.

3.4.1. Fuse

Fuse is a type of protective device used to disconnect the fault from the power system. The structure of fuse consists of a thin copper wire located inside a cylinder tube with two metal contacts. The copper wire will break down when a high current produce from fault is flowing through it [31]. Once the copper wire has broken, the power system will be in open circuit condition and isolated from the fault. Fuse can be used for many applications such as electrical machine protection, conductor wire, and electrical equipment. However, fuse required to be replaced manually once broken. Fuse can be divided into few categories which are low voltage fuse and high voltage fuse. Low voltage fuse usually uses for the industrial and domestic application. While high voltage fuses use is for high voltage applications such as transmission system or substation.

3.4.2. Circuit Breaker

Circuit breaker is a switch that is used to interrupt the flow of current in the electrical system. The current flow is interrupted when the circuit breaker changes the condition of the system from a close circuit into an open circuit. Circuit breaker usually combines with a relay which relay will give a command to the circuit breaker to open the circuit. Circuit breaker is very important in the electrical power system which helps in protecting the electrical equipment from affected by the fault current [32]. There are a few examples of circuit breaker used in the

electrical power system which is air circuit breaker, vacuum circuit breaker, oil circuit breaker and sulfur hexafluoride (SF6) circuit breaker.

3.4.3. Protective Relay

Protection relay is types of protection device that use voltage or current as the input source and perform trip when only the fault is meet the characteristic of the relay. Relay structure consists of a magnetic coil and a contact. This contact has two condition which is normally open (NO) and normally close (NC) condition. When fault occurs, fault current will flow through the relay coil and energized the coil to produce a magnetic field so that the switch inside relay could operate. There a various type of relay used in electrical power systems such as overcurrent relay, differential relay and directional relay [33].

3.4.4. Lightning Arrestor

Lightning arrestor is a protection device used to protect electrical equipment from a lightning strike [34]. Usually, the lightning arrestor is made of metal rod installed on the top of a building. The rod is connected directly to the ground through the wire to give a safe path for lightning to be discharged directly to the ground without affecting the system or any equipment. Lightning arrestor is used at the substation system. Lightning is very dangerous because it carries a very high voltage and current which can cause severe damage to the electrical power system equipment and interrupt the process of transmitting power to the consumer.

4. Conclusion

This paper discusses type of fault occurs in the electrical power system and technique used to locate the fault and also the general protection device used to isolate the electrical system at fault. In general, there are a few types of fault that frequently occur in the electrical power system which is series fault, shunt fault, symmetrical fault and unsymmetrical fault. Shunt fault is divided into several types which is a single phase to ground fault (SPG), phase to phase fault (PP), double phase to ground fault (DPG) and three phases to ground fault (TPG). This type of fault frequently occurs in the transmission system and distribution system, and it happens because of wind, lightning, fall tree and poor condition of the insulator.

Fault is a very serious matter in the electrical power system which it can damage the electrical equipment and interrupt the entire power system. Fault location technique and protection device are a method that can be used in electrical power system to determine the location of the fault and prevent faults from damaging the electrical equipment. Fault location technique can be classified into two which is conventional fault location technique and artificial fault location technique. There are two methods used in conventional fault locating technique which is traveling wave method and impedance based method. For artificial fault location technique, there are two methods used which is a fuzzy logic method and a neural network method. The conventional method is simple and more time efficient. However, this method might be not accurate for a large power system. Artificial method has very high accuracy compared to the conventional method. Another option to prevent fault is by using a protective device such as fuse, circuit breaker, protection relay and lightning arrestor.

As a summary, there are many methods and technique can be used to locate the fault in the electrical power system. Each type of technique has their advantage and disadvantage. Applying fault location technique in the electrical power system can fasten the process to identify the location of a fault. Application of protective device also helps in isolating the electrical power system from a fault so that the overall system can be protected from fault. Therefore, fault location technique and protection device is an essential thing in the electrical power system to ensure the overall system is operating in a good performance.

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