An Experimental Setup to Study the Effects of Switcing Transients for Low Voltage Underground Cable

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Abstract. Successful delivery of electrical power depends upon the reliability of system such as protection of electrical equipment, delivery media and condition of environment. Unlike overhead transmission lines, an underground cable is not exposed to the variable weather condition, so the reliability of electrical power delivery is more in comparison with overhead lines. An experimental set-up has been developed to conduct switching transient of power cable with induction motor acting as a load, and the current and voltage data are saved in a digital storage oscilloscope during the transient operation and analysed properly. Switching operation mainly creates surges and moves through the cable circuit. *R*, *L* and *C* parameters of the cable have been calculated using traditional method of determination. The aim of this paper is mainly to energise a low-voltage distribution cable and to study the behaviour of switching transient. In addition to switching transient, different types of fault such as line to ground fault and double line to ground fault have been created in an unloaded cable. A MATLAB/Simulink platform has been used to study the cable parameters and its characteristics.

Keywords: Experimental set-up · Underground cable · Distributed pi network of underground system · Switching transient · Fault analysis

1 Introduction

Underground distribution system is for maintenance and for the installation of a new one. For safety point of view in highly density populated area, uses of underground cable have seen sharp hike in recent times. To enhance the relibility of power system it is really a challenging task for the power engineer to detect and locate various types of faults in underground cable. There are various traditional fault location methods [1] such as Murray loop method and acoustic detection method which helps in locating the faults, still for accuracy fault impedance calculation is an essential factor for power cables. The power is being transmitted through both overhead line and UG cable. Unlike overhead lines [2], the special characteristics of underground cable have larger capacitance value

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in comparison with inductance. So while analysing various types of cable, a lot of complications [3] in calculating cable size may come. A cable system mainly consists of core, sheath and ground which may create extra complications in calculating impedance in comparison with overhead lines. This cable connects the generating stations to the load end through the transmission system. As proper model of cable describes accurate results of switching transient, so proper statistical analysis [4] of simulated model has been proposed in this paper. Due to the introduction of distributed generation [5], the traditional power system network is getting segregated into small section or cluster where more importance is given to the renewable sources to inject their power through LT line. So, the transient analysis of LT line is a major task nowadays. Impact of frequency dependence of cable parameter, length and number of pi sections [6] helps in improving the system accuracy. Overload and steady overvoltage [7] along with transient behaviour of mixed cable system have been well described by the author. Low-voltage distribution system is mostly composed of compound sections of line and cables with various types, sizes and length. Arcing and spitting phenomena mainly occur due to switching of unloaded cable by load break elbow or circuit breaker. Energisation [8] and de-energisation operations create multiple re-strikes in voltage and current waveforms. Basically in an electrical power system, current blockage or unwanted creation of conducting path is known as fault. Fault is mainly an accidental and unwelcome parameter for power system, so voltage and current analyses [9] with proper protection are important. For locating fault in an underground cable, proper line model analysis is highly required. It is foremost duty of the power engineers to evaluate the parameters such as voltage and current during fault condition. So that as per the fault level, damaging effects of the fault can be reduced by using protective devices. Various types of offline and online methods help in detecting the location of fault. It is also difficult to trace incipient fault [10], so a various incipient fault detection method is to be studied. To deliver electricity to the end user, electrical distribution is the final stage. For curtailment of transmission line losses and to model the transmission system efficiently, the generated voltage is stepped up to higher voltage but this transmission voltage is not used by the consumer. So, the transmission power line will move into a distribution substation where step down of voltage occurs and which can be utilised by various industrial, commercial and residential consumers.

Nowadays as underground system plays a major role due to its advantages compared to overhead lines, residential and commercial distribution is processed through underground cable. DG penetration in low voltage distribution system mainly creates voltage instability issue in the system. So transient analysis is a challenging task for low-voltage network consists of underground cables. For protection of any system, an actual model is always helpful for analysis, design and control. In this paper, an experimental set-up has been developed and transient analysis has been done by switching the cable through a circuit breaker of an unloaded and loaded LV cable. The transient nature of voltage and current has been analysed which has captured through a DSO.

1.1 Experimental Set-up for Four-Core Cable

In this paper, experimental data of underground cable have been analysed. So, switching transient of a low voltage 1.1 kV four-core cable has been created. The experimental set-up has been designed as shown in Fig. 1b. A 400 V supply is given to a four-core armoured PVC cable having length 50 mt. A number of case studies has been analysed by considering unloaded and loaded cable for transient analysis. The specification of the cable which we have used for our experiment is a 10 mm^2, four-core, PVC-insulated armoured cable, circular solid aluminium conductor having approximate AC resistance 3.95 Ω/km, approximate capacitance 0.6 mfd/Km and approximate reactance 0.091 Ω/Km. The system has been developed with proper protection by using relay and circuit breaker to avoid unnecessary damage to the system. We also have used a three-phase, one HP, 50 Hz, 415 V squirrel cage induction motor as a load for experimenting the switching transient.

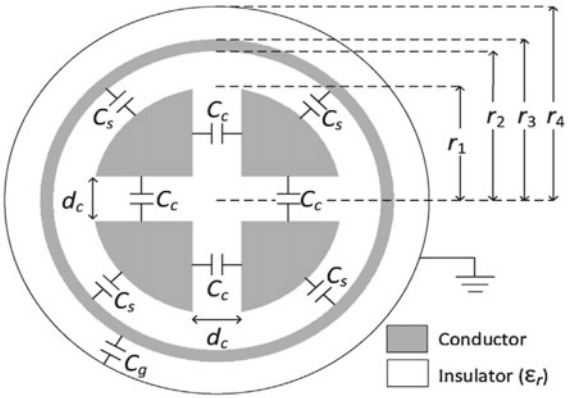
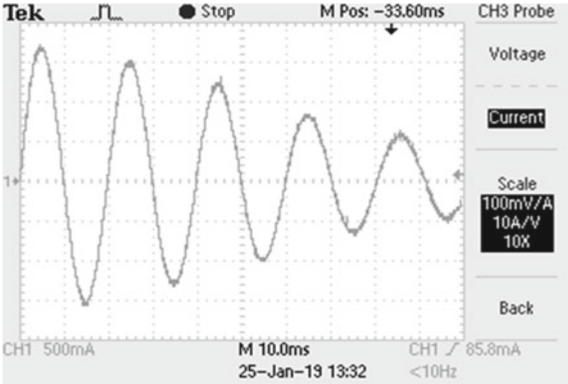


Fig. 1. **a** Approximate diagram of a four-core cable [13], **b** experimental set-up, **c** switching transient analysis of *R* phase in DSO, **d** switching transient analysis of *R* phase, **e** switching transient analysis for three phases in DSO, **f** switching transient analysis of *R* phase, **g** current during *L-G* fault occur, **h** current during *L_L_G* fault occur

Fig. 1. (*continued*)



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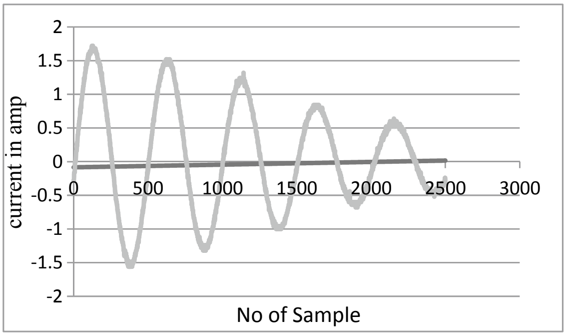

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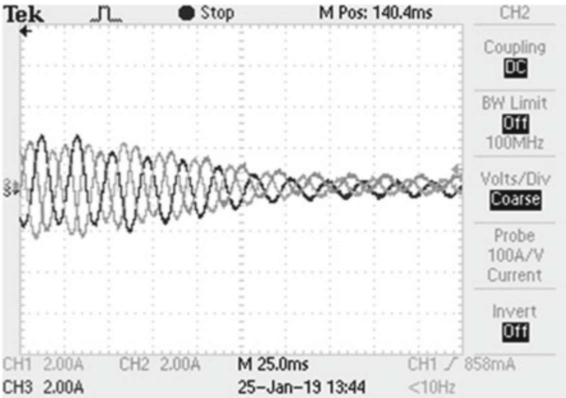

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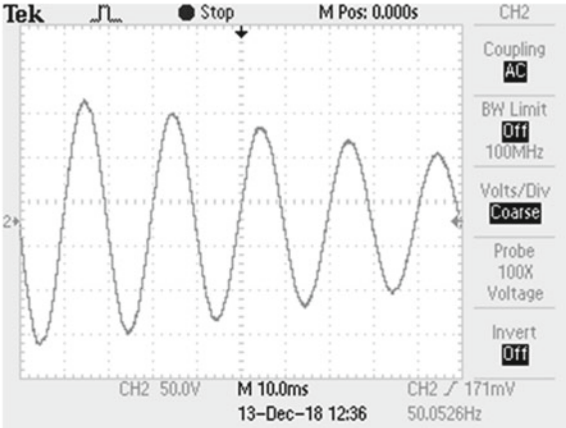

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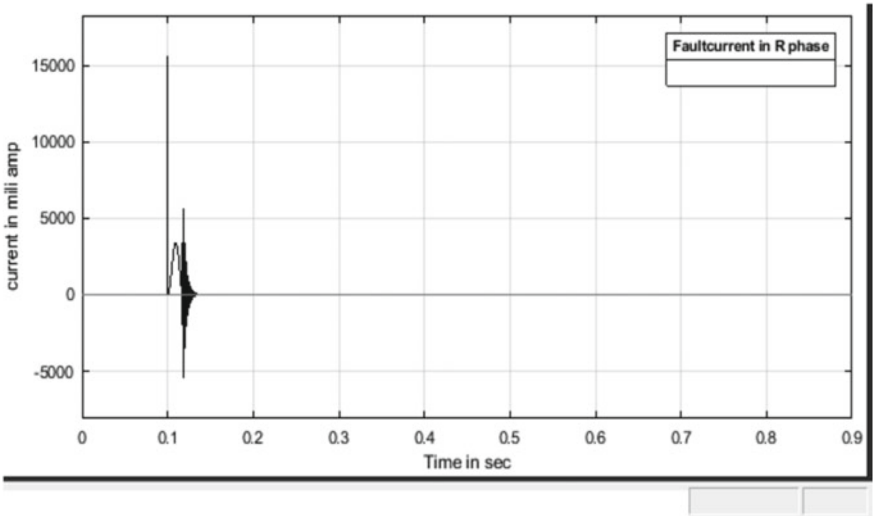

Fig. 1. (*continued*)

Figure 1a depicts regarding a four-core cable which is used mainly for the distribution purpose. In some cases also three and half core cables are used. The cable in this paper has four cores with PVC insulation as a layer. A conducting layer is present named as armour whose main function is to give mechanical protection to the cable. For modelling of the cable, it is highly essential to calculate [11, 12] the R L C matrix of the cable. The capacitance and impedance matrix calculations are highly important to do fault analysis. The data have been used to simulate the four-core cable.

In the above figure, the total number of sample is 2500 and during the switching the transient current is very high. Figure 1c and d shows how the current during the starting period increases rapidly.

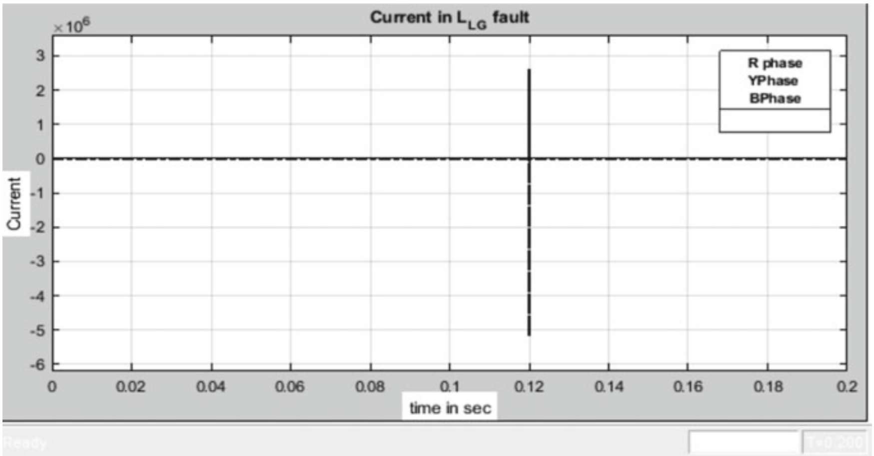

Fig. 1. (*continued*)

In the above figure, the switching transient of three-phase induction motor has been analysed and it has been seen that the starting current is quite high after few seconds the system becomes steady one.

2 Analysis of Three and Half Core Cable

In Fig. 1e, a three and half core cable having length 7 mt has been used to do the analysis. The induction motor has operated with different load conditions, and the current, voltage and power measured in three phases are given in Table 1.

Table 1. Analysis of three and half core cable

Data	*R*	*Y*	*B*
Current (Amp)	1.80	1.67	1.63
Real power (W)	75	42	75
Power factor (lag)	0.19	0.11	0.20
Voltage (sending end) (V)	395.3	391.6	394.6

The specification details of the cables are 16 mm^2 armoured cable having approximate capacitance 0.830 microfarad/Km. The current waveform is shown in the Fig. 1f.

Switching action mainly starts when either load break switches, circuit breaker operates or fuse operates. As we know, switching action defines both closing operation and opening operation only. Transient current will flow through the system subsequent to closing operation. We have analysed the transient current for distribution cable.

3 Fault Analysis of Underground Cable Using MATLAB/Simulink

We have considered a three-phase, 11 kV source with four numbers of single-core cable. The fault has been created at the receiving end of the unloaded cable, and the voltage and current waveforms have been analysed using MATLAB/Simulink. The *R*, *L* and *C* parameters of the cable have been calculated and used in the cable Simulink model, *R*, *L*, *C* parameters are calculated in matrix form, and these matrix data act as input to cable model. Sheath voltage has also been observed during fault. A relay circuit has been designed which sends a signal to the breaker after an immediate fault occurs in the system. Both *L-G* and *L-L-G* have been created in the system, and results have been examined properly.

Figure 1g gives entire information for *L_G* fault occurred in the R phase of an unloaded cable. Initially, the current is zero across the receiving end but when a *L-G* fault occurs after 0.1 s, a high current flows through the short-circuited path and the relay senses the fault, the circuit breaker trips. The current in three phases becomes zero after immediate effect of the breaker. Figure 1h represents the current when the fault occurs in both *R* phase and *Y* phase and ground.

4 Conclusion

In this paper, various tests of underground cable have been verified in laboratory. Switching transient in electrical power system is a major issue, so experimental results have been analysed properly for a low-voltage distribution cable. A simulation model has been developed for pi equivalent distribution cable, and the transient current graph has been analysed for both line to ground fault and double line to ground fault. The amplitude of current is suddenly increased at the instant of fault occur. The *R*, *L*, *C* parameter calculation plays a vital role for simulating the fault. Hardware implementation can be done to analyse the fault analysis in future to validate the simulation model, and also DWT analysis can be done for the transient voltages and currents analysis.

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