Improving the Reliability of the Transmission and Distribution Network

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Abstract— **The transmission and distribution network play a central role in the electricity system. According to this, their operational safety and reliability are highly important due to the continuous availability of electrical energy. Live Working (hereinafter referred to as LW) is a group of activities where line workers work on energized network elements, reducing the number of blackouts and interrupts on the network. However, in the last few years the electricity system has changed, so that new challenges have been appeared for system operators. One of the main goals is to increase the flexibility of the transmission and distribution network while maintaining the reliability level. As a result, new methods such as Dynamic Line Rating (hereinafter referred to as DLR) are being introduced to increase the capacity of transmission lines. In addition to the emergence of new methods, existing technologies also need to be reviewed. The main aim of this article is to present how live line maintenance (LLM) equipment test and technology education were revised, and how DLR method could improve the reliability of the distribution network.**

Keywords — distribution network, live workong, LW, live-line maintenance, LLM, dynamic line rating, DLR, system resilience, equipment testing, LLM education

I. Introduction

When it comes to electricity, it is now unthinkable that we should deprive customers of service continuity. Avoiding power cuts, maintaining a high level of availability for networks, ensuring the safety of operators and third parties, continuously adapting to technical developments: these are the issues in Live Working (LW). Invisible to users, this technique is now essential and forms an integral part of the design of electricity transmission and distribution networks [1].

Several million work sites every year, tens of thousands of operators, countless power cuts avoided: LW represents a very important activity, supporting quality of service and security of the transmission network. Developing working rules and tools, providing and maintaining these tools, as well as a professional approach and sustaining the skills of field teams are key parts of the activity [1][2].

Electrical installations are designed to transmit and distribute electrical power across the whole country. Their size depends on the specific dictates of electrical phenomena – such as the necessary separation between conductors of different phases. In particular, the electrical insulation of conductive elements is ensured by air distances and insulating materials: glass, porcelain, different composites etc.

The same principle applies to LW, with the additional constraint of an operator and tools that move in the air gap. So additional rules are needed to take these constraints into account and so the safety of operators can be ensured [2].

II. Live Working in General

A. *Concept of the LW*

The introduction and implementation of maintenance of electrical installation using the live working method can be classified among the innovative efforts of organizations.

LW includes all activities in which a worker deliberately makes contact with live parts or reaches into the LW zone with either parts of his or her body or with tools, equipment or devices being handled [3].

Note: At low voltage, live working is carried out by the worker, when making contact with bare live parts. At high voltage, live working is carried out by the worker, when entering the live working zone, regardless of whether contact is made with bare live parts or not [3].

LW is a method of maintaining electrical installation that was originally established at the beginning of the 20th century. The first use of the method was mentioned as early as in 1913 in the USA. In spite of a hundred-year tradition, live working has gained a new development impetus in the recent period due to the restructuring of the sector of transmission and distribution of electric power. It could be argued that by the opening of the electric power market, old monopolies in the electric power transfer and distribution seemed to have vanished [2].

LW has a hundred-year tradition in the world. The history of LW development is represented by many authors [1-8]. Table 1 presents several historical data. Hungary began very early with the development of its own LW technology in the early 1960s. Slovenia started introducing LW 10 years ago.

TABLE I. HISTORY OF LW DEVELOPMENT

1913	The first carrying out of LW was documented in the USA.
1920	Canada
1920 – 1930	Germany, Sweden, SSSR (Russia), Switzerland
1932	Australia
1933 (1975)	Poland
1939	Great Britain
1945	Chile
1952	China
1962	Hungary
1963	France
1971	Argentina
19xx	Brazil, Spain, Italy, Ireland, Colombia, Peru, Ecuador, Uruguay, Venezuela, Romania, Czech Republic, Slovakia, Portugal, Norway, Belgium, New-Zealand, India etc.
20xx	Croatia, Slovenia, Turkey

Although a hundred-year tradition of live working exists, it represents a new method of maintenance of electrical installation in the generation, transmission and distribution of electric power as well as in the industry and different institutions [2].

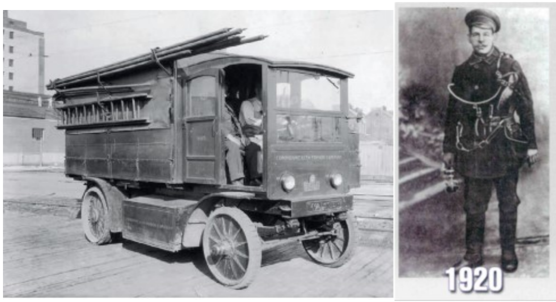

Fig. 1. Truck for Live Working and live line worker , USA, 1920s. [1][2]

B. *SWOT analysis of the LW*

In order to present the potential of LW in maintenance works a short review of SWOT analysis is presented here [2]:

Strength of LW works are:

- safe, tested procedure,
- the risk and number of accidents can be decreased,
- the malfunctions can be repaired immediately, their expansion can be prevented,
- no consumer disturbance and increased availability,
- it can be combined with regular technology,
- less environmental damage.

Weaknesses of LW works are:

- high investment cost and requisition costs dependent out task and technology,
- higher than average maintenance costs,
- increased administration tasks,
- the complex economic analysis of the investment.

Opportunities of the technology are:

- stricter regulations from the authority of energetics for consumer disturbance,
- national high quality educational system,
- the live line maintenance (LLM) administration is significantly reducible with modern consistent technology.

Threats of the technology are:

- the uncertainty of the national entrepreneurs implementing LLM,
- changing political environment,
- buying new technologies without the required technological knowledge.

III. LW WORKING METHODS

There are three methods of LW: hot stick working, bare-hand working and insulating glove working. The difference mainly lies in the position of the operator relative to the voltage on which he wishes to work [1][2][3].

A. *Insulating Glove Method*

The method of live working in which the worker, whose hands are electrically protected with insulating gloves and possibly insulating arm sleeves, carries out his work in direct mechanical contact with live parts. For low voltage installations, the use of insulating gloves does not exclude the use of insulating and insulated hand tools and suitable isolation from earth [3].

In the insulating glove working method, the operator is protected depending on the voltage range of the parts he is working on and enters the area located between live exposed parts and the safety distance. Used for low voltage (LV) and medium voltage (MV), this method cannot be used for high voltage (HV) because large distances are required for safety. For MV, the operator uses insulating gloves and works from an insulated arm platform. It is more ergonomic than hot stick working and also allows easier movement close to the supports (poles) on MV [1].

Fig. 2. Insulating glove method [2]

B. Hot Stick Method

The method of live working by which the worker remains at a specified distance from the live parts and carries out his work by means of insulating sticks [3].

In the hot stick working method, the operator remains at earth voltage. In order not to come into contact with exposed live parts, he works using insulating tools fixed to the end of sticks or insulating ropes. Used in all voltage ranges, this method requires low investment, but it is ergonomically limited, particularly when the distances for the work become large. For MV, a metal-armed lifting platform can be used. For HV, work is generally done from the tower for works on lines and from the ground for works in substations [1].

Fig. 3. Hot stick method [2]

C. Bare Hand Method

The method of live working in which the worker carries out his work in electrical contact with live parts. For the maintenance work, his potential is raised to the phase voltage and suitably isolated from the surrounding [3].

In the bare-hand working method, the operator is insulated from the earth and brought to the voltage of the element he is working on. He is therefore in a similar position to a bird sitting on an electric line. At all times he must remain at the working distance from all elements in his environment that are at a different potential to the element he is working on. This applies to him and to the tools or conductive parts he handles. Used for MV and HV ranges, this method is very ergonomic that makes the work comfortable. The work is done from a platform insulating the operator from earth voltage. For MV, an insulating-arm lifting platform can be used. For HV, a IPT (Insulating Positioning Tower) is currently used for work in substations, and a hoist ladder, beam ladder or LW chair for working on lines [1].

Fig. 4. Bare hand method [2]

Whatever the approach method used, LW demands specially designed tools and accessories. They are grouped into different families based on their function: handling, positioning the worker, job type etc. The working method and voltage range are considered in their design. To avoid any risk of short-circuit or electric shock, tools must be compatible with the sizing principles for the electrical installation as well as acceptable physiological thresholds for the human body [1].

IV. Testing of Equipment and Training for LW

LW can be considered a contribution to safety and quality of electrical installation maintenance procedures on all voltage levels. There have been quite a few attempts around the world to promote the concepts of maintenance work without accidents or with “zero accidents” [2].

The problem of the field "Inspection and Testing of Equipment and Training for Live-Line Work on Overhead Lines" is very topical, as in the development and use of the LW method there is a need for an expert guidance. There are numbers of open questions in this area, as there are different standards and practices worldwide. Considering the topical findings, CIGRE Paris set up a Working Group (WG B2.64) with the aim of making recommendations in this area.

Live-line maintenance is widely applied worldwide at low, medium and high voltage levels in the grid of both transmission and distribution system operators because of its technical and economic benefits [4].

This way of work requires special tools to guarantee the maximal safety of the workers. All the equipment used for different tasks executed by live-line methods have to proceed various inspections before use [4]. Another important aspect regarding to different live-line activities is related to the education of workers.

A. Inspection and Testing of Equipment

Inspection and testing of equipment could be type tests at the factory, acceptance tests before the first use, on-site tests before every use and periodic tests after a pre-defined period of time [4].

Nowadays there are many different international standards and national regulations regarding to the inspection of different LW equipment [4]. Unfortunately, there is not any frame to define the different kinds of test and the periods of them, so the condition, the way of certification and expiration of inspections can be varied in a very wide range depending on the country and even the company where they are used [4].

Tools and equipment used for LW are subjected to a wide range of stresses during its use as well as when being transported to the working place and also during storage. In order to ensure that the tools and equipment are safe to use at all times, they must be designed and manufactured in such a way that they can withstand any possible exposures to the stresses during its entire life cycle. A system of tests on the tools and equipment helps to ensure the safety of the workers while LW is being performed [4].

These tests generally include the control of physical, operational, mechanical, electrical and thermal properties of the tools. Keeping in mind, the scope of the tests to be simulated depends generally on the type and purpose of use, the exposure to mechanical stresses, and the operating voltage of the electrical system at which LW shall be performed [4].

TABLE II. RESPONSIBILITIES REGARDING TO DIFFERENT TYPES OF TESTS AND INSPECTIONS [4]

Type of test/inspection	Point in time	Responsible
Type Test	new equipment	Manufacturer
Routine Test	new equipment	Manufacturer
Sampling Test	new equipment	Manufacturer
Acceptance Test (Hand-Over Test)	new equipment	Employer (before purchase)
Periodical test	during lifetime	Employer (periodically)
Pre-job Inspection	during lifetime	Employee (before every use)

The minimum requirements of the necessary tests for LW tools and equipment can be seen in Table II. including the type, performance and scope that are defined in numerous International and National Standards (i.e. CENELEC, IEC, ANSI, ASTM, CEA) [4].

B. *Training for Live-Line Work on Overhead Lines*

Distribution and transmission operators ensure safe and secure operation of the network. In this context, it is necessary to take into account the requirements of safe and healthy work on the network and the installations.

It is very important that LLW providers are competent, as much as efficiently and safely as possible by individual actions.

Competence should be emphasized with high-quality, basic training and regular periodic refresher training. Basic live working training is essential for the safety of all workers, which is provided, with training for those tasks, which they will be required to perform.

The Basic Live Working training consists of theoretical and practical knowledge which will be required to be demonstrated by the recipient of the training after the completion of the training on the Live Working activities. This will be undertaken on the grid systems used during the training. Basic Live Working training may also be required if the person has lost competence due to minimal Live Working activity or has exceeded the period of validity of his or her Live Working training certificate [4].

Refresher live working training is to be used for those tasks for which an individual has previously been trained and qualified as well as the introduction of new application and or equipment. An extension training (further training) can be an integral part of the refresher training beyond the scope of the basic or the latest refresher training for given voltage levels and methods. The extension part of the training must consider sufficient theoretical and practical training for the new procedures based on the requirements of the Basic Live Working Training. Live Working Refresher Training should be done before exceeding the validity of the Live Working training certificate which maybe a requirement in some jurisdiction [4].

Basic and refreshment trainings can be very different in each country, so the way and the requirements of the examinations. The same theoretical and practical topics of education and the same requirements of knowledge is a need from the aspect of the possibility of cross-country working. The proper education can guarantee the same level of knowledge and the safety of the work all the time – and also make the possibility of independent and international audits and certifications [4].

V. CONCEPT OF DYNAMIC LINE RATING

A. *In general about DLR*

The availability of electricity and the maintenance of safe operation are extremely important for the system operator. A good and effective method to ensure these are the LW, but not the only one, which will ensure the proper operation of the power system. Another method is Dynamic Line Rating, which enables better use of existing electrical infrastructure without any deep modification of the infrastructure. By applying DLR higher transmission capacity could be achieved for the conductors of the power grid [6][8].

In contrast to the currently used Static Line Rating where the ampacity limit of the wire is calculated by the presumed worst case scenario of the environmental parameters, in case of DLR the ampacity is calculated by time to time following the changes of the environment. This can be implemented with sensors on the conductor and so called weather stations which send information to the transmission system operator (TSO) about the power line in real time [9][10][11].

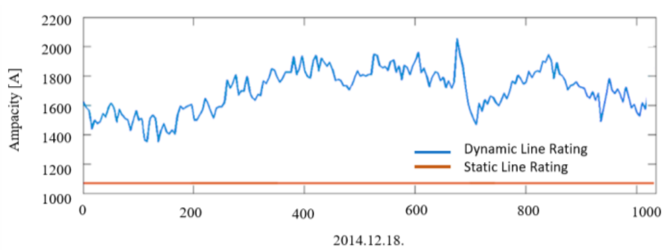

Fig. 5. Comparison of ampacity in case of SLR and DLR [12]

The main advantages of DLR are that it is a cost-effective method and the system implementation is easy and quick compared to building new power lines. Regarding to current level, in almost 95 % of time the ampacity calculated by DLR is significantly higher than the static rating value. Moreover, DLR could increase the reliability of supply and in those cases (5% of the time), when the DLR value is lower than Static

Line Rating (SLR) one, the stability of the grid is getting increased and so that a safer operation can be implemented. There are also additional benefits applying DLR in case of extreme weather conditions. This method is able to prevent undesirable icing of the overhead lines (OHLs) or melting the established ice layer from the conductors [12][13].

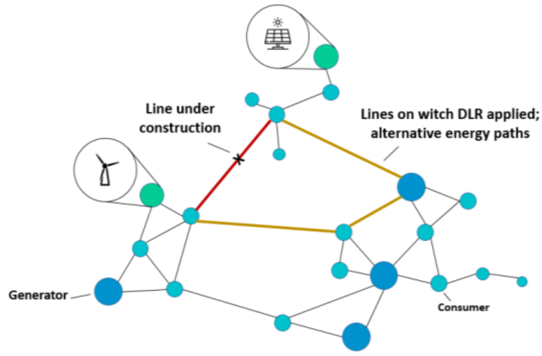

Fig. 6. Illustration of the use of DLR if LW cannot applied on the line [13]

B. *Weather stations*

The essence of DLR is the real-time monitoring of the environmental and load parameters around the OHL. As a result of monitoring large number of data are available from the sensors and weather stations which are transferred to a data center wireless [13][14].

Fig. 7. Weather station installed on the high voltage tower [13]

In general, the monitoring of the environmental parameters is less complicated than the measurement of the load or temperature parameters of the conductor. In cases, where meteorological stations are near the OHL, TSOs could use data measured in these stations for the ampacity calculations. However, if the spatial or time resolution are not satisfactory local weather stations could be installed on the OHL. These weather stations do not need any contact to the conductor, so that the anemometers, solar radiation measurement panels etc. are usually installed on the peak of the high voltage tower which means easier implementation [12][14].

C. *DLR sensors*

All OHL has a maximum conductor temperature that cannot be exceeded in order to avoid undesirable increase of sag in each spans. The temperature of the conductor increases due to the Joule-heat of the current which means that the ampacity of the OHL depends on the thermal state of the wire. According to this, conductor temperature sensors are also necessary for the application of DLR. There are a lot of type of the sensors with different principle of measurement and implementation but the common in these devices is that they are installed on the conductor.

Fig. 8. Different DLR sensors on the line (USi, Arteche, OTLM, Lindsey, Micca, Ribe Group) [15]

The main scope of these sensors is to measure the temperature of the surface of the conductor but in the most cases there are also additional measurements of other parameters. A lot of sensor are able to measure the sag angle, conductor vibration or the current of the conductor [12][13][14].

The advantage of the sag measurement is that it changes as a result of the average temperature while the direct temperature measurement of the sensor carries information about one point of the span. The determination of the current of the wire also makes the temperature measurement more precise. Most of these sensors are self-supplied from the conductor but there are also battery-based implementations [12][14].

VI. Synergy of the LW and DLR methods

As a result of these mentioned attributions, DLR could be an important method for grid management in the near-future. There may be cases where there is no possibility to apply Live Working in maintenance works. This may be due to several reasons e.g. there are countries where barehand method of LW is not applied. However, in these cases the continuity of operation is also important for the TSO and the consumers. At this point DLR could be applied on the surrounding lines to increase their transfer capacity locally. As a result of applying DLR there are alternative paths for the energy to bypass the de-energized part of the grid. In this way DLR could be applied as a complement method of Live Working in order to increase operational safety.

Another important common point for LW and DLR is the sensor for the real-time OHL monitoring. A promising concept could be in this case is to install these devices onto the conductor via LW methods. The most sensors are able to be installed in LW, and in this way unnecessary de-energizing could be avoided. On the other hand, for the safe sensor installation there is a need for a uniform, strict regulation that defines the exact rules of the working method and also on-site training to get proper experience on the OHLs.

VII. Conclusion

Safety and security are highly important in case of grid management but the continuity of supply and reliability are also an integral part of system operation. In order to satisfy the demand of the consumers there are different grid management methods such as LW and DLR. While LW is in progress since 1920s, the technology and working methods have been changed from time to time. International committees such as CIGRE ensure a platform to uniform the different regulations that can vary from country to country. These brochures conclude the working methods, inspections, equipment tests and training methods which makes LW not just efficient but also safe. On the other hand, DLR is a novel method to exploit better the potential of our existing electrical infrastructure and so that safety and reliability could be increased. As a result of DLR, the ampacity of the conductor could be increased which is beneficial for the TSO and also the consumers. There is a possibility the apply LW and DLR individually, or as a complement method of each other. Moreover, the installation of DLR sensors provide an alternative way to combine these methods in order to reach higher efficiency. However, to implement these kind of combined application in the future there is a need for a strict and exact standard to maintenance the level of safety and security that characterizes the existing live works.

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