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Reliability and Maintenance Management of Power System Networks

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ABSTRACT

The paper outlines management aspects of reliability and maintenance of power system networks, in particular for underground cables. It highlights the importance of monitoring the network for preventive maintenance and techniques of quick detection of the faults and their rectification to restore continuity of power. The paper recommends introduction of automation in fault localization through Supervisory Control and Data Acquisition (SCADA). Elements of SCADA in maintenance have not been introduced so far because though detection is possible but for rectification of any kind of fault manual techniques are necessary. New techniques and new instruments have been innovated in this paper with emphasis on management and efficiency.

This research adds a dimension to the modern techniques in providing a single equipment Master Cable Fault Locator for management of faults in power and communication networks accurately and efficiently. In the earlier literature separate instruments were discussed for the telecom and power cables thus requiring higher investment and related disadvantages. An associated facility with this equipment is also developed referred here Cable Route Tracer. This also works for all types of cables and not only does this trace the route but also identifies the cable in the pit.

The paper substantiates the advantages of using these new technology products for reducing the down-time and improving accuracy in the work. The research findings are not limited to any geographical boundaries. The paper highlights the implications of the research and suggestions for future work in preventive maintenance of power system networks.

Keywords: *management, reliability, automation, cable maintenance, cable fault locator, cable route tracer, economics*

1. INTRODUCTION

To achieve uninterrupted power supply, Grid Power Network and Distribution Network have to be designed keeping in mind reliability considerations of interconnections and subsequently their well planned maintenance schedule with minimum shut down. Regular maintenance is necessary for long life, trouble free performance and periodic upgrading of the system. The subject of reliability related to power system has been given importance from the beginning of the invention of technology but extra cost is associated in introducing this factor. Now, importance is attached to control, monitoring, forecasting and fault analysis that new technology instrumentation and subsystems entails. Study of reliability of a system includes the emergency measures, precautions and routine testing that the operator could incorporate in the maintenance work to prevent system failure. The application of probability theory provides a means of quantitative evaluation of reliability factors.

All modern systems are designed to meet conditions of environment that is temperature and humidity and also working environment like shock, vibration, stress and strain, electrostatic fields etc. Enhancing reliability through overdesign is uneconomical. With the recognition of reliability and maintainability as vital factors in operation and maintenance, greater emphasis has to be given in providing training in these concepts and the system should be modernized by including the latest control devices to monitor the system parameters.

Apart from overhead transmission lines there are huge networks of underground power cables maintained by various government and private sectors. Avoiding power failures throughout peak time is an important planning for sectors where power failures can cause huge economic losses. This paper discusses about maintenance of Low voltage and High voltage underground power cables during their service period and tackling the situation during faults in these cables.

From reliability point of view, interconnection of the power system, whether it is transmission lines or underground cables, there are certain standard patterns like series, parallel and ring formations. Standby and redundant links of course adds to the cost. Preventive or pre-breakdown information monitoring also contribute to avoiding the total breakdown, to achieve higher reliability state. Monitoring and control instrumentation are essential factors of every design. The supply should not be interrupted and to this objective additional cost compromise has to be made. Overhead lines are maintained by electricity authorities whereas underground cables are maintained by the industrial and telecommunication industry.

The cables can be classified into two categories: 1) Power Cables 2) Telecommunication cables.

The power cables are carrying the power from the supply points provided by the electricity authority to the industry to take the power within their plant to different machinery. Depending on the industry these cables can be of various sizes and lengths.

The second category is the telecommunication cables which also have long lengths of cables, for example, cables that are running intercity and covering several kilometers with few sections and interconnects several telephone exchanges within the city. This is enormous underground network maintenance and requires a well trained management division.

Another user of the large cable network is Indian Railways which has Telecom, Signal and Power cable networks running parallel along the railways tracks. Railway Signal cables must be maintained properly to guide the scheduling of the trains. The railways also use overhead lines for high speed propelling of surface trains.

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Defence establishments are users of long lengths of cables of all types that is power, signal and telecom cable. The Mining sector has long power cables running in the underground mines for power supply for lighting and transporting carts as in the sub-ways maintained by railways for underground trains. Industries like steel, mines, cement, textile and engineering have a good number of cable networks within their premises. Apart from the lighting loads of street lights, houses, offices etc. in the township there are several crucial areas that require proper management of maintenance of electricity for example the hospitals.

In some cases it may even be recommended to have own generators instead of depending upon transmission system for uninterrupted power supply because slightest interruptions in some cases can cause loss. In steel industry the quality of steel is affected due to interruption of power even for a minute.

Two types of power transmission systems have been analyzed for reliable maintenance and proper management in terms of rectifying the faults efficiently:

1. High voltage Overhead Lines
2. High and Low Voltage Underground Cables

As discussed earlier new equipment and techniques have been developed for quick maintenance. The overhead lines transmit bulk power over long distance lines carrying high voltages of 11, 000 to 400, 000 Volts running cross-country and exposed to different terrains comprising mountains and valleys full of large trees. In addition, these lines have to also face high wind, rains and lightning and therefore are often subjected to frequent faults as compared to underground cable networks. Common overhead line faults are:

1. Snapping of a conductor due to high winds. The conductor may hang in the air causing open fault or touch the ground causing a short fault. 2. Leakage of current through the defective insulator during rains causing a low insulation fault between conductor and the earth on the tower or pole. 3. Double line to ground faults and 4. Three phase to ground fault.

The underground cable networks suffer faults due to 1) Aging of the cable insulation 2) Seeping of water in the cable through pin hole 3) Thermal heating due to overload. 4) Digging of the terrain for road widening and constructions. 5) Travelling waves entering from the overhead lines in to cable at their junction point.

2. OBJECTIVE

The objective of the research here is to:

(i) study the present state of the art of maintenance management of electrical power systems

(ii) provide a better design of testing equipments by eliminating the existing bottleneck in the maintenance of the underground networks

(iii) design the equipments that can give a quick and correct results for testing the faulty cable networks

(iv) introduce reliability in the transmission of power without any interruption for long spell.

(v) The equipment innovated should meet the requirements of cables of different lengths and cross - sections

The objectives are arrived at by virtue of practical project work of maintenance management of underground cables assigned by the company where the author worked and encountered problems due to limitation of the existing testing equipment and reliability.

2.1 How this study is unique?

Generalized equipment for testing all types of cables e.g. power, signal and telecom has been developed. The principle used for designing the Master Cable Fault Locating instrument for locating low insulation faults is unique and this makes it a global bench mark for this design. No other instrument globally uses this kind of design. The particular advantage of the technique is that this instrument can handle the faulty cable that contain induced potential coming on to it from neighboring overhead lines thus it eliminates the errors in the results due to this factor.

3. METHODOLOGY

A practical survey was conducted by visiting industries and other main users of power such as township under the management of BHEL, Bhilai Steel Plant, CPWD, Mines and MES to study the present status and the bottlenecks encountered in efficient management of maintenance and requirement of reliability. As the survey showed that there was no suitable equipment for the cable maintenance hence this project was undertaken to introduce new equipment and techniques to modernize the existing and introduce automation in fault localization for efficiency, economics and reducing down-time. The new equipments were tested on different types of cables as stated in the objectives and after several months of efforts the following two equipments satisfied most of the criteria of the objectives of the research:

3.1. Master Cable Fault Locator

This equipment has the capability to locate all types of faults in various cable networks and it is easy to operate by pressing a single switch after making the circuit connections. The types of faults it can handle are a) Low Insulations faults up to 2 Mega Ohms b) Short and Earth Faults in both power and telecom cables. This instrument provides the distance to fault but the maintenance team still faces the difficulty of reaching the point of fault because the cable route and its length is not recorded and in most cases totally unknown. Hence another product is complementary to the Master Cable Fault Locator.

3.2. Cable Route Tracer

This comprises a Transmitter and Remote Sensing Receiver.

The transmitter sends the signal in the cable under test to activate its entire length. This signal is detected by the remote sensing receiver above the ground guiding the operator for tracing the route of the cable. If this is done along with the Roadometer both the route and the length of the cable can be accurately known. Hence one can reach the point of fault as indicated by Master Cable Fault Locator. The results of the experiment described provide the accuracy as analyzed in the section marked discussions.

The experiments were performed on the real faulty cable in the industry and township and results were verified by digging the area of the cable for accuracy and efficiency of fault localization. Tests were also performed on a fault simulating test board. Details are discussed.

Study was undertaken to introduce reliability in network through the design of the system by making standby provision and automation to eliminate the failed link and switching over to restore the system through the standby. Having done this the next important and a recurring task is management of maintenance of repairs of the failed elements.

4. EARLIER INVESTIGATIONS

The earlier investigations presented here do not discuss the features of cable fault locator for the underground cables but only overhead lines publications are not available for the research in underground cable fault locators.

Hideyuki Takani, et al (2006) has developed a fault locator which is incorporated in a line current differential protection relay and this uses positive sequence quantities. This paper presents an advanced fault location method and a new algorithm. Its use is limited to overhead lines.

Alexander, et al (2001) show the calculations for fault location based on quantities from a single line terminal. A better estimate of the fault location can be made when current from other lines are used in the calculations. Its use is limited to overhead lines.

Abdelsalam Mohamed Elhaffar et al (2008) present a fault locator based on the characteristics of the travelling waves initiated from the fault with the objective to propose an automatic technique based on travelling waves to locate the faults in the lines.

Radojević, et al (2009) present outline of new efficient settings, it does not require line parameters to determine the fault. The solution for the most common fault, the single line to ground fault, is presented and thoroughly tested for use in overhead lines.

Jan Izykowski, et al (2007) in their work, the new algorithm designed for locating faults on a three-terminal transmission line has been presented. The set of the fault-locator input signals is taken for developing the fault-location algorithm for applying current differential relays. They have shown that it can be accomplished using phasors of three-phase current exchanged by the current differential relays.

Mohammad Abdul Baseer (2013) has investigated the problems in fault localization using traveling wave voltage and current signals obtained at a single end of a transmission line. Fourier transform is applied to traveling wave signals to obtain their frequency components in the fault signal.

Mahmoud S Awad (2012) presents an on-line fault location algorithm for both single-ended and double-ended power lines. It uses the steady-state data of voltages and currents available by the measuring equipment and calculates the fault location.
Simulation studies have shown that the proposed algorithm yields quite accurate estimates.

Ai-hua Dong, et al (2013) in their paper introduces overhead line fault detection and location system as the core of industrial control computer. The software and hardware, the methods of current change and zero current detection are used.
Andrichak, et al (1991) discusses the problems that are encountered in design and application.

D Ouahdi, et al (2009) has presented an algorithm of impedance relay against short circuits and over voltages. This algorithm is based on theory of symmetrical components. To prevent the operation of the relay in over load mode a voltage drop check has been introduced.

K. Warwick, A.O. Ekwue and R. Aggarwal, (1997) discuss in their paper 'aging infrastructure of power industry, economics of aging coupled with well developed process of optimizing equipment life cycle. This paper discusses about maximizing life time of electricity network components through proper maintenance strategy and to minimize maintenance cost in the same time without decreasing the reliability of supply.'

Bing Jiang, and Alexander Mamishev (2004) their paper focuses on one trend of power system monitoring, namely, mobile monitoring. The developments in robotic maintenance for power systems indicate significant potential of this technological approach. Authors discuss integration of several important relevant sensor technologies that are used to monitor power systems, including acoustic sensing, fringing electric field sensing, and infrared sensing.

Bing Jiang and Alexander V. Mamishev the authors describe several important relevant sensor technologies that are used to monitor power systems. Sensor technologies relevant to monitor the distribution system have been presented. They include acoustic sensing discrimination of energized cables, analysis of acoustic signatures of partial discharges, the fringing electric field sensing, acoustic sensing, and infrared sensing. The main purpose of this multi-sensor system is to monitor the aging status, water uptake, and incipient faults in electrical insulation. The framework of multi sensor signal processing challenges has been outlined as well.

5. BOTTLENECK IN LOCATING FAULTS

The manual methods of testing the underground cable consume more time in the calculations and other factors whereas the software based equipment can handle the calculations and process the data with a touch of a button. The time of operation is hardly a few seconds after connecting the equipment to the test cable. The SCADA automation enables us to make the operations automatic and transmit the data about the faulty cables to the supervisor.

This research adds a dimension in providing single equipment for management of faults in Power and Communication networks accurately and efficiently. In the earlier literature separate instruments were discussed for the telecom and power cables thus requiring higher investment and related disadvantages.

Only one technique was primarily used that was based on Pulse Reflection method which has limitations of locating only short and break faults in the cable whereas the practical cable networks have partial or low insulations faults and also earth or armor faults.

5.1 Effective Solution

The instruments designed overcome these limitations of the earlier technology. The new equipment uses digital technology and works on the principle of ratio of voltages to obtain the distance to fault. This has apart from the above advantages two additional features, firstly the ratio readings eliminate errors of measurement and provide highly accurate results and second the induced potential coming on the cable under test from the overhead line in the vicinity is deducted from the reading before obtaining ratio whereas this is not possible in case of pulse reflection method and therefore the equipment presented in this research paper enhances the understanding and provides the method to overcome the bottlenecks.

The Master Cable Fault Locator is an Integrated Circuit (IC) based design to make the calculations from the acquisition of the data. The Cable Route Tracer and Identifier uses a special transducer to receive the electrostatic and electromagnetic signal from the cable under test and converts it in to a voice signal which announces the route of the cable. The equipment has no limitation in terms of length and the cross sections of the cable.

Some of the imported equipment working on high voltages are bulky and expensive and which suffer portability but the handy features of the two equipments the authors have presented are light weight and mounted in a suitcase with wheels.

6 EQUIPMENT DESIGNED FOR MANAGEMENT OF FAULTS IN CABLES

There is no instrument available globally other than Master Cable Fault Locator for locating low insulation faults presented in this paper. This instrument has high utility in testing faulty cables in Railways as these cables always have foreign potential coming due to induction from the overhead lines running along the rail track just above the cables.

1. MASTER CABLE FAULT LOCATOR

It uses new technology; to obtain distance to fault by making correction for any Foreign Potential (FP) existing on the cable due to induction from HT source in the vicinity and displays the result on the digital meter. The Master Cable fault Locator adjusts itself automatically to the conditions of the fault, length and cross section of the cable and gives the accurate results. See figure 2 for photo of the equipment.

The equipment can handle: (1) Cable length up to 25 km (2) Types of cables: Power: LT / HT, Telecom and Signal of various gauges (3) Types of faults: (a) Phase to Phase (b) Phase to Phase and Earth (c) Phase to Earth (d) Short or Low Insulation up to 1 Mega Ohm

(4) The electronic circuit in conjunction with the relay collects data from the cable under test within 2 seconds when the STORE button is pressed, Result of the DISTANCE TO FAULT is displayed by pressing the COMPUTE button.

The Master Cable Fault Locator works on low voltage low current and comprises new Integrated Circuit Technology. The main circuit of the Master Cable Fault Locator consists of Intelligent Digital Meter comprising microprocessor based electronic-chip circuits with Memory and logical programmable software for taking into memory the data from the test circuit.

The percentage distance to the point of fault in the cable under test is calculated by the formula provided in the memory: Percentage Distance
$D = 2\ Eb1/ (Eb1+Eb2)$. The Fp (Foreign Potential) value is automatically subtracted from the measured value of Eb1 and Eb2 before calculating the percentage distance to fault.

6.1 Operation

The Master Cable Fault Locator is connected as per test circuit shown in figure 1, by identifying good and faulty cores with the help of insulation tester. After the battery supply is connected to the Master Cable Fault Locator Unit, the instrument is switched on and Compute button is pressed. This circulates current in the loop of the cable under test and takes into memory the parameters and the calculations as per the formula and displays percentage distance to the point of fault.

6.2 Fault Simulating Test Board

This is a self check arrangement which confirms the satisfactory working of the instrument and for training the user about the working of the instrument in different fault conditions. The fault simulating test board comprises three rows representing RYB Phases and the fourth row is representing armoring of a cable. The total length of the row is divided into five sections. Each section comprises a fixed resistance and all are of equal value. On the test board resistors of 20 ohms in each section is provided. Figure 1 shows a good and faulty conductor looped at the other end that has to be simulated on the test board here by creating a fault between two rows and repeating the experiments at various sections by simulating low insulation and other faults using patch chords.

2. CABLE ROUTE TRACER

It consists of Transmitter and a programmed Remote Sensing Receiver. See figure 8 (Photo of the equipment)

The Transmitter sends an audio signal and the Receiver announces the direction of the fault and takes along the direction of the fault and the announcement stops upon reaching the point of Fault. It is 100% accurate, works for up to 5 meters depth of cable. Transmitter is Mains operated (230 volts AC). Receiver requires Power supply from: 2 nos. of 1.5 V torch cells.

The receiver detects the electro-static and electro-magnetic signal sent by the transmitter. Both are tuned to 50 Hz upwards multi range frequency of the audio signal. The transmitter is provided with tone control and two terminal output with provision for connecting to the cable under test. The functions of the route tracer are as follows:

(i) Pin Pointing The Earth Fault:

Helps in diagnosing and pin pointing the fault where the cable cores are short with the earth. This helps in digging a small portion only in the right area. The signal sent in the cable from the transmitter returns from the point of fault to the ground. The sensor is pointed along the cable to receive signal. The hand held Receiver/ Sensor will announce the direction of fault along the cable length and the announcement will stop at the point of fault. See figure 4

(ii) Tracing The Route Of The Cable:

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The signal is fed from the transmitter into one core of the cable which is earthed at the other end. The Remote Sensor receives signal above the ground along the cable route (figure 5, 6 & 7). Traces the cable route above ground for cable depth up to 5 meters and works up to 25 km length for all types of cables: power and signal / telecom cables of any gauge. Signal strength sent in the cable is monitored on ammeter of the transmitter. Receiver is a hand held pocket size design comprising of audio device of solid state technology with latest IC's. (See figure 8).

3. THUMPER AND RECEIVER UNIT

Thumper is a high voltage equipment giving a pulsating output and it discharges high energy in the order 500 joules to 1000 joules depending upon its design, because of the high energy there is a thumping sound at the point of fault being magnetic field and acoustic based the Receiver Unit picks up these signals in the field and accurately locates the fault. It is useful in locating break or high resistance low insulation faults.

This equipment works on 230 Volts, 50 Hz, and single phase Alternating Current (AC) giving a variable output from zero to 12, 000 Volts Direct Current (DC). It consists of high voltage Transformer, Capacitor Bank, Diode Bridge, and Resistance Bank.

7. EXPERIMENTS AND TEST RESULTS

Field test were conducted on different faulty cables and also by simulating cable faults of different category in the laboratory by using Master Cable Fault Locator and Cable Route Tracer that were innovated.

7.1 Experiment 1

The test circuit is shown in the figure 4 and 5. The procedure for tracing the route is shown in figure 6 and 7 respectively. A faulty cable located in the premises of CPWD Hyderabad was tested. The High voltage cable under test had low insulation fault of 10 mega ohms value between yellow phase to armor, length of the cable was 1 kilometer. Here the cable with fault resistance of 10 mega ohms was burnt by using the Thumper. The fault level got reduced to below 1 mega ohm after a few thumping operations. Then the Cable Fault Locator was connected to the faulty cable by forming the test circuit as per the figure 1. The instrument indicated distance to fault of 350 meters. The route of the cable was traced using the Cable Route Tracer. The distance to fault of 350 meters was measured by the Roadometer. After digging the ground the fault was seen on the cable as per the results indicated by the Master Cable Fault Locator.

7.2 Experiment 2

A faulty cable was selected at Military Engineering Services (MES) at Air Force Station, Hyderabad. This was a low voltage cable of 1500 meters length with short and earth fault between the yellow and blue cores and the armor. The Master Cable Fault Locator was connected as per the test circuit of figure 1. The equipment indicated the fault at a distance of 500 meters.

The fault was verified by digging the ground. The result given by the instrument was correct.

7.3 Laboratory Experiments

Figure 3 shows different types of faults that were simulated on Fault Simulating Test Board designed for the purpose. The results of different experiments are shown in table 1.

8. DISCUSSIONS

The Master Cable Fault Locator has the SCADA automatic feature of Data Acquisition from the faulty cable when the command is given through Supervisory Control by pressing the COMPUTE Button. The instrument then sends the signal in the faulty cable and captures the data from it. Then the software provided in the instrument makes calculations and displays the results of distance to fault on the Digital Meter. This information is stored in the memory until it is cleared.

From the field experiments and the results verification the accuracy of the equipment was established. The accuracy obtained for cable fault localization of Experiment no 1 on high voltage cable of Central Public Works Department (CPWD) was within three meters of the results indicated by the Master Cable Fault Locator. The accuracy of tracing the cable route was 100 % for the cable depth of 5 meters.

Experiment no 2 was conducted on the cable of Air Force establishment of Military Engineering Services (MES), Hyderabad. The accuracy obtained for low insulation, short and earth faults were within 2 meters of the results indicated by the Master Cable Fault Locator.

The experiments were conducted on the simulated faults of different types shown in figure 3 (a to f). The results obtained as shown in table 1is within the accuracy of 99.7 %. From the experimental verification of all the three equipment it is established that these can handle all types of faults in high voltage and low voltage cables within good practical accuracy to maintain the cable network efficiently and economically within the budgeted costs. The time taken for testing is less than 30 min and rectifying the fault through digging the ground and cable jointing is another two to three hours. Field tests and laboratory tests show the capability of the equipment in locating 1. Low - Insulation. 2. Core to core. 3. Core to earth faults.

9. CONCLUSIONS

Master Cable Fault Locator instrument provided with the feature of SCADA automation has a single switch operation. When the switch marked COMPUTE is pressed it gives Supervisory command to the instrument to capture the data from the faulty cable where the instrument is connected. The data is stored in the software of the instrument and it makes the calculations using the formulae (1) also stored in the software memory. The final results of distance to fault are displayed on the Intelligent Digital Meter.

The paper highlights Master Cable Fault Locator that can locate low insulation, short and earth faults caused by deterioration of the insulation or external damage. No suitable handy and cost effective Cable Fault Locator exists that can handle this kind of partial faults particularly when such faults are susceptible to acquiring induced potential from the high voltage sources of overhead lines in the vicinity. The Master Cable Fault Locator works on the Potential Distribution principle and it is provided with software to take the data to memory and calculate percentage distance to fault.

$$\textit{Percentage distance} = \frac{2\,(ebi \pm Fp)}{(ebi \pm Fp) + (eb2 \pm Fp)} \quad \text{-------} \quad (1)$$

Where, eb1 = potential as shown in the figure from the test point to fault point of the loop. eb2 = balance potential from the other end of the loop up to the point of fault. Fp = potential between the two faulty cores, Anand Khare (1985). This data is taken to the memory and calculations are made as per the formula provided in the memory. Instrument automatically does the calculation from the data on pressing COMPUTE Button and the results are displayed on the intelligent DPM (Digital Panel Meter). The SCADA feature enables the instrument to adjust the magnitude of current depending on the cross section and length of faulty cable.

The instrument is versatile to locate all types of faults that occur in POWER, TELECOM & SIGNAL CABLES. The requirement of a perfect good core to form circuit is not crucial because a comparatively better core can serve this purpose. This instrument has superior features to pulse reflection type of cable fault locators because the Pulse Reflection instrument has limitation in locating low insulation faults, faults with induced potential and earth faults. Other severe disadvantages are it must have RLC parameters in sufficient measure for the reflection of the pulse. For cables of different gauges the technique becomes inadequate. The Master Cable Fault Locating Instrument innovated here is free from these limitations and it can handle any cross section and length of the cable by automatically adjusting the signals.

The **Cable Route Tracer** described here has Audio Visual signal output. This route tracer has new features compared to existing technology which is based on technique of metal detection which gives a bleep signal which is misleading when large networks of cable are present.

The design described in this paper is of the audio signal of musical range which can be easily identified and sensed when fed to the core of the cable which is earthed at the far end. See the connection circuit in figure 5. The signal generates electromagnetic and electrostatic fields in the core under test. As the core is earthed the signal is easily detected above the ground by the Sensor which detects electrostatic and electromagnetic fields through the transducer of the sensing device. By walking with the sensor pointed to ground, the sensor will pickup music signal, see figure 6. The sensor is provided with a built in amplifier and speaker to announce the route of the cable through a musical tone. The Route Tracer also identifies a particular cable from a bunch of cables in the pit. See the connection circuit in figure 7 for identification of the cable in the pit. With this arrangement of circuit, transmitter signal will only flow in the faulty cable under test.

9. 1 Implications

The significance of the work is that the product designed fulfills the need for a low cost, portable and accurate equipment that can be used for all types of cables in private and public establishments for locating cable faults that is low insulation, short and earth and present a generalized solution for locating all types of faults in power and telecom cables of different cross section length; it is a user friendly Intelligent Automatic Cable Fault Locator Set preprogrammed to provide the results within seconds with a touch of the button. The Master Cable Fault Locator has reached perfection. This equipment alone can take care of all types of faults in all types of cables as discussed in the earlier sections.

9.2 Future Research

Preventive maintenance is needed so that pre-breakdown monitoring of the power system network can be done to avoid the faults and take timely measures in its rectification and minimizing the unexpected failures and reducing the down time.

Monitoring includes periodic testing of the network say insulation testing of the cables or oil testing of transformer's to evaluate its fitness. Instrumentation can be used to monitor temperature rise, partial discharges in the cables, transformers oil, dancing of overhead transmission conductor and corona due to air ionizing around high voltage conductors resulting into power loss and increase chances of conductor failure. Transducers for pressure, sound, magnetic field, leakages of current or partial discharges and vibrations can be utilized in monitoring to generate warning signal of the forthcoming faults.

Research is required to strengthen the monitoring technique and equipment through remote sensing.

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FIGURES AND TABLES

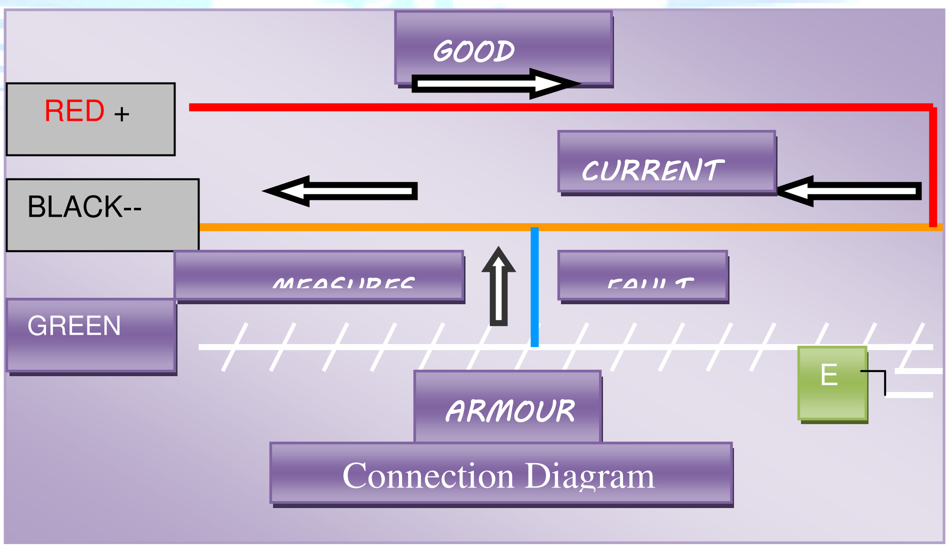

Figure 1 shows the connections forming the test circuit

Figure 2 (Photo) shows the Master Cable Fault Locator
With courtesy of the MRPC Company Hyderabad

TABLE NO. 1

Type of Fault	Fault at 40 %	Fault at 60 %	Fault at 80 %
Low Insulation	39.9 %	60 %	79.9 %
Core to Core	40.1%	59.9 %	80 %
Core to Earth	40 %	60.1 %	79.8 %
Core to Core & Earth	39.8 %	60 %	79.9 %

The table no.1 shows performance of the instrument on Simulated Test Board

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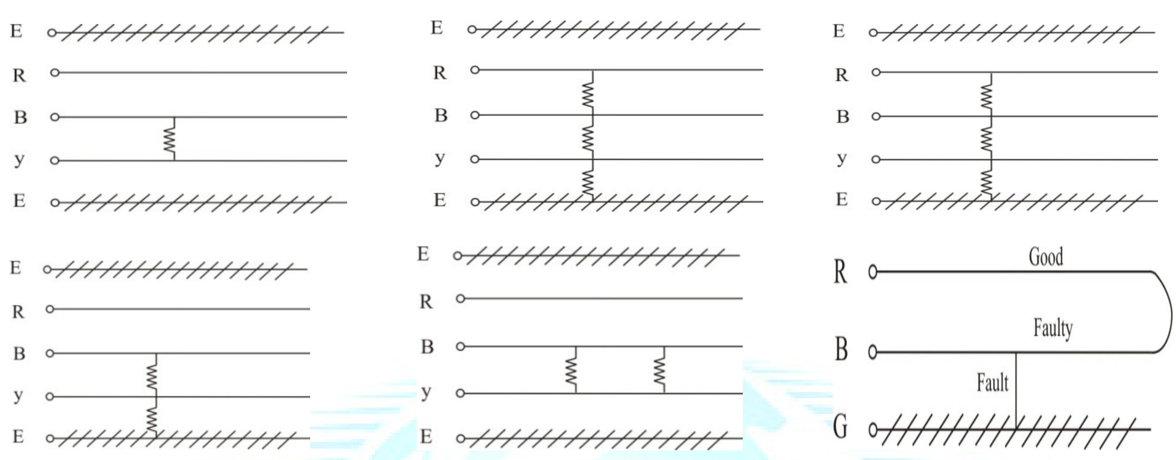
3 (a) 3 (b) 3 (c)



3 (d) 3 (e) 3 (f)

Figure 3 (a to f) show type of faults that were simulated in the laboratory to conduct experiments.

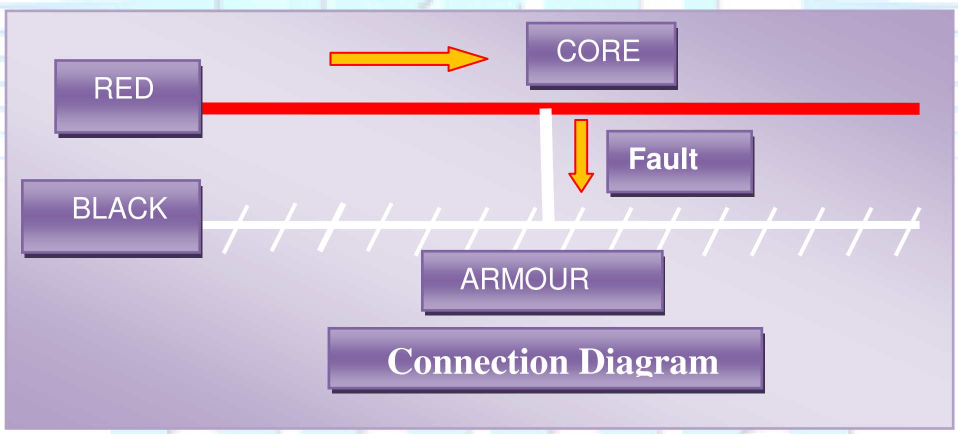


Figure 4 shows Transmitter connections for Pin pointing and Earth faults

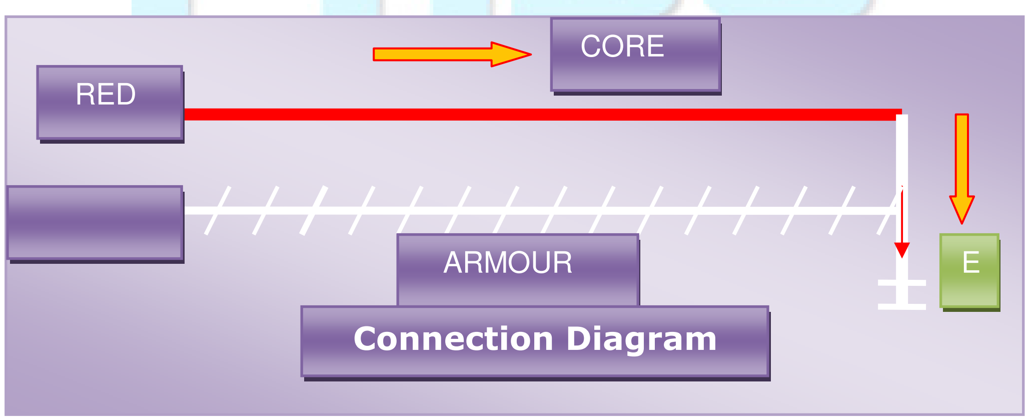
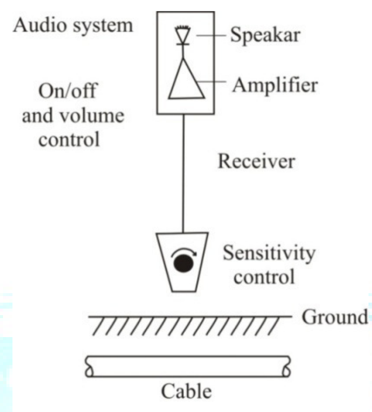
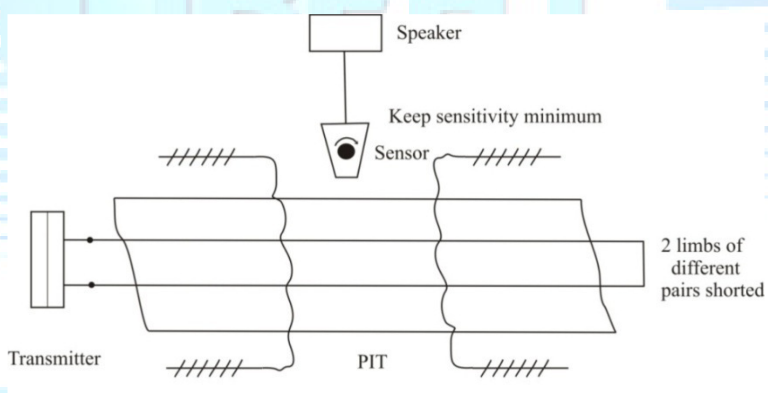


Figure 5 shows Transmitter connections for Cable Route Tracing



Tracing Cable Route

Figure 6 shows Receiver Device pointed to the ground to catch the signal



Identifying the cable in the pith

Figure 7 shows two cores of the cable shorted at End 2

Figure 8 shows the photo of the Receiver of the Cable Route Tracer
With courtesy of the MRPC Company Hyderabad