On-line Monitoring and Trending Analysis of Dielectric Losses in Cross-bonded High Voltage Cable Systems

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ABSTRACT

Cross bonding of metal sheaths across phases has been widely applied to high voltage (HV) single-core Cross-linked Polyethylene (XLPE) cable systems, especially in long distance transmission and distribution lines. This is done in order to reduce induced voltages and circulating currents and their effects. On-line monitoring provides an advanced way to achieve condition monitoring in real time effectively and realistically. Dielectric Loss (DL) measurement through on-line monitoring, which in practice is based on measured reference voltage and insulation leakage current, indicates the general state of cable insulation. As a result of the interconnection of three-phase metal sheaths, the circulating currents generated due to unbalanced length of the interconnected sections and the superimposed leakage currents of different interconnected sections will make the measurement and differentiation of variation in cable sections more complex. An improved on-line measurement of relative DL in HV cross-bonded XLPE cables is proposed in this paper, based on a model cross-bonded connection applied in physical circuits. Clamp-type power frequency current sensors, installed to collect sheath currents, are sited at the linking lines near link boxes. The proposed leakage current separation method (LCSM), to be implemented in practice, is able to distinguish the leakage current under cross-bonded connection. The Relative Tendency of DL in Comparison of Three-phase Leakage Currents (RTDL-CTLC) is put forward to determine the relative insulation conditions of interconnected sections. By comparing the result of theoretical analysis and that of simulation, there is a good consistency with high accuracy. The data obtained in an 110kV cable tunnel, China, will be used to verify the method in future work.

KEYWORDS

Cross-bonding; XLPE; Leakage current; Relative tendency; Dielectric loss

INTRODUCTION

High voltage (HV) Cross-linked Polyethylene (XLPE) cables are becoming increasingly important as assets in urban transmission and distribution networks [1]. During service life, these cables are vulnerable to failure due to a range of causes, including adverse environmental conditions, third party damage, poor workmanship, manufacturing problems, operational or maintenance reasons, and age related degradation [2]. On-line monitoring of HV cable insulation condition can improve reliability and provide possibilities for continued operation of the cable system, life assessment and comprehensive diagnostics [3]. Partial discharge (PD) monitoring allows identification and location of specific areas in a cable where the insulation system can no longer support the electrical field. However, it does not identify all degradation mechanisms. Dielectric loss (DL) is an important parameter to measure the insulation condition, as it reflects deterioration of the entire insulation system [4].

In the main, measurements of DL are applied to cable systems using off-line methods. Paper [5] developed a method for deducing the DL of a solid dielectric from the charging current that flows after the sudden application of a direct voltage. It is shown that, subject to certain conditions, the loss factor can be deduced from the charging current after applying a step DC voltage. Paper [6] described a dissipation factor measurement of paper insulated lead covered (PILC) cable insulation at ultra-high frequency. Paper [7] described a method, to some extent resembling the Schering Bridge, in that they incorporate a low-loss condenser of known capacitance and negligible loss angle. Most of the off-line test measurements applied are AC bridges, such as the Schering Bridge [8][9]. Although they can be of high accuracy they require a cable outage, adding cost and additional stress in local components.

On-line monitoring of DL is the subject of many research papers. Paper [10] states that analyzing the trend of the on-line monitored dielectric dissipation factor is a very effective method of assessing the insulation: a trend-extracting method using a filter is put forward in its research. Paper [11] proposed a definition of dielectric loss factor with harmonics: two approaches, namely the decoupling algorithm and the approximating algorithm, are presented to implement the methodologies. Paper [12] used the characteristic of an orthogonal vector in the inner product space. In this paper DL is defined as the ratio of norms of the active current to the reactive current: the leakage current signal was decomposed to orthogonal active and reactive components. However, the cross-bonding connection has not been taken into consideration.

In order to meet the requirement for long-distance transmission of electricity by HV single-core XLPE cables, cross-bonding of the outer sheath has been adopted to reduce the induced voltages [2]. In the system investigated, the installation method has the metal sheath of different phases connected through link boxes, and both end terminals are grounded, as shown in Figure 1. As a result of this connection method, the signal passing through the connecting cables to the link boxes contains superimposed leakage currents from different interconnected sections. In addition, when the lengths of HV cable sections is unbalanced, there will also be circulating currents. Some work has focused on the sheath circulating current but could not tell which cable section had higher degradation factor. So it is still a great challenge to distinguish the dissipation condition of each interconnected section.