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Modeling of flashover arcs in medium voltage networks due to direct lightning strikes

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ABSTRACT

Distribution line faults in many cases are caused by direct lightning strokes to overhead lines resulting in a disruption between phase and ground in the form of flashover arc. Therefore, it is important to accurately simulate the lightning behaviour for the protection studies of distribution networks. This paper investigates the influence of considering the dynamic arc model and the actual volt–time characteristics of line insulators in the evaluation of lightning overvoltages. A full-scale experimental set-up was installed in the high voltage laboratory to study the dynamic interaction between fault arc and power system with grounded and ungrounded cross arm configurations. The least square method has been used to extract the arc parameters from the experimental results for modeling purpose. The model of experimental set-up has been implemented in Alternative Transients Program–Electromagnetic Transients Program (ATP–EMTP) software and the experimental results have been reproduced by computer simulations with reasonable accuracy. Based on the comparison of experimental and simulation results, it is concluded that the actual volt–time curves and the arc model that characterize the behaviour of line insulators should be considered during the simulation of the lightning performance of overhead distribution networks.

Introduction

MEDIUM voltage (MV) distribution lines up to 20-kV do not have a shield wire and are thereby prone to lightning strikes. Field statistics have shown that the majority of direct lightning discharges to unshielded lines result in single-phase as well as multi-phase faults [1,2]. This can produce a fault arc from phase to ground on the surface of insulator through air. Consequently, the fault arc appears in the form of flashover causing a fault on the power system.

In Finland, most of the 20-kV distribution networks are single-circuit wood pole construction with ungrounded steel cross-arms. However, at the same time, the cross arm of wood pole is grounded at some locations for protection purposes. The benefit of grounding the cross arm is to suppress the fault currents into ground produced by lightning strikes. However, in this case, the flashover path is simply between the phase conductor and the earthed cross arm causing a single-phase fault. Therefore, the total critical flashover voltage (CFO) for the flashover path is provided by the insulator alone i.e. 136-kV in case of 24-kV pin type insulator. For ungrounded cross arm configuration on MV wood poles, direct lightning strike to the phase conductor always results in a multi-phase fault. For example, in case of two-phase fault, the flashover occurs over the line insulator between the struck phase and cross arm and then from cross arm to the neighbouring phase. The reason is that the wood pole has very high lightning impulse strength so that the weakest flashover path is always across the two neighbouring insulators through metallic cross arm. Now, the total CFO for the flashover path is provided by the series combination of two insulators, which, of course, is higher, compared to the case of an earthed cross arm [3]. This means that the lightning impulse strength required to produce a flashover in ungrounded cross arm is higher than the earthed one.

Previous studies have analyzed the transient performance of MV overhead networks due to direct lightning strikes [4–11]. In such studies, the flashover criterion for the insulators is usually modeled by the closing of a parallel switch when the voltage across it exceeds 1.5 times the line CFO [3]. Once, the switch closes, the arc appearing during flashover is represented by a linear resistance, for which more accurate arc models are needed. The consideration of such simplified criterion of flashover and arc appearing during flashover can result in significant error in the calculation of lightning overvoltages [12]. Therefore, the models of important

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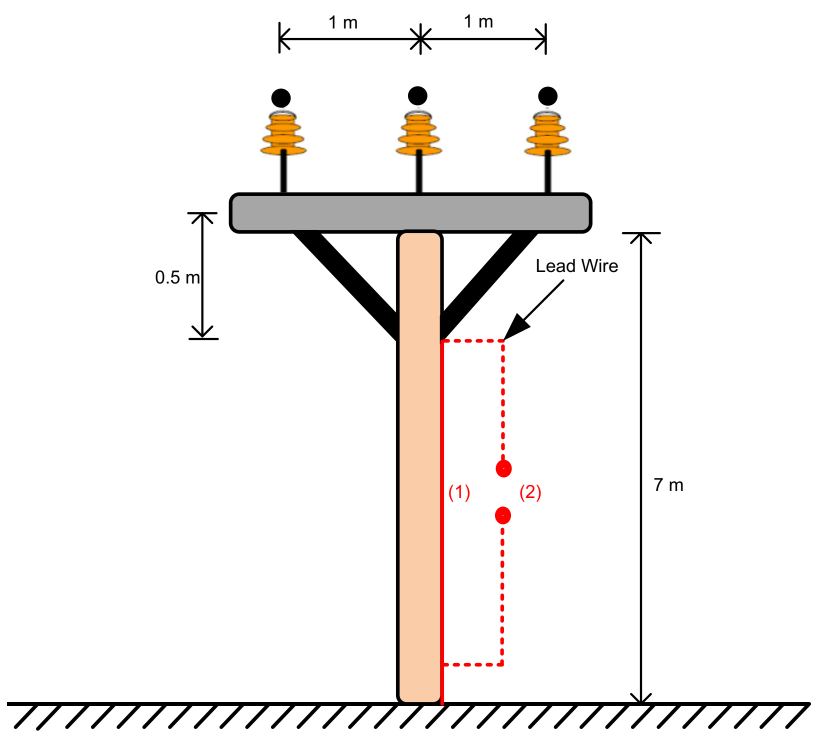
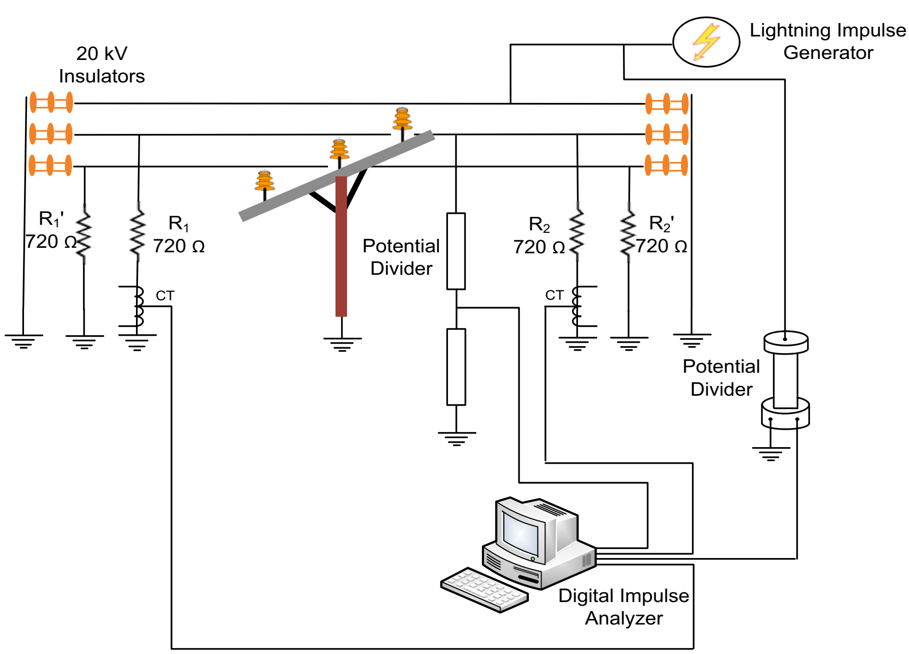


(a) Dimensions of the medium voltage wood pole overhead line with (1) cross arm grounded with lead wire (2) cross arm ungrounded by removing lead wire



(b) Complete experimental set-up

Fig. 1. Full scale experimental set-up consisting of a test distribution line with measurement system and impulse generator (a) dimensions of the medium voltage wood pole overhead line with grounded and ungrounded cross arm configurations, and (b) complete experimental set-up.

phenomena associated with flashover arc behaviour should be incorporated in order to accurately estimate the lightning performance of overhead distribution lines.

The aim of this paper is to investigate the influence of considering the dynamic arc model along with the actual volt–time curves of the insulation in the calculation of lightning overvoltages. The full-scale lightning flashover experiments were performed in the high voltage laboratory at Aalto University, Finland. The measurements have been conducted with grounded and ungrounded cross arm configurations to investigate single-phase