Study of Impedance Relay

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***Abstract*— With the Increase in line lengths, power transmitted introduced a number of new problems in relation to protection. New methods have become necessary to handle such problem. Firstly important to see these lines are not unnecessarily disconnected, at the same time shorter operating times for protective relays are demanded on faulted section sections to preserve stability. Moreover, extreme variations of fault current are often encountered with long lines necessitating the protective relays to take this aspect. Two major types of transmission line protection been developed extensively to meet requirements are distance and carrier current systems. Pilot wire system of protection is not applicable to long and overhead transmission lines because of high cost of pilots and unreliability. Transmission line demo panel is designed to demonstrate fault clearing process on transmission line using distance (impedance) relay. The principle of operation of these relays depends on fault current and power factor under fault conditions. As a matter of fact such relays are designed to operate according to impedance of line up to fault point or ratio of voltage to current under fault condition. As fault impedance is proportional to distance of line from location of relay to fault point, relay indicates distance over which fault has occurred.**

***Index Terms*— Transmission lines protection ,line lengths and power transmission ,protective relays, fault current , power factors, distance relay, protective relays, fault simulation, distance and carrier current systems.**

I. INTRODUCTION

As the demand of electrical power grows, power systems become complex and difficult to manage. An essential property of any complex system is that it must continue to operate satisfactorily, when a part of the system is subjected to random disturbance. A major objective of an electricity supply authority is to maintain continuity of supply to its customers which can be achieved by installing protection equipment capable of high speed, selective isolation of faulted sections of the power system. Rapid clearance reduces the effect of system disturbance and provides maximum safety to the equipment and to people who may be in the vicinity of the fault. Protective relays must be capable of discriminating between healthy and faulted sections of the network, so that disruption of power supplies is kept to a minimum. When a fault occurs on a transmission line, it is necessary to identify the location of the fault in order to trip circuit-breakers at each end of the faulted line section, and thus isolate that section from the power system. The fault location is determined by measurement of impedance of the faulted conductors between the relaying location and fault. In absence of fault resistance, this impedance is directly proportional to corresponding "distance" from relay location to fault location.

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All electric power systems constitute certain basic components such as generating stations, transformers, transmission lines and motors. The function of protective relay is to affect disconnection of any faulty section of the power system from service. A fault is said to have occurred in a section when it starts behaving in an abnormal manner due to any reason. This may cause damage to the equipment or otherwise endanger the effective and healthy operation of the system. A protective relay senses the abnormal condition and the task of isolation of the faulty section are achieved through a circuit breaking device which is capable of disconnecting the faulty element.

With the evolution of technology, there has been a continuous development in the design of protective relays. The use of microprocessors for achieving various relay functions is one of the most notable advancements that has taken place. The use of computers has imparted enormous flexibility in designing the required protective features in the relay. In order to ensure the smooth functioning of any modern power system, the provision of protective relays is a must. Like all other constituents of the power system, protective relaying should also be evaluated on the basis of its contribution to the best economically possible service to the customers. By prompt sensing and removal of the faulty section, the effects of the following undesirable situations, which adversely affect the overall economy of power system operation, are minimised.

1. The cost of restoring the damaged section.
2. The chances of the fault spreading and subsequent damage.
3. The down-time of the equipment.
4. The loss in revenue and the strained public relations due to equipment outage.

II. IMPORTANCE OF PROTECTIVE RELAYING

Inadequate protection lead to major fault that could have been avoided, e.g. thermal overload protection of motor prevents overloading of motor and thereby insulation failure is avoided. Damaged equipment needs time for repairs and maintenance. By adequate protection, damage can be eliminated or minimized. A fault in equipment in supply system leads to disconnection of supply to a large portion of the system. If the faulty part is disconnected, damage caused by the fault is minimum and the faulty part can be repaired quickly and the service can be restored without further delay. Better service continuity has its own merits. Thus the protective relaying helps in improving service continuity and its importance is self-evident.

A. RELAY

"An electrical relay is a device designed to produce sudden, pre-determined changes in one or more electrical output circuits, when certain conditions are fulfilled in electrical input circuits controlling device."

Protective relaying is necessary with almost every electrical plant, and no part of power system is left unprotected. The choice of protection depends upon several aspects such as type and rating of protected equipment, it importance, location, probable abnormal conditions, cost, etc .Between generators and final load points, there are several electrical equipments and machines of various ratings. Some faults keep occurring on these equipments due to various abnormal conditions, thus relays are used for protection purpose.

Protective relays sense abnormal conditions in a part of power system where fault occurs and gives an alarm or isolates that faulty part from the healthy system. Relays are compact, self contained devices which respond to abnormal conditions. Relays distinguish between normal and abnormal conditions. Whenever an abnormal condition develops(shown in fig.1),relay closes its contacts. Thereby trip circuit of circuit breaker is closed and faulty part is disconnected.

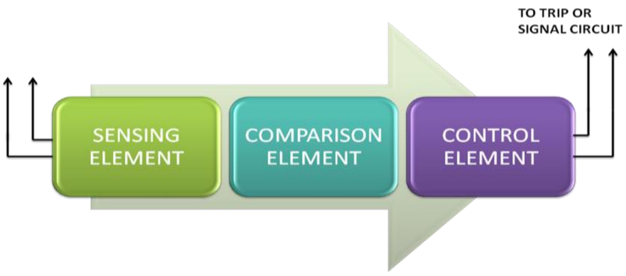

Fig1. Relay Mechanism

B. THE FUNCTIONS OF PROTECTIVE RELAY:

- To sound an alarm or to close trip circuit of circuit breaker so as to disconnect a component during an abnormal condition in the component.
- To disconnect abnormally operating part so as to prevent subsequent faults.
- To disconnect faulty part quickly so as to minimize the damage to the faulty part.
- To localise effect of fault by disconnecting faulty part from the healthy part, causing least disturbance to healthy system.
- To disconnect the faulty part quickly so as to improve system stability, service continuity and system performance.

Faults cannot be avoided completely but can be minimized. Protective relaying plays a vital role in minimizing faults and also in minimizing damage in event of faults.

C. DESIRABLE QUALITIES OF PROTECTIVE RELAYING

Protective relaying should have certain qualities as follows,

1. **SELECTIVITY, DISCRIMINATION:** ability to correctly locate and classify fault. A relay should be able to discriminate whether fault is in its control or not. This control of a relay is called zone of protection.
1. **SENSITIVITY:** Minimum level of fault current at which relay operation takes place decides sensitivity of system, expressed in apparent power VA.
2. **RELIABILITY:** Ability to 'not to fail' in its function.
   - % Reliability = (No. of correct trips)/ (No. of desired trips) × 100
   - % Reliability should not be less than 95%.
3. **ADEQUATENESS:** adequateness of protection is judged by considering following aspects--Rating of protected machine; Location of protected machine; Probability of abnormal condition due to internal and external causes; Cost of machine; Continuity of supply as affected by failure of machine.
4. **FAST OPERATION: O**perating time of relay is usually one cycle.
5. **STABILITY**: Stability is used to characterize false tripping.

D. TYPES OF RELAYS:

Although all varieties of the protective relays aim to achieve the same functions as described above, these can be grouped into the following three distinct generations shown in fig.2:

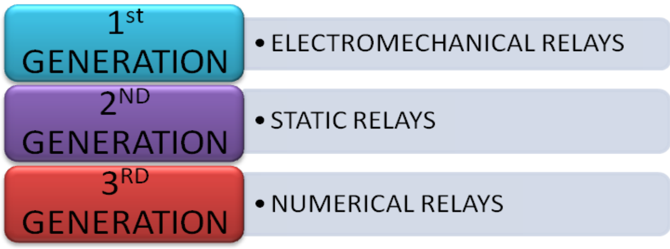

Fig2. Types of relays

III. PRINCIPLE OPERATION OF DISTANCE RELAY

Since impedance of transmission line is proportional to its length, for distance measurement it is appropriate to use a relay capable of measuring impedance of a line up to predetermined point (the reach point).Such a relay is described as a distance relay and is designed to operate only for faults occurring between relay location and selected reach point, thus giving discrimination for faults that may occur in different line sections. Basic principle as illustrated in figure 3, involves division of voltage at relaying point by measured current. The apparent impedance is compared with reach point impedance. If measured impedance is less than reach point impedance, it is assumed that a fault exists on line between relay and reach point. The reach point of relay is point along line impedance locus that is intersected by boundary characteristics of relay. Distance relay is broader name of the different types of impedance relay.

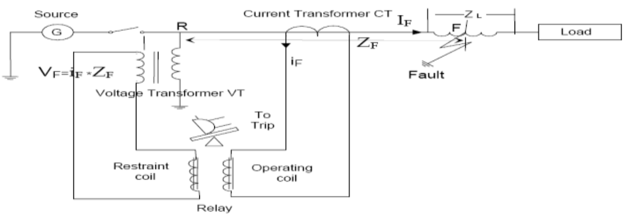

Fig.3 Principle of operation of distance relay

Relay is connected at position, R and receives a secondary current, i_F, equivalent to primary fault current, I_F. The secondary voltage, V_F, is equivalent to product of fault current "I_F" and impedance of line up to point of fault, Z_F. The operating torque of this relay is proportional to fault current "I_F", and its restraining torque is proportional to voltage "V_F". Taking into account the number of turns of each coil, there will be definite ratio of V/I at which torque will be equal. This is the reach point setting of the relay. The relay will operate when the operating torque is greater than restraining torque. Thus any increase in current coil ampere-turns, without a corresponding increase in voltage coil ampere-turns, will unbalance relay. This means V/I ratio has fallen below reach point. Alternatively if restrain torque is greater than operating torque, relay will restrain and its contacts will remain open. In this case V/I ratio is above the reach point. The reach of a relay is distance from relaying point to point of fault. Voltage on primary of voltage transformer, VT, is:

$V = EZ_F / (Z_S+Z_F)$
The fault current,
$I_F = E / (Z_S+Z_F)$
The relay compares secondary values of V and I, as to measure their ratio which is an impedance Z_m.

A. OPERATING CHARACTERISTIC OF IMPEDANCE RELAY

The operating characteristic of impedance relay in terms of voltage and current is shown in Fig.4, where effect of control spring is shown as causing noticeable bend in characteristic only at low-current end. For all practical purposes, the dashed line, represents a constant value of Z, may be considered the operating characteristic. The relay will pick up for any combination of V and I represented by point above the characteristic in positive-torque region, or, in other words, for any value of Z less than constant value represented by operating characteristic. By adjustment, slope of operating characteristic can be changed so that relay will respond to all values of impedance less than any desired upper limit.

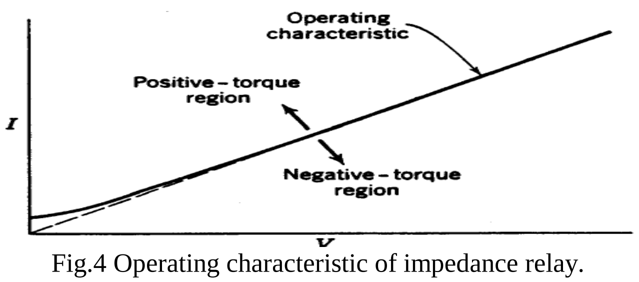

Fig.4 Operating characteristic of impedance relay.

A more useful way of showing operating characteristic of distance relays is by means so-called "impedance diagram" or "R-X diagram." Operating characteristic of impedance relay, neglecting control-spring effect, is shown in Fig.5 on this type of diagram. The numerical value of ratio of V to I is shown as the length of a radius vector, such as Z, and phase angle q between V and I determines position of vector, as shown. If I is in phase with V, the vector lies along the +R axis; but, if I is 180 degrees out of phase with V, vector lies along the -R axis.

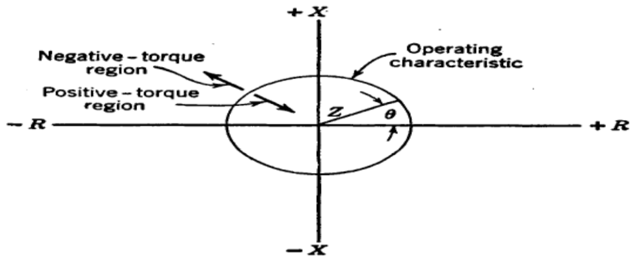

Fig.5 Operating characteristic of an impedance relay on the R-X diagram

If I lags V, vector has a +X component; and, if I leads V, vector has a -X component. Since operation of impedance relay is practically or actually independent of phase angle between V and I, operating characteristic is a circle with its center at origin. Any value of Z less than radius of circle will result in production of positive torque, and any value of Z greater than this radius will result in negative torque, regardless of phase angle between V and I.
At very low currents where operating characteristic of Fig.6 departs from a straight line because of the control spring, effect on Fig.5 is to make radius of circle smaller. This does not have any practical significance, however, since proper application of such relays rarely if ever depends on operation at such low currents. Although impedance relays with inherent time delay are encountered occasionally, we shall consider only high-speed type. The operating-time characteristic of a high-speed impedance relay is shown qualitatively in Fig.6. The curve shown is for a particular value of current magnitude. Curves for higher currents will lie under this curve, and curves for lower currents will lie above it.

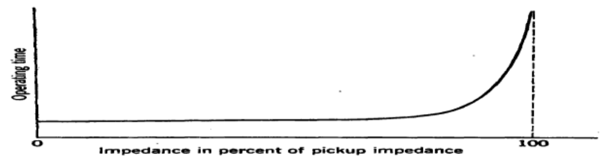

Fig.6 Operating-time-versus-impedance characteristic of a high-speed relay for one value of current.

In general, however, operating times for currents usually encountered in normal applications of distance relays are so short as to be within the definition of high speed, and variations with current are neglected. In fact, even increase in time as impedance approaches pickup value is often neglected, and time curve is shown simply as in Fig.7

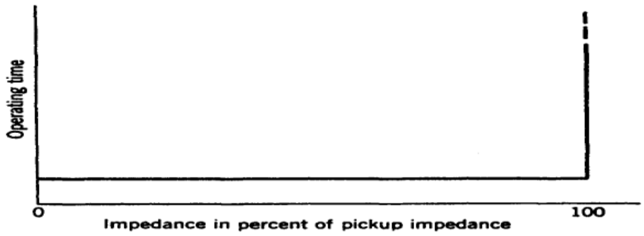

Fig. 7 Simplified representation of Fig.6

Various types of actuating structure are used in construction of impedance relays. Inverse-time relays use shaded-pole or watt-metric structures. High-speed relays may use a balance-beam magnetic-attraction structure or an induction-cup or double-loop structure.

B. TYPES OF DISTANCE RELAYS

(1) Impedance relay
(2) Reactance relay
(3) Mho relay
(4) Modified impedance relay

IV. ZONES OF PROTECTION

Distance relays are set basis of positive-sequence impedance from relay location up to point on line to be protected. Normally, three protection zones (fig. 8) in direction of fault are used in order to cover a section of line and to provide back-up protection to remote sections. Some relays have one or two additional zones in direction of fault plus another in opposite sense, the latter acting as a back-up to protect the bus bars. In majority of cases the setting of the reach of three main protection zones is made accordance with following criteria:
Zone 1: This is set to cover between 80 and 85 per cent of the length of the protected line;
Zone 2: This is set to cover all the protected line plus 50 per cent of the shortest next line
Zone 3: This is set to cover all the protected line plus 100 per cent of the second longest line, plus 25 per cent of the shortest next line.

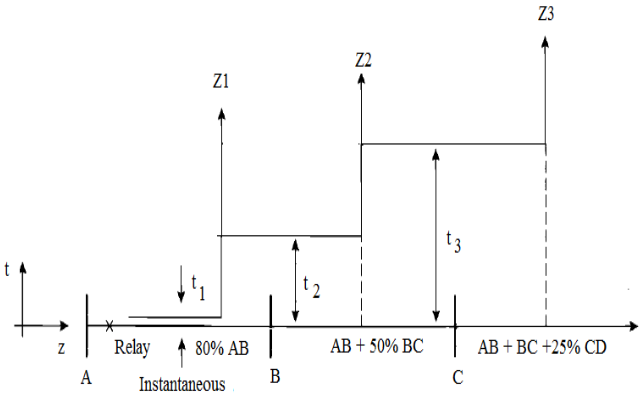

Fig.8. Distance relay protection zones

In addition to unit for setting the reach, each zone unit has a timer unit. The operating time for zone 1, t1, is normally set by manufacturer to trip instantaneously since any fault on protected line detected by zone 1 unit should be cleared immediately without need to wait for any other device to operate. Operating time for zone 2 is usually of order of 0.25 to 0.4 s, and that of zone 3 is in range of 0.6 to 1.0 s. In the case of zone 3, when the settings of relays at different locations overlap, then timer for zone 3 of furthest relay should be increased by at least 0.2 s to avoid incorrect co-ordination. However, operating time for zone 3 unit should also be set at a value which ensures that system stability is maintained and, if necessary, consideration may have to be given for reduce zone 3 operating time in such circumstances. Since tripping signal produced by zone 1 is instantaneous, it should not reach as far as bus bar at the end of first line so it is set to cover only 80-85 per cent of protected line. The remaining 20-15 percent provides a factor of safety in order to mitigate against errors introduced by measurement transformers and line impedance calculations. The 20-15 per cent to end of line is protected by zone 2, which operates in t2 seconds. Zone 3 provides the back-up and operates with a delay of t3 seconds. Since the reach and therefore operating time of distance relays are fixed, their co-ordination is much easier than that for over current relays.

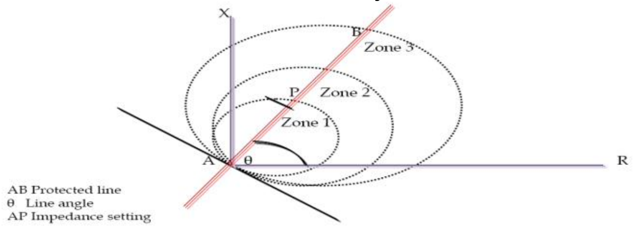

Fig.9Typical three zones distance protection

It is clear from fig.9 that operating time of relay is not the only factor to be considered while selecting a distance protection for real-world transmission line applications .The setting of distance relays should ensure that they are not going to operate when not required and will operate to trip when necessary.

V. DISTANCE RELAY IMPLEMENTATION:

Discriminating zones of protection can be achieved using distance relays, provided that fault distance is a simple function of impedance. While this is true in principle for transmission circuits, the impedances actually measured by a distance relay also depend on the following factors:
1. The magnitudes of current and voltage (the relay may not see all the current that produces the fault voltage)
2. The fault impedance loop being measured
3. The type of fault
4. The fault resistance
5. The symmetry of line impedance
6. The circuit configuration (single, double or multiterminal Circuit)
It is impossible to eliminate all of the above factors for all possible operating conditions. However, considerable success can be achieved with a suitable distance relay. This may comprise relay elements or algorithms for starting, distance measuring and for scheme logic.
The distance measurement elements may produce impedance characteristics. Various distance relay formats exist, depending on the operating speed required and cost considerations related to the relaying hardware, software or numerical relay processing capacity required. The most common formats are:
a) A single measuring element for each phase is provided, that covers all phase faults.
b) A more economical arrangement is for 'starter' elements to detect which phase or phases have suffered a fault. The starter elements switch a single measuring element or algorithm to measure the most appropriate fault impedance loop. This is commonly referred to as a switched distance relay.
c) A single set of impedance measuring elements for each impedance loop may have their reach settings progressively increased from one zone reach setting to another. The increase occurs after zone time delays that are initiated by operation of starter elements. This type of relay is commonly referred to as a reach-stepped distance relay.
d) Each zone may be provided with independent sets of impedance measuring elements for each impedance loop. This is known as a full distance scheme, capable of offering the highest performance in terms of speed and application flexibility

Furthermore, protection against earth faults may require different characteristics and/or settings to those required for phase faults, resulting in additional units being required. A total of 18 impedance-measuring elements or algorithms would be required in a full distance relay for three-zone protection for all types of fault.

With electromechanical technology, each of the measuring elements would have been a separate relay housed in its own case, so that the distance relay comprised a panel-mounted assembly of the required relays with suitable inter-unit wiring. Figure 11 shows an example of such a relay scheme.

Digital/numerical distance relays (Figure 12) are likely to have all of the above functions implemented in software. Starter units may not be necessary. The complete distance relay is housed in a single unit, making for significant economies in space, wiring and increased dependability, through the increased availability that stems from the provision of continuous self-supervision.

Fig.10.a Electromechanical Relay Fig.10.b Digital/numerical distance relays

A. EFFECT OF ARC RESISTANCE AND POWER SURGES ON THE PERFORMANCE OF DISTANCE RELAYS

a) EFFECT OF ARC RESISTANCE:

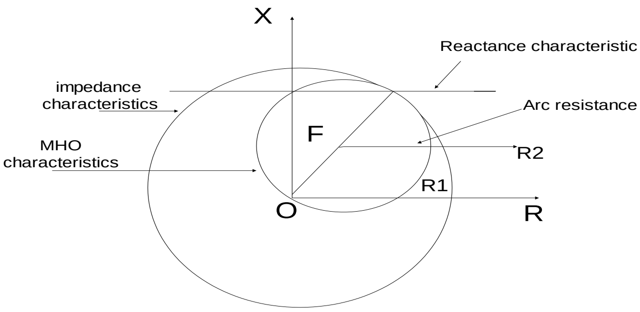

Fig.11. EFFECT OF ARC RESISTANCE ON THE PERFORMANCE OF DISTANCE RELAYS

If a flashover from phase to phase or phase to ground occurs, an arc resistance is introduced into the fault path. The arc resistance is appreciable at higher voltages. The arc resistance s added to the impedance of the line and hence, the resultant impedance which is seen by distance relay is increased. In case of ground faults, the resistance of the earth is also introduced into the fault path. The earth resistance includes the resistance of tower, tower footing resistance and earth return path. Earth resistance and arc resistance combined together are known as fault resistance. In case of phase to phase faults, the fault resistance consists of only arc resistance as there is no earth resistance in this case.

The arc resistance is given by the Warrington formula.

$R_{arc}= 29X10^{3}.l/l^{1.4}$ (Ohm)

Where l=length of the arc in meters in still air and I=fault current in amperes. Initially, l will be equal to the conductor spacing for phase faults, and the distance from phase conductors to the tower for ground faults. The arc length is increased by the cross winds which usually accompany a lightning storm.

The arc resistance taken into account the wind velocity and time is given by,

$R_{arc}=16300(1.75S+vt)/I^{1.4}$

Where , S = conductor spacing in meters, V = wind velocity in km per hour,

t = time in seconds and I = fault current in amperes.

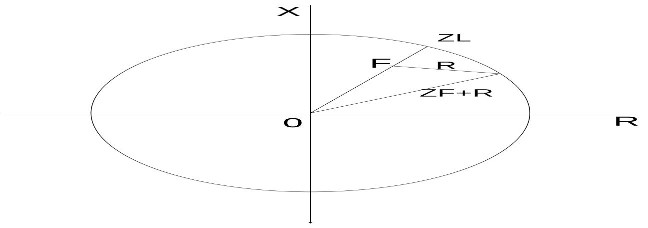

Fig.12 Effect of arc resistance on impedance relay

Arc resistance is treated as pure resistance in series with the line impedance. When the line is fed from both ends, the current flowing in the fault is fed from both sides. In this situation the arc contains a very small fictious reactive component which is negligible.

b) EFFECT OF POWER SURGES (POWER SWINGS) ON THE PERFORMANCE OF DISTANCE RELAYS

Consider a transmission line connects two generating stations. Current flowing through transmission line depends upon phase difference between voltages generated at two ends of line. Phase difference is equal to rotor angle. Phase angle between generated voltages changes during disturbances which arise because of removal of fault or sudden change in load. During disturbances, rotor angle of generator swings around the final steady state value. When the rotor swings, rotor angle changes and current flowing through line also changes. Such currents are heavy and are known as power surges so long as phase angle between generated voltage goes on changing, current 'seen' by relay is also changing. Therefore impedance measured by relay also varies during power swings. Thus a power surge 'seen' by relay appears like a fault which is changing its position from relay location.

From the characteristics of different relays it can be seen that relay characteristic occupying greater area on the R-X diagram remains under influence of power surge for greater period and hence, it is more affected by power surges. The MHO relay having least area on R-X diagram is least affected. Impedance relay characteristic has more area than MHO relay but lesser area than reactance relay. Therefore, while it is more affected than MHO relay, its effected less than the reactance relay. In other words, it moderately affected.Reactance relay occupying largest area is most affected.

VI. PROJECT WORK

Fig. 13 shows the circuit diagram of this project

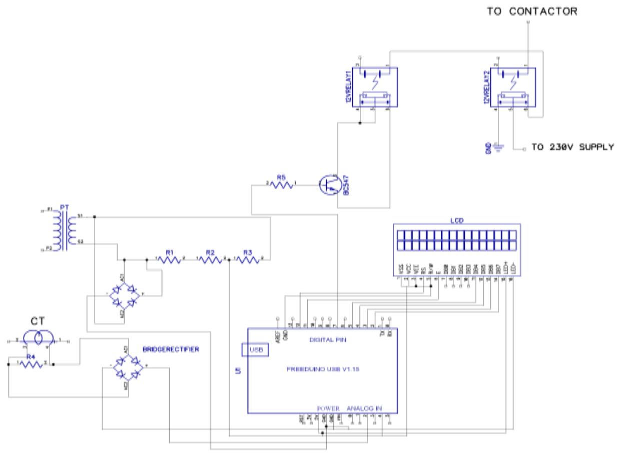

Fig.13 Circuit diagram of microcontroller based impedance relay

VII. DEVELOPMENT OF PROGRAM FLOWCHART

The development of the project is shown below in fig 14.a and fig 14.b

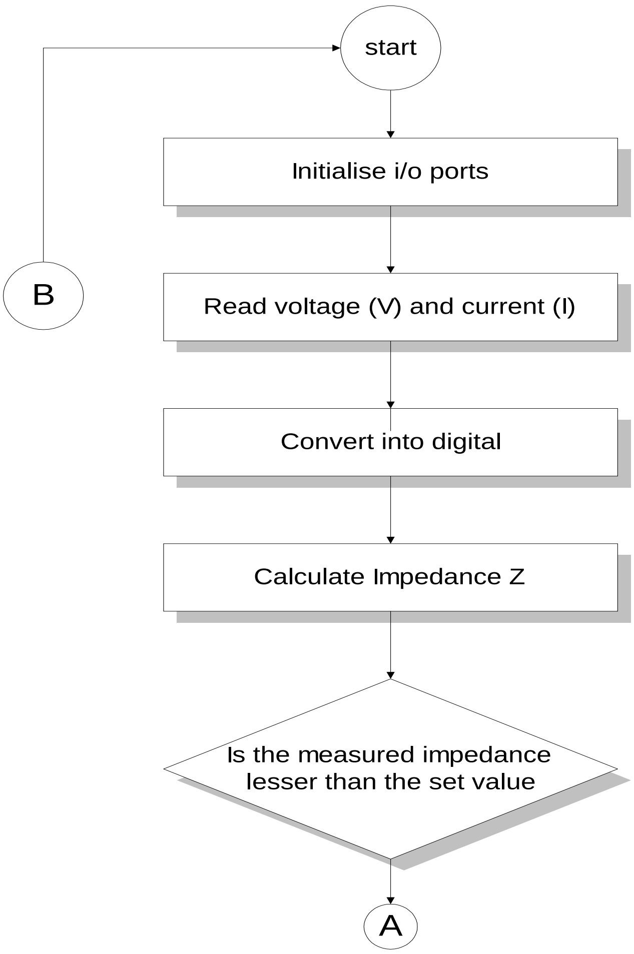

Fig.14.a FLOWCHART

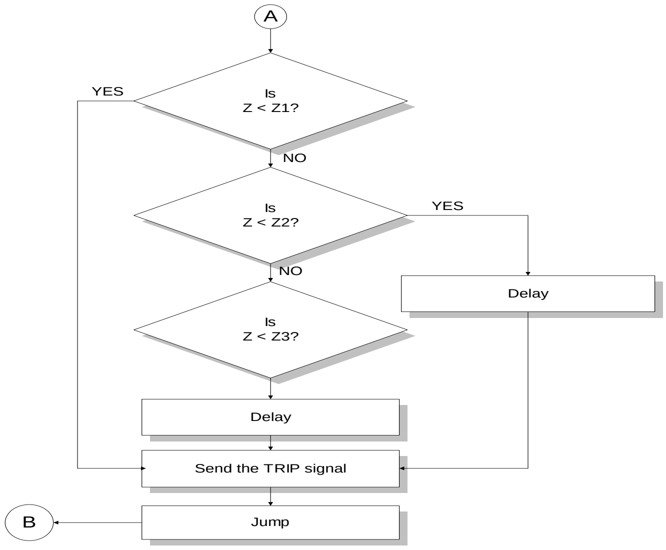

Fig.14.b FLOWCHART

VIII. RESULT

CASE 1: HEALTHY CONDITION
Transmission line length=400km
Impedance measured by RLC meter: 780+j11.93 Ω
Impedance per KM: 1.95+j0.029 Ω/km
Impedance observed on LCD: 0.434

CASE 2: FAULT IN ZONE 1 (AT DISTANCE 100KM)
Impedance measured by RLC meter: 181+j3.68 Ω
Impedance per KM : 1.81+j0.0368 Ω/km
Impedance observed on LCD: 0.064

CASE 3: FAULT IN ZONE 2 (AT DISTANCE 200KM)
Impedance measured by RLC meter:179.5+j3.78 Ω
Impedance per KM : .897+j0.0189 Ω/km
Impedance observed on LCD: 0.15

CASE 4: FAULT IN ZONE 4 (AT DISTANCE 400KM)
Impedance measured by RLC meter:183.9+j1.80 Ω
Impedance per KM : 0.4597+j.0045 Ω/km
Impedance observed on LCD: 0.22

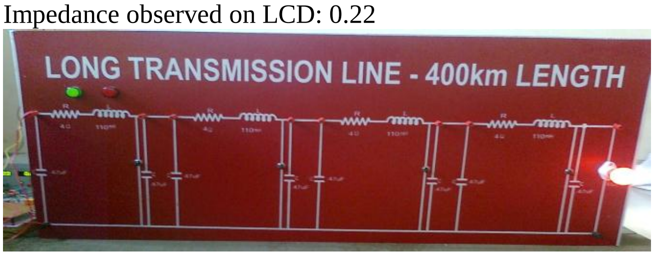

Fig.15NORMAL CONDITION

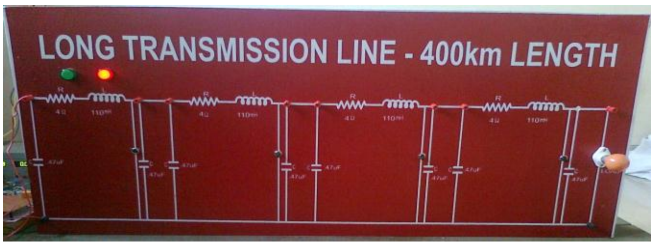

Fig.16 FAULT CONDITION

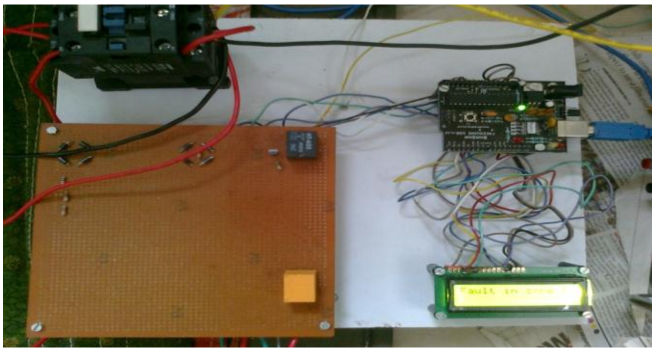

Fig17. FAULT INDICATION DISPLAY ON LCD

IX. CONCLUSION

In this project work we observed that when the fault is created, microcontroller calculates the impedance, if impedance is less than set value, relay operates and gives signal to the contactor to de-energize. Thus transmission line gets disconnected from the supply.

The microcontroller based relays are invading the power system network since they are flexible and reliable. The same board can be used for over current and directional over current protection and hence cost of the relay will be less compared to conventional type.

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