NEW ENHANCEMENTS FOR CABLE FAULT LOCATION IN COMPLEX MEDIUM VOLTAGE DISTRIBUTION NETWORKS

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ABSTRACT /SUMMARY

Even with ever improving cable technology and broadly adopted diagnostics tools, classic cable fault location applications remain a daily challenge for distribution grid operators. A benchmark study shows that operators face about 8 MV-faults per 1000 km line length every year.

But cable fault location is by no means a basic routine job. "Every fault is unique!." The adequate practical tools in terms of test technologies are available. Nine field proven methodologies for different fault types and network arrangements are described. A majority of faults can be found with a fairly standard procedure; however operators and testing professionals also need to cope with the extremes. The biggest challenge is not missing testing technology.

New enhancements therefore focus on supporting users and organisations of powerful test equipment better. This means support not only for the specific measuring task but support a long the complete job from assignment to repair and final report. A practical case from winter cable fault location in the swiss alps illustrates the practical challenges.

RELEVANCE OF CABLE FAULT LOCATION

Based on BAUR internal studies [1] the Medium Voltage (MV) distribution grid comprises of some 30 million kilometres power cables worldwide. MV-Cable lines represent a significant portion of grid operators network-assets. Therefore importance of effective maintenance and fault location for underground cable distribution grids is vital and the relevance is increasing due to several factors.

New MV-Cable Lines

The trend to substitute overhead lines with underground cables remains despite the higher investment cost. Increased regulatory pressure results from environmental impact and reliability performance. In some countries like the Netherlands cable ratio is 100%. In Austria –traditionally with a low cable ratio, operators reach also cable ratios above 60%. [2]

Often integration of renewable energy is happening at Medium Voltage level. Regulations are forcing utilities to connect these new generation capacities, resulting in additional MV cable lines. Offshore-Wind Projects like Baltic 1 in Germany with 23 new 33kV offshore submarine cables are other examples of increasing footprint of MV cable lines. Such installations also illustrate the increased but sporadic need for fault location equipment handling long cables. We could successfully gain experience on fault location systems operating on cable circuits over 400 km length in the Mediterranean. The average MV distribution cable however is about 800 m long.[1]

Increased complexity of distribution grids

The technical setup of MV grids is getting more and more complex. Most cable lines exist for decades. Necessary repairs and network enhancements, have led to many mixed lines comprising of cable sections with different insulation material (oil impregnated paper lead - PILC, Plastic- PE, XLPE,PVC or Rubber - EPR). Joints, often the weakest part in a insulation system, exist from different manufactures, different assemblers and different technology (resin,/ heat shrink etc.) in one and the same circuit. Many cable lines are operated in a closed/open ring configuration, allowing reliable power supply and fast automated power supply restoration after a fault. However there are also T-Branched grid sections and single or parallel supply lines to critical large connections. On top the distribution grid is aging. Many lines are operated for more than 40 years. Less than 50% of grid operators deploy a proactive condition based maintenance strategy by conducting Loss Factor and Partial Discharge cable diagnostics. With limited investment in scheduled replacements, it often means "waiting until it fails". Even with deployment of condition based maintenance, the need for classic cable fault location technology remains, as 45% of faults result from external action like construction [3]. Commercial pressure on the maintenance expenditures and high penalties for power outages with commercial customers are two more but contradicting factors calling for effective cable fault location.

In the Study underlying this paper [1] we have learned from utilities around the world key distribution grid indicators. We have been able to build a model to quantifying the relevance of cable fault location for different utilities environments. To exemplify we have listed data for a rural distribution network, a cosmopolitan distribution network (industrialized country) and a cosmopolitan distribution network (developing country).

Grid Type	Total Grid	MV cable	Cable Faults	Average MV circuit
Rural (industrialized)	11500 km	3900 km	20/year	500m
Cosmopolitan (industrialized)	77100 km	24700 km	289/year	1300m
Cosmopolitan (developing)	7300 km	3100 km	27/year	860m

Table 1: key distribution grid indicators

We concluded in this study that in average a distribution grid operator has to cope with about 8 severe (MV) fault per year for every 1000km of MV-network. Cosmopolitan operators face several hundreds of faults per year making this a daily job for specialized teams. In Sweden this would mean 7 faults per day.

Modern diagnostics tools help not only to judge the condition of older cables but ensure high quality construction work. Many faults are critical after years only. A immediate assessment after laying helps to reduce future faults. But even with the best diagnostic tools the need for classic cable fault location technology remains.

FAULT LOCATION METHODOLOGY

Talking to fault location experts around the globe one often hears: "Every fault is unique". Depending on the fault characteristic, the most appropriate fault location methodology has to be selected. The success of a cable fault location depends greatly on practical ability to categorize faults based on experience of the user. A thorough understanding of power cable design, operation and the maintenance is needed to judge individual cases. Especially the design of the jointing grounding system, details about the cross bonding arrangement, information about joint material, cable insulation type (e.g. PILC, XLPE) and the cable laying method (direct buried, tunnel etc.) help to select the right methodology. Information about the history of each circuit is additionally helpful. This requires trained personnel ensuring the correct fault location procedure.

Nevertheless cable faults can be categorized in according to their loop resistance.

<u>Cable Fault Categories [4]:</u>

1. Fault between core-core and/or core - sheath:
   - Low resistive faults (R <100-200 Ω), short circuit
   - High resistive faults (R > 100 - 200 Ω)

     Intermittent faults (breakdown faults, need certain voltage level or energy to trigger fault)

     Interruption (cable cuts)
2. Defects on the outer protective shield (PVC, PE) - Cable sheath faults

Most of the cable faults occur between cable core and sheath. Most tricky are intermittent faults, as they may not be present continuously and require a certain break-down voltage and energy. This highlights the challenge for fault location equipment to cover several applications with an easy to handle system. Table gives an overview on fault categories and testing appropriate testing methodologies.

Low resistive fault	TDR -Time Domain Reflectometry
Interruption	TDR -Time Domain Reflectometry
Intermittent faults	SIM/MIM - Multiple Secondary Impulse Method
Intermittent faults long cables	ICM – Impulse Current Method
Intermittent faults High breakdown voltage	Decay-Method
Sheath faults	Bridge measurement (Muray/Glaser)
Intermittent faults in wet Joints	Burn Down Technique

Table 2: Fault location Methodologies

Looking closer we found that the majority of cable faults can be located using a fairly standard set of methodologies. By starting with resistance measurement, followed by a simple Time Domain Reflectometry and concluding with the advanced Secondary Impulse Method, one can Pre-locate the distance to the fault from the substation for most low and high resistive, including intermittent faults. The second task is pin pointing the fault out in the field eventually supported by cable tracing and cable identification.

However operator's investment in equipment and the skills of testing professionals also needs to cater for extremes. One specialty being long cable circuits sometimes several hundred kilometres long (ICM). Others include very wet joints (Burn Down), solid short circuit faults (Bridge), unusual insulation material (Bridge), T-branch-MV-networks (Differential ICM) und usage of the very same equipment also for LV-faults e.g. in lighting systems (high energy at lower breakdown voltage). To cover these, fault location equipment provides various performance parameters like Measuring Range, Surge Energy, Output Voltage and Current. The principle methodologies and technologies for fault location have not changed in recent years and still remain up-to-date.

The biggest challenge for operators and users is to cope with this complexity of network environment and testing portfolio there is not much need for yet another testing technology.

NEW ENHANCEMENTS

New enhancements in fault location technology focus on a system to better support users with integrated flexible tools supporting especially the commercial and organizational challenges faced. We observed the general trend of decreasing test and measurement expertise in many field-maintenance teams. In Addition smaller maintenance teams get broader responsibilities, resulting in a broader technology scope and less frequent use of each technology. Based on this insight we developed a User Experience Circle concept, supporting the overall task for Test-Crews not only the technical testing job.

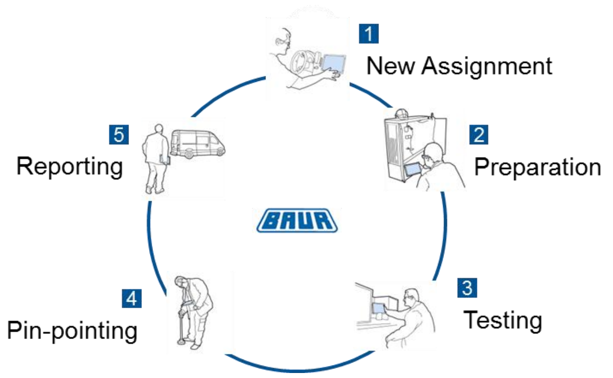

Figure 1 – User Experience Circle

The job starts usually with a **new fault location assignment**. As explained it can be essential to have as much information about the defective cable system as possible. With the assignment essential information about the cable system needs to be provided to the test technician.

After arrival at the substation a set of **preparation** activities and overall first environmental fault analysis is done. This also includes disconnection and switching activities involving highly important operational safety procedures and communication followed by visual inspection and grounding/connection of the testing system.

Only now the **testing** and fault location procedure starts with Pre-location. This step determines the distance to the fault from the substation where the testing equipment is connected. A complex task as described before. System support to select the most appropriate procedure can be provided.

With **Pin-Pointing** the exact location of the fault along the cable line is determined and marked for repair measures. Depending on the exact location the actual repair method can vary. Context Information helps to optimise this and minimising the stress put on the cable system.

After completion the fault location activities should be documented in a **report** to be available for subsequent work and later asset management analysis. In case of Service Providers, a detailed documentation for reporting and billing is required.

Key areas for improvement:

Modern software controlled systems provide support along this complete experience cycle. However some additional criteria must be kept in mind: One being robust, reliable construction, especially with additional computer systems integrated. Moreover the system should be upgradeable with cable diagnostics and should retrofit in existing cable Measurement infrastructure. There are mainly three areas of improvement with modern cable fault location equipment.

First**, ease of use** for test crews simplifying the test process, avoiding operating errors and reducing training effort whilst maintaining transparency and control.

Second, supporting test crews with more **flexible and more fault adequate procedures** in order to find faults reliably and reduce negative impact on cables (by using suboptimal methodologies)

Third, **information integration** with corporate, technical or environmental information sources supports users and organization with better asset information and allows better informed decisions.

PRACTICAL CASE

January 2012 in the Swiss canton of Ticino. Temperatures up to -20°C and snowfall forcing the test engineer going to work by helicopter to the mountain to a point of about 2,000 meters altitude. A medium voltage cable has failed at the Robiei Power Plant. The Robiei Power Plant is one of six water or pump-fed storage power plants operated by Maggia Kraftwerke AG. The electric power for the plant is supplied through 16 kV medium voltage cables. The defective cable passes through a tunnel between the Bedretto Valley and the Maggia Valley. It is several kilometres long. The largest part of the route it takes is in water. It is especially important here to exactly locate the fault in the forefront of a repair because the repair method greatly depends on the location. If the fault is in the dry part, conventional repair is carried out, in the water part, however, custom-made joints must be used and the tunnel must be drained for the repair. The equipment and personnel is dropped at the tunnel entrance. A hand-held echometer, a surge voltage generator, a burn down transformer and a measuring bridge unit for sheath testing and fault location, all produced by Baur Prüf- und Messtechnik GmbH, Sulz Austria, will be used.

After employees of Maggia Kraftwerke have shovelled a pathway to the tunnel, the test engineer begins with the grounding and precautionary measures, only then does he connect the equipment. With the equipment sheath test, resistance measurement, SIM/MIM measurement, fault burning, can be performed. The troubleshooting should be successful - it's just a matter of time.

First step is the resistance test immediately followed by an TDR measurement. Measurements already provide an initial result: According to the measurements, the cable is not 4200 m as expected, rather only 800 m long, and in all three phases - i.e. a clear interruption of all three conductors. At 800 m distance, in the walkable and dry part of the tunnel, one should find a joint if the network documentation is right. Now a surge generator is connected and the trained engineer performs acoustic pin pointing in the area of the joint. The flashover at the fault point is clearly audible. A service team must replace the defective joint. A few days later, the broken point is removed; a 15 m long cable piece is used and is connected with the old cable pieces with two new joints. In early February, the final cable test can be done from the opposite side in the Maggia valley to confirm successful repair. On this day the equipment can be transported with the goods ropeway from San Carlo to the Robiei power plant. With this, the complete test engineering equipment is available in the vehicle. A VLF cable test (Very Low Frequency) with 0.1 Hz using the BAUR device "viola" confirms it: The line is now intact again, the repair was successful.

REFERENCES

[1] Lehner, Gerstner, Buschjost, Haag, „Kabeldatenbank“, 2011, BAUR Prüf- und Messtechnik GmbH, A-6832 Sulz, 37-50

[2] TIWAG Netz AG, 2012, "Netzkennzahlen", *TIWAG-Netz AG, A-6065, Corporate Website*

[3] Bewag Aktiengesellschaft & Co. KG, „Bewag verbessert Versorgungssicherheit“ Pressemitteilung 2001

[4] Tobias Neier, 2009, “Cable Fault Location in LV, MV and HV Underground Cable Networks”.BAUR Application Guideline V1, 9-15.