CHAPTER ONE

INTRODUCTION

1.1 General Concepts:

The development of modern power systems for the direction of extra-high voltage, large capacity, far distance transmission and the application of advanced technologies, is placing higher demands on the safety, stability and economic operation of power systems.

The electrical energy produced at the power station is transmitted at very high voltages by 3-phase, 3-wire system to step-down sub-stations for distribution so we use substations to do this function, but unfortunately this system is exposed to many types of faults, either for internal reasons related to the design elements and tolerance to specific values of the current and voltages, or to external causes as a result of weather and operators mistakes. Therefore we need to use protection system to safe the substation equipment and also to reduce the effects of fault on the other parts of the system. Because of the importance of substations in transmission system and to achieve maximum qualities of: speed, sensitivity, reliability, economic, selectivity, and stability, various patterns of protection are used.

Protective system means use the suitable devices to detect the faults and isolated the faulty element e.g. use relay, circuit breaker, trip circuits, C.T and other protective relaying equipment. To protect the substation we must use this device to a chive different type of protection such as over current, differential, over voltage and under voltage protection. All equipment's of substation must have primary (main) protection and secondary (backup) protection. The backup protection operates in case of main protection failure.

1.2 Problem Statement:

Considering Alshugura and Local Market substations (Sudanese National Grid) are strategic substations because of feeds wide area of industrial and residential load, southern of Khartoum. The transmission line (distance 5.3Km) between these two substations is 110 KV, protected by distance protection against faults.

Through the Fault Recorder found that any fault in feeders of 33KV side the Local Market substation, outage the (110KV) transmission line by zone one Alshugura distance relay without selectivity operation.

1.3 Objective:

1. Discuss the cause of overreach for Alshugura distance relay, when the fault is outside the area of zone one.
2. Design alternative protection scheme for Alshugura and Local Market transmission line, instead of distance relay.

1.4 Methodology:

1- A literature study on both distance protection scheme and its shortcoming.

2- Determine the cause of the problem from distance protection scheme shortcoming and match them with the case study.

3- A literature study on line differential protection scheme.

4- Using the ETAP program in some calculations.

5- Discussions result.

1.5 Thesis Layout:

The research contains five chapters:

Chapter two: contains general concept of protection, zone of protection, fault recorder concept, importance devices of protection and its role in protection system.

Chapter three: contains a literature study on distance protection with its shortcoming and literature study on line differential protection.

Chapter four: contains the problem description with the case study and apply a suitable solution to the problem.

Chapter five: contains conclusion and some recommendations that are supposed to do in the future.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction:

Protection is the main part of electrical power engineering that deal with the protection of electrical power system from the fault through isolation of faulted parts from the rest of the electrical network. The modern society has come to depend heavily upon continuous and reliable availability too computer-and a high quality of electricity too and the telecommunication networks ,railway networks banking and post office networks continuous process industries and life support systems are just a few applications that just can't function without a highly reliable source of electric power .and add to this ,the mind –boggling number of domestic users of electricity whose life is thrown out of gear ,in ease the electric supply is disrupted. Thus, the importance of main tuning continuous supply of electricity round the clock can't be over emphasized. No power system can be designed in such a way that would never fail. So one has to live with the failures, in the language of protection engineers this failures are called faults.

2.2 Power System Protection – Main Functions:

1- To safeguard the entire system to maintain continuity of supply.

2- To minimize damage and repair costs.

3- To ensure safety of personnel.

2.3 Power System Protection – Basic Requirements:

The principal function of protective system is to cause the prompt removal from service of any element of the power system when it starts to operate in an abnormal manner or interfere with the effective operation of the rest of the system. In order that protective system may perform this function satisfactorily, it should have the following qualities:

1-Selectivity: It is the ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system, e.g. to detect and isolate the faulty item only.

2-Stability: To leave all healthy circuits intact to ensure continuity of supply. A failure on the system leads to a great reduction in the system voltage. If the faulty section is not disconnected quickly, then the low voltage created by the fault may shut down consumers' motors and the generators on the system may become unstable.

3-Speed: To operate as fast as possible when called upon, to minimize damage, production downtime and ensure safety to personnel.

4-Sensitivity: To detect even the smallest fault, current or system abnormalities and operate correctly at its setting e.g. it is the ability of the relay system to operate with low value of actuating quantity.

5-Reliability: It is the ability of the relay system to operate under the pre-determined conditions. Without reliability, the protection would be rendered largely ineffective and could even become a liability.

6-Economy: The most important factor in the choice of a particular protection scheme is the economic aspect. Sometimes it is economically unjustified to use an ideal scheme of protection and a compromise method has to be adopted. As a rule, the protective gear should not cost more than 5% of total cost.

7-Adequateness: Each relay designed to suit or detects a certain type of faults.

2.4 Types of Protection:

When a fault occurs on any part of electric power system, it must be cleared quickly in order to avoid damage and interference with the rest of the system. It is a usual practice to divide the protection scheme into two classes. Primary protection and back-up protection.

2.4.1 Primary (main) protection:

It is the protection scheme which is designed to protect the component parts of the power system. Thus each line has an over current relay that protects the line. If a fault occurs on any line, it will be cleared by its relay and circuit breaker. This forms the primary or main protection and serves as the first line of defense. The service record of primary relaying is very high with well over ninety percent of all operations being correct. However, sometimes faults are not cleared by primary relay system because of trouble within the relay, wiring system or breaker. Under such conditions, back-up protection does the required job [1].

2.4.2 Back-up protection:

It is the second line of defense in case of failure of the primary protection. It is designed to operate with sufficient time delay so that primary relaying will be given enough time to function if it is able to. Thus relay *provides* back-up protection for each of the lines. If a line fault is not cleared by its relay, the relay on the group breaker will operate after a definite time delay and clear the entire group of lines. The backup protection must be from different type and prefer to be from another company to avoid the manufacturing problems [1].

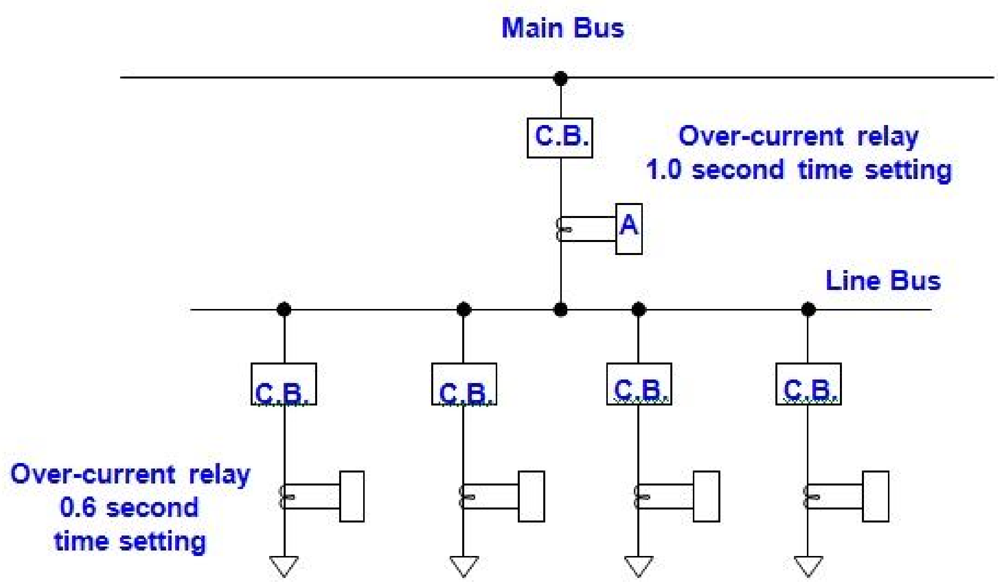


Figure 2.1: Main and back up protection

2.5 Protection Zone:

In order to provide selectivity to the system, it is a usual practice to divide the entire system into several protection zones. When a fault occurs in a given zone, then only the circuit breakers within that zone will be opened. This will isolate only the faulty circuit or apparatus, leaving the healthy circuits intact. For a failure within the region where two adjacent zones overlap, more breakers will be opened than the minimum necessary to disconnect the faulty section. But if there were no overlap, a failure in the region between zones would not lie in either region and, therefore, no breaker would be opened. For this reason, a certain amount of overlap is provided between the adjacent zones. Zone in differential protection means another meaning, in zone indicate to internal fault and out zone indicate to external fault [1].

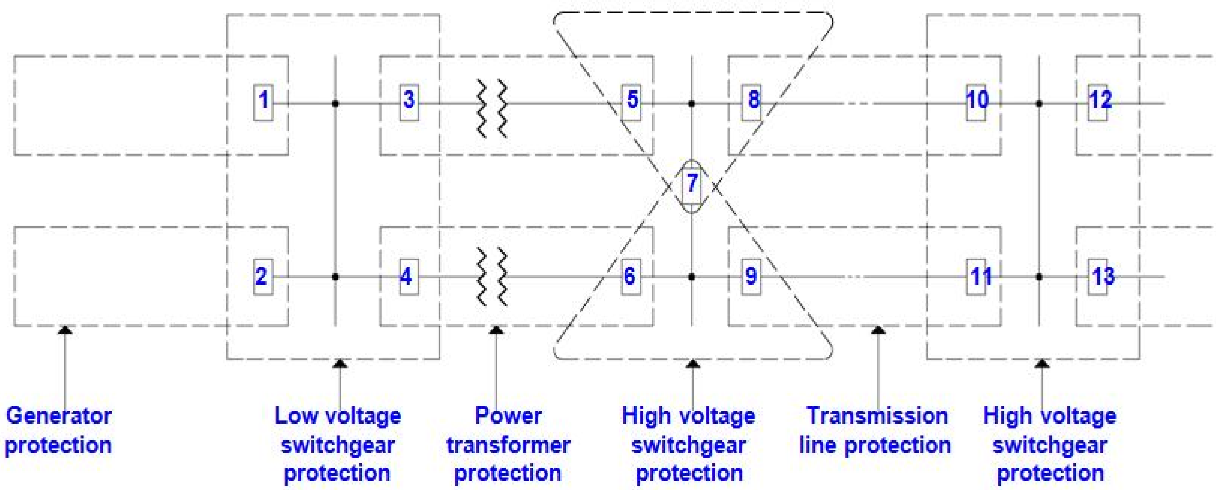


Figure 2.2: Zone of protection [1]

2.6 Time in Protection:

The time is important factor in the protection because the failure of equipment's depends on the fault subjected and time of fault, in other hand the stability of power system depends on the time of clearing the fault. The total time required between the instant of fault and the instant of final arc interruption in the circuit breaker is called fault clearing time; and it's the sum of relay time and circuit breaker time. The relay time is the time between the instant fault occurrence and the instant of closure of relay contacts .The circuit breaker time is the time taken by circuit breaker to operate to open the contacts and to extinguish the arc completely. The fault clear time should be as small as possible to have high speed operation of protective system. Though the small fault clearing time is preferred, in practice certain time lag is provided. This is because have clear discrimination between primary (main) and backup protection. Thus the fast protective system is an important quality which minimizes the damage and it improves the overall stability of the power system [1].

2.7 Faults in Power System:

Most of the faults on the power system lead to a short-circuit condition. When such a condition occurs, a heavy current (called short circuit current) flows through the equipment causing considerable damage to the equipment and interruption of service to the consumers. Type of fault:

2.7.1 Symmetrical faults:

That fault on the power system which gives rise to symmetrical fault currents (i.e. equal fault currents in the lines with 120° displacement).

2.7.2 Unsymmetrical faults:

Those faults on the power system which give rise to unsymmetrical fault currents (i.e. unequal fault currents in the lines with unequal phase displacement).

2.8 Protection System Components:

Protection system usually comprises four components:

2.8.1 Instrument transformers:

If the voltage or current in a power circuit are too high to connect measuring Instruments or relays directly, coupling is made through transformers. Such 'measuring' transformers are required to produce a scaled down replica of the input quantity to the accuracy expected for the particular measurement; this is made possible by the high efficiency of the transformer. During and following large instantaneous changes in the input quantity, the waveform may no longer be sinusoidal; therefore the performance of measuring transformers is important. The deviation may be a step change in magnitude, or a transient component that persists for a significant period, or both. The resulting effect on instrument performance is usually negligible; although for precision metering a persistent change in the accuracy of the transformer may be significant. However, many protection systems are required to operate during the transient disturbance in the output of the measuring transformers following a system fault. The errors in transformer output may delay the operation of the protection or cause unnecessary operations**.** Therefore the functioning of such transformers must be examined analytically [1].

2.8.1.1 Voltage transformers:

A voltage transformers step down the high voltage of the line to level safe enough for the relay system (pressure coil of relay) and personnel to handle.

The standard secondly voltage on line-to-line basis is 110V. This help in standardizing the protective relaying equipment irrespective of the value of the primary is connected in parallel at the point where a measurement is desired, unlike a CT whose primary is in series with the line in which current is to be measured. Three types of voltage transformer are used for protective-relaying purposes, as follows:

1-The instrument potential transformer: A potential transformer is a conventional transformer having primary and secondary windings. The primary winding is connected directly to the power circuit either between two phases or between one phase and ground, depending on the rating of the transformer and secondary winding is connected to the requirements of the application.

2-The capacitance potential device: A capacitance potential device is voltage-transforming equipment using a capacitance voltage divider connected between phase and ground.

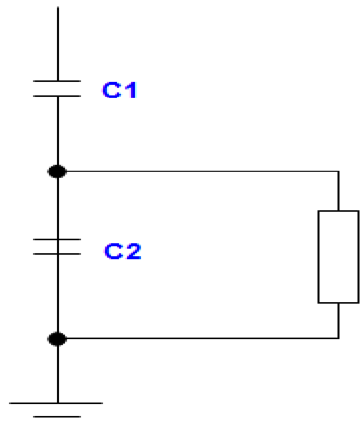


Figure 2.3: Capacitance potential device

3- Cascade Voltage Transformer:

The capacitor VT was developed because of the high cost of conventional electromagnetic voltage transformers but, the frequency and transient responses are less satisfactory than those of the orthodox voltage transformers. Another solution to the problem is the cascade VT shown in Figure 2.4.

The complete VT is made up of several individual transformers, the primary windings of which are connected in series as shown in Figure 2.4. Each magnetic core has primary windings (*P*) on two opposite sides. The secondary winding (*S*) consists of a single winding on the last stage only.

Coupling windings (*C*) connected in pairs between stages, provide low impedance circuits for the transfer of load ampere-turn between stages and ensure that the power frequency voltage is equally distributed over the several primary windings.

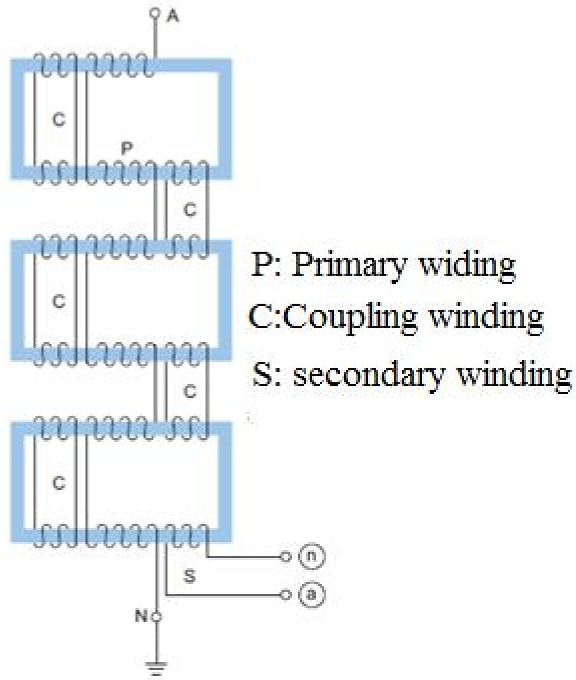


Figure 2.4: Cascade voltage transformer [1]

- **Transient performance:**

Transient errors cause few difficulties in the use of conventional voltage transformers although some do occur. Errors are generally limited to short time periods following the sudden application or removal of voltage from the VT primary. If a voltage is suddenly applied, an inrush transient occurs, as with power transformers. However, the effect is less severe than for power transformers because of the lower flux density for which the VT is designed. If the VT is rated to have a fairly high voltage factor, there is little inrush effect. An error appears in the first few cycles of the output current in proportion to the inrush transient that occurs.

When the supply to a voltage transformer is interrupted, the core flux does not immediately collapse. The secondary winding maintains the magnetizing force to sustain this flux and circulates a current through the burden, which decays more or less exponentially. There may also be a superimposed audio-frequency oscillation due to the capacitance of the winding. If the exciting quantity in ampere-turns exceeds the burden, the transient current may be significant [1].

- **Errors on voltage transformer:**

The ratio error is defined as:

$$E = \frac{K_n V_s - V_p}{V_p} * 100\% \quad (2.1)$$

Where:

K_n is the nominal ratio

V_p is the primary voltage

V_s is the secondary voltage

If the error is positive, the secondary voltage is greater than the nominal value. If the error is negative, the secondary voltage is less than the nominal value. The turn's ratio of the transformer need not be equal to the nominal ratio and a small turn's compensation is usually used so the error is positive for low burdens and negative for high burdens. The phase error is the phase difference between the reversed secondary and the primary voltage vectors. It is positive when the reversed secondary voltage leads the primary vector [1].

2.8.1.2 Current Transformers:

A current transformer is an instrument transformer intended to have its primary winding connected in series with the conductor carrying the current to be measured or controlled. The ratio of primary to secondary current is roughly inversely proportional to the ratio of primary to secondary turns and is usually arranged to produce either five amperes or one ampere (IEC Standard) in the full tap of the secondary winding when rated current is flowing in the primary.

The current transformers have two jobs to do firstly, its step down the current to such levels that it can be easily handled by the relay current coil and Secondly, its isolates the relay circuitry from the high voltage of the EHV system. In practice there are always some errors. The error creeps in, both in magnitude and in phase angle. These errors are known as ratio error and phase angle error [1].

- **Errors on current transformer:**

The transformation of current induces errors.

Some energy from the primary winding is use to:

- Establish magnetic flux in core.
- Change the direction of the magnetic flux in the core named hysteresis losses.
- General heat due to eddy current.
- Establish leakage flux.

- Ratio Error

This is the difference in magnitude between I_p and nI_s and is

$$E = \frac{nI_s - I_p}{I_p} * 100\% \quad (2.2)$$

- Phase Error is

$$E = tan^{-1}\left[\frac{I_m}{I_m + I_c}\right] \quad (2.3)$$

- Composite error is

$$E = \frac{100}{Ip}\sqrt{\frac{1}{T}\int_0^T (\mathrm{nI_s} - \mathrm{I_p})^2\, dt} \qquad (2.4)$$

Where:

n is current transformer ratio

I_p Is primary current

I_s Is secondary current

I_m Is Magnetizing component

I_c Is Iron loss component [1]

2.8.2 Relay:

Relay is equipment can be detect abnormal power system condition, and initiate corrective action as quickly as possible in order to return the power system to its normal state. The protective relay operates after a fault has occurred and it helps in minimizing the duration of trouble and limiting the outage time and related damage. From the very beginning of the history of power system, relays have been developed for protection system [1].

- **The first electromagnetic relays:**

This kind of relay called (electromechanical) because they contains moving parts utilized in closed circuit operation cutter.

The idea of working this types of relay depend on the passage of electric current in the coil creates a magnetic field an accompanied by magnetic force acting on the disc iron subject to rotation. This idea used in the case of (induction disc relay) and this magnetic force proportional directly to the cause flowing in the coil in the cases of the faults radically increased power and thus be sufficient force to move and manage the disk. The main features of these types are Stability (not affected by tremors in network) and Great expertise of engineers in these types. While disadvantages of these type of relay are relatively slows due to the moving parts and therefore needs time to start a movement, Require regular main lenience of moving parts also It needs to calibrate each period to ensure the accuracy of measurement.

- **Static relays:**

This type began to appear in the early sixties. It does not contain moving parts and it depends to operational amplifiers technology to compare the value of the current flowing certain setting up circuit. If the current flowing in the circuit exceeds setting values then the operational amplifiers sends a signal to the circuit breaker but the difficulties of this type are instability and affection by changing in temperature.

- **Digital relays:**

This type began to appear in the early seventies it's also called (numerical relays). This kind solved all the problems faced by electromagnetic and static relays. Its converts voltages and current signals to numbers stored in computer memory with constantly update because of the impossibility of storing all value. This types of relays stored cycle or store value and tracking the change in the values program stored in the device and by depending on the size of the values received by the device can be determined if there's faults or not.

This type has been developed so that possible change the set values automatically after the evolution of the digital communication has become the exchange of information between devices prevention is easy and became its ability to detect fault and accurately classified enormous. Two of the voltages and current and when ever anew value it came repeals the oldest.

- **Adaptive digital relays:**

It was begun to appear in the late eighties it's considered an extension of the digital relays with some improvement. These types used possibilities of micro processor technology. The main features of this types is Possibility of amending setting values automatically and Distinguish between natural increase in load and faults which create a current resemble load.

- **Multifunction digital relays:**

It was begun to appear in nineties. In this type were merged many of prevention services in one device. The hardware for each digital devices prevention is almost similar but the difference in the software. In this kind of relay can be store many program representing various devices within one relay. But the disadvantages of these types any stopping occurred in this multifunctional device causing a disaster due to the absence of full protection system there for backup protection tend to be designed from another company or exploitation of ancient protective equipment at the station and make it represent prevention backup for these new devices.

2.8.3 Batteries:

To provide power in case of provide disconnection in the system.

2.8.4 Circuit breakers:

The circuit breaker is an electrically operated switch in capable of safely making as well as breaking short circuit currents. The circuit breaker is operated by the output of the associated relay. When the circuit breaker is in the closed connection, its contacts are held closed by the tension of the closing spring. When the trip coil is energized, it releases a latch causing the store energy in the closing spring about a quick opening operation.

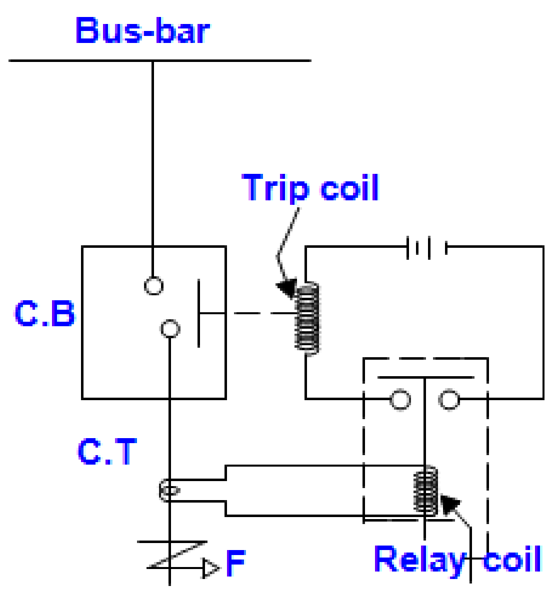


Figure 2.5: Trip circuit of circuit breaker [1]

2.8.5 Digital fault recorder:

Digital fault recorder or DFR is the equipment for recording the disturbance or fault in the power system, from this data we can analyze:

- The performance of protection system.
- Circuit breaker status.
- Communication signal.
- Type and cause of fault.
- Fault location.
- Response of power system.

That for improve the power system stability

CHPTER THREE

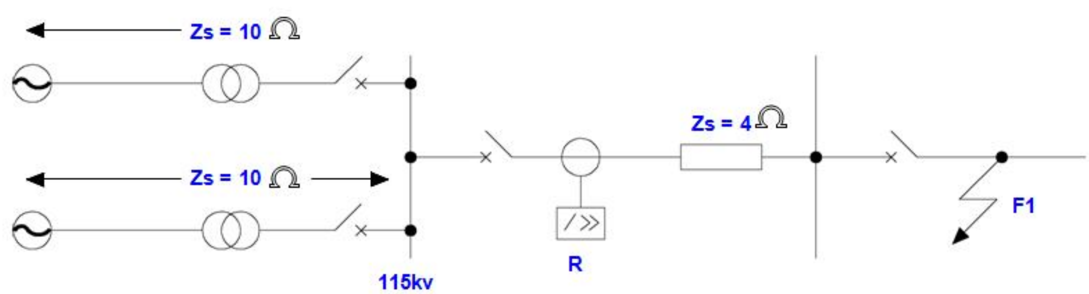
LINE PROTECTION SCHEMES

3.1 Line Distance protection:

3.1.1 Introduction:

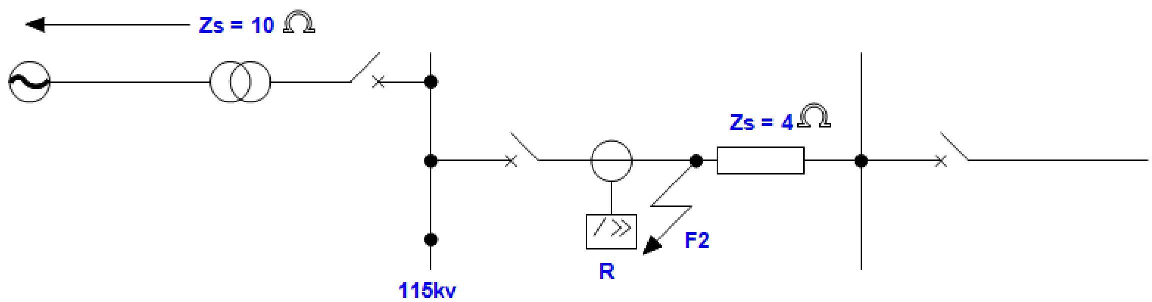
The problem of combining fast fault clearance with selective tripping of plant is a key aim for the protection of power systems. To meet these requirements, high-speed protection systems for transmission and primary distribution circuits that are suitable for use with the automatic re-closure of circuit breakers are under continuous development and are very widely applied.

Distance protection, in its basic form, is a non-unit system of protection offering considerable economic and technical advantages. Unlike phase and neutral over current protection, the key advantage of distance protection is that its fault coverage of the protected circuit is virtually independent of source impedance variations. This is illustrated in Figure 3.1, where it can be seen that over current protection cannot be applied satisfactorily.



$$I_{F1} = \frac{115 \times 10^3}{\sqrt{3} \times (5 + 4)} = 7380A$$

Relay R setting > $7380A$



$$I_{F2} = \frac{115 \times 10^3}{\sqrt{3} \times (10 + 4)} = 6640A$$

There for, for relay operation for line faults,

Relay current setting < $6640A$ and > $7380A$

This is impractical, over current relay not suitable

Must use Distance or Unit protection

Figure 3.1: Advantages of distance over overcurrent protection

Distance protection is comparatively simple to apply and it can be fast in operation for faults located along most of a protected circuit. It can also provide both primary and remote back-up functions in a single scheme. It can easily be adapted to create a unit protection scheme when applied with a signaling channel. In this form it is eminently suitable for application with high-speed auto-reclosing, for the protection of critical transmission lines [1].

3.1.2 Principles of distance relay:

Since the impedance of a transmission line is proportional to its length, for distance measurement it is appropriate to use a relay capable of measuring the impedance of a line up to a predetermined point (the reach point). Such a relay is described as a distance relay and is designed to operate only for faults occurring between the relay location and the selected reach point, thus giving discrimination for faults that may occur in different line sections.

The basic principle of distance protection involves the division of the voltage at the relaying point by the measured current. The apparent impedance so calculated is compared with the reach point impedance. If the measured impedance is less than the reach point impedance, it is assumed that a fault exists on the line between the relay and the reach point. The reach point of a relay is the point along the line impedance locus that is intersected by the boundary characteristic of the relay. Since this is dependent on the ratio of voltage and current and the phase angle between them, it may be plotted on an R/X diagram. The loci of power system impedances as seen by the relay during faults, power swings and load variations may be plotted on the same diagram and in this manner the performance of the relay in the presence of system faults and disturbances may be studied [1].

3.1.3 Relay performance:

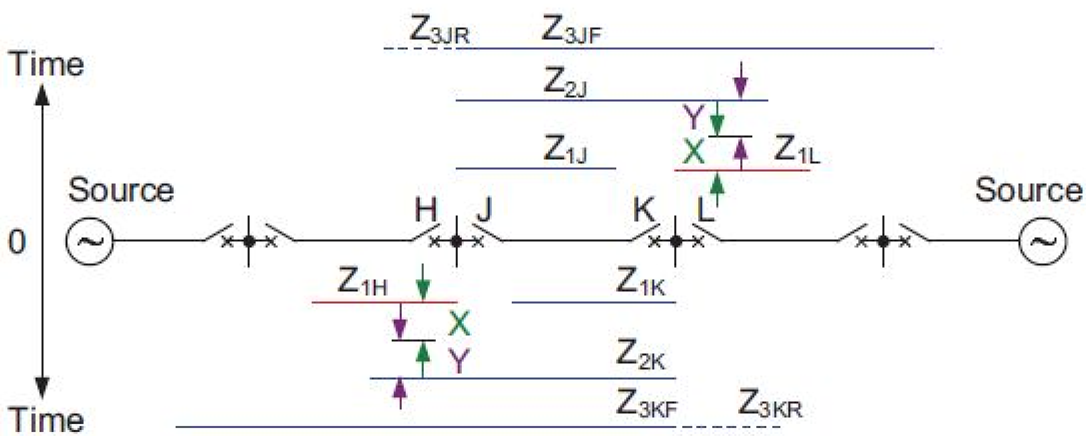
Distance relay performance is defined in terms of reach accuracy and operating time. Reach accuracy is a comparison of the actual ohmic reach of the relay under practical conditions with the relay setting value in ohms. Reach accuracy particularly depends on the level of voltage presented to the relay under fault conditions. The impedance measuring techniques employed in particular relay designs also have an impact. Operating times can vary with fault current, with fault position relative to the relay setting, and with the point on the voltage wave at which the fault occurs. Depending on the measuring techniques employed in a particular relay design, measuring signal transient errors, such as those produced by Capacitor Voltage Transformers or saturating CTs, can also adversely delay relay operation for faults close to the reach point. It is usual for electromechanical and static distance relays to claim both maximum and minimum operating times.

However, for modern digital or numerical distance relays, the variation between these is small over a wide range of system operating conditions and fault positions [1].

3.1.4 Zones of distance protection:

Careful selection of the reach settings and tripping times for the various zones of measurement enables correct coordination between distance relays on a power system. Basic distance protection will comprise instantaneous directional Zone 1 protection and one or more time-delayed zones.

Typical reach and time settings for 3-zones distance protection are shown in Figure 3.2. Digital and numerical distance relays may have up to five or six zones, some set to measure in the reverse direction [1].



Zone 1 = 80-85% of protected line impedance
Zone 2 (minimum) = 120% of protected line
Zone 2 (maximum) < Protected line + 50% of shortest second line
Zone 3F = 1.2 (protected line + longest second line)
Zone 3R = 20% of protected line
X = Circuit breaker tripping time
Y = Discriminating time

Figure 3.2: Typical time/distance characteristics for three zone distance protection

3.1.5 Distance relay characteristics:

A much more useful way of showing the operating characteristics of distance relay is by means of "Impedance diagram" or the "R-X diagram". The numerical value of the ratio V to I is shown as the length of a radius vector Z and the phase angle between V and I determines the position of the vector. Any value of Z less than the radius of the circle well result in the protection of a positive torque (Relay operate) and any value of Z greater than the radius of the circle will produce negative torque (Relay non operate) regardless of the phase angle V and I.

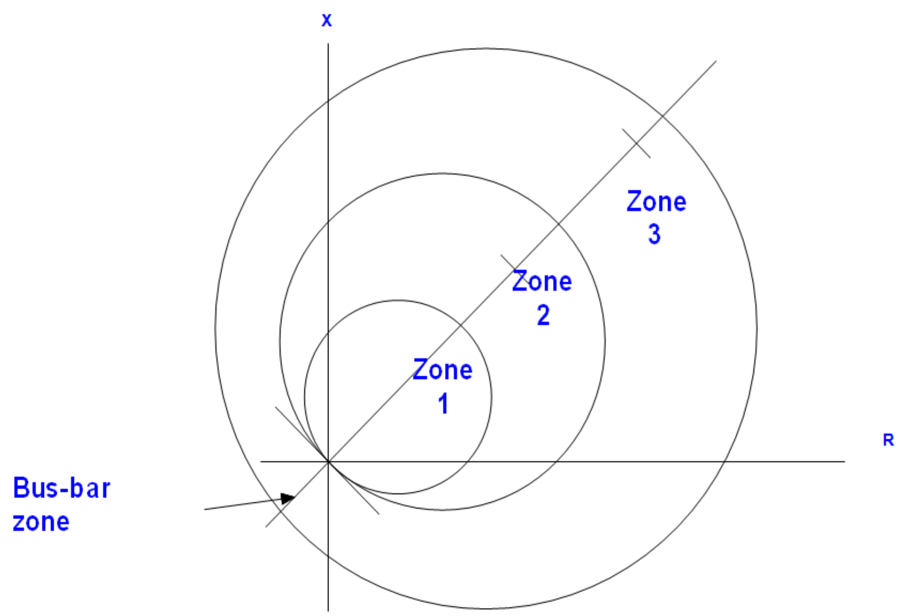


Figure 3.3: Plain impedance relay characteristic

3.1.6 Relationship between relay voltage and Z_S/Z_L ratio:

A single, generic, equivalent circuit, as shown in Figure 3.4, may represent any fault condition in a three-phase power system. The voltage V applied to the impedance loop is the open circuit voltage of the power system. Point R re presents the relay location; I_R and V_R are the current and voltage measured by the relay, respectively. The impedances Z_S and Z_L are described as source and line impedances because of their position with respect to the relay location. Source impedance Z_s is a measure of the fault level at the relaying point. For faults involving earth it is dependent on the method of system earthing behind the relaying point. Line impedance Z_L is a measure of the impedance of the protected section**.** The voltage V_R applied to the relay is $Z_{R*}Z_L$. For a fault at the reach point, this may be alternatively expressed in terms of source to line impedance ratio Z_s/Z_L using the following expressions:

$$V_R = I_R Z_L \quad (3.1)$$

Where:

$$I_R = \frac{V}{Z_S + Z_L}$$

Therefore:

$$V_R = \frac{Z_L}{Z_S + Z_L} V \quad (3.2)$$

Or

$$V_R = \frac{1}{\left(\frac{Z_S}{Z_L}\right) + 1} V \quad (3.3)$$

Voltage divider theory

Where:

Z_S = system source impedance behind the relay location

Z_L = line impedance equivalent to relay reach setting [1]

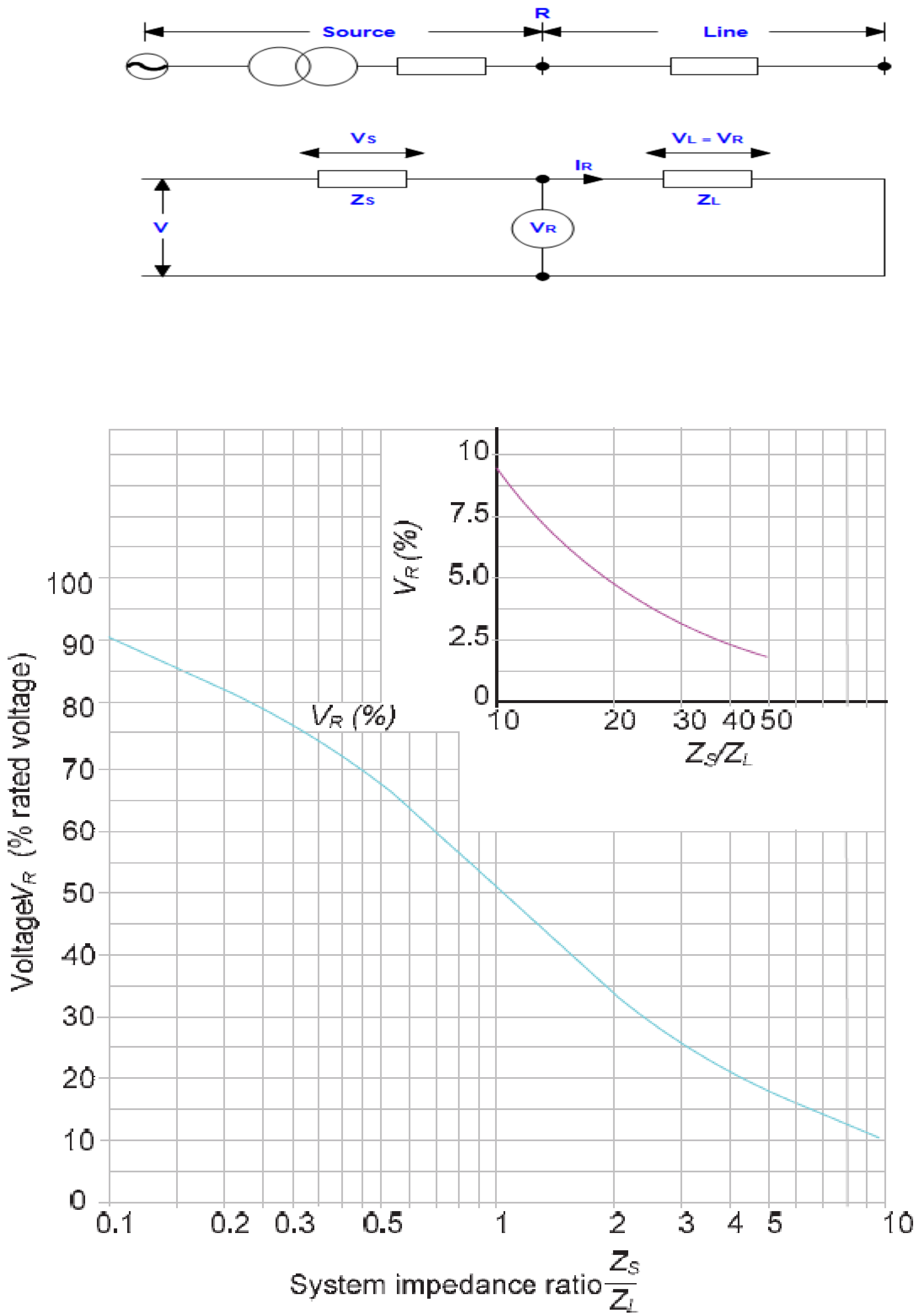


Figure 3.4: Relationship between source to line ratio and relay voltage

3.1.7 Distance relay application problems:

Distance relays may suffer from a number of difficulties in their application. Many of them have been overcome in the latest numerical relays. Nevertheless, an awareness of the problems is useful where a protection engineer has to deal with older relays that are already installed and not due for replacement [1].

3.1.7.1 Minimum voltage at relay terminals:

To attain their claimed accuracy, distance relays that do not employ voltage memory techniques require a minimum voltage at the relay terminals under fault conditions. This voltage should be declared in the data sheet for the relay.

With knowledge of the sequence impedances involved in the fault, or alternatively the fault MVA, the system voltage and the earthing arrangements, it is possible to calculate the minimum voltage at the relay terminals for a fault at the reach point of the relay. It is then only necessary to check that the minimum voltage for accurate reach measurement can be attained for a given application. Care should be taken that both phase and earth faults are considered [1].

3.1.7.2 Minimum length of line:

To determine the minimum length of line that can be protected by a distance relay, it is necessary to check first that any minimum voltage requirement of the relay for a fault at the Zone 1 reach is within the declared sensitivity for the relay. Secondly, the ohmic impedance of the line (referred if necessary to VT/CT secondary side quantities) must fall within the ohmic setting range for Zone 1 reach of the relay. For very short lines and especially for cable circuits, it may be found that the circuit impedance is less than the minimum setting range of the relay. In such cases, an alternative method of protection will be required. A suitable alternative might be current differential protection**,** as the line length will probably be short enough for the cost-effective provision of a high bandwidth communication link between the relays fitted at the ends of the protected circuit. However, the latest numerical distance relays have a very wide range of impedance setting ranges and good sensitivity with low levels of relaying voltage, so such problems are now rarely encountered. Application checks are still essential, though. When considering earth faults, particular care must be taken to ensure that the appropriate earth fault loop impedance is used in the calculation [1].

Transmission lines are sometimes classified as short, medium, and long. The IEEE Power and Engineering Society (PES) Power System Relaying Committee (PSRC) established the following criteria for line length in terms of the SIR [5]:

Short line: SIR > 4.0.

Medium line: 0.5 < SIR < 4.0.

Long line: SIR < 0.5.

Short line protection problems related to the high SIR value include low voltage at the relay location during faults and CCVT transients. Detecting high-resistance faults is another short line protection problem [2].

For a distance element, the main protection issue presented by a high SIR is the voltage measured at the relay for an out of- zone fault. If the SIR is high, the voltage will be small and measurement errors can dominate the reach calculation. Distance elements use a comparator that uses current and voltage. We can think of current as an operating quantity and voltage as a restraining quantity. Errors in measuring the voltage can result in reduced restraint and overreach.

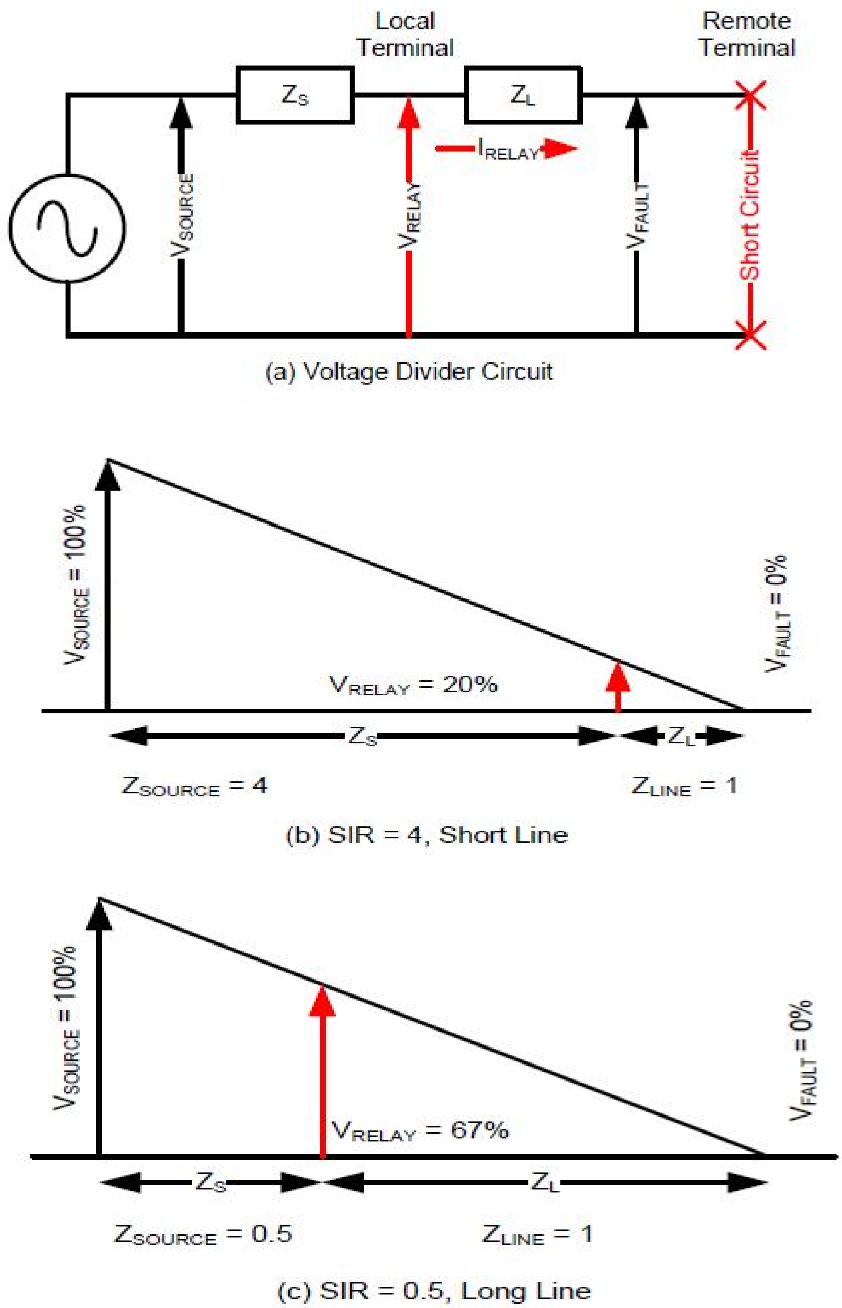


Figure 3.5: SIR as voltage divider circuit

It can be seen that for an SIR > 4, the voltage at the relay will be less than 20 percent nominal [4].

Let us look at a Zone 1 under-reaching element on an SIR = 4 line. The element is set with a typical margin of 80 percent of the line impedance. With instrument transformer errors and relay measurement errors, can the relay differentiate between a fault at the reach point and one at the remote bus? In this example, the nominal line-to-neutral voltage is 66.4 V. For an out-of-zone fault, assuming no fault resistance, the ideal secondary voltage at the relay would be 13.28 V. For the same fault at the Zone 1 reach point, the ideal voltage at the relay would be 11.07 V. This gives us a difference of 2.21 V between a fault at the reach point and an out-of-zone fault.

The big question now is, "What is the accuracy of the voltage transformer (VT) and the protective relay?" A typical capacitor-coupled voltage transformer (CVT) used for protection has an accuracy of at least 1 percent (steady state) and a transient response of less than 10 percent in the first cycle. Protective relays typically have a transient accuracy error of 5 percent or less. If we now add these errors quadratically, we obtain an overall measurement error of 11.2 percent. So the voltage for a fault at the remote bus with error could be as great as 13.28 V • 11.2% = 1.49 V, which is 67 percent of the voltage difference of 2.21 V. This results in the relay having trouble differentiating between an in-zone and out-of-zone fault [4].

3.1.8 Calculate of system impedance ratio SIR:

There are a number of ways that the source impedance SIR can be defined such as Thévenin Equivalent Impedance, Alternative Method and Recommended Method. This search has been used Recommended Method to Calculate SIR. The recommended method to calculate the source impedance (Z_S) for the purpose of classifying line length is to place a short circuit at the remote bus. This is the boundary of the line zone and the point that we do not want to overreach. Thus, it represents a realistic condition that the relay will see in service. The source impedance is calculated as the voltage drop from the local source to the relay location divided by the fault current in the relay.

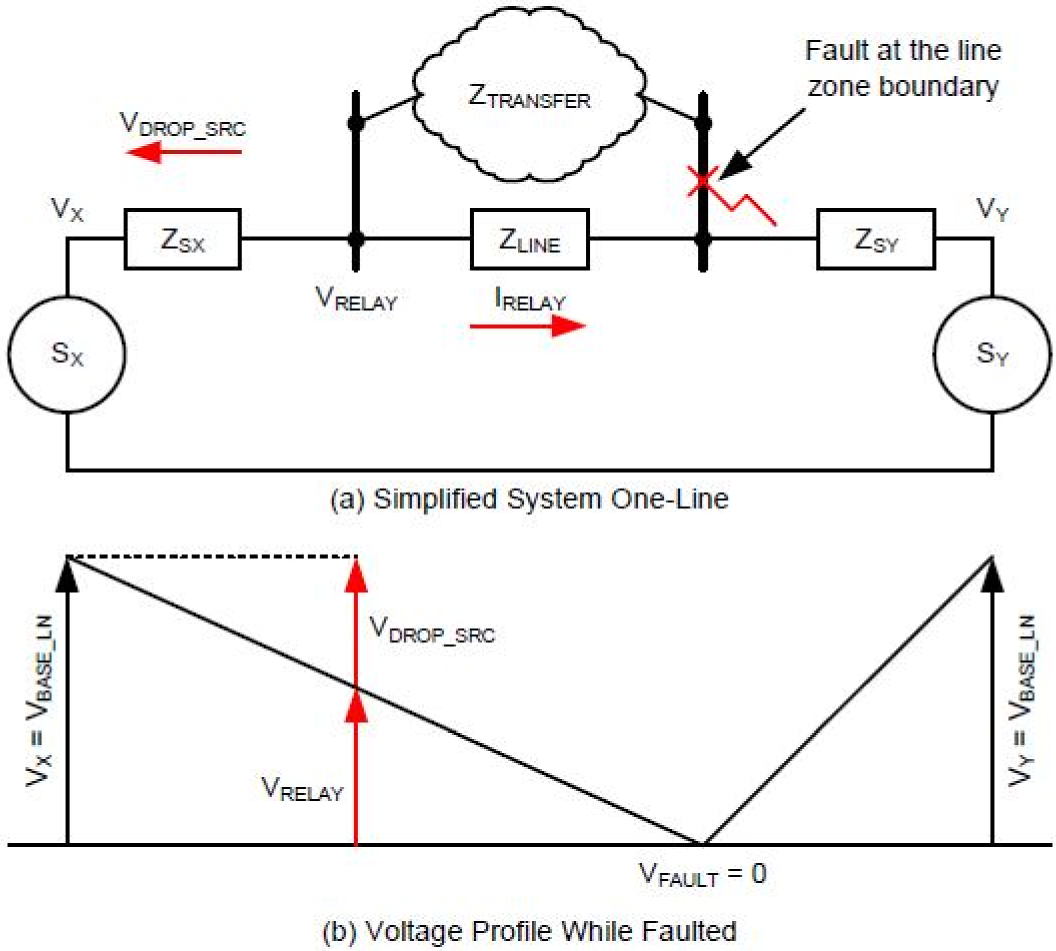


Figure 3.6: Calculating ZS Using the Voltage Drop Across the Local Source Impedance

Use equations (3.4) and (3.5) to calculate the source impedances for the phase and ground fault loops, respectively.

$$Z_{S-3PH} = \frac{V_{DROP-SRC}}{I_{RELAY}} = \frac{V_{BASE-LN} - V_{RELAY}}{I_{RELAY}} \tag{3.4}$$

$$Z_{S-LG} = \frac{V_{DROP-SRC}}{I_{RELAY}} = \frac{V_{BASE-LN} - V_{RELAY}}{I_{RELAY} + (3I0_{RELAY*K0})} \tag{3.5}$$

Where:

$V_{BASE-LN}$ Is the system base voltage, phase-to-ground, which defines the voltage at the perfect source in primary units.

V_{RELAY} Is the phase-to-ground voltage at the relay for a fault at the remote bus in primary units.

I_{RELAY} Is the phase current at the relay for a fault at the remote bus in primary units.

$3IO_{RELAY}$ Is the zero-sequence current at the relay for a single-line-to-ground fault at the remote bus in primary units. K_0 Is the zero-sequence compensation factor for the line as defined by (3.6).

$$K0 = \frac{Z0_L - Z1_L}{3 * Z1_L} \tag{3.6}$$

Where:

Z_{1L} Is the positive-sequence line impedance.

Z_{0L} Is the zero-sequence line impedance [4].

3.2 Line Differential Protection:

Differential protection principally operates based on Kirchhoff current laws. The line differential protection relays also detect the leakage currents that will occur on the line according to this law. The currents entering a node are positive, and the currents leaving the node are negative. Here the node point is the protection element and the protected element is the transmission lines [3].

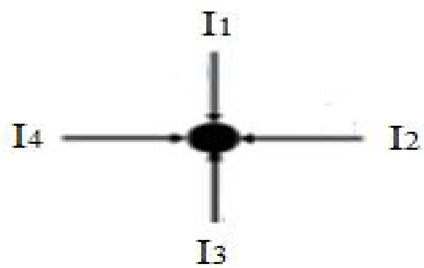


Figure 3.7: The currents entering a node

As shown in Fig. 3.7, the currents entering a node are positive, and the currents leaving the node are negative. Here the node point is the protection element and the protected element is the transmission lines.

3.2.1 Internal and external faults:

Behavior of the relay is observed in the protected area and out of the protected area in Fig. 3.8.

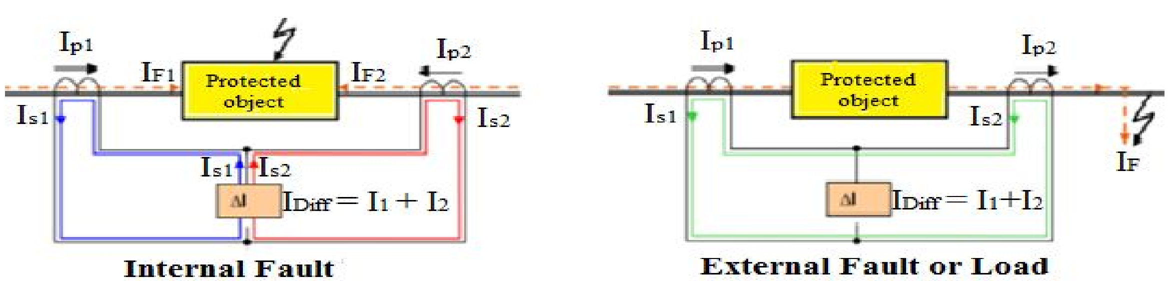


Figure 3.8: Internal and external faults and load

If the current transformer ratio (CT ratio) is assumed to be 1:1 in order to simplify the operations, while a fault occurs in the protected area: i.e. the transmission line [3].

3.2.2 Relay communication and protection zone:

As shown in Fig. 3.9, the protection zone is the area between the current transformers connected to relevant relays at both ends.

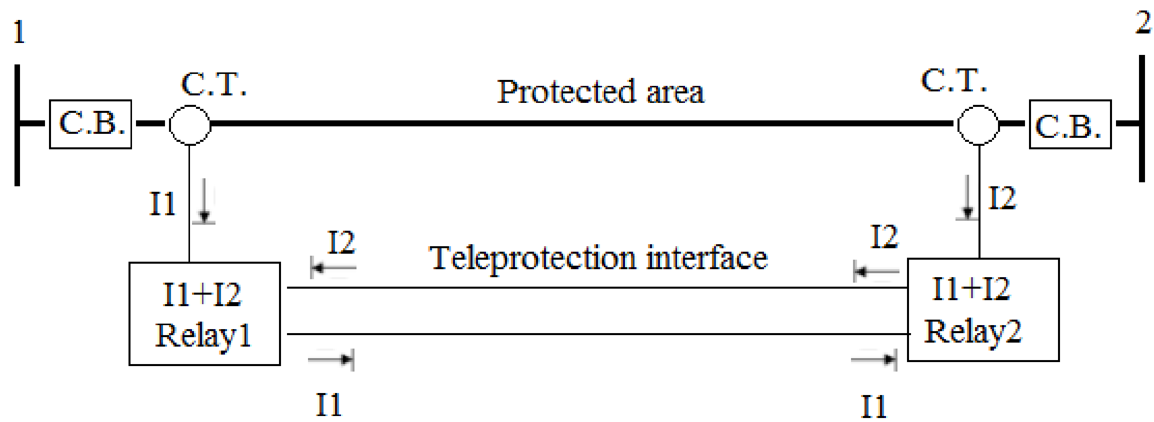


Figure 3.9: Protected area and teleprotection interface

Line differential protection is not possible with a single relay since there exists distance in the protected zone. Two relays located at the two ends provide instant communication and information sharing. The communication system between two relays is called teleprotection communication. Both relays simultaneously send current values to the other one and both relays measure the differential current. At the moment of failure, when the relay sees the differential current, it sends trip to its own circuit breaker and the circuit breaker of the remote end. Both relays actually work like a single relay [3].

3.2.3 Differential protection tripping characteristic:

While everything is clear in theory, there are some uncertainties in terms of conditions in practice. Even in the case of normal operation, differential currents can occur. 1 Differential current due to line capacity. 2 Differential current due to linear errors of current transformers. 3 Differential current due to nonlinear fault of current transformers. These three conditions that can occur in the system have an effect on the opening characteristic. This can be seen in Figure 3.10 below.

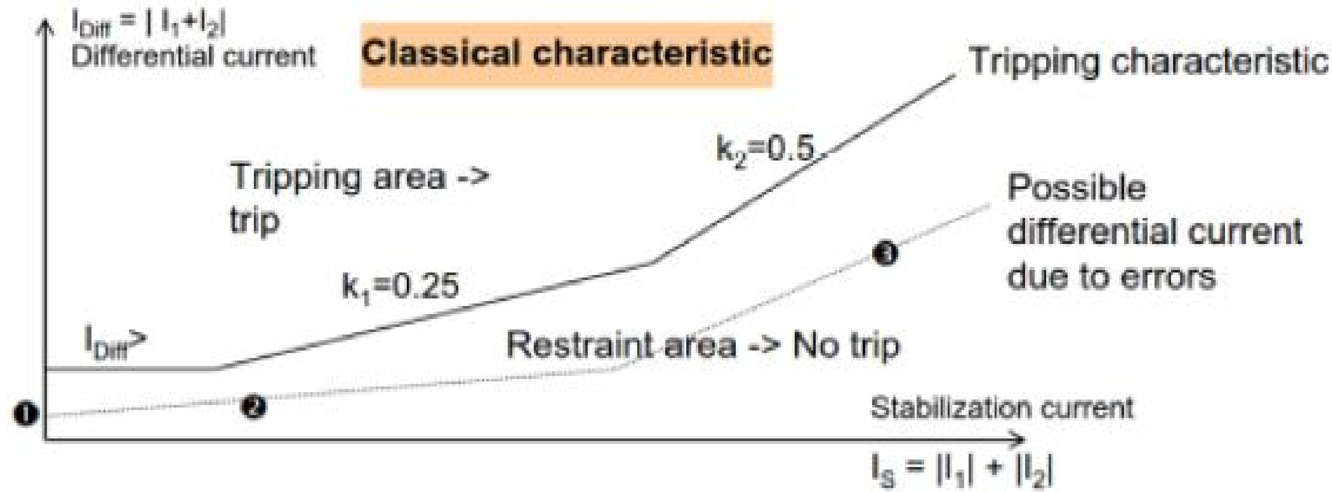


Figure 3.10: Line Differential Relay tripping characteristic

As the current values (Is, stabilization current) increase, the error margin increases. With this in mind, unwanted tripping is prevented. A graph is created by adjusting $K_1$and K_2 values and the slope between the tripping area and restraint area.

A failure in the system will cause the differential current value to increase too much, so the operating area enters the tripping area and the relay clears the fault from the system by sending a trip to the circuit breaker without delay [3].

CHPTER FOUR

RESLTS AND DISCUSSION

4.1 Introduction:

Historically Alshugura and Kilo-X substations (Sudanese National Grid) was connected though transmission line. After growth area of local market, own substation was established between Alshugura and Kilo-X, therefore the transmission line has been connect between Alshugura substation and Local Market substation (5.3Km Short Line), and from Local Market substation to Kilo-x substation.

Kilo-X substation (Sudanese National Grid) is fully loaded substation therefore Local Market substation has fed only from Alshugura substation and it becomes radial substation (terminal substation). Although the change has been made with new substation, line protection between ALSHAJRA and Local Market substations has remained distance protection.

4.2 Alshugura and Local Market Transmission Line Data:

Length = 5.3Km

Conductor type &Size = 2*240$mm^2 ACSR$

Nominal voltage = 110 KV

R_1 = 0.067 Ω/Km

X_1 = 0.269 Ω/Km

R_0 = 0.262 Ω/Km

X_0 = 1.044 Ω/Km

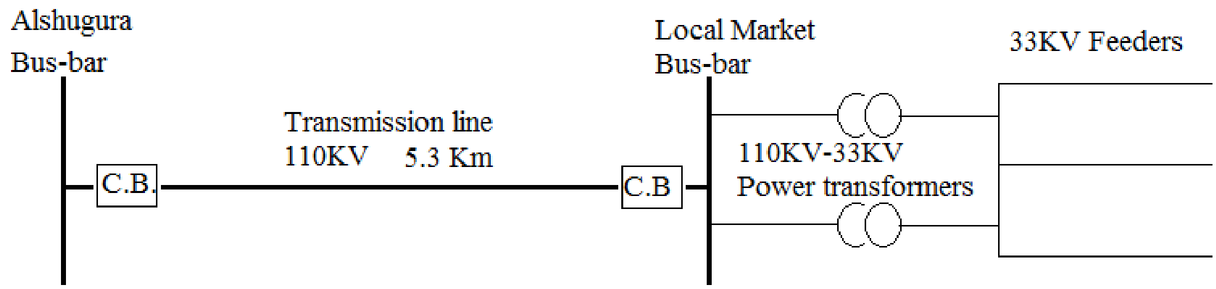


Figure 4.1: Alshugura and Local Market transmission line Data

4.3 Classification the Length of Transmission Line between Alshugura and Local Market Substations:

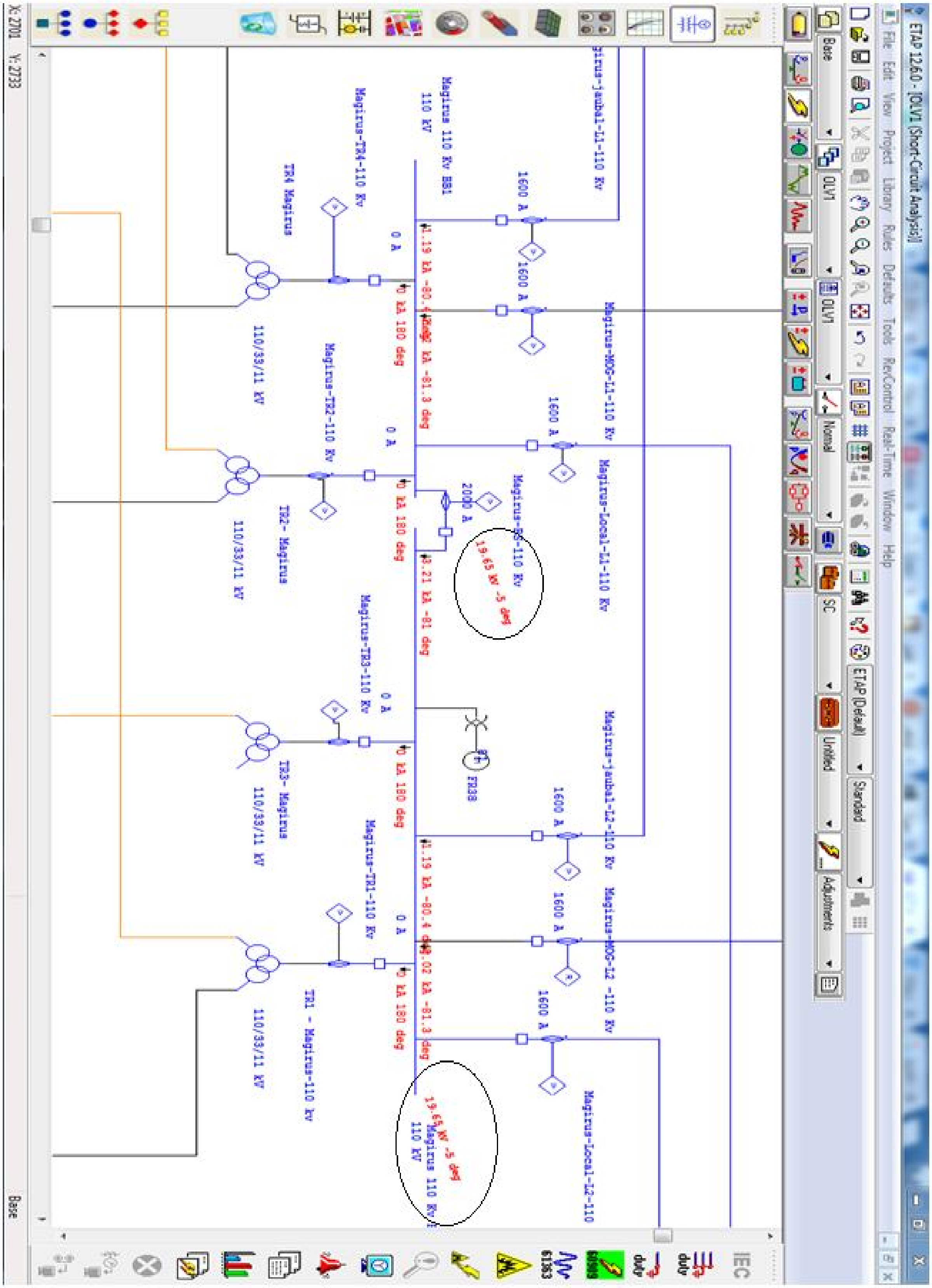
Classifying the length of a line is an important step in determining the transmission line protection philosophy and relay settings. The length of a line can be defined by physical distance, impedance, or its source impedance ratio (SIR). The SIR is the ratio of the source impedance Z_S, to the line impedance Z_L.

From discussions for chapter three, we can see why using SIR to define line length for the purpose of setting relays is appropriate. However, this can complicate matters for the relay setting engineer. It can be somewhat confusing when a line is short from one terminal and medium or long from the other terminal. This can happen when one terminal is connected to a strong bus and the other is connected to a weak bus. To further complicate matters, the positive- and zero sequence source impedances can vary considerably, such that a line could be short for ground faults and medium or long for phase faults, and vice-versa. It is also not unusual to find a line that is medium or long for system normal conditions, but short under N – 1 conditions, with the strongest source behind the line terminal out of service. The important message here is that it is necessary to calculate the SIR of the line being worked on at the start of performing setting calculations. In addition, it is recommended to calculate the SIR under system normal and under N-1 conditions to make the engineer aware of how system topology changes can affect protective elements [4].

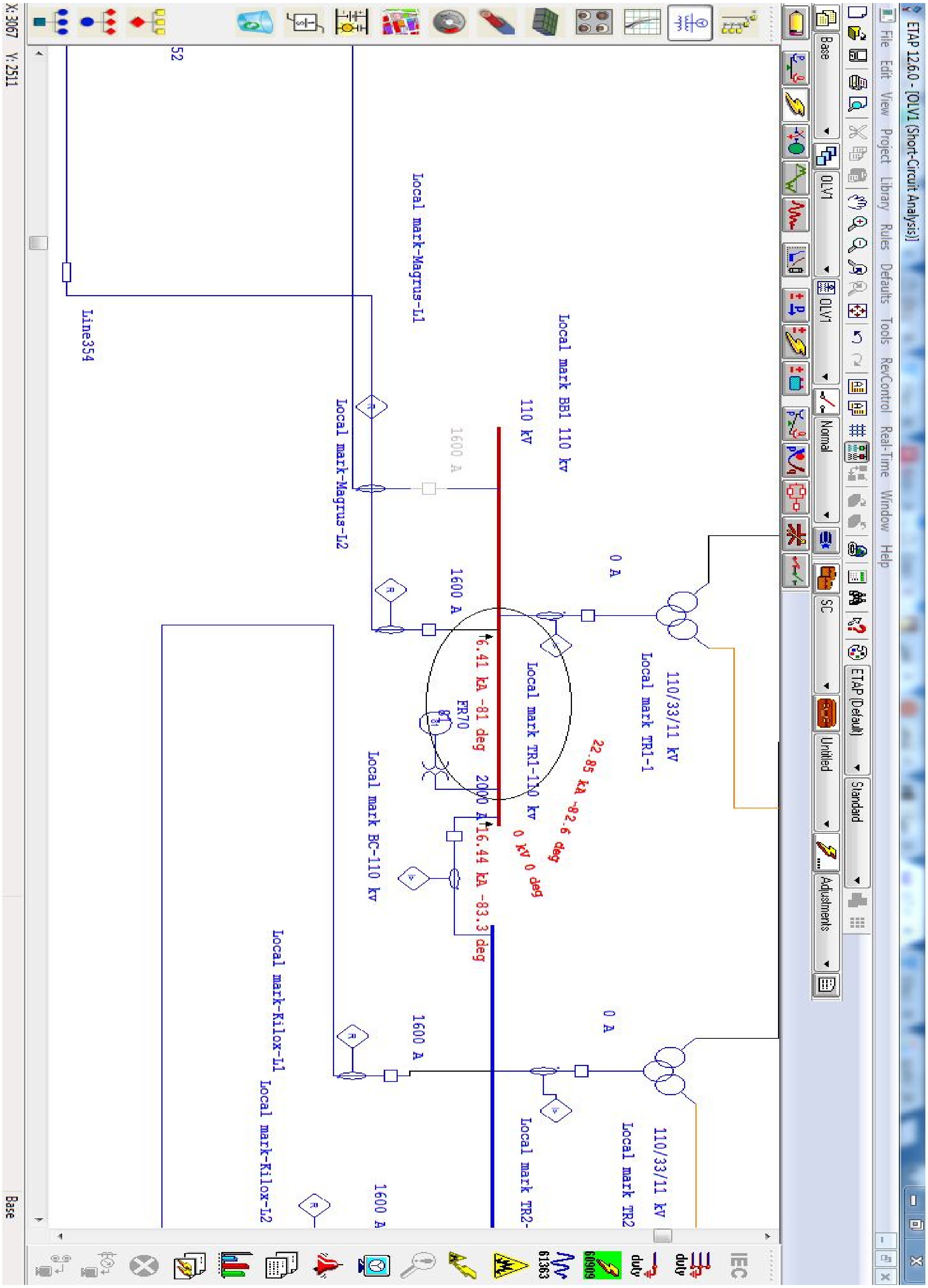
4.4 The Result:

According to IEEE Power and Engineering Society (PES) Power System Relaying Committee (PSRC), transmission line classified as short line when system impedance ratio (SIR) at the beginning of the transmission line is equal or more than 4 [5].

Right now we will calculate SIR of Transmission Line between Alshugura and Local Market Substations by used a Recommended Method (Back to page 29). Firstly we must define values of $V_{BASE-LN}$, V_{RELAY} and I_{RELAY} from ETAP program.



ETAP 12.6.0 - [OLV1 (Short-Circuit Analysis)]
Magirus 110 Kv BB1
110 kV
Magirus-MOG-L1-110 Kv
Magirus-Local-L1-110 Kv
Magirus-jaubal-L2-110 Kv
Magirus-MOG-L2 -110 Kv
Magirus-Local-L2-110
Magirus-TR4-110 Kv
Magirus-TR2-110 Kv
Magirus-TR3-110 Kv
Magirus-TR1-110 Kv
TR4 Magirus
TR2- Magirus
TR3- Magirus
TR1 - Magirus-110 kv
110/33/11 kV
Magirus 110 Kv
1600 A
2000 A
0 A
0 kA 180 deg
19.65 kV -5 deg
FR38



ETAP 12.6.0 - [OLV1 (Short-Circuit Analysis)]
File Edit View Project Library Rules Defaults Tools RevControl Real-Time Window Help
Local mark BB1 110 kv
110 kV
1600 A
0 A
110/33/11 kV
Local mark TR1-1
Local mark TR1-110 kv
22.85 kA -82.6 deg
0 kV 0 deg
6.41 kA -81 deg
2000 A
16.44 kA -83.3 deg
ER70
Local mark-Magrus-L1
Local mark-Magrus-L2
Local mark BC-110 kv
Line354
Local mark-Kilox-L1
Local mark-Kilox-L2
110/33/11 kV
Local mark TR2
Local mark TR2-
X: 3067 Y: 2511

Though used ETAB program found that

$V_{BASE-LN}$ = $110KV/\sqrt{3}$ = 63.5 KV

V_{RELAY} = 19.56 KV

I_{RELAY} = 6.41 KV

$$Z_{S-3PH} = \frac{V_{DROP-SRC}}{I_{RELAY}} = \frac{V_{BASE-LN} - V_{RELAY}}{I_{RELAY}}$$

$$Z_{S-3PH} = \frac{63.5-19.56}{6.41} = 6.87\ \Omega$$

$$Z_L = (R1 + jX1)\ \Omega/Km \times Length \quad (4.1)$$

Z_L = (0.067+J0.269) × 5.3 = 1.469 Ω

Then:

$$SIR = \frac{Z_S}{Z_L}$$

$$SIR = \frac{6.87}{1.469} = 4.68$$

4.5 DISCUSSION:

The SIR ratio of transmission line between Alshugura and Local Market substations is more than 4; therefore transmission line is short line. Short line protection problems related to the high SIR value include low voltage at Alshugura's relay location during faults. If the output voltage is momentarily lower than the true value, the relay may overreach and trip for faults beyond the steady state reach setting.

Since the transmission line was short line, distance protection scheme is not suitable to protect the transmission line between Alshugura & Local Market. The transmission line would protect by line differential Technique.

Line differential protection schemes do not require voltage information, thereby avoiding problems for out zone operation (over reach), close-in faults, blown potential fuses, Ferro-resonance in VTs, transients in CVTs, and voltage inversion. However, line differential elements may require voltage information to calculate the line charging current in applications for long lines or cables.

Sudanese grid contains fiber optic that connects between each substation and other, this makes it easy to transmit current data between the two relays.

CHAPTER FIVE

CONCULOTION AND RECOMMENDATION

5.1 Conclusion:

The objective of this research is to discuss the cause of overreach problem in protection scheme of transmission line between Alshugura and Local Market substations (Sudanese National Grid), and to design alternative protection scheme for this transmission line instead of the old protection scheme (distance relay).

First of all literature studies on both distance protection scheme and its shortcoming have been revised. And then determine the cause of the problem from distance protection scheme shortcoming and match them with the case study.

Overreach problem in distance protection scheme related to shortness of transmission line include high SIR ratio which include low voltage at the relay during faults. Low voltage makes an error in V.T measurement there for makes an error in distance relay impedance measurement

We proposed line differential protection scheme as alternative method to protect short transmission line. Thus solve problem of overreach in distance relay.

5.2 Recommendations:

- In the case of new transmission lines, we recommend calculate a value of SIR to define line length for the purpose of selecting a suitable line protection schemes.
- For long transmission lines, line differential protection is unhelpful because; Lines will often be longer, and hence have higher charging current.
- High-speed backup distance protection elements may be brought into service automatically, in instances where signaling channel failure has been detected.
- There are other alternative methods that apply in the protection of short transmission lines rather than line differential scheme such as PILOT-WIRE scheme, we recommend comparing them with regard to speed, safety, economics, and added back-up protection necessary.

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