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Special Insulator for Installation of Optical Phase Conductor on 15 kV Line

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Abstract

Thanks to the recent improvements in the technology of glass fibres and the development of digital data transmission techniques, optical fibres have made their way into power distribution and industry. Several kinds of optical cables are installed on high voltage networks. In most cases, they are embedded in the overhead ground wire. Some of them are installed in medium voltage distribution networks. Then the optical cable is either self-supporting or embedded in the conductor. The latter solution requires a special insulator-separator. Results of test carried out on such insulator-separators made of polycarbonate, silicon rubber-thermosetting, silicon rubber-RTV, polymer concrete are presented.

1. Introduction

The major technical and technological advances made in the production and transmission of electric energy have generated a demand for information transmission systems to support a wide range of operating and management functions (monitoring, mainntenance control), data processing and so on. These systems have to meet stringent requirements as regards the safety, reliability and efficiency of the overall electric power system.

The following conventional ways of transmitting information have been used in power-supply systems in the world [1,2,3]:

- high-frequency transmission over the same network employed for energy distribution,
- transmission over lines leased from other users,
- microwave radio-communication systems,
- geostationary satellite communication systems.

Digital electronics made it possible to minimize the costs and at the same time to maximize the information transmission capacity by employing the state-of-the-art technologies in the main data transmission systems and integrating them into one flexible network. The operation of digital networks as regards data transmission and advanced system control techniques is far better and more efficient than that of analog networks.

In recent years, fibre optic cables (optical waveguides) are the most modern and economical solution, particularly that they can be run on the existing power lines or the ones to be built.

2. Fibre optic cable solutions for electric power systems

As a result of the progress in the optical fiber production technology made in the last several years, it has become possible to use optical fibres for the transmission of information over high-voltage lines. Many companies (BICC Cables, Pirreli, Focas, Alcoa Fujikura Ltd., and other) have designed fibre optic cables which can be buried directly in the ground, run in ducts and water-main pipes, be laid in rivers, or be suspended from overhead transmission line supports. Big advantages of optical fibres are their total immunity to electromagnetic interferences and high transmission capacity. On the negative side, they are highly sensitive to mechanical strain and therefore such factors as wind pressure, icing, attack by birds, vandalism, and so on must be taken into account in the case of routes which include power lines.

Currently, there are available the following designs of fibre optic cables to be run on HV lines:

- OPGW (optical ground wire) cables run within ground wires,
- ADSS (all dielectric self-supporting) cables suspended from overhead transmission line supports below the working conductors,

- Fibwrap (Skywrap) cables wrapped around the ground wire and in some cases run on the phase conductors. They do not include any metal components.

The market has been dominated so far by OPGW. The reason is that the majority of optical cable lines are installed at the time of line repairs and the old ground wires are then replaced with PPGW. This technology is used for HV lines. In the case of 110 kV lines, the ADSS cable is sometimes installed in lieu of OPGW.

Less common are designs of optical cables to be run directly within the phase conductors on local, medium and low voltage lines. They require a unique design of the signal input, output and amplification areas. At these places the optical wire must be separated from the phase conductor.

3. Optical cable routes

The restructuring of the Polish electric power system includes the development of telecommunication networks for the power industry and other users [4]. About several thousands of fiber optic cables are to be installed in Poland in the period 1992-2000. The main routes are the 400 kV, 220 kV and 110 kV power networks. Optical cables supplied by Fujikura Ltd. have been installed on these lines. Each such optical cable consists of 12 or 24 single mode optical fibers with transmission speeds of 140 Mb. at the wavelength of 1300 nm. In the regions where there are no power lines in the above voltage range, the signals transmission is distributed via medium voltage lines, which have this advantage over the HV lines that they reach practically every place in Poland. ADSS cables can be used here or if the support structures have no sufficient margin of mechanical strength, one of the phase conductors is replaced with an optical phase conductor (OPCON). The latter solution was employed by Energoprojekt S.A. and Alcoa Fujikura Ltd. in the case of 15 kV lines in a certain area of Poland [5]. It involves the use of an insulator-separator which ensures the dead outlet of the optical fibers which are separated from the phase conductor and led to signals processing splice boxes Fig.1.

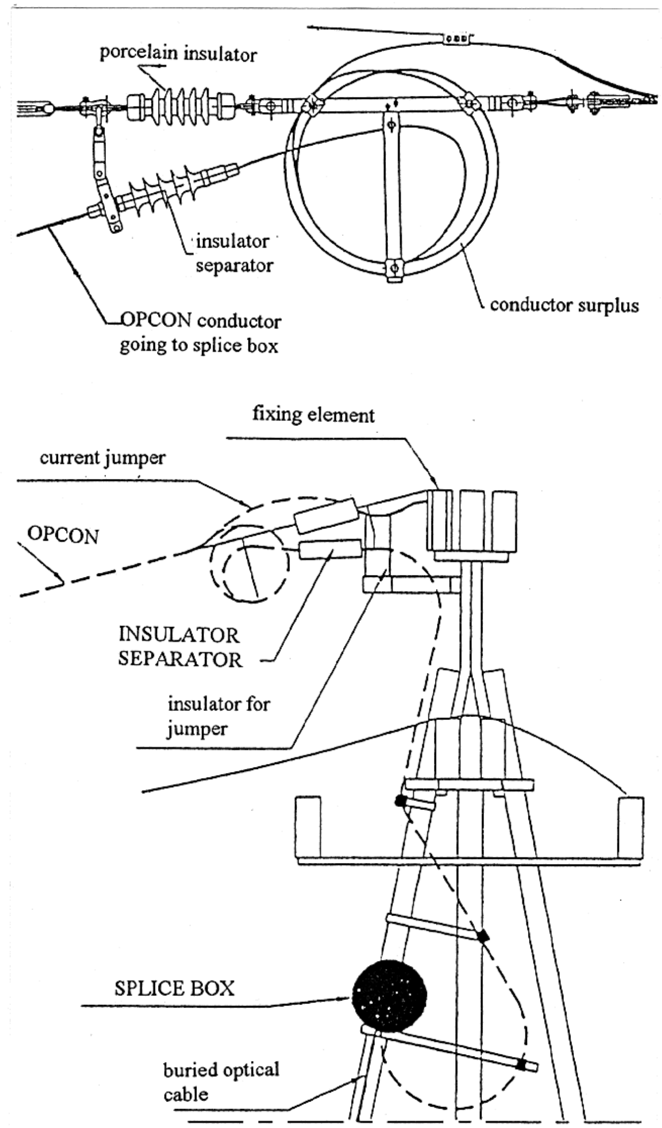

Fig.1. Dead-end set for OPCON conductor with insulator-separator and conductor upper surplus port; OPCON and fittings arrangement on tower with splice box.

4. Insulator-separator on 15 kV line

Because of the atypical design of the fibre optic system's insulator-separator for the U_n = 15 kV rated voltage line, this design's strength characteristics in the conditions of voltage and environmental hazards had to be tested. The insulator-separators are installed in pollution zone III, for which the surface conductivity of an artificial pollution layer is $\kappa = 30\ \mu S$. The tests were carried out on four types of insulator-separators differing in their insulation material and design. The insulator-separators were made of the following materials:

- polycarbonate PC (USA),
- silicon rubber thermosetting SR-th (Rychem),
- silicon rubber SR-RTV /room temperature vulcanizing/ (Wacker Chemie),
- polymer concrete PDC-PoCo (PDC USA).

The silicon rubber insulators were made in Poland.

5. High-voltage tests on insulator-separator

The range of high-voltage tests on the insulator-separator included: power frequency and lightning impulse dry withstand tests, power frequency wet withstand tests, power frequency performance under artificial pollution. The tests were conducted according to the relevant Polish Standards (PN) and International Standard IEC 507. The following voltage sources were used: a TP 800 kV test transformer, a TUR 500 kV 4-stage impulse generator, and a TPZ artificial-pollution-test transformer.

5.1. Power frequency dry test

The power frequency dry tests included withstand voltage trials and the determination of flashover voltage U^*_{50}. The alternating voltage source used for these tests was a 50 Hz, 800 kV/6 kV, 240 kVA system consisting of two high-voltage transformers connected in a cascade. This system supplied short-circuit current I_s > 40 mA for the whole voltage measurement range. The AC voltage was measured by a capacitive divider equipped with a digital voltmeter.

The tests were conducted according to the Polish Standards for insulators working under rated voltage U_n = 15 kV. The test voltage - U_t of 38 kV was connected to the insulator-separators for 60 seconds. All the insulator-separators withstood the AC dry tests. Flashover voltage U^*_{50} for the particular insulator-separators was, respectively, as follows:

- PC - 116 kV (an insulator-separator made of a cylindrical tube),
- SR-th - 131 kV (an insulator with sheds),
- SR-RTV - 137 kV (an insulator with sheds),
- PDC-PoCo - 145 kV (an insulator with sheds).

5.2. Power frequency wet test

The tests were conducted under artificial rain, according to the Polish Standards and IEC. The insulator-separators were sprayed with tap water for 15 min. prior to the test, and then for 2 min. with testing water having the resistivity of 100 Ωm. The voltage of 0.75 U_t was connected to the insulators-separators, which was then raised to the full withstand voltage value of U_t = 38 kV and maintained at it for 1 min. The alternating voltage source here was a TPZ 300, 6 kV/160 kV, S = 300 kVA, tap-changing transformer. All the tested insulators-separators withstood the AC wet tests, i.e. no flashover occurred and there was no damage to the surface.

5.3. Lightning impulse test

The lightning impulse tests were conducted according to the Polish Standards. Each insulator-separator was subjected to fifteen voltage impulses of each polarity - U = 95 kV. The source of the impulse voltages was a 2.2 kJ, 500 kV, 4-stage Marx-system impulse generator made by TUR (Germany). The generator was adjusted to a 1.1/46 μs lightning impulse waveform. Lightning impulses were measured by a capacitive-resistive divider with response time T = 8 ns and peak voltmeters MUT 7 (TUR) and SV 642 (Haefely). All the tested insulators withstood the lightning impulse dry test without a flashover and surface damage.

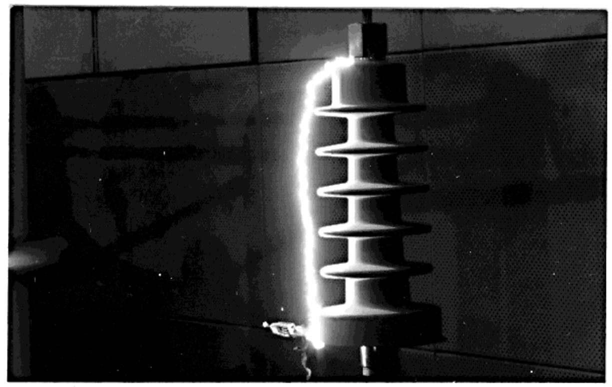

Fig. 2. Exemplary lightning-impulse-test flashover along insulator-separator made of polymer concrete PDC-PoCo.

5.4. Power frequency performance under artificial pollution

According to the Polish Standards, an insulator working at the rated voltage of 15 kV must withstand the 50 Hz alternating voltage of 13.1 kV at pollution test. All the insulator-separators were covered with a layer of artificial solid pollution based on TONOKO with a proper amount of NaCl added. The salt was used to obtain surface conductivity values corresponding to the appropriate pollution zones in Poland. These values were obtained after a cycle of drying and water-mist wetting. Then the required test voltages supplied by the TPZ 300 transformer were applied to the insulator-separators. If in four successive tests carried out for the particular test voltage and pollution-layer conductivity values no flashover occurred, the outcome of the test was positive (the insulator-separator withstood the test). If one flashover occurred, a fifth (crucial) test was conducted - flashover was a negative outcome and no flashover, a positive one. Results of these tests have been compiled in Table 1.

The insulator-separator made of polycarbonate PC, despite its excellent electroinsulating properties, did not meet the requirements for pollution zone III. It turned out to be not resistant to surface discharges which left trackings on its surface. Furthermore, the occurring surface arcs damaged the nylon tube shield connected to the ground-end of the insulator-separator and as a result, the optical wire running inside it was damaged Fig.3.

The other insulator-separators passed the artificial-pollution test required for zone III. The insulator-separators made of silicon rubber RTV and those made of polymer concrete PDC-PoCo also passed the test for pollution zone IV (κ= 50 μS). On the basis of the results of these tests, a decision was taken to install insulator-separators made of silicon rubber RTV on 15 kV power lines Fig.4.

Table 1. AC performance under artificial pollution:
U = 13.1 kV

Insulator material	Results of pollution tests					
	κ [μS] / Zone					
	8 / I	15 / II	30 / III	40	50 / IV	60
polycarbonate - PC	positive	positive	negative			
silicone rubber- thermosett.-SR-th			positive	positive		negative
silicone rubber - SR-RTV			positive	positive	positive	negative
polymer concrete - PDC-PoCo			positive	positive	positive	negative

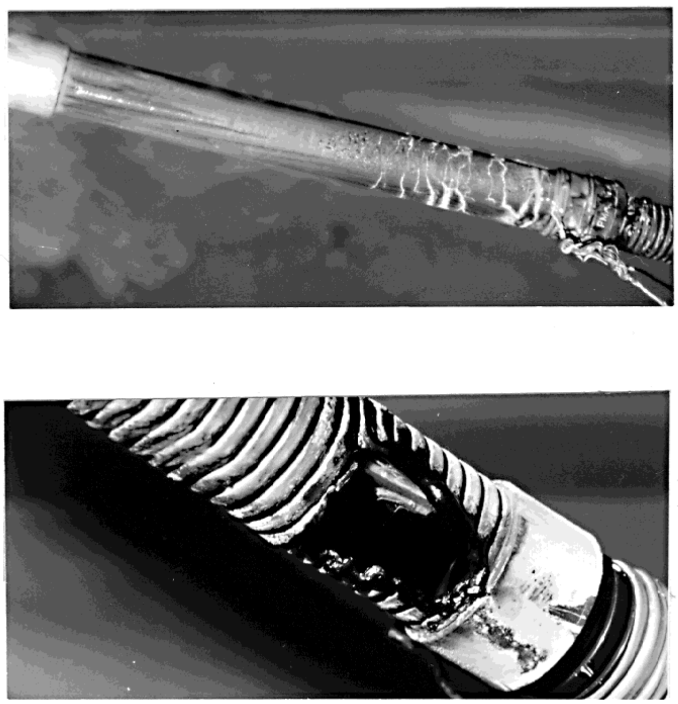

Fig. 3. Discharges along contaminated insulator-separator made of polycarbonate - PC at U = 10.1 kV and damage to nylon tube which shields optical wire.

6. Conclusions

The transmission of information by a fibre optic cable embedded in the phase conductor of the 15 kV power line requires a special insulator-separator. Several designs of insulator-separators of both Polish and foreign make were considered. They were tested for their compliance with the high-voltage requirements for pollution zone III. The tests have shown that not all the materials from which these insulator-separators are made meet the requirements for this zone. Polish-made insulators made of silicon rubber RTV were installed on the 15 kV power line.

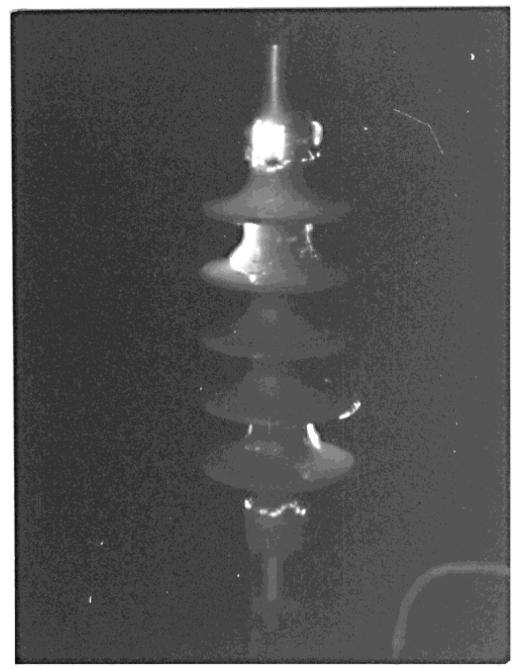

Fig. 4. Artificial-pollution testing of insulator-separator made of silicon rubber RTV at U = 13.1 kV and κ = 50 μS.

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