ON-SITE CONDITION ASSESSMENT OF MEDIUM VOLTAGE CABLE

By Vern Buchholz, P.Eng.

Utilities and industrial plants across North America make extensive use of medium voltage (5 to 35 kV) power cables. In many cases, these cables are approaching or have already exceeded their design life. The question then becomes: How does a company maximize the service life of its medium voltage cables? This article will discuss various methods of on-site cable condition assessment or diagnostic testing.

Condition assessment testing doesn't just mean simple "proof" or "high-pot" testing. Condition assessment testing (although it should find serious defects) is not a simple go/no-go test, but is designed to provide a ranking of the cable system and assist in prioritizing future cable maintenance and replacement. After all, no cable test has yet been developed which will determine the "remaining life" of a cable. The ultimate purpose of cable condition assessment is to improve system reliability and minimize long-term cost.

Most modern cables have a polymeric insulation, either polyethylene (PE) or Ethylene-Propylene Rubber (EPR). Older design medium voltage cables were Paper-Insulated Lead-Covered (PILC). Any diagnostic testing must take into account cable design.

Cable condition assessment testing can be divided into five parts:

- Insulation material
- Metallic shield or neutral
- Jacket — on some cables
- Accessories including splices and terminations
- Local environment and operating conditions

The exact test used in each of these parts will differ, depending on the design of the cable. I will cover tests available for each of the five basic parts with reference to the two designs of cable.

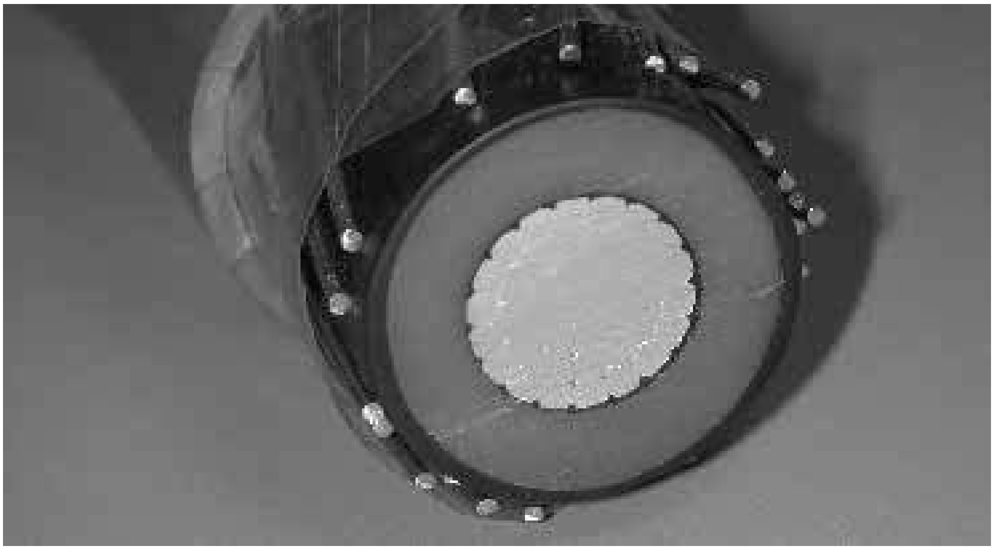
TABLE 1: INSULATION EVALUATION TESTS

Insulation General Health Tests

Test Type	Manufacturer	Equipment	Website	Short Description
Dielectric Spectroscopy	Programma	IDA 200	www.programma.se/ida200.html	Capable of measuring capacitance and dielectric losses from 0.0001 to 1000 Hz. Can be used on PILC and has option for polymeric.
LIpATEST	Powertech Labs	LIpATEST service	www.powertechlabs.com	Applies a stepped dc voltage up to 1.5 x normal voltage. Measures leakage current down to 0.1 nA at each step. Suitable for polymeric and PILC.
Recovery Voltage Method	Seba KHT	CD 31	www.kmt.de/	Applies 1 -2 kV dc to cable. Measures recovery voltage after discharge period. Suitable for PILC cable.
Relaxation Current	Seba KHT	KDA-1	www.kmt.de/	Applies 1 kV dc to cable. Measures relaxation current after discharge period. Suitable for PE or XLPE cable.
Very Low Frequency Dissip. Factor	Baur	PHG TD/PD	http://www.baur.at/en_baur/_products/h_phg_tdpd.htm	Applies HV ac between 0.01 and 1 Hz and measures Dissipation Factor (DF). Also measures PD. Suitable for polymeric and PILC.
Very Low Frequency Tan Delta		Tan Delta Bridge TDB-60	http://www.hvinc.com/vlf40prd.htm	Applies HV ac VLF at 0.1, 0.05, or 0.02 Hz, and measures Tan Delta. Suitable for polymeric and PILC.

Partial Discharge Locators

Test Type	Manufacturer	Equipment	Website	Short Description
60 Hz PD	Imcorp	Medium Voltage Testing Service	http://imcorp.uconn.edu/	Energizes cable at 60 Hz voltage up to 3 times operating voltage. Record and locate PD. Suitable for polymeric and PILC
60 Hz PD	DTE Energy technologies	Cable Wise Services	www.dtetech.com/pressroom/pdf/cablewise_brochure.pdf	Detector placed on energized terminations or splices. Measures and locates nearby PD in cable or accessory. Suitable for polymeric and PILC.
Oscillating Wave PD Test	LDIC	CDA PD Detection System	http://www.ldic.de/products/eng_pd.html	Cable is charged then discharged through a capacitance with an oscillating wave near operating voltage and frequency. Record and locate PD. Suitable for polymeric and PILC.
Oscillating Wave PD Test	Tettex Instruments	Oscillating Wave Test System	www.haefely.com/measuring_diagnostics/pd.html#OWTS	Energizes cable with an oscillating wave near operating voltage and frequency. Record and locate PD. Suitable for polymeric and PILC.
Very Low Frequency PD	KEMA-Powertest's	Power Cable Diagnostic Service	www.kema-powertest.com/field_services.htm	Energizes cable at 0.1 Hz near operating voltage. Record and locate PD. Suitable for polymeric and PILC. Available for branched circuits.
Very Low Frequency PD	Baur	PHG TD/PD	http://www.baur.at/en_baur/_products/h_phg_tdpd.htm	Applies HV ac between 0.01 and 1 Hz. Measures and locates PD. Also measures DF. Suitable for polymeric and PILC.



Modern XLPE insulated feeder cable with copper shield/neutral and PVC Jacket

INSULATION TESTING

At present, there is no standard condition assessment test for cable insulation. In fact, no one test is yet a clear leader or will tell everything about the insulation. Table 1 lists tests that are now available for insulation evaluation on the North American market. I've tried to include all the tests that I know and have divided them into "general health tests", which look at the condition of all the insulation and cannot locate problems, and "partial discharge locators", which can locate partial discharges that are signs of incipient faults along the cable system. Most of these tests, being developed in the last 10 or so years, are relatively new to cable diagnostics. Each provides information about insulation "quality" and will give indications of degraded insulation. Test results are subject to interpretation. For a detailed description of a test, consult the manufacturer or visit their website, given in Table 1.

The Insulated Conductors Committee (ICC) of the IEEE Power Engineering Society has a working group to develop a series of guides on cable field testing. They have recently published the first guide in a series: IEEE Std 400-2001, "IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems".

At Powertech Labs, we have been using a technology called LIpATEST. We developed LIpATEST and have been using it on XLPE over the last 10 years and more recently on PILC. The technique applies a stepwise increasing dc voltage from a highly regulated, very low ripple power supply. The leakage current is measured with a sensitive, highly filtered, dc pico-ammeter, which is fiber-optically coupled to the data acquisition system. The maximum voltage applied is settable and does not exceed 1.5 times normal voltage. The test is computer controlled and the test duration is less than 10 minutes per cable. The equipment is suitcase-sized and easily transportable.

METALLIC SHIELD OR NEUTRAL CONDITION ASSESSMENT

Copper shields or neutrals over polymeric cables may suffer mechanical damage during installation, or over time experience damage from temperature cycling, particularly under cable clamps. The lead sheath on PILC may be subject to fracture and creep, resulting in cracks and breaks. Corrosion may also be a serious form of shield damage in both copper and lead, even in fully jacketed cables. Breaks in the metallic shield on polymeric cables may lead to points of high electrical stress, which may lead to local partial discharge and ultimate failure.

CORRODED METAL SHIELDS CAUSE FAILURE FROM OUTSIDE IN

To determine the condition of the cable shield, an initial assessment is made with a dc resistance meter. If the resistance reading is high, Low Voltage Time Domain Reflectometry (LV TDR) can be used to locate the points along the cable where the neutral or shield is deteriorating. The LV TDR sends a low voltage, fast rise-time pulse down the cable, and an oscilloscope in the unit shows reflections when cable transmission characteristics change. Reflections show cable splices as well as shield breaks. The LV TDR test equipment is very small and easily transportable.

If the neutral or shield is damaged or corroded at many points along the length of the cable, a recommendation to replace the entire cable may be made. If the corrosion is isolated to only a few points, these locations may be cut out and

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new sections of cable spliced in place.

In the case of PILC cable, cracks or breaks in the lead sheath can lead to oil seepage or water invading the insulation. If the phase conductors are not individually shielded, the lead acts as the shield on a PILC cable, and lead breaks may cause high electrical stress points. An LV TDR check of the cable may show reflections at very large holes in the lead. With respect to duct installed PILC, many lead breaks occur in manholes, at duct exits and around splices.

A close visual inspection may locate problems in the manholes. To locate small cracks or incipient problems, a metallurgical examination may be necessary.

CABLE JACKET TESTS

In jacketed cables, the jacket may be compromised during installation, or may age and crack, particularly when

Section of cable with heat damaged insulation

exposed to certain chemicals or soil conditions. A damaged jacket is often a first indication that further problems may be encountered. To test a cable jacket, the cable must be de-energized and the shield/neutral grounds must be disconnected. A dc voltage check with a multimeter between the floating shield and ground will indicate if the jacket is intact. A potential of several volts on the metallic shield will indicate corrosion activity and a compromised jacket is likely the problem. Switching the multimeter to the micro-amp range and measuring the short circuit current can give an indication of the magnitude of corrosion and jacket damage. If the jacket appears to be intact, the jacket insulation resistance should be checked with a Megger.

CABLE ACCESSORY TESTING

Cable accessories, including splices or joints, and terminations or elbows, are some of the most vulnerable parts of an underground installation. Failure mechanisms in accessories are varied, but one of the most common causes of failure is improper installation. Often poor installation does not result in failure for many years. To determine the condition of accessories on-site, generally two symptoms are assessed: elevated operating temperature and presence of partial discharges.

Operating temperature is easily measured on an energized, current carrying accessory with a hand-held, infrared detector. The load current must be recorded during the temperature measurement test. Obviously, the higher the current, the higher the temperature. In

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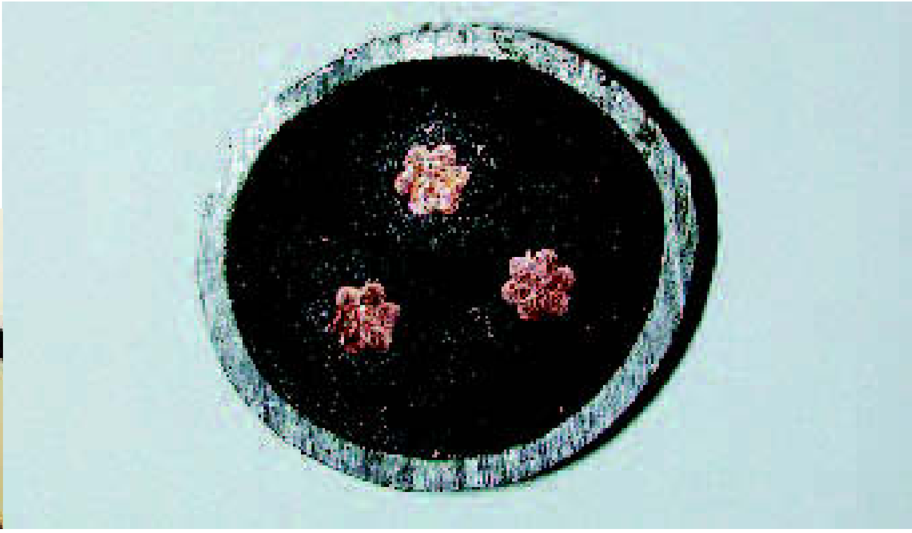

Older 3-phase PILC cable without jacket. Note the phases are not individually shielded.

general, the surface temperature on a splice or termination should be lower than the surface temperature on the incoming cable. If not, an accessory problem is indicated.

Partial discharges (pd) in accessories can be located using a number of off-line or on-line techniques as given under "Partial Discharge Locators" in Table 1. In addition, we have found that sonic or RF detectors are very useful in listening for pd in terminations or accessible splices. Non-contact sonic probes may find surface discharges, which indicate contamination that may lead to a breakdown. A contact sonic probe or RF detector is required to detect internal discharges. Since cables must be energized for pd testing, contact probes should be electrically isolated from the person doing the test.

LOCAL ENVIRONMENT AND OPERATING CONDITIONS

A good deal of information that will help determine the condition of the cable system can be had with simple observations or questioning site personnel during the testing. Always try to find out and record:

- Current loading and duty cycle
- Fault levels
- Previous failures
- Lightning levels and whether arrestors are installed
- Water table fluctuations
- Workmanship of the installation
- Surface contamination on accessories

Corroded metal shield causing failure from outside in

An environmental test that may be helpful is a test to determine the chemical composition of groundwater. This may be required particularly when surface deterioration is seen on accessories or jackets. One operating condition that can seriously affect cable life is elevated temperature. It may be possible to monitor cable-operating temperature by installing thermocouples at "hot spots" along the cable. The environmental assessment should be done in conjunction with diagnostic tests to prioritize cable maintenance and replacement.

CONCLUSION

A cable condition assessment program should evaluate all parts of the cable system. Any test program must be designed to find serious cable defects requiring immediate attention, and to assist in prioritizing future cable maintenance and replacement. The ultimate purpose of a test program is to improve system reliability and minimize long-term cost.

Vern Buchholz is Director Electrical Technologies at Powertech Labs. For more information visit www.powertech-labs.com. **ET**