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Short Circuit Testing of Cables: HPL Experience

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Abstract

Cables form the backbone of modern power transmission and distribution systems. Even though, short circuit faults are more common with overhead transmission lines than with underground cables, the thermal and dynamic stress associated with short circuit make it a mandatory withstand requirement. High Power Laboratory has been regularly carrying out short circuit tests on LT and HT cables. This paper presents an overview of the tests carried out and their results.

Keywords: Cable, Short-circuit Currents, Thermal Stresses

1. Introduction

Short circuit testing of power cables is an evolving area in the absence of any definite standard. The permissible short circuit current for power cables is governed by IEC 60949[1]. Even though the standard covers the calculation of permissible short circuit currents under adiabatic and non-adiabatic conditions, the standard stops short of prescribing a definite procedure for testing. That leaves power cables as the only important component of the grid without a well-established short circuit testing procedure and criteria of evaluation. This has led to the evolution of tailor-made short circuit procedures. Previous studies have been carried out on the short circuit testing and design of cables and are presented in[2,3]. The High Power Laboratory (HPL) at CPRI, Bangalore has been regularly conducting short circuit tests on cables following a plethora of procedures. This paper presents the commonly encountered short circuit testing procedures and characteristic failures.

2. Procedure of Short-Circuit Testing

Short circuit test is carried out on conductor and/or sheath and screen. The conductor is subjected to a short circuit current corresponding to the system fault level of the end user, usually for one second. The system fault level, generally, falls short of the absolute thermal capacity of the cable. The thermal capacity of the cable is calculated by the following formula given in IEC 60949[1]

$$I_{AD}{}^2 t = K^2 S^2 \ \ln\frac{(\theta_f + \beta)}{(\theta_i + \beta)} \qquad (1)$$

Where I_{AD} is the adiabatic (without heat transfer) short circuit current in amperes, t is the duration in seconds, K is the material constant, S is the geometric cross-sectional area in mm^2, θ_f is the final allowed temperature, θ_i is the initial temperature and β is the reciprocal of the temperature co-efficient of resistance. The values differ for copper and aluminium. The values of short circuit current given by the standard for a maximum temperature of 250°C and the test current usually applied to cables of different cross-section are given in Table 1.

From the table, it is clear that the theoretical adiabatic capacity of the cable far exceeds the testing requirements corresponding to the system fault level.

Short circuit testing is usually carried out on sheath and screen along with the conductor. The sheath/screen may be tested alone or in series with the conductor. Figure 1 illustrates the testing connections.

Pre-heating is often done before applying short circuit current. The conductor is heated up to 90°C or 105°C depending on the utility practice[4]. 90°C is the temperature corresponding to load current and 105°C is the temperature corresponding to temporary emergency overloading. In rare cases, the procedure insists on maintaining preset temperature of the sheath and screen

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Table 1. Short circuit currents in test and recommended by IEC

Conductor Material	Cross-section (mm^2)	Test Current (kA) and duration (s)	Current recommended by IEC (kA)
Copper	630	31.5 - 3	37.1
Aluminium	630	31.5 - 3	24.8
Aluminium	500	47.2 - 1	59.0
Aluminium	630	59.2 - 1	74.4
Copper	630	90.1 - 1	112.4
Copper	630	59.5 - 1	112.4
Copper	300	42.9 - 1	53.5
Aluminium	400	37.6 - 1	47.2
Copper	300	40.0 - 1	53.5
Copper	630	90.1 - 1	112.4
Aluminium	1000	94.3 - 1	118.0
Copper	300	45.0 – 0.12	488.6
Copper	2500	63.0 - 1	446.1

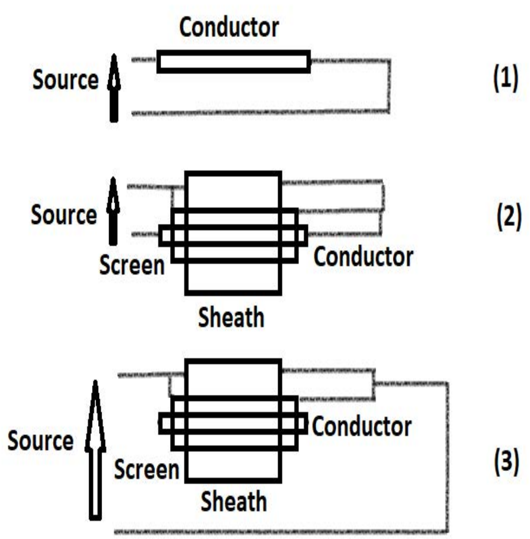

Figure 1. Common connections adopted in short circuit testing.

as well. Most often short circuit current is applied once for a duration of one second or three seconds. In some cases, the short circuit current is applied three times after allowing the conductor to cool down to ambient temperature or the pre-heating temperature each time.

3. Performance Evaluation and Failure Cases

Visual inspection for any damages is the main criterion followed for evaluation of performance in short circuit test. Usually, it is limited to the outermost layer of insulation. In some cases, a section of the cable with a length of one meter is inspected after removing all the layers. This reveals damages to the insulation as well as the conductor sustained due to short circuit.

The final temperature of the conductor is also a criterion of evaluation. Usually, a threshold of 250°C is adopted for copper and 200°C is adopted for aluminium. In certain cases, a threshold of 250°C is adopted for aluminium also. The temperature limits of copper screen and lead/aluminium sheath are 250°C and 200°C respectively. There was no case where this threshold was exceeded. As previously mentioned, the test currents were well within the adiabatic capacity of the cables. Also, during a duration of one second, the cooling also comes into play. The assumption of adiabatic process is no longer valid and the non-adiabatic factor, which depends on the extent cooling can be determined from the observed temperature by the following equation:

$$\varepsilon = \frac{I_{SC}}{I_{AD}} \quad (2)$$

Where I_{AD} is the adiabatic short circuit current determined using (1) for the observed final temperature. The observed temperature and calculated non-adiabatic factor for selected cases are presented in Table 2.

Table 2. Measured temperature and adiabatic factor

Conductor Material	Test Current (kA)	Observed Temperature (°C)	Non-adiabatic factor
Aluminium	31.5	130	1.70
Aluminium	44.6	241	1.05
Aluminium	47.2	233	1.05
Aluminium	59.2	158	1.70
Aluminium	59.5	196	1.25
Copper	42.9	207	1.14
Aluminium	37.6	227	1.14
Copper	40.0	185	1.19
Copper	90.1	199	1.22
Aluminium	94.3	198	1.21

It can be seen that the non-adiabatic factor varies from 1.05 to 1.7. A value of 1.05 indicates near-adiabatic condition while a value of 1.7 indicates moderately effective cooling during short circuit. Hence it is difficult to make general conclusions about the extent of cooling during short circuit. The efficacy of cooling could be dependent on the voltage level, design etc.

Failure due to the thermal effects of short circuit is the most common type of failure. The insulation part is usually fully charred while the metallic structure remains with carbonization. A failure of aluminium conductor LT cable is shown in Figure 2. Due to high temperature, one phase conductor got sheared.

Figure 3 shows a failure in the HT cable but with less devastating effects. The insulation is burned out, but the conductor is intact.

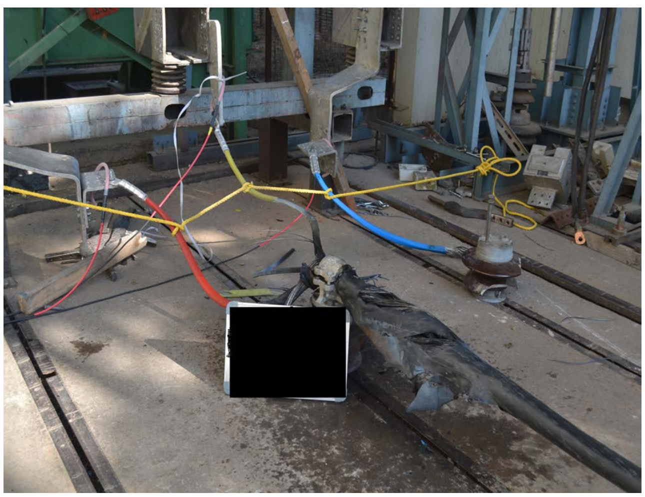

Figure 2. Thermal failure in LT cable.

Figure 3. Thermal failure in HT cable

The testing requirements usually state that the cable be tested with the symmetrical short circuit peak of √2 times the RMS value. This tests only the thermal withstand capability of the cable. A few tests demand a peak factor of 2.5 times the RMS value of the current. The electromagnetic forces depend on the configuration of the three phase cables. Flat configuration and delta configuration are usually adopted for cable systems, as illustrated in Figure 4.

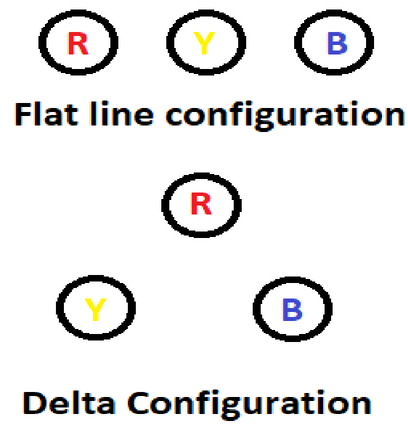

Figure 4. Cable configuration

In delta configuration, the maximum force is experienced by the phase having the asymmetric peak current. The force is formed as a result of the interaction between the current and flux and hence it pulsates with a frequency of 100Hz. The forces experienced by the conductors in delta configuration with an asymmetric peak current of 1.78 times the symmetrical RMS current in the R phase, is illustrated in Figure 5. The absolute peak seen in R phase is 2.67 p.u.

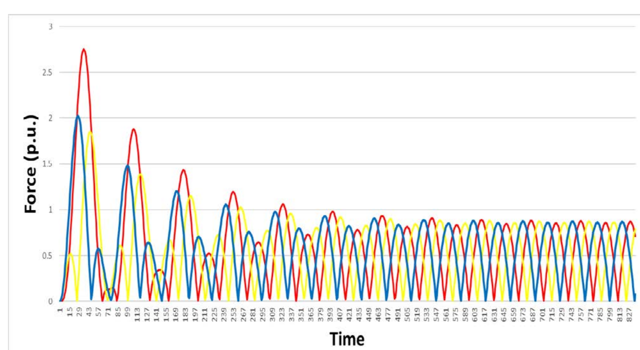

Figure 5. Short circuit forces in delta configuration.

In flat line configuration, the peak force occurs in Y phase cable irrespective of the phase carrying the maximum asymmetric peak current. This is due to the additive flux coming from the two neighbouring cables. The short circuit force is maximum when the asymmetric peak is in the B phase cable i.e., on the cable carrying the current lagging the Y phase current. The force experienced by the three phase cables with a peak asymmetrical current of 1.78 times the symmetrical current on the B phase is illustrated in Figure 6.

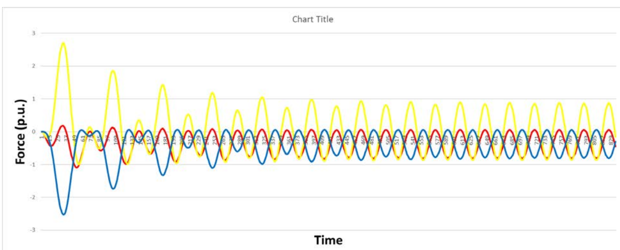

Figure 6. Short circuit forces in flat line configuration.

Figure 7. Dynamic effects on three phase cable in delta configuration.

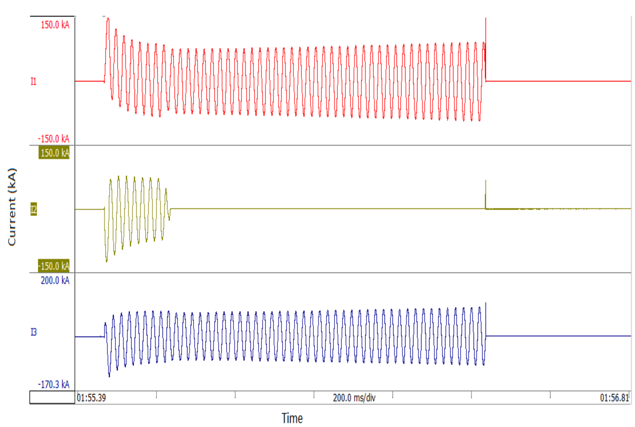

Figure 8. Current waveforms in a dynamic failure.

The peak force seen in the delta configuration is 2.70 p.u. which is almost equal to that seen in flat line configuration. Hence the two configurations are almost same in severity.

The usual dynamic effects of short circuit current include the breakage of cleats, twisting of cables etc. A case of dynamic failure is illustrated in Figure 7. The recorded current waveforms for a dynamic failure are shown in Figure 8.

The condition of the cable after the short circuit test is also judged by supplementary tests. They include high voltage test on the insulation, conductor resistance measurement and partial discharge measurement. They are carried as per IS 7098: Part 2: 2011[5] for cables in the concerned voltage range. The conductor resistance should not cross the specified thresholds as per standard. The partial discharge limit is 5pC for type tests.

4. Conclusion

Short circuit test is an onerous test for LT and HT cables. The lack of standard procedures and criteria of evaluation has resulted in a plethora of custom-made short circuit test procedures and criteria of evaluation. The thermal and dynamic effects of short circuit, result in characteristic failures which are highlighted in this paper.

5. Acknowledgement

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6. References

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