Review of lightning monitoring systems on transmission lines under 50 kV

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Abstract

Lightings are one of the major threats to transmission lines, because they carry very high currents and they are hardly predictable. The overvoltages result in producing malfunctions of the transmission lines such to destroy the insulation system and cause economic and physical damages to people and services. The aim of the paper is to review most commonly exploited lightning monitoring systems and devices in Italy and other European countries, as well as to find out available sensors and some different ways that information can be send to users by transmission lines .

1. Introduction

This document is an introduction to the basic solutions adopted to measure and communicate the variations in the operating conditions of transmission lines due to lightings, one specific filed in high voltage engineering. Section 2 introduces different kinds of sensors, transmitters and communication devices to provide all the information needed to study and address the lightning issue. Before dealing with particular voltage levels such as the ones under 50 kV, it is also useful to introduce the different subdivisions adopted in Europe, especially in Italy, and the standards that rule the lightning issue. These will constitute the background framework in this discussion.
Overhead power transmission lines are classified according to voltage ranges in the electrical power industry:

- **Low voltage** (LV) – less than 1000 volts, used for connection between a residential or small commercial customers and the utility;
- **Medium voltage** (MV; distribution) – between 1000 volts (1 kV) and to about 33 kV, used for distribution in urban and rural areas;
- **High voltage** (HV; subtransmission less than 100 kV; subtransmission or transmission at voltages such as 115 kV and 138 kV) - used for sub-transmission and transmission of bulk quantities of electric power and connection to very large consumers;
- **Extra high voltage** (EHV; transmission) – over 230 kV, up to about 800 kV, used for long distance, very high power transmission;
- **Ultra high voltage** (UHV) – higher than 800 kV [1].

Our review, then, will cover low, medium voltage and the lower levels of high voltage. CENELEC (European committee for electrotechnical standardization) has adopted the IEC TC81 (Technical Committee on Lightning Protection of the International Electrotechnical Commission,) standards. TC81 divides the standards into four parts: protection of structures against lightning - general principles, risk management, physical damage and life hazard, electrical and electronic systems within structures.

2. Measurement systems and devices

The three important elements of a measurement system are: sensor, transmitter and the transducer. The sensor produces a response representing the value of the process variable. A transducer, which is within the transmitter, converts this response to a standard instrument signal. The transmitter amplifies this standard signal and sends it to a controller and/or other instruments.

2.1 Sensors

The sensor is a primary sensing element and exists in close proximity to the process. The sensor measures the controlled variable in the process and sends a non-standardized signal to the transmitter [2]. When selecting the sensor, several factors should be considered, for instance: range, response time, accuracy, precision, sensitivity, dead band, costs and installation problems [3]. Here there are three possible solutions to take trace of the lightning.

2.1.1 Rogowski Coil

It is an electrical device for measuring alternating current (AC) or high speed current pulses. It consists of a helical coil of wire with the lead from one end returning through the centre of the coil to the other end, so that both terminals are at the same end of the coil. The whole assembly is then wrapped around the straight conductor whose current is to be measured, see figure 1. Since the voltage induced in the coil is proportional to the rate of change of current in the straight conductor, then the output of the Rogowski coil is usually connected to an electrical (or electronic) integrator circuit to provide an output signal that is proportional to the current.

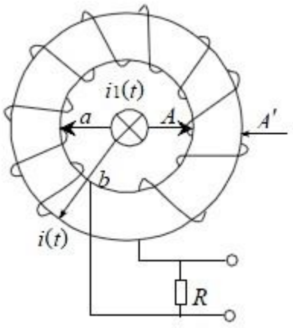

Figure 1. Rogowski coil

Advantages:

- it is not a closed loop, because the second terminal is passed back through the center of the toroid core and connected along the first terminal. Thus, it is open-ended and flexible;
- Rogowski coil can measure the waveform and amplitude of the lightning current;
- with a plastic or rubber tube as its core and not an iron core, it has a low inductance and can respond to fast-changing currents;
- with no iron core to saturate, the exciting characteristic of the coil is highly linear even when subjected to large currents;
- a correctly formed Rogowski coil, with equally spaced windings, is largely immune to electromagnetic interference.

Disadvantages:

- the output of the coil must be passed through an integrator circuit to obtain the current waveform. The integrator circuit requires power, typically +/-15Vdc and it is lossy whereas a traditional split-core current transformers do not require integrator circuits;
- there are uncertain factors during the measurements.

2.1.3 Current transformer

A wire coil is wound round one or both halves, forming one winding of a current transformer. The conductor around which is clamped forms the other winding, see figure 2. Like any transformer this type works only with AC or pulse waveforms. When measuring current, the subject conductor forms the primary winding and the coil forms the secondary.

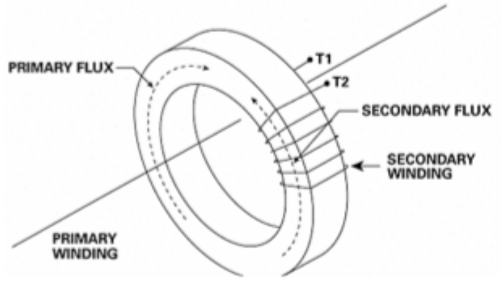

Figure 2. Current transformer

The alternating current flowing in the primary winding circuit produces an alternating magnetic field in the core, which then induces an alternating current in the secondary winding circuit. An essential objective of current transformer design is to ensure that the primary and secondary circuits are efficiently coupled, so that the secondary current bears an accurate relationship to the primary current. A disadvantage is the error in the value of the current through the transformer since the total primary current is not is not entirely transformed in the secondary current.

2.1.4 Hall effect IC sensor

Hall Effect current sensors can measure all types of current signals i.e. AC, DC or pulsating current.
Output Hall voltage is given as:

$$V_H = R_H \cdot \frac{I}{t \cdot B}$$

Where: V_H is the Hall Voltage in volts, R_H is the Hall Effect co-efficient, I is the current flow through the sensor in amps, t is the thickness of the sensor in mm and B is the Magnetic Flux density in Teslas.
The output voltage, called the Hall voltage, (V_H) of the basic Hall element is directly proportional to the strength of the magnetic field passing through the semiconductor material (output $\propto$ H)[4]. Hall Effect Sensors are available with either linear or digital outputs. The output signal for linear sensors is taken directly from the output of the operational amplifier with the output voltage being directly proportional to the magnetic field passing through the Hall sensor.

Advantages:

- Hall effect devices, appropriately packaged, are immune to dust, dirt, mud, and water;
- they are non-contacting current sensors;
- the device has three terminals. A sensor voltage is applied across two terminals and the third provides a voltage proportional to the current being sensed. Therefore, no additional resistance need be inserted in the primary circuit and the voltage present on the line to be sensed is not transmitted to the sensor, which enhances the safety of measuring equipment.

Disadvantages:

- Magnetic flux from the surroundings (such as other wires) may diminish or enhance the field the Hall probe intends to detect, so as to render the results inaccurate;
- Hall voltage is often on the order of millivolts, and the output from this type of sensor cannot be used to directly drive actuators but instead must be amplified by a transistor-based circuit.

2.2 Transmitters

The transmitter contains a transducer which converts the non-standardized signal of the sensor into a standardized form and amplifies it. If digital signals are being used, the transmitter will convert the signal to digital. The transmitter this article concerns is the Smart Transmitter, see figure 4.

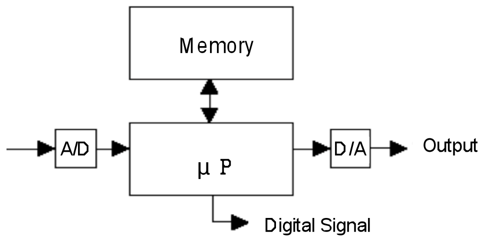

Figure 3. Smart transmitter functions

They can convert analog signals to digital signals (A/D), making communication swift and easy and can even send both analog and digital signals simutaneously as denoted by D/A. Components of the smart transmitter are illustrated in figure 5.

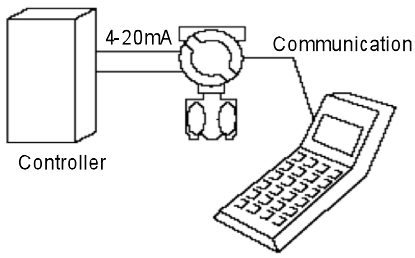

Figure 4. Smart Transmitter Components

The controller receives the output signal from the transmitter and sends it back to the final control element. The communicator is a hand-held interface device that allows digital instructions to be delivered to the smart transmitters. Testing, configuring and supply/acquiring data are all accomplished through the communicator. The communicator has a screen which displays the input or output information and can be connected directly to the smart transmitter, or anywhere on the loop in parallel.
Advantages of smart transmitters include ease of installation and communication, being able to self-diagnosis, increased reliability being less subjected to temperature and humidity effects, vibrations are less harmful, improved accuracy and inventory reduction.

2.3 Communication Devices

A broad variety of specialized data communication devices are available to suit the communication needs and it’s possible to introduce the commonest dividing them in modems and wireless systems[5].

2.3.1 Modems

Common modems available for data acquisition are:

a. **Limited distance modem** - low-cost general purpose modems can be used to transmit non-critical data up to 12 miles. As distance increases, transmission speed decreases. At 12 miles, speed is 1.2 kbps. At one mile, speed is 19.2 kbps, and at one half mile, 57.6 kbps. It requires four wires (two twisted pairs) for full duplex operation. To achieve the highest speed of 57.6 kbps, special high-speed, optically coupled circuits are required;
b. **Fully isolated modem** - when data is important, it must be protected against noise, common mode voltage problems, and electrical transients. Optical isolation and dc-to-dc transformer coupling create an isolation barrier of 1000 V rms. An isolated modem has the same transmission speed as a limited distance modem;
c. **Signal-powered fiber optic modem** - in environments with much electrical noise, a fiber optic modem can be used;
d. **High-speed fiber optic modem** - this device transmits data at speeds up to 5 Mbps 1.2 miles over a fiber optic link. As above, the transmitter/ receiver plugs into the data port at both ends. For more distance, a repeater can be installed.

Signals on fiber optic cable are immune to EMI and RFI. Fiber optics are being used more often as user applications demand higher and higher bandwidths. There are three basic fiber optic cables available: multimode step index, multimode graded index, and single mode. Multimode fibers usually are driven by LEDs at each end of the cable, while single mode fibers usually are driven by lasers. Single mode fibers can achieve much higher bandwidths than multimode fibers, but are thinner and physically weaker than multimode.

2.3.2 Wireless Systems

Before the advent of reliable radio data transmission to reach remote locations, communications required hard wiring. The wires had to be strung on utility poles or buried underground, which is neither cheap nor convenient. Today, transmitting data by radio-frequency is possible in a variety of manners:

a. **Microwave** - requiring line-of-sight between antennas, microwave systems can transmit data up to 32 miles. Such a system consists of an operator base station that can communicate with one or more remote terminal units (RTUs);
b. **Unlicensed link** - these narrow-band units operate in the 900-MHz band, and work at distances to 1 mile. With antennas or repeaters, distance can reach 90 miles at speeds to 115 kbps with a response time of 5-15 milliseconds between units;
c. **Spread spectrum** - when interference is present in the 900 MHz band, spread spectrum radios frequency hops from 902 to 928 MHz to get away from the offending interference.
d. **Licensed RF** - if data acquisition needs cannot be met by 900-MHz devices, devices that operate on licensed frequencies can connect up to 10,000 remote units. The limited availability of frequencies keeps these systems out of metro areas. Utilities in outlying areas are big users of licensed systems.
e. **Trunked or cellular** - for mountainous, or city settings where line-of-sight systems are impractical, trunked radio is a solution. The radio signal is transmitted through repeaters by the same service providers used by taxicabs. Cellular telephones also can be used to transmit data in such situations.
f. **Satellite technology** - remote transmitters for stationary platforms or mobile are being used to transmit real-time data via uplinks to a communications satellite and back down to ground stations. Telephone companies can provide switched services between the satellite system and enterprise networks.

3 Conclusion

This paper is a review, focusing on monitoring and communication systems, showing useful tools, widespread and well-established technologies to study the lightning effects on transmissions lines. Some are viable in particular conditions, while others require remarkable investments. There is not a best solution for all the cases but these most commonly exploited ones.

4 References

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