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Review on Traditional and Advanced Power System Protection Schemes

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ABSTRACT: Power system protection is a very important consideration in the design of an electrical power system. There is need to protect electrical power components from dangerous faults. This is warranted by the need to increase the life of the components, avoid unnecessary expenditure in frequent replacement of obsolete components and to ensure that there is a continuous supply of power to serve the needs of the ever growing economy. This paper reviews the various protection schemes as well as transformer protection schemes. Sincetransformer performs a great job in the power system to change voltage and current level so proper protection for the transformer is important to maintain reliability in the system

KEYWORDS: Power System, Relay, Protection, Power transformer

I.INTRODUCTION

In the design of electrical power transmission and distribution system, there are various factors that need to be considered in the quest to satisfy the needs of electricity consumers. Electrical power systems experience faults at various times due to various reasons. These faults must be foreseen and safety precautions applied to the power system. The power systems engineer must include in his design, safety measures in order to avert any destructive occurrences that the system may undergo at any given time. Power system protection is very essential and necessary for a dependable electrical power supply. It ensures that the system is protected from itself and that the consumer is also safe as he benefits from the electrical power supply. An electrical power system consists of various components such as generators, switches, transmission cables, transformers, capacitor banks among other components. It cannot therefore operate without an effective protective device to keep these components safe and the system stable. Faults in a power system refer to the undesired conditions that occur in the electrical power system. These conditions may include short circuit, over current, overvoltage, high temperatures among others.

It is clear that over time, there has been an increase in human population, economic growth and technological advancement. This has continuously made the demand for electrical power to go high because as technology, human population and economy grows; there is an increase in demand for power as many more electrical loads are introduced into the supply line. An increase in load leads to a lot of current drawn from the power line. At times the demand goes above what the power distributor can supply. The consequence of this is that electrical power overload cases become common thus posing danger to power system components. This therefore throws in the need for devices that can monitor the rate of power consumption in accordance with the level that a given system is designed to sustain. Such a device must be designed to cut off consumption if the system oversteps its ability thus being dangerous to users and the components. In this project, we look at the protection of power transformer from various faults that may occur and may be destructive to the component if left undetected. The transformer is a very important component in an electrical power system as distribution of electrical power to consumers is more efficiently effected. Every transformer is designed to comfortably supply a given load. Cases of overload or short circuits can lead to transformer being damaged. To combat such occurrence, an elaborate system that monitors these excesses in supply parameters needs to be built. Such a device controls the flow of electrical power to the load so that the transformer is not overworked. Over current relays and overvoltage relays have been used for a long period of time and have been electromechanically controlled. In this system, a microcontroller is used to monitor cases of electrical faults and communicate to a switch to isolate the transformer from the system.

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1. **Electric Power system**

An electric Power system refers to a network that constitutes electrical components/machines used in the supply, transmission and consumption of electric power [1]. The diagram below illustrates a complete electric power system. It involves generation, transmission and distribution of electric power to various categories of consumers. The generation plant is normally located far from the load centre. There are different levels of electric power consumption depending on the purpose for which a consumer uses electricity. Electrical power consumers may be industrial, commercial or domestic. These consumers require different levels of electric power supply. In order to meet their specific needs, certain devices that adjust the voltage levels accordingly have to be used. Some of those components include: step up and step down transformers, capacitor banks, protective devices etc.[2].

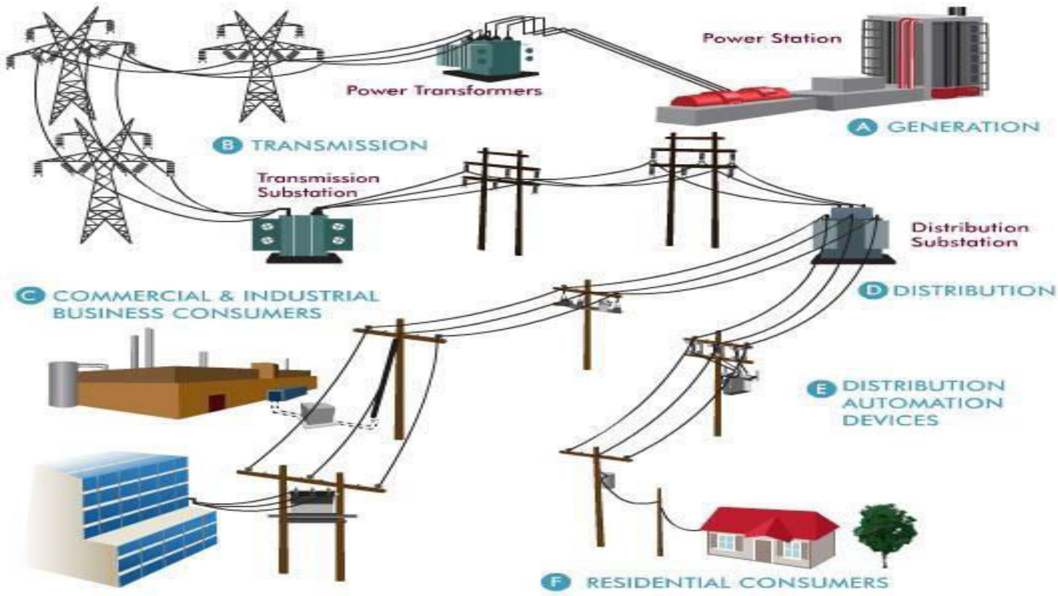

Figure 1.Generation, transmission and distribution of electrical power.

II.EVOLUTION OF POWER SYSTEM PROTECTION

The evolution of power system protection started with the invention of electromagnetic (EM) over current and differential relays in the early 20th century. After these two relays, EM-based directional relay and distance relay was invented followed by the power line carrier [3]. As the burden on the power system increased, EM relays were insufficient to provide the desired fast protection response. The advancement in microprocessor technology enabled the incorporation of digital relays in the power system. The prototype of a digital relay was developed in 1970 and the first commercial microprocessor-based relay was developed in 1980 [4].Advancement in numeric relay technology opened the door for adaptive relaying features for the protection system. As the modern power system was highly loaded, the protection and control systems were operating under very tight margins. In that scenario, it was very difficult to maintain system stability and reliability during abnormal operating conditions [5]. As an integrated system, wide-area disturbances in power systems were very common[6].The main accountability in this process is to sense the abnormal condition and disconnect the abnormal portion from the healthy system and local protection schemes were employed to do the same[7] These local systems were not fully capable to respond for large power system disturbances. In 1988, the invention of phasor measurement unit (PMU) was a milestone for power system engineers [8] Incorporation of the global positioning system (GPS) with PMUs gave the concept of WAMS. The WAMS was implemented with novel algorithms for fast and accurate fault detection and separation [9]. The concept of special protection scheme (SPS) was also developing with PMU technology. SPS was the foundation block for the evolution of SIPS technology. In 1996 a survey was published on Industry Experience with SPS [10] that shows the main application of SPS was for generator rejection.

In recent years, the traditional power system has switched to a different dimension. Incorporation of a huge amount of renewable energy and implementation of flexible AC transmission system (FACTS) devices play a very difficult scenario for the proper operation of conventional protection schemes[11].Recent developments in communication and

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microprocessor technologies enabled the idea of a new protection principle that exchange information from multiple electrical equipment. These developments enable protection schemes to maintain the integrity of the power system. Integrated protection schemes are equipped with modern technologies to secure the power system integrity under all abnormal conditions and known as the SIPS [12].

III.POWER SYSTEM PROTECTION

A branch of electrical power engineering that deals with protection of Power system from faults is known as power system protection. It does this by isolating the faulted parts of the system from the rest of healthy electrical network [13]. The diagram below shows a model of a power protection system.

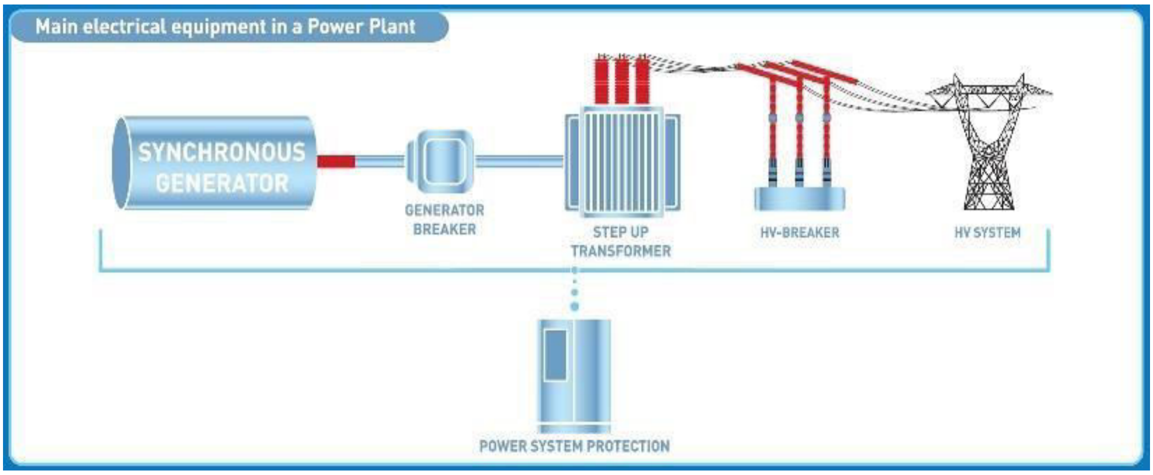

Figure2.Power system protection

The main aim of power system protection scheme is to switch off a section that is faulty in the system from the remaining live system. This ensures that the remaining portion is able to function satisfactorily locking out chances of damage that may be caused by fault current.
A circuit breaker closes automatically as a result of trip signals it receives from the relay whenever a fault is detected. The basic philosophy of a power protection system is that system faults cannot be prevented from flowing in the system but can be stopped from spreading in the system.

3.1 IMPORTANCE OF POWER SYSTEM PROTECTION

Occurrence of fault is hazardous to both electric power user and the electric system itself. To the user, life is of most important concern. The main concern of the system is to ensure a stable supply of electric power to consumer and to ensure that the electrical components do not get destroyed. In summary, power protection is necessary to:

a. *User/Personnel*- ensure safety i.e. Prevent injury/accident.

b. *Electrical equipment* - to protect the equipment from cases of over current, overvoltage and frequency drift that can destroy the equipment.

c. *General Safety* -Prevent secondary accidents that occur as a result of system fault like fire.

d. *Power Supply Stability*- Ensures a continuous and stable supply of electrical power.

e. *Operation Cost* -Ensure optimal operating efficiency so as to reduce equipment maintenance/replacement cost

3.2 TYPES OF PROTECTION SYSTEMS

Implementation of power system protection can be done in two ways. These are: the unit protection and non-unit protection [13].

Unit Protection

The unit protection scheme protects a definite\discrete zone bounded by the protection system. Differential relay protection is normally employed in this scheme. This is illustrated in Figure 3

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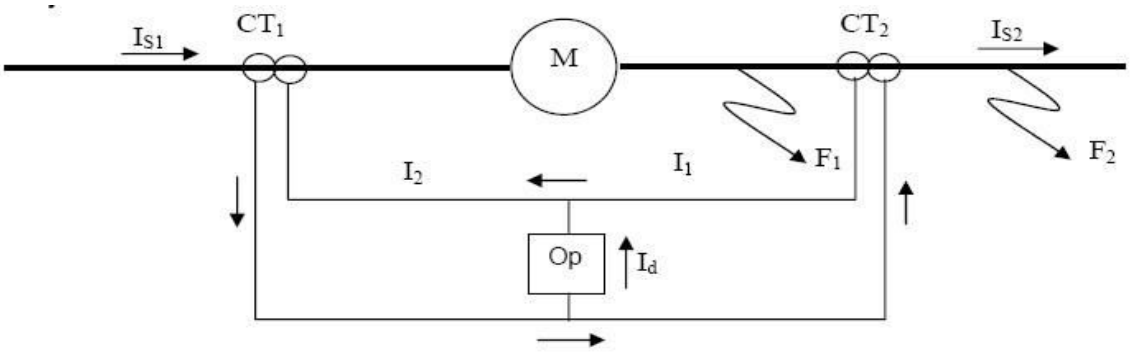

Figure 3.Unit protection

Non-Unit Protection

The Non-Unit protection protects a system\zone and can overlap with another protection zone in the system. This scheme ensures an isolation of the entire circuit (a larger area) in case a fault occurs as illustrated in figure 4

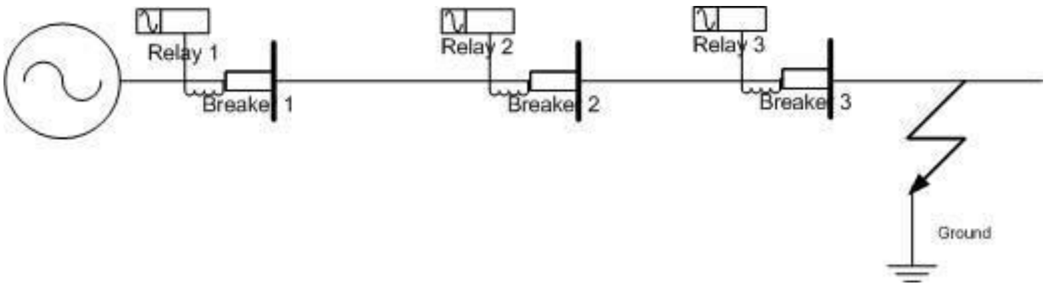

Figure 4.Non-unit protection

3.3 POWER PROTECTION ELEMENTS

There are 4 types of these elements, namely instrument transformers, switchgears, protective gears and station batteries.

1. Instrument transformers: these include current transformers and voltage transformers. Instrument transformers step down current and voltage from the power line to level that can be measured safely.

2. Switchgears: switchgears basically include circuit breakers. Circuit breakers are the main part of a protection system. They break contacts of the system in case of a fault. They include minimum oil, bulk oil, SF_6, vacuum and air blast circuit breakers. Mechanisms of operation of circuit breakers include: hydraulic, solenoid, spring and pneumatic [14].

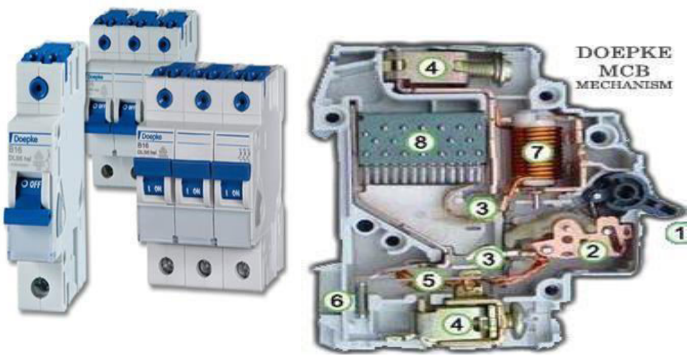

Figure 5.Circuit breaker

3.Protective gear: consists of protective relays like voltage, current, impedance, frequency and power relays, based on operating parameter, definite time, inverse time, and stepped relays, classified according to operating characteristic, differential and over fluxing relays classified according to logic. When a fault occurs, relay sends signal to relay to the circuit breaker completing its circuit thus making it to trip [14].

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4.Station batteries: all circuit breakers in a power system operate using direct current. The current is provided by battery banks that are installed together with the circuit breaker. It is thus an essential element in a power protection system.

Figure 6.Station battery

3.4 FUNCTIONAL REQUIREMENT OF A PROTECTION RELAY

In order for a protection relay to operate effectively, it must have the following qualities [14].

a. Reliability: power protection relays should remain inoperative always as long as a fault does not occur. But when a fault occurs, they should respond as quickly as possible.
b. Selectivity: it must only operate on the section that has experienced a fault to avoid unnecessary power outs due to wrong detections. It should also respond only when a fault occurs.
c. Sensitivity: The relaying equipment should be highly sensitive so that it can be relied on to provide the required detection.
d. Speed: the relaying equipment must operate at the required speed. It should not delay so as to give time for system equipment to get destroyed. It should also not be too fast to cause undesired operation.

IV. TRANSFORMER PROTECTION

Electrical power systems have various devices that aid in the transmission and distribution of electrical power. One such component is the power transformer. A transformer can be described as an electrical device used in electric power system to transmit power between different circuits, applying the principle of electromagnetic induction. The transfer of energy from one circuit to another makes use of basic magnetic fields. The flow of electric current in a conductor induces magnetic field around that particular conductor. If another conductor is brought within the effect of the first conductor, such that they are linked, voltage induction takes place in the second conductor. Transformer theory and application is based on the principle where magnetic field in one coil causes voltage induction into another coil. Sizes of transformers vary according to their applications from the tiny ones used in microphones to the ones weighing hundreds of tones used system grid. Transformers are used in electronic appliances and in electrical power networks. Transformers are therefore very important in transmission, distribution and consumption of electrical power[14].
There are two basic principles that explains the operation of a transformer
Magnetic field can be caused by electric current.
A varying magnetic field linked to a coil induces voltage across the ends of the coil by means of electromagnetic induction.

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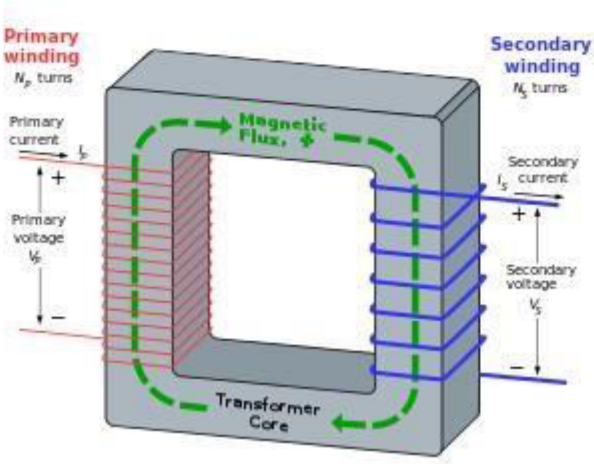

Figure7Electro-magnetic induction

As shown in the diagram above, as current passes through the primary coil, it causes magnetic field. The primary and the secondary windings are woven around a core whose magnetic permeability is very high. This is to ensure that a large percentage of the magnetic flux pass through the primary windings and the secondary windings.

Power transformers are transformers used in transmission networks for example in transmission substations. Their power rating is normally more than 200KVA [14]. Substation transformer is used to step down the utility service voltage. Some of the characteristics of power transformers include;

- 33kv and above voltage rating
- High operating efficiency close to 100%
- They are big in size compared to distribution transformers
- Low energy loss due to very little load fluctuations
- Operating temperature dependent on the power output rating,
- Power rating- over 200KVA

Figure 8Photo of a power transformer

4.1 CAUSES OF FAULT IN POWER TRANSFORMER

There are many faults that can occur in a transformer owing to a variety of reasons as follows[14]:

1. Winding and core fault is the most frequent type of fault in a power transformer. This can be attributed to weakening of conductor insulation. Phase faults rarely occur in the transformer, they may however occur at the terminals of that are found within the transformer protection zone.
2. Most power transformers use oil for cooling and insulation, oil leakage can also be a cause of fault in a transformer.

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3. The inrush current that occurs momentarily when a transformer is energized can also be treated as a fault unless conditions are set for its detection.
4. Inter-turn faults may occur and cause rise in hot spots within the transformer winding.
5. Transformer may experience over fluxing which may be as a result of transformer operating at low frequency at rated voltage. Over fluxing may also be caused by overvoltage operation at rated frequency.
6. Sustained overload can also be a cause of fault in a transformer

4.2 TRANSFORMER PROTECTION SCHEMES

There are several schemes used in transformer protection. A few are presented below.

1. Percentage differential protection

This protection scheme is used to protect transformers against internal short circuits. It is an effective method to protect transformer against internal faults. It may however not be effective in protecting the transformer against ground fault in case of ungrounded or high impedance grounding. The following factors affect differential current in a transformer and should be taken into consideration while using differential protection scheme to protect a transformer [15].

2.Magnetizing inrush current: this is the maximum instantaneous current that a transformer draws when it is first switched on. Power transformers can draw as high as 830 times its rated current depending on its resistance. Inrush current if not taken care of can thus be detected by the system as a fault and thus cause unwanted response. The diagram below shows a typical waveform of inrush current.

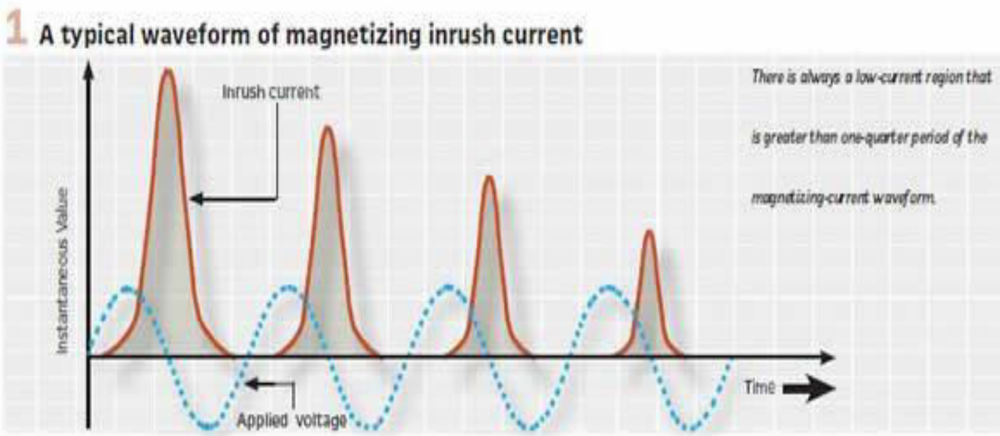

Figure 9Waveform of a magnetizing inrush current

3.Over excitation: Over excitation when referring to a transformer means an increase in magnetic flux in the core above allowable/normal levels. This causes the magnetizing current to increase. It can lead to destruction of the transformer if the situation is not taken care of. Over excitation in transformers is caused by overvoltage I the network.

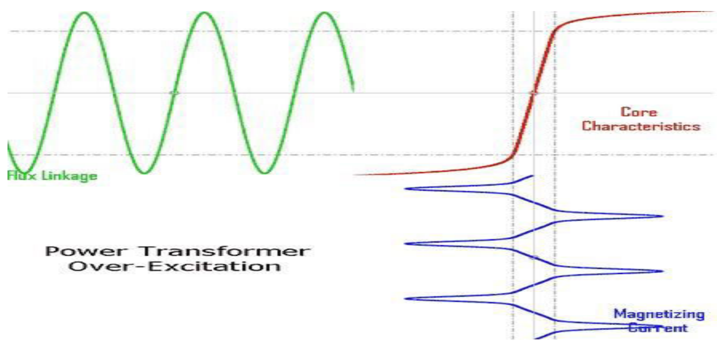

Figure 10. Over-excitation waveform

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CT saturation: this is a phenomenon where a CT is no longer able to produce an output that is proportional to its primary current as per the transformation ratio. The main reason for this is the property of the core to go into magnetic saturation due to high currents or large burden at the secondary side. His can cause relay operating current to flow as a result of distortion of the CT current [7].

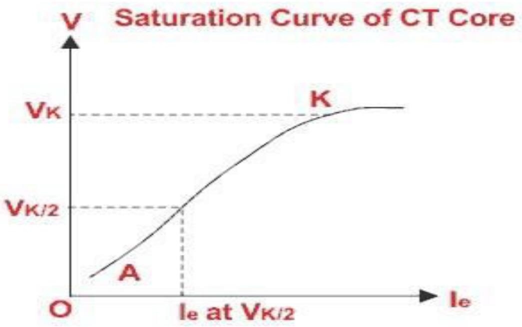

Figure 11. CT Saturation curve

Different primary and secondary voltage levels: that is the secondary and voltage CTs are of different ratios Phase displacement in delta wye transformers.

4.Transformer differential relay

In order to take care of the above variables, a differential transformer relay that is less sensitive (in the range of 15%-60%) is applied.

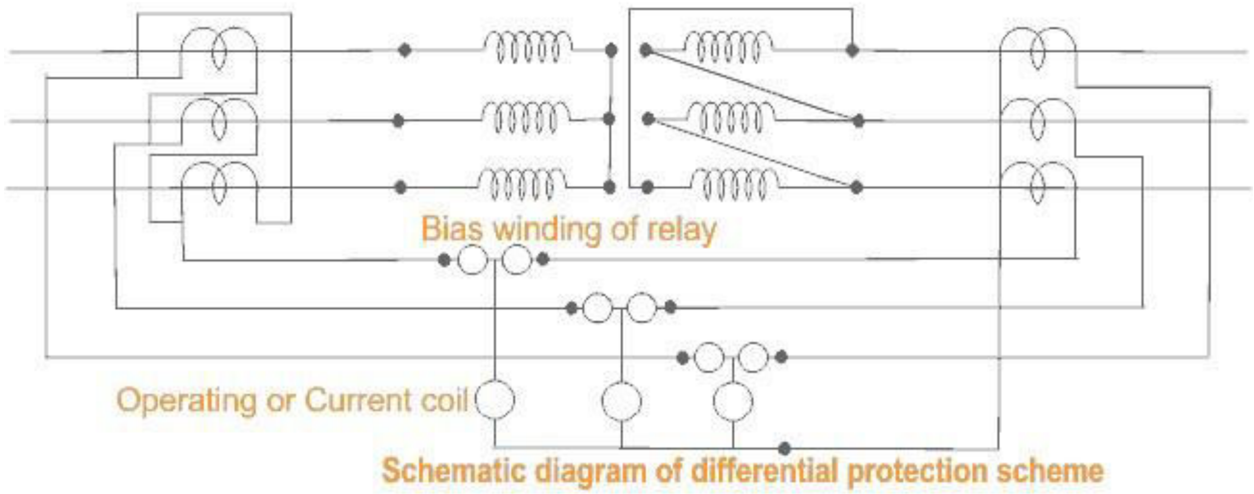

Figure 12.Differential protection Scheme

5.Harmonic restraint relay

Differential relay can fail due to magnetizing inrush current. The magnetizing inrush current waveform normally consists of several harmonics while the internal fault current consists of the fundamental component. To solve the problem of inrush current, a harmonic restraint relay is used. It is only effective during inrush current and remains inactive the remaining times.

6.Restricted Earth Fault

Restricted earth fault protection is used in power transformer to detect the transformer's internal earth fault. This scheme is connected as shown below. It is restricted to the transformer winding; otherwise, it may operate for any ground fault anywhere in the system. It detects faults with values below pick up of differential relay.

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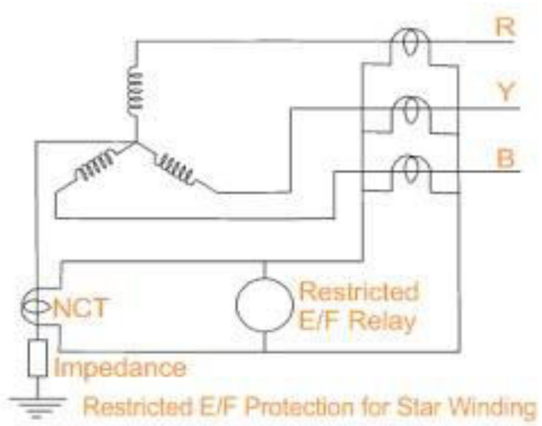

Figure 13 Restricted Earth Fault Protection

7.Over current protection

Over current protection scheme ensures that the transformer is protected from momentary excess current caused by overload, power surge etc.

In electric power system, over current refers to a situation where more than current intended flows through a conductor. This leads to excessive heat generation and thus the risk of causing fire or causing destruction to electrical equipment. Over current is caused by short circuit, overloading or wrong design.

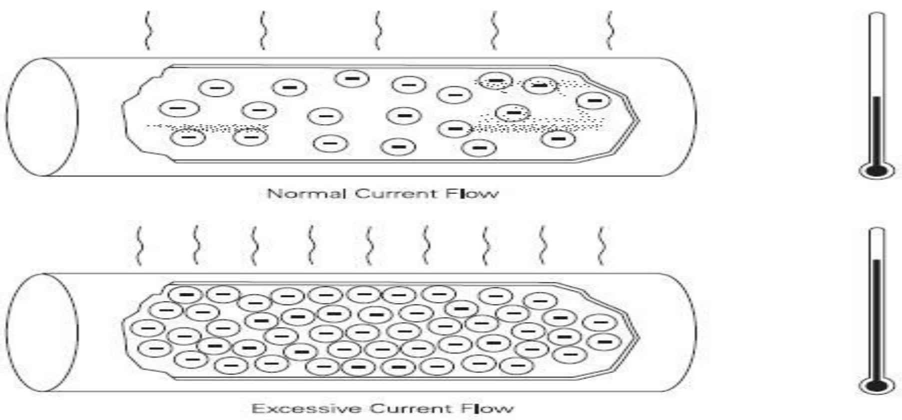

Figure 14over current Phenomenon

This phenomenon can be prevented using over current protection. This scheme is normally used for large transformers (over 5MV)

V. CONCLUSION

This paper represents the basic, advanced level information and provides an overview of the different type and schemes of the power system protection. This paper contributes to different advanced and traditional based protective relay used for the transformer. There are many issues are occurred in the transformer, so to protect transformer proper protective gear arrangement is required.

The protection schemes so far designed can successfully protect the transformer, other circuits and mitigate the risk of enormous destruction.

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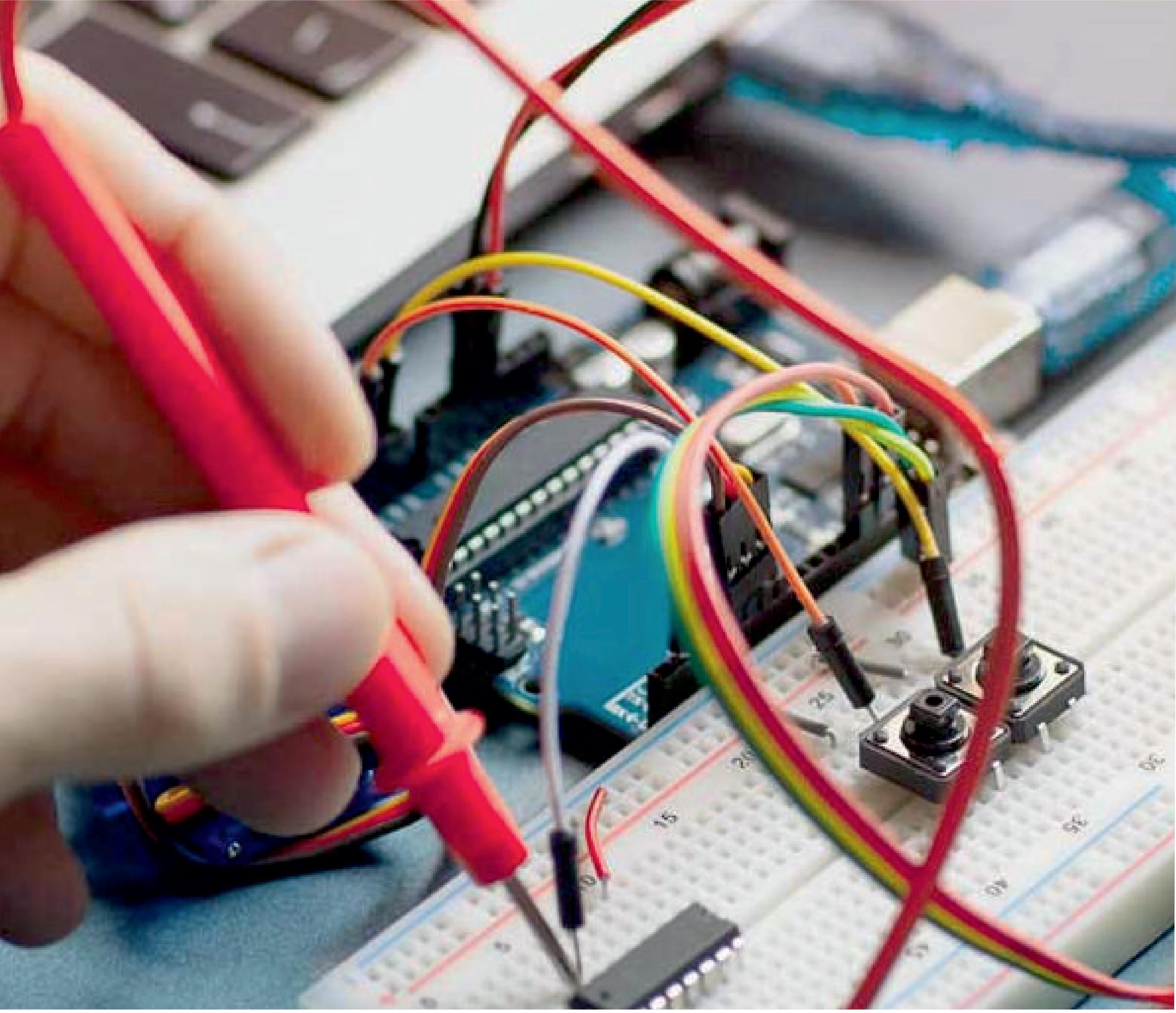

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