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Impact of surge arrester number and placement on reliability and lightning overvoltage level in high voltage substations

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ABSTRACT

Surge arresters are the most critical equipment for protecting high voltage substations. They play an important role in substations for limiting switching and lightning surges and diverting these surges to ground. On the other hand, surge arrester number and placement for high voltage substations can be determined based on some evaluations in the designing process of substations. Surge arresters can be placed on the both ends of substations, transformers, circuit breakers, reactors, capacitors and also high long bus-bars and etc. Therefore, failure of arresters during overvoltage can put substations in risk condition. Moreover, surge arresters may be inclined to be short circuit during normal operation condition due to ageing process and/or improper quality. This paper attempts to assess reliability of three common substation configurations namely: (1) one breaker and a half; (2) double-bus double-breaker; and (3) ring bus-bar in different placement of surge arresters. At first, maximum voltages on equipment are calculated in different lightning stroke locations through simulation in EMTP-RV. Studies without surge arrester and the presence of surge arrester in different locations are analyzed and compared. Then surge arrester's placement impacts on the substations reliability indices are calculated in normal operating condition and overvoltage condition by minimal cut set method and simulation results. Analytical studies reveal that surge arrester can increase substations reliability. But for low annual number of lightning stroke, substation reliability may decrease. Also increasing surge arrester number more than substation need reduces reliability.

Introduction

Substations as pivotal parts of electrical network, providing power to consumers through overhead transmission and distribution lines. In today's world, increasing demand of energy and growth of power network make the substations more important and cause paying more attention to reliability of substations, particularly high voltage ones. The first priority in substations is to detect and remove the failures in the transmission system, since the failures particularly due to overvoltages such as lightning and switching can leave a lot of people without electricity. The incidence of lightning strokes is a very serious problem as it can produce dangerous overvoltages, causing power supply interruptions that result in costly damage to equipment and also imposing an extra cost to the power utility because of the undelivered energy [1].

For protecting the network against lightning surge, shield wires and surge arresters are used. Shielding failure may occur during overvoltage, which can cause insulation failure of equipment. Consequently, installation of surge arresters in the existent networks will be effective to reduce failures of the insulation and lightning outages, that is, to improve the reliability of the network [2]. Surge arresters are devices that are connected between the phase and the earth and they protect distribution and transmission lines and their equipment from external and internal overvoltages, providing a low impedance path to ground for the overvoltage current. The voltage–current (*V–I*) characteristic of a surge arrester is non-linear, that is, the voltage at the terminals increases above a certain limit proportionally less than the increase in the current [3]. The schemes of lightning overvoltage protection are specified according to type, number and location of surge arresters at the substation [4]. Since the 1980, polymeric ZnO surge arresters have been developed and put into operation on transmission lines [5] because of having better *V–I* characteristic than old types.

Misoperation of protection systems can be caused either by not responding when it should (failure to operate) or by operating when it should not (false tripping) [6]. The failure of an arrester is not a common event, however, possible reasons for failure of an arrester are overloading of the active elements by energy or

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current, moisture ingress, partial flashover of one or several units in a multiunit arrester caused by external pollution or high overvoltages, thermal instability due to the effect of heavy external pollution, high temporary overvoltages, damage of some blocks in one or several units due to energy and current discharge which leads to power frequency overload of the remaining part of the arrester, mechanical overloading which leads to an electrical failure, inhomogeneities in the ZnO blocks, poor electrode adhesion to the material, insufficient surface insulation, etc [7]. The degradation in arrester elements may cause the increment of leakage current, resulting in excessive heat and unexpected aging [8] that increases failure probability of arresters. If arrester becomes short circuit during normal operating condition or open circuit during overvoltage, it will result in load interruption and perhaps great damage to substation equipment such as transformer or capacitive voltage transformer (CVT).

In order to evaluate the arrester failure impact on substation reliability, the substation will be simulated by Electro Magnetic Transient Program (EMTP) and then by cut set method and simulation results, reliability indices will be estimated in normal operating and overvoltage conditions. Numbers of arrester and their location, annual lightning stroke and its location have prominent effect on reliability indices.

Substations simulation

In this paper three common configurations of high voltage substations (230/63 kV) consists of one breaker and half, double breaker and ring bus-bar (Fig. 1) are selected to study surge arresters impact on them. These substations are simulated in EMTP-RV software.

To get acceptable and reasonable results from simulation, power system components such as transmission lines, towers, substation equipment should be properly modeled.

There are fast wave front surges for which a ZnO arrester exhibits the dynamic effects. IEEE model which is considered for the arresters, can represent these effects (Fig. 2) [9]. IEEE model parameters and characteristics of the arresters are shown in Table 1. In this table, V_r and I_d are the arresters rated voltage and discharge current respectively.

The steel towers are usually represented as a single conductor distributed parameter line terminated by a resistance representing the tower footing impedance [10]. It has been known in general that the footing impedance tends to be capacitive in the case of a high resistivity earth, and inductive in the low-resistivity earth. A problem of the representation is the footing impedance can be resistive, inductive and capacitive depending on the season and the weather when a measurement is made. Therefore, it is not easy to select a model of the footing impedance and this is the reason why a resistance model is adopted [11]. Constant parameter (CP) line is used to simulate single conductor of tower model. Towers surge impedance and wave velocity as the principal parameters of CP line are determined 160 Ω and speed of light respectively. The resistance considered for towers footing resistance is 5 Ω.

Under lightning overvoltage, substation equipment can be represented by capacitors, because duration of lightning wave is very short. Electrical parameters of lines and equivalent capacitance of substation equipment used for simulating the substations are given in Tables 2 and 3. In Table 2, R_0, L_0 and C_0 are zero sequence parameters and R_1, L_1 and C_1 are positive sequence parameters.

The lightning surge is modeled by a current and a parallel resistance (Cigre model). The resistance value is taken to be 400 Ω, which was derived by Bewley [11]. According to IEC 62305-1 [12], the first lightning stroke is standardized as a unipolar current impulse with a rise time to peak of 10 μs, and a time-to-half value

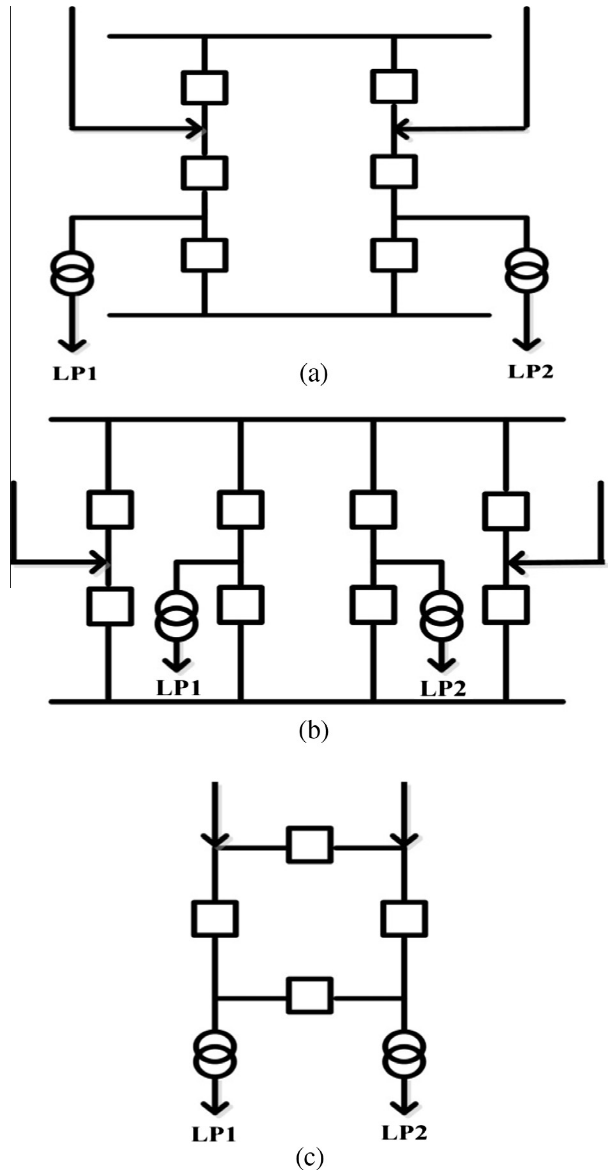

Fig. 1. Configuration of substations, (a) one breaker and half, (b) double breaker and (c) ring bus-bar, selected to be simulated.

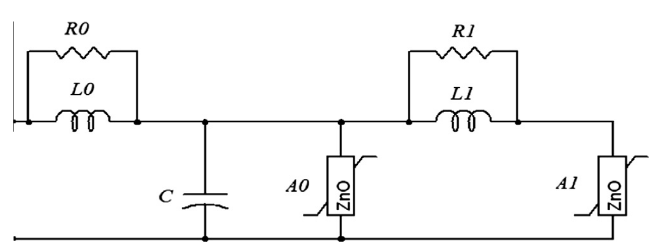

Fig. 2. IEEE model of surge arrester.

of 350 μs. The waveform is in general terms referred to as '10/350 μs', with a peak amplitude of 200 kA considering Lightning Protection Level 1 (LPL1). The subsequent stroke is a single pulse or multiple pulses of short duration, high current gradients and limited peak amplitudes. In the standard [12], this component is identified as an impulse current having a rise time to peak of 0.25 μs and a time to half value of 100 μs, with a peak value of 50 kA considering LPL1. The effects of first lightning stroke (10/