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A Review on Equipment Protection and System Protection Relay in Power System

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Abstract: Power system equipment is configured and connected together with multiple voltage levels in existing electrical power system. There are varieties of electrical equipment obtainable in the power system predominantly from generation side up to the distribution side. Consequently, appropriate protections must be apt to prevent inessential disturbances that lead to voltage instability, voltage collapse and sooner a total blackout took place in the power system. The understanding of each component on the system protection is critical. This is due to any abnormal condition and failure can be analyzed and solved effectively due to the rapid changing and development on the power system network. Therefore, the enhancement of power quality can be achieved by sheltering the equipment with protection relay in power system. Moreover, the design of a systematic network is crucial for the system protection itself. Several types of protective equipment and protection techniques are taken into consideration in this paper. Hence, the existing accessible types and methods of system protection in the power system network are reviewed.

Keywords: Protection equipment, Power system protection, System protection

1. Introduction

In power system, the potential of disturbances occurred during operation condition is higher which is either small or larger disturbances. Therefore, an efficient system should be designed to survive larger or small types of disturbance as well as to avoid any equipment damage [1-3].

Besides that, the disturbances that occurred in the power system can cause serious consequences which can affect the safety of the personnel in charged due to the unpredictable and unexpected failure in the power system. For example, in an isolated power system, the disturbances occurred and cause the power grid failed to supply sufficient power to the consumers due to both the power system frequency and the rotating speed of turbine drop to the lower level which gives bad impacts on system stability [4-6].

In power system, there are several types of system protection that are taken into account such as out-of-step, isolated system and rate of change of frequency. Each system has its functionality in power system protection. Each system will be discussed in details in the next section.

Power system and the normal and abnormal condition are always related to each other's. The situation mostly occur every time during every period of time. This will bring to decrease the power system quality in term of generation and distribution. During the abnormal condition, the fault occurs drawn a large current to the system which could damage or failure of the equipment [7].

In order to avoid this problem especially abnormal condition to be affecting the operating of equipment in a power system is by power system protection. Instance, the transformer is one of an important equipment in a power system that needs to provide protection. If one of the transformer failure to operate.

2. Protection Types

2.1 Numerical Domain

The disturbance can be overcome by developing protection system in order to prevent the effects of a disturbance. There are several types of disturbances that can cause system failure and damage to the equipment such as loss of synchronism between generator and utility system. Out-of-step protection system is proposed to avoid or mitigate the disturbances. This paper focuses on out-of-step, islanding system and rate of change of frequency system protection as showed in Fig. 1.

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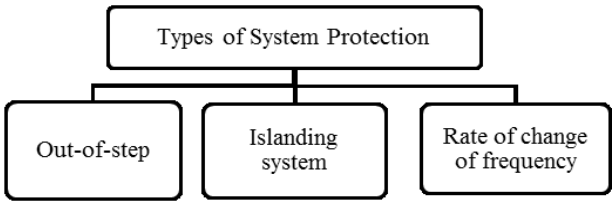

Fig.1 Types of system protection

2.1.1 Out-of- Step Relay

Techniques which capable to avoid or mitigate disturbances are out-of-step protection system as mention earlier. Out-of-step relay is a system that implemented in the power system to avoid any tripping occurred especially during stable swing. Besides that, this technique also widely uses when the system encounters an unstable condition. For example, areas must be separated in two interconnected systems in order to prevent the shutdown of a major portion of the power system or any equipment damage occurred. The out-of-step protection can be classified into two groups which are out-of-step tripping (OST) and out-of-step blocking (OSB). OST usually used during uncontrolled tripping of circuit breakers occurred which can cause damage to the equipment and affect personnel safety. OSB used to avoid any system separation from occurring at any locations in the system [8-12].

K. Malmedal et. al. stated that the out-of-step relay system can help to block other relay that causes a generator to ride through disturbances which can cause failure or trip the generator [13]. In the other words, the out-of-step protection system can block the tripping of breakers during unstable condition occurred and disconnect the generator during fault which can cause disturbances on the system. In addition, author also addressed on the out-of-step relay setting in order to perform the transient stability study for a generator. This setting is allowing the out-of-step protection system to trip the generator instead of blocks tripping due to undesirable if transient stability study was performed in the system.

Furthermore, John Berdy proposed that out-of-step relaying should be provided in the system during a loss of synchronism of the electrical center that located in the region from the high voltage parts of the step-up transformer to the generator [14]. Numerous factors such as maximum generator slip, loss of synchronism characteristics, expected current levels in the relays and characteristics of stable swings may occur. Hence, all possibility must be taken into consideration during applying this system protection on the generators or other system.

2.1.2 Islanding System

Islanding method is one of the protection method which widely apply in this field. The concept is to reduce the affected range to minimum and enhance fault detection by islanding the system which subjected in fault condition. Islanding system of self-adaptive is the new research in the field of islanding control [15]. Out-of-step scheme is widely used by installing the out-of-step relay in some area and it trip the measured data exceed their thresholds. Islanding system has different approach where self-adaptive islanding system is a type of emergency control where the system information which consists of two important parts, instability mode detection and islanding boundary searching.

Samui, A., and S. R. Samantaray state that the islanding is a condition that involves the utility, load and generation which are isolated from all of the utility system and operate by itself [16]. The undesired condition can happen due to the system continue to energize the isolated section and posing a threat to personnel safety. The more distributed generation includes into the power grid, higher the risk of damage and safety. The special protection scheme for islanding system called as islanding detection relays. It can be developed by different technique and several of detection of isolating condition by considering several aspects which consist of active, passive and communication based methods.

Kar, Susmita, and Subhransu R. Samantaray mention that the distributed generation unit needs an islanding detection device in order to avoid any problem that can affect a system such as the generator which can give problems to utility service personnel and equipment [17]. The performance of proposed relays was evaluated by authors in order to test the efficacy of the system. The proposed relay is passive anti-islanding relay which developed based on data-mining model by considering different types of distributed generation unit and load patterns.

2.1.3 Rate of change of Frequency Relay

In power system, the rate of change of frequency (ROCOF) is widely used in protecting the system from any disturbances. Sigrist, Lukas [18] states that the ROCOF has been utilized for under frequency load shedding scheme. In this scheme, ROCOF is used to estimate the amount of the lost generation as well as the amount of load to be shed. The under frequency load shedding (UFLS) is the scheme that used to protect the system especially during instability of frequency. In the designed system, UFLS apply in ROCOF relays to accelerate the system actions during disturbances.

Besides that, the UFLS with ROCOF enable to secure frequency from falling depth effectively and reduce the possibility of over-cut as stated by Jiang Huilan et al. [19]. Several ways are proposed in order to improve the UFLS performance. That consists of dynamic adjustment of the frequency of the first run and frequency differentials, real-time estimation of system power shortfall and self-adaptive improvements of the amount of load shedding at each step.

However, in [20] the new scheme was developed in order to overcome all the disadvantages especially in a complex system. In previously scheme, the system has a weak ability in term of the self-adaptive and causes the load shedding speed become slower due to some certain

permanent thresholds that decide offline on the base of experience and simulations. Therefore, the new scheme was developed based on the rate of change of frequency. This system is important for power system utilities in preventing the frequency drop during disturbances occurred which can cause severe imbalance between generator loads. Hence, the system must be an adaptive load shedding and dynamic adjustments to shed and ranges of thresholds.

2.2 Equipment Protection

An electrical power system includes various voltage levels which even more than 415V. Hence, the devices and equipment that may experience different life span usage. Overloading for a motor will cause bearing to worn out faster. Beside of the supply issue, equipment surrounding condition also affects the lifespan. For example, placing the motor in a dusty area will not just reduce the efficiency and lifespan, it also increases the maintenance demand. For cases on the transmission line, mostly fault happens due to that natural forces. Trees which fall or cause touching to the line with eventual resultant a fault [21]. Incident such as lightning strike also can cause insulation failure. Pollution is one of that cause which may affect increase degradation performance of insulators and expose it which increases the breakdown possibility [22]. Under frequency or over frequency of a generator may consequence in mechanical damage to the turbine by requiring tripping of an alternator. Low frequency operation was found potential to reduce the performance of a turbine and cause damage [22].

All abnormal cases which mention and un-mention needs to be avoided in term of equipment safety. Equipment safety mostly focusses on human safety in operating the equipment. The small amount of current of 50mA is sufficient enough brought fatal to human life. Operating equipment which is abnormal or under fault will endanger to the operator. Hence, if there is a possibility of the equipment onto damage, thus it necessary to isolate and de-energize the equipment [23].

The electrical power system authority has a duty to make sure the electrical equipment must under the periodic maintenance and overall performance test in order to avoid operating under abnormal conditions. It encompasses equipment protection and system protection. Equipment protection is deals with detection of a fault in the equipment itself and consequent protection. There are methods that used in order to protect the equipment from abnormal condition [24] such as Differential Protection, Overcurrent Protection, Distance Protection and Directional Overcurrent Protection (DOC).

3. Methodology

3.1 System Protection Relay

In out-of-step system protection, various method adopted in order to enhance the system protection based on their application such as protection of local types which use the locally available measurements for out-of-step regime detection and system wide measurement which based on out-of-step protection that uses measurements from several location in network. The new approach for out-of-step regime detection was introduced which the wide area measurements technology is combined with modeling technique [25, 26]. The system structure is based on generation sources electromotive forces vectors angle control which angle control-based method detection on the difference between two voltage phasor because an effectiveness of the system is highly depending on the voltage phasor modeling precision.

Bahman Alinezhad and Hossein Kazemi Karegar [26] propose a new method for out-of-step backup protection based on wide area measurements. In this system, the current phasor and synchronized voltage of the generators transfer to the Phasor Data Concentrator. PDC will decompose the current and voltage signal. In some decomposition levels, the voltage and current signals is analyzed and compared with Energy V-I plane which will show the generator instability.

The islanding system protection also have various method were implemented in the power system in order to isolate the system from posing risk to the equipment, public safety and the system itself. Samui, A., and S. R. Samantaray proposed new passive islanding detection technique using the Wavelet Singular Entropy Index (WSEI) for distributed generator [30]. WSEI is used to indicate the undesired energy distribution in the time-frequency domain. Besides that, this system also can differentiate between non-islanding and islanding conditions which play an important role in the power system protection. Wang C et. al. proposed self-adaptive islanding relay which can be divided into two parts as mentioned before, instability mode real-time detecting and islanding boundary real-time searching [27]. This scheme is proposed in order to protect the system from any failure and overcome the disadvantages over traditional islanding scheme which cannot consider the instability modes.

The rate of change of frequency is widely used in UFLS scheme to prevent the frequency drop after the disturbances happened in the power system.

New system was proposed based on rate of change of frequency [20]. The author focus on UFLS scheme in the multi-machine power system which considered several aspects in order to develop a good system such as the load shedding should be adaptive and the shedding and range of thresholds should be dynamic adjustments. Some simulation also has been carried out on a multi-region model in order to ensure the system will not be overloaded. Sigrist Lukas states that the system also uses the rate of change of frequency to decide how much load needs to be shed for UFLS scheme as well as to protect the system from frequency instability [18]. Hence the author proposed a centralized UFLS scheme for small isolated power system based on ROCOF measurements. From ROCOF measurements, amount of load that has to be shed can be estimated. In power system, there are various types of method used in system protection but in this paper only focuses on several method for every type

of system protection that has been explored based on certain application.

3.2 Equipment Protection Method

3.2.1 Differential Protection

Mostly differential protection is provided for the electrical power transformer which is in rated more than 5MVA.

This method or scheme for protect transformer has many advantages compared with the other schemes of protection. The faults occur in the transformer can be detected by using Buchholz relay. However, certain fault cannot be detect by this relay. Example as flash over occur at the bushings will not sufficiently covered by Buchholz relay. Hence, differential relays use to detect such type of faults. Moreover Buchholz relay is provided in transformer for detecting any internal fault in the transformer but Differential Protection scheme detects the same in faster way. The differential relays normally response to those faults which occur in side the differential protection zone of transformer [28, 29]. The differential protection scheme is illustrated in Fig. 2.

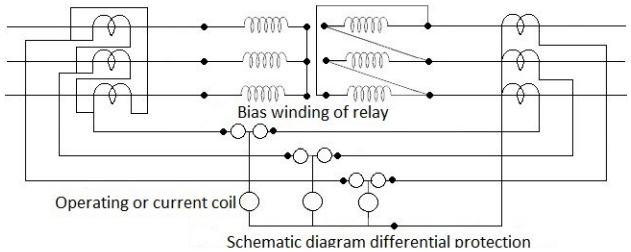

Fig.2 Differential protection scheme

Abu-Elanien et. al. proposed technique for differential protection of Multi-terminal High Voltage Direct Current (MTHVDC) transmission lines [30]. They are used for discrete wavelet transform in order to detect the DC fault and filter out the frequency transients overlaid on the current signals. Then, to discriminate the internal faults and external faults in each section of the MTHVDC used in operating signal and restraining signal. Moreover, these two signals depend on the energy of the current signal. There is proposed protection algorithm that simulate by different types of faults, fault resistances and inception times. The three-terminal model is managed by the simulation.

3.2.2 Overcurrent Protection

The overcurrent protection is required for transformers transformer only which not included the winding part of primary and secondary or the equipment that connected to the secondary sides. However, this could lead to a large inrush current approximately 0.01 second which experience by the transformer during the first half cycle. Then, it is increasingly to 1 second until transformer reaches normal magnetizing current. Furthermore, the fuss is selected in order to provide flow to inrush current to flowing without harm transformer. It has time-current resist values of at least 12 times transformer primary rated current for 0.1 second and 25 times for 0.01 second. Instance, overcurrent devices would be particular at about 110 to 125 percent of the transformer full-load current rating in order to prevent oversized conductors. Additionally, when use a smaller overcurrent protection, devices would be of the time-delay type on the primary side to compensate for inrush currents which reach 8 to 10 times the full-load primary current of the transformer for about 0.1 s when energized firstly [31-33].

3.2.3 Directional Overcurrent Protection

Directional overcurrent protection so called all protection system. It can detect the minimum fault level and intended to operate and stabilize any fault that not intended to operate. Directional overcurrent protection is usually applied to a grid transformer's incomer. The minimum fault level is can find at phase to earth fault which close to the source on the 132kV system the source circuit breaker is open that is back fed through the transformer. Then, the minimum fault is the contribution from the grid network. Directional overcurrent protection relays take the inputs from a set of current transformers (CT) in order to determine the amount of current flow while a set of potential transformers (VT) to determine the direction of power flow. The direction is defined by separating usually via a 90° quadrant connection of the line current with the phase to phase voltage of the other two lines [37-39].

4. Summary

Based on the methods that have been discussed on the previous section, it can be concluded that each type of system protection has a different method in order to protect the system. However, all the method have same purposed which used to protection the system but the differences are on the way they carried out and design the system itself. Based on out-of-step protection system, not all methods find their practical implementation. There are several types of out-of-step method which are, distance algorithm-based methods, $U_{cos\varphi}$ algorithm, energy function-based method and angle control-based methods. The most widely used methods in this system were distance algorithm-based and angle control based methods due to the effectiveness of protection operation are depending on the voltage phasor modeling precision [24, 40]. In the islanding system, there are various types of method used to detect the islanding events which are active, passive and communication based methods. However, there are many other methods have been presented in recent years. As discussed before, the passive types is one of the method that has been used but in this method, the main challenge is during designing process by choosing the most significant parameter and threshold value in order to detect the islanding as well as to avoiding the tripping. Furthermore, the rate of change of frequency system also can be divided in to three categories which are traditional, semi-adaptive and

adaptive method. Previously, most widely used is the traditional method. However, this system may easily lead to over-cut and miss the suitable time for load shedding. For the semi-adaptive, it quite same as traditional method especially during serious faults where the operating curve same as traditional. Nevertheless, the semi-adaptive better than the traditional method in term of selectivity during the active power shortfall is small. In order to decide the amount of load shedding, the adaptive method is more suitable method according to the frequent changes of real-time system. But there are also some problems by using this method. Therefore, UFLS scheme that based on the rate of change of frequency can help in protecting the frequency falling depth effectively as well as to reduce the possibility of over-cut.

Meanwhile, all the equipment protection methods have their own advantages and sufficiently to be protecting the equipment from abnormal operating condition. Otherwise, all the methods are widely used for different types of equipment such most used is to protect the transformer. This is because the transformer is a most expensive equipment in the power system and costly if it is experience damaging [27]. Therefore, from view of the differential protection is best choice to protect the transformer due to use relay.

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