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Performance Evaluation of Optical Fiber Ground Wire Cable During Short Circuit Condition

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Optical ground wires (OPGW) are increasingly being used on overhead transmission lines throughout the world. OPGW conductors protect the power line against lightning or short-circuit and provide communication through optical fibers embedded inside the conductor. In case of conventional ground wire, the permissible instantaneous temperature is limited by the highest allowable loss of tensile strength of metallic materials caused by annealing and bird-caging. Since OPGW conductors are expected to give protection to the embedded optical fiber, they shall meet a further requirement; i.e. the temperature of the conductor shall not rise in such extent that it may cause degradation in the parameters of the optical fiber. The highest temperature that the conductor may reach during and after short-circuit depends on the conductor design. This paper describes the testing requirements and the performance evaluation of typical OPGW conductor during short circuit condition as per IEEE Standard 1138.

Keywords: *Optical ground wire cable (OPGW), EHV transmission line, Single Phase to Ground Fault,Short Circuit Test, Bird Caging,*

1.0 INTRODUCTION

An OPGW cable was patented by BICC in 1977 and installation of optical ground wires instead of conventional ground wires on overhead transmission lines became widespread starting in the 1980s. The optical fibers within the cable can be used for high-speed transmission of data, either for the electrical utility's own purposes like protection and control of the transmission line, voice and data communication or may be leased or sold to third parties to serve as a high-speed fiber interconnection between cities.

2.0 OPGW CABLE

The OPGW is a multilayer structure, which is specially designedto be installed as overhead cable on power transmission lines toprotect them against lightning, and simultaneously transmitinformation through its optical fibers. The overhead lines presentsome advantages compared to underground cables such as lowerinstallation and maintenance costs [1], better safety, and since theoptical fibers pack is placed in a metal tube in the center of thecable structure, they are immune to electromagnetic interference.Thus, the cable can be used for high-speed transmission of dataand to be part of long distance telecommunication lines with highreliability [2].

A typical OPGW is composed of a dielectric core (optical fiberspack) protected by an aluminum tube, which is covered by armorwires usually made of steel. There are mainly two types of OPGW construction. First one is central construction type

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(Figure 1): Aluminum-clad steel wires are stranded together around the central stainless-steel tube.

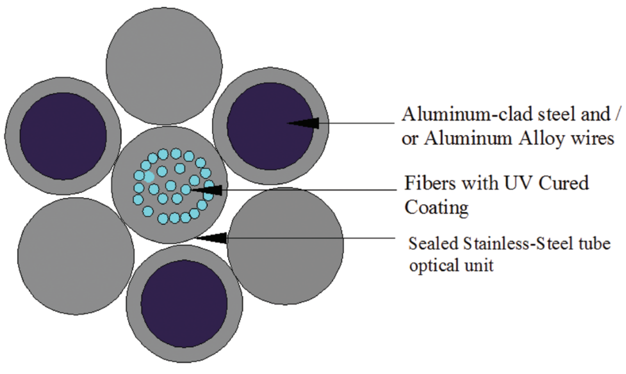

FIG. 1 CENTRAL CONSTRUCTION TYPE OPGW

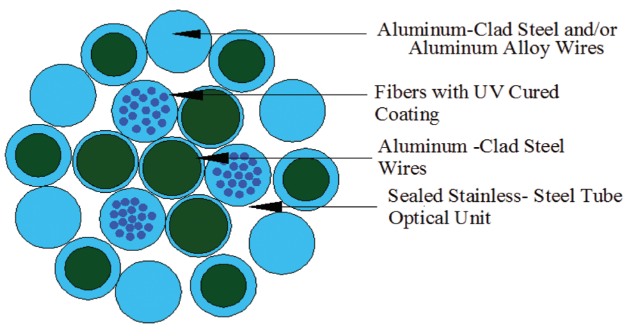

FIG. 2 LAYER CONSTRUCTION TYPE OPGW

Second one is layer construction type (Figure 2) one or more stainless-steel tube shall be stranded together with aluminum clad steel and/or aluminum alloy wires.

The main parameters of OPGW are mechanical and electrical parameters, which must be considered when selecting OPWG conductors for installation in existing transmission circuits. The mechanical considerations are primarily dependent on the sag tension and wind load characteristics, which need to be compatible with the existing construction to ensure new loads and safety conditions are met [3].

The required electrical parameters for OPGW selection are dependent on the relative fault contributions at each line terminal, the length and layout of the circuit, the impedance of the earth grids of all surrounding substations, the tower and pole footing impedances, the protection clearance times and the OPGW construction, impedance and rating.

3.0 APPLICATION OF OPTICAL FIBER CABLE IN OHTL

Optical cables are used in EHV overhead power transmission lines. Optical cables are placed either in ground conductor or phase conductor shown in Figure 3.

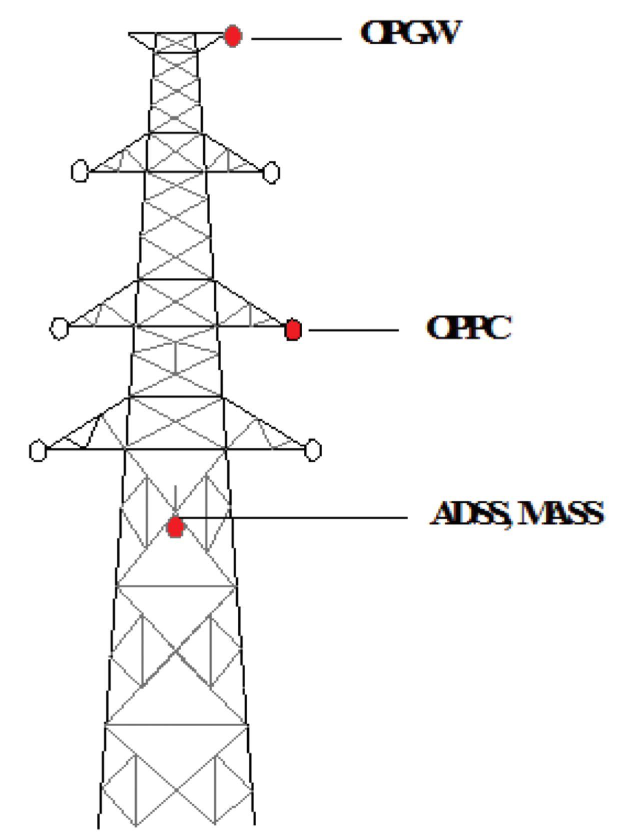

FIG. 3 TRANSMISSION LINE WITH DIFFERENT OPTICAL FIBER CABLES

Table 1 gives information of different optical fiber cables and its applications

TABLE 1	
OPTICLE FIBER CABLE VS APPLICATION	
OPGW:	Dual performance of ground wires with communication capabilities.
OPPC:	Dual performance functions of phase conductors with communication capabilities.
ADSS:	Non-metallic self-supporting optical fiber cables directly between two power towers.
MASS:	Metallic self-supporting optical fiber cables directly between two power towers.

Figure 4 shows the application of OPGW cable between substations through overhead transmission line [4].

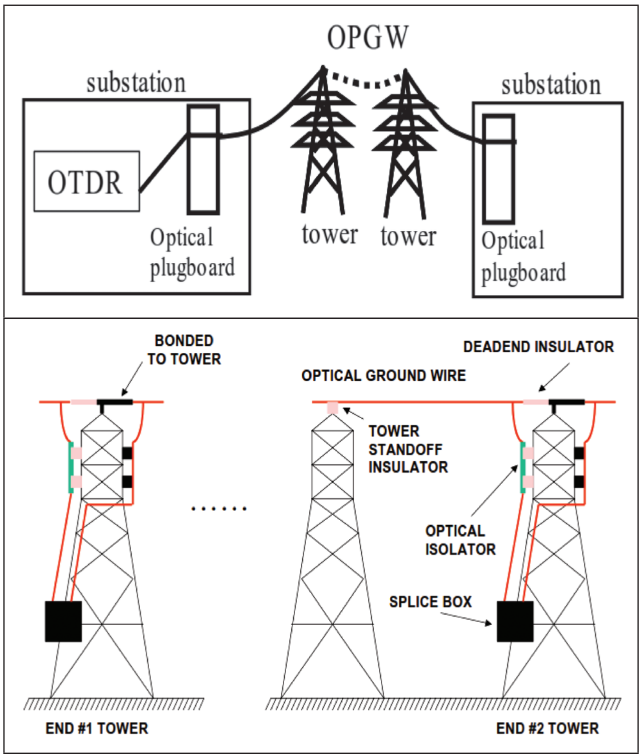

FIG. 4 APPLICATION OF OPGW CABLE BETWEEN SUBSTATIONS THROUGH OVERHEAD TRANSMISSION LINE

4.0 FAULTS IN POWER SYSTEM

Single phase to ground fault is the most frequent faults among different types of faults likely to occur in the electric power system. The single phase to ground fault current; it has 3 ways of return; a) OPGW b) both ground wires c) the ground. When phase to ground fault occurs, short circuit current will result in an increased temperature of OPGW, which is crucial to power line communication. To determine the thermal standard of the OPGW (Optical Ground Wire), it is necessary to know the magnitude of current that will pass through the OPGW in case of single phase to ground fault. This type of fault is simulated in testing laboratory with short circuit test.

5.0 SHORT CIRCUIT TEST

The importance of the Short-circuit Test is to subject the OPGW cable to short-circuitconditionsthatrepresent fieldconditions. Damage can be inflictedtothe cable strands through bird caging, lossoftensile strength, or melting orsofteningofnon-metalliccomponents because of excessively high temperatures. The optical signals may also beadversely affected byshort-circuit conditions [6].

Objective of short circuit test is:

- Verify the mechanical performance of the OPGW cable when subjected to the specified short- circuit conditions.
- To verify the optical performance of the OPGW cable when subjected to the specified short-circuit conditions.

5.1 Experimental Test Set-Up

Figure 5, shows the short-circuit test set-upfor OPGW cable at HPL, CPRI Bangalore. The experimental test set-up for the Short-circuit Test is shown in Figure 6.

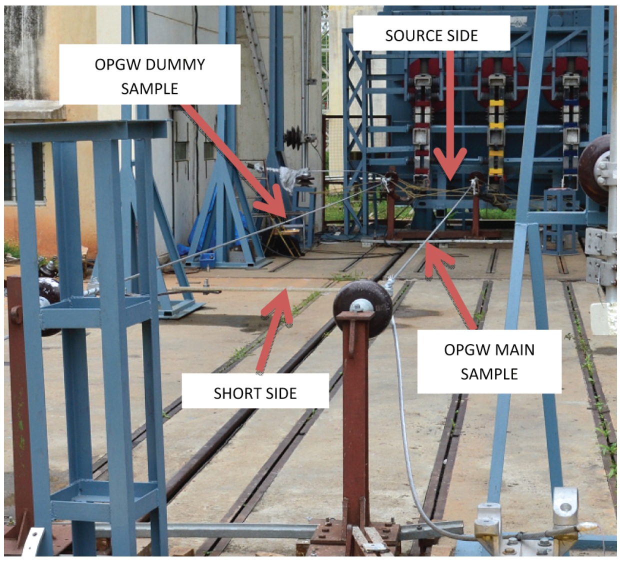

FIG. 5 THE SHORT-CIRCUIT TEST SET-UP FOR OPGW CABLE AT HPL, CPRI BANGALORE

5.2 Apparatus

Two OPGW cable samples shall be used for this test. One sample is used to monitor the performance of the optical fibers and to observe any physical damage that might occur during the test. The second sample is used to measure the temperature at several points in the cross-section

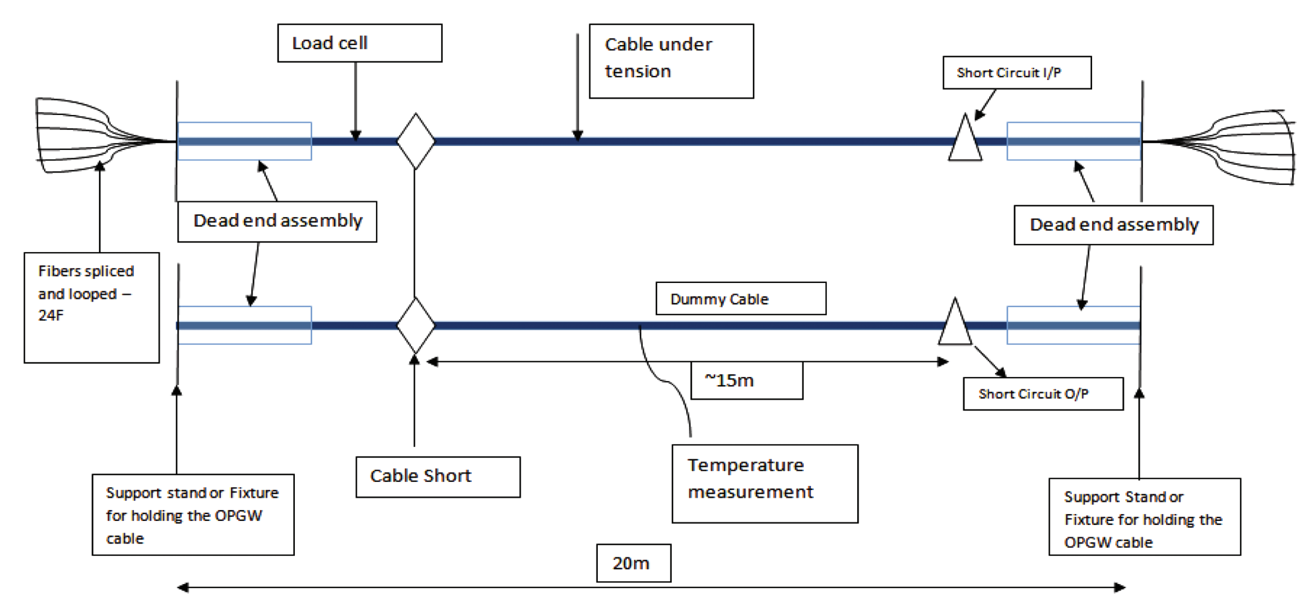

FIG. 6 THE SHORT-CIRCUIT TEST SET-UP

of the cable. Ifplaced outdoors, the samples shall be positioned such that effects due to wind, solar radiation, etc., are the same on the samples.

The cables shall be electrically connected in series so that they are subjected to the same short-circuit current. Suitable means, such as low level circulating ac current, shall be used to maintain the temperature of the cables as measured by the temperature sample to the manufacturers specified reference temperature for short-circuit capacity of the cable [6].

5.3 Optical Sample

The length of cable between the current injection points shall be at least 10 m. The optical fibers shall be terminated beyond each dead-end clamp. A suitable means shall be used to tension the cable from 15 % to 20 % of the RTS of the OPGW cable when the cable is at the manufacturers specified reference temperature. A suitable device such as a dynamometer or load cell shall be used to measure the tension in this sample [6].

5.4 Temperature Sample

The temperature in this sample shall be measured at three locations or more. This is normally achieved using fast-responding thermocouples. However, other techniques that provide reliable and accurate data may be used if available. If thermocouples are used, they shall be spaced approximately 1 m apart, at the midpoint of the sample. They shall be installed in the cable to provide the temperature at the following points in the sample:

a) Located where the maximum temperature rise is expected. Depending on the design of the OPGW cable, this would normally be aluminum component(s) such as the wires, an aluminum tube, or the slotted central core, if applicable.

b) Located where the second highest temperature rise is expected. This may involve an aluminum component and a steel component or two steel components.

c) Located inside the optical unit with the intent of measuring the temperature of the optical fibers.

Thermocouples may be “pinched” between two adjacent components. It is recognized that the thermocouple will be influenced by any components making contact with the junction. The thermocouples shall be isolated from other instrumentation to prevent electrical interference. A suitable means (e.g., turnbuckles, hydraulic cylinder) shall be used to tension this cable but it is not necessary to measure the tension [6].

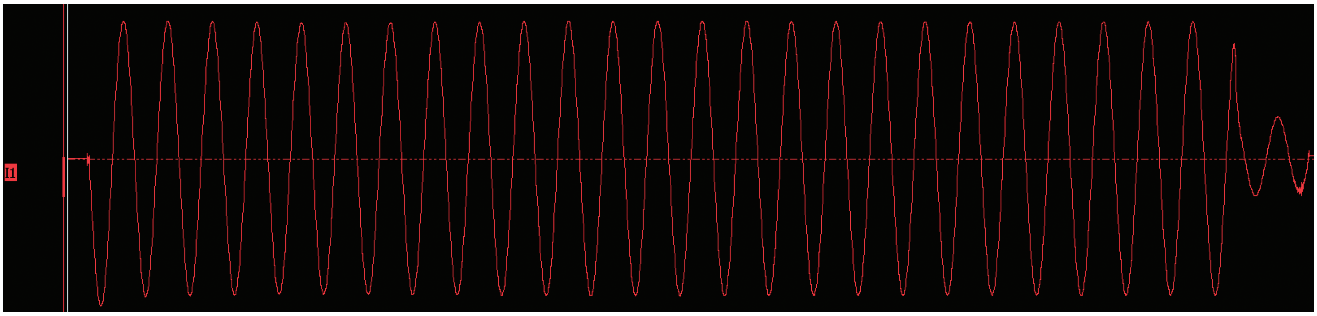

FIG. 7 APPLIED SHORT-CIRCUIT SYMMETRICAL CURRENT (40 kA RMS FOR 0.25 s)

5.5 Instrumentation And Data Acquisition

For each short-circuit application, or "pulse," a suitable data acquisition system shall record the short- circuit current, the optical power readings from the optical sample and the thermocouple readings from the temperature sample.

The aluminum, steel, and non-metallic components of the cable will reach their respective maximum temperatures at different times. Typically, the optical unit will take the longest time. For this reason, the data shall be acquired for sufficient time after each pulse in order to record the maximum temperatures of all components. The temperatures in the metallic components may reach their respective maximums in less than 1 s. For this reason, the data sampling rate shall be fast enough to capture these maximums [6].

5.6 Procedure

The cables shall be heated to the manufacturers specified reference temperature as indicated by the highest reading thermocouple in the temperature sample. All thermocouples shall be maintained at a constant temperature. The optical signals shall be stable for at least 15 minutes before proceeding.

If required, "preliminary" pulses, not to exceed about 50% of the supplier's specified short current value, may be applied in order for the test lab to establish the proper electrical parameters. Preliminary pulses are not considered part of the "official" test. If necessary, the optical signals shall be allowed to stabilize after the preliminary pulses before proceeding with the official test. Once stable, the difference between the power meters shall be zeroed 5 min before the first official pulse and shall be considered the start of the official test.

The cable shall then be subjected to five official pulses. For the official pulses, the minimum and maximum values for the electrical parameters are shown in Table 2:

TABLE 2

MIN AND MAX VALUES FOR THE ECLECTRICAL

Parameter	Duration (T)
FaultI^2t	Minimum kA^2/s specifiedbysupplier
Fault duration	Same as primary protection breaker operation, if known. Other wise, maximum 0.5 s (30 cycles)

The cable shall be allowed to cool to the specified reference temperature after each pulse as measured by the highest reading thermocouple. The cable will be held at the reference temperature for at least 5 minutes between pulses.

For each pulse, the fault current and duration may vary slightly from the target values. The objective is to achieve the I^2t level for each pulse. To recognize the practical issues of performing this test, the following allowances are made. The average of the five pulses shall exceed the minimum I^2t level specified by the supplier. However, no single pulse shall be less than 95% of the minimum I^2t level.

The optical sample shall be visually inspected for bird caging or other damage periodically throughout the test. Because the cable components can be disturbed when the thermocouples are installed, observations made on the temperature sample are not considered official.

After the final pulse, the optical and temperature data shall continue to be acquired for at least 15 min after the thermocouple with the highest reading has returned to the reference temperature. Final optical and temperature readings and observations of the cable shall be taken at this time. This designates the official end of the short-circuit test. Figure 7 shows, the appliedshort-circuit arc current and its time.

The optical cable sample shall be dissected after the test. Attention shall be paid in particular to the sections of cable closest to the terminating hardware, and at the midpoint of the span. Each separable component of the cable shall be separated and inspected for excessive wear, discoloration, deformation, or other signs of breakdown [6].

5.7 Acceptance Criteria

The successful OPGW should fulfill the following acceptance criteria's:

a) Any cracking or breaking of any component of the optical sample shall constitute failure. This assessment is made with the naked eye.

b) There shall be no bird caging of any of the strands of the optical sample. Bird caging is defined as one or more cable strands that permanently protrude greater than one strand diameter from the normal cable geometry. A strand will be considered to have bird caged if light can be seen between the protruding strand and the cable. This observation will be made after the cable has cooled to the reference temperature after the last pulse. Temporary bird caging during the pulses shall not constitute failure. Figure 8 shows the bird caging phenomena of OPGW due to short circuit test.

c) There shall be no permanent increase in optical attenuation greater than 0.05 dB/fiber at nominally 1550 nm ± 20 nm for single-mode fibers.

FIG. 8 BIRD CAGING OF OPGW DUE TO SHORT CIRCUIT CURRENT

d) If specified, the maximum temperature of any metallic component shall notexceed the manufacturers' value at any time during the test. Additionally, the temperature of the optical core shall not exceed 180°C at any time during the test. Higher temperatures may be allowed if agreed upon between manufacturer and end user.

e) Any excessive wear, discoloration of fibers, deformation, or other signs of breakdown shall constitute failure [6].

6.0 CONCLUSION

The communication between the substations, PLCC completely replaced by optical fibers embedded inside the conductor (ground conductor or phase conductor) over transmission line. The transmission line and ground conductors are exposed to atmosphere. The highest temperature that the conductor may reach during and after short-circuit (line to ground fault) depends on the conductor design. This highest temperature of the conductor may cause degradation in the parameters of the optical fiber.Hence, the short circuit test on optical fibers embedded inside the conductor (ground conductor or phase conductor) is necessary for assessment of performance. This paper describedthe requirements & theperformance evaluation of typical OPGW conductor during short circuit condition as per IEEE Standard 1138.

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