Failure Prediction of Underground Distribution Feeder Cables from IEEE Transaction on Power Delivery, Vol. 9, No. 4. October 1994, use analytical approach to predict distribution feeder cables life. It was developed by Ebsco Services Incorporated for the Con Edison Co, of New York. The prediction was based on Weibull formula of probability [12].

In TNB, research in cable joint failures is in its early stage (discussion with Engineering Department). The 'Statistik Kerosakan Sambungan dan Tamatan Kabel 11 kV Bagi Tempoh Mei 1994 hingga Ogos 1995' prepared by Engineering Department is the early effort by the department [11].

insulator.

2.1.2 Conductor

The conductor used in distribution cable in the earlier days was copper. As the price of copper increases in the 50s, aluminium conductors were introduced with less mechanical strength for annealed aluminium but fortunately conductivity is little changed by working. Compared with copper, aluminium has a number of technical disadvantages, all of which can be satisfactorily overcome to benefit from its economic attraction [7].

2.1.3 Types of Cable

There are three types of underground cables widely used in TNB. The three types are:

- Paper insulated cable (PILC)
- Crosslinked Polyethylene (XLPE) cable
- Oil filled cable

2.1.3.1 Paper insulated cable

In TNB, paper insulated cables are widely used in the distribution system. This type of cable uses paper as its insulating agent between conductors

(in the case of multiple cores) and also between conductor(s) to earth. The insulated conductors are then sheathed with lead.

The most common failures of paper insulated cables are due to mechanical damage to the insulation and ingress of moisture. There are three basic reasons for failures:

- breakdown due to ionisation

  Ionisation takes place within gaseous void between paper next to the conductor due to mechanical movement and loading of the conductors.

- thermal breakdown

  At around the operating temperature, a rise in temperature increases the dielectric loss, so giving a larger heat generation to the surrounding. If the rate of temperature increase is greater than the rate of dissipation, the dielectric will overheat and fail electrically.

- breakdown under transient voltage conditions

Cable insulation subjected to transient voltages such as lightning, fault current passing through or switching surges, which are higher than the impulse voltage for which the cable is designed.

2.1.3.2 Crosslinked Polyethylene (XLPE) Cable

In the 80's, XLPE was introduced. XLPE cable shows improved current rating at higher ambient temperature compared to paper insulation in the PILC cable. The introduction of XLPE cable brings about a new set of working knowledge and skills needed to handle the new type of cables. The major causes of failures are electrical discharge and water tree.

2.1.3.3 Oil filled cable

Oil filled cable is another type of cable used by TNB. This type of cable is used mainly in the 33 kV distribution and transmission system.

2.1.4 Expected life span

The life span of cables cannot be determined without hard data to back it. In UK, it is stated that possibly there are cables installed over 60 years and American cable were laid since 1962 [7]. In TNB, cables have been laid in the 50s [1].

2.1.5 Cable Laying

Cables are laid direct in ground or in ducts/trenches and buried first with sand to absorbed vibration and avoid water clogging. In the case of cables laid direct in ground, bricks or protective slabs are used after the sand layer to protect the cable from external intrusion such as excavation. The bricks or slab forms as a warning to excavators that there is something underneath the bricks/protective slabs.

2.2 CABLE JOINT

Cable normally comes in 250 or 500 meter drum. For usage longer than the standard manufactured length, the cables need to be jointed. This is called straight through joint.

At the end of the line where the cable needs to be connected to an equipment/apparatus such as switch gear or machine, the cable is jointed to a termination and called termination joint.

The act of jointing of cables must be done to match the production of the cable. Jointing is the act of reconstructing two cables or a cable and equipment to become one with the same technical capability as that of the original cable. Thus it is essential to know the electrical system, design and construction of cables and jointing.

Straight through joint is done in joint pit which is slightly bigger than the cable trench for ease of movement. The bedding of the joint pit must be deeper than the cable trench as to allow the smooth construction of jointing the cable. The joint must be supported firmly to avoid mechanical damage due to movement and at the same time giving rooms for expansion and contraction [7].

2.2.1 Cable Jointing Techniques

There are three common jointing techniques practised in TNB:

- Compound filled joint
- Heat shrinkable material
- Resin filled joint

Other jointing techniques such as tape joint is not widely used in TNB.

2.2.2 Knowledge and Skills

Jointing is the act of reconstructing a cable. To fully master jointing skills, the jointer needs to understand the construction of the various types of cables to be jointed. With the knowledge of cable construction, the reconstruction of cable during the jointing process will meet the required standard..

There are four major steps to reconstruct a cable:

- cable preparation
- connecting the conductors
- insulating
- replacing the shield and jacket

There are five major steps to construct a cable termination:

- cable preparation
- provide stress insulation
- install termination insulation
- install connector
- seal cable end

2.2.3 TNB Practice on Cable Jointing

Traditionally, the method used in TNB for medium voltage and low voltage jointing of PILC cables has been the compound filled joint technique that is joint boxes filled with hot bitumen compound.

In 1977, TNB introduced the use of Thermofit Termination as alternative to conventional compound boxes [8]. In 1982, TNB introduced Thermofit Heat

Shrinkable for high voltage straight through joint for PILDSTA 11 kV and 6.6 kV cable [9].

The introduction of XLPE cable in the early 90s brought about new techniques of jointing cables. The XLPE cables introduced to the existing system make it inevitable to make transition joint (XLPE cable jointed to PILC cable). Impregnating compounds can have the effect of causing swelling and loss of mechanical properties in some polymeric insulations and can affect the resistivities of the semi-conducting screen in the polymeric cable [7].

2.2.4 Cable Jointer Training Scheme

The introduction of aluminium as the core conductor, makes it inevitable that joint has to be made with two cables of different conductor types, copper of the older cable and aluminium of the new cable. Copper being a better conductor can carry higher current ratings than aluminium and hence the difference in size as a new aluminium cable is introduced into the existing copper cable system.

The introduction of new type of joints and rapid development of Malaysian economy increases the number of cables laid and hence joints to connect or terminate the cables. The challenge of updating jointers' skills within a short period posed a complex scenario.

2.0 CABLES, CABLE JOINTS AND IMPACT OF UNAVAILABILITY OF SUPPLY AND PROFITABILITY

Study about what caused cable joints to fail started since the introduction of cables. Most of the study emphasis on the technical aspect of cable joint failures. Electric Cables Handbook edited by D. McAllister explains why cables and cable joints failed and measures to overcome it.

2.1 CABLE S

Cables are normally associated with conductors that are insulated and normally used in underground systems. The conductors are normally called cores. Cables are either single core, two cores, three cores and four cores depending on the usage.

Lately, there are aerial bundle cables that are strung on poles. Aerial bundle cables used in TNB are up to 11 kV.

2.1.1 Cable design

There are three main components to consider during design and construction. The three components are conductor, insulator and mechanical protector. The conductor acts as the path for electricity to flow, insulator acts as barrier to electrical collision and mechanical protector to protect the conductor and

cables and positions of cable joints should be shown [1], [10].

2.2.6 Causes of Cable Joint Failures

As discussed in the cable type section, the factors affecting cable failures will also be applicable to cable joint performed to that particular cable.

Mechanical and water ingress are the main root causes of cable joint failures [7]. These factors set the pace for electrical failure build-up. Three modes of failures describe almost all failures in cable joints are overheating, interfacial breakdown and insulation breakdown [13]. Overheating leads to the general degradation of the joint and either dielectric failure or thermal runaway occurs. Interfacial breakdown is caused by an arc forming a breakdown channel along some internal interface (XLPE). Insulation breakdown is caused by an arc propagating radially through the insulation layer of the joint.

2.3 Impact of Cable Joint Failures on Availability of Supply and Profitability

There are four important factors to be considered for the study of impacts of breakdowns. The four factors are:

- customers dissatisfaction
- loss of production

- costs of repair
- opportunity loss

Long term effects of repeated failures are:

- erosion of customers' confidence
- lose sight of the dynamics of system
- unnecessary stress to the staff
- erosion of staffs' moral and confidence

This paper will only discuss the first three effects.

2.3.1 Customers Dissatisfaction

Customers in this section are defined as individual who is affected by the interruption of electricity. These customers may and may not sign contract with TNB. Non contract customers are users of electricity through third party customers. Examples of these non contract customers are hotel guests, staff of an organisation, users of public utilities which depends on electricity for their services and other indirect customers. The large power customers will be discussed in the production loss section.

Almost all buildings are air-conditioned and become dark without lighting even

during the day. Services to these buildings are mostly driven by electrical motors such as lifts, escalators etc.

Almost all houses in urban areas use air-condition. Most families do their marketing weekly nowadays, keeping their one week stock in the refrigerators or freezers.

The above factors are not exhaustive lists of activities, services, equipment and apparatus that depend on electricity supply. Any disruption of electricity supply will definitely caused inconveniences to customers.

Repeated interruptions of electricity supply will erode customers' confidence toward TNB.

2.3.2 Loss of Production

Factories are big consumers of electricity. Almost all machinery and equipment used for productions consumed electricity. The usage of computers in high technology factories is critical to the control of data and sequence of interrelated machinery and equipment.

Some production processes required continuous supply of electricity. Any disruptions of electricity supply for more than a certain period of time will spoil

the raw materials used in the making of certain products. Examples of such products are bread, ice creams, petrochemicals and other products normally associated with heat.

In organisations and commercial centres, computers are the main brain of their business activities. These include the expert system, decision support system, transactions, executive information system, invoicing, journal and database management system.

These activities are all dependent on electricity. Disruption of electricity supply means loss of productivity and materials.

For TNB, the productivity loss is direct.

2.3.3 Costs of Repair

The costs of repairing the faults include:

- manpower
- materials
- transportation

The process of repairing faults involved engineers, technicians, skilled workers and general workers. These highly skilled staffs can be utilised in new projects

that can bring new revenues rather than repairing existing installations for existing customers.

Once a joint failed, the cables will become shorter. Therefore, two joints and a minimum of 10 meters of new cable are needed for the repair jobs. These two joints and the cable can be used for connections of new customers.

There are four distinct activities in the process of restoring supply. Any forced outage (unavailability of supply due to fault) will trigger the standby engineer and other technical staff to start the first process of localising the fault. Localising fault is a process of determining the faulty section and restoring supply to the unaffected section. Once the fault is localised, the next stage is to locate or pinpoint the fault. Once the fault is located, a new cable is laid and jointed at both ends. Once jointed and tested, the supply is then normalised.

2.3.4 Opportunity Loss

Opportunity loss is defined as demand that cannot be not realised due to factors which can normally be overcome through calculated risk taking, applying the right strategy, planning and implementation. Opportunity loss can occur in new and existing market.

In Tenaga Nasional Berhad, loss of business opportunities includes:

- costs of repair
- sales of electricity

Cost of repair described in the subsection above reflected in the opportunity loss. This is because the costs of repair can be channelled to new projects for the connection of new customers.

Opportunity loss due to sales of electricity depends on the load connected to the systems that fail. For cable joint failures, the load loss can be as high as four megawatts.

2.4 RECENT STUDY ON CABLE JOINTS

A paper on Early Detection of Faults in Underground Distribution Cable Joints by Partial Discharge Measurements tries to measure the Partial Discharge level of cable joints in service. The idea is to predict when cable joints will fail. This is for prediction and safety of staff when they do cable joint near a live cable joint. This paper by L. Lamarre, D. Fournier and R. Morin from Institut de reherche d'Hydro-Quebec (IREQ) was presented at the International Conference on Properties and Application of Dielectric Materials, July 1994 in Brisbane, Australia [13].

IKATAN provides training on all cable jointing techniques. Jointer mate must sit and pass cable jointing test at IKATAN before being promoted to cable jointer. Privateers who wish to become cable jointing contractor must pass the same test. Training on the theoretical and practical aspects of jointing is conducted before the test for those who needs it. The test is for both knowledge and skills. The other most important aspect covered in the test is on workmanship and electrical safety.

2.2.5 Cable and Cable Joint Records

Cables are laid in ground along roads and highways. Joints are made at an interval of 250 meters (normal new drum length) [5], [6]. As time goes by, the physical appearance of the environment change and it is difficult to locate the cable route. Better devices have been developed to trace cable route. However, due to interference from external signals, its usage is much to be desired.

Records of cable route should be maintained to facilitate tracing the cable route when needed, such as excavation work at the vicinity of the cable route. Without proper records, locating cable can be of inconvenience to others. It involved digging trial holes to locate the cable.

Cable records should show exact locations of cables with respect to permanent land marks and buildings and also depth at which the cables are laid. Core sizes of