Ultra steep wavefront transients characterized by high dU/dt values are extremely dangerous to the electrical equipment such as transformers and motors. According to “Industrial Power Engineering and application handbook”¹ as many as 35% of total dielectric failures in power equipment are caused by surge. The high frequency components present in the spectrum of the surge result in a very non-uniform potential distribution, leading to local overstressing of the insulation system. Due to the complicated internal structures of electrical apparatus resulting in a multi-resonant circuit nature, high frequency components may additionally lead to a local amplification of voltage. Overstressing the insulation system reduces significantly the equipment lifetime and often leads to internal short-circuit.

I. Technical background

The growing demand for increasing the withstand level of the distribution transformers results in a need to apply non-conventional design of the windings leading to increased cost of both the design and manufacturing of the transformers. Of special concern are transformers working in distribution networks exposed to frequent atmospheric discharges. Operators of those networks often request compliance with a highly demanding norm, requiring testing the transformers with a steep-fronted impulse. According to a Finnish standard (SFS 2646), the steepness of the test voltage is 2MV/us². The transformer, according to the norm is protected with a 2 x 40 mm double spark-gap located in a proximity to the transformer. The nature of a spark-gap, being a relatively slow device result in that the voltage at the transformer terminals may, under the test conditions, reach levels highly exceeding the standard BIL levels for a given transformer type.

Experimental results confirm the above and indicate that a spark gap may not provide sufficient protection for distribution transformers³ of the standard design. The common solution to the problem is to apply a special winding design with increased insulation level and with additional elements equalizing the initial potential distribution.

II. SmartChoke – series filter based protection

An alternative to a special transformer design is to introduce a series filtering element (choke) upstream the protected equipment. The basic principle of the use of the series element is to provide an appropriate impedance-frequency characteristic, so that the device is transparent at 50/60 Hz but provides suppression for very high frequency components.
In this approach the phase-to-ground capacitance C is the equivalent phase-to-ground capacitance of the transformer. The concept is schematically presented showing an idealized picture of a voltage waveform of a 2 MV lightning impulse chopped at the front with a spark gap. The unprotected equipment (eg, pole-mounted transformer) would experience the phase-to-ground voltage of peak value exceeding 270 kV, characterized by a dU/dt of 2 MV/µs. If the series choke element is installed upstream the protected device, its high frequency impedance combined with the phase-to-ground capacitance of the transformer form a low-pass filter, reducing the dU/dt but also, in consequence, the peak value of the voltage surge reaching the transformer.

III. SmartChoke protected Transformer

The series choke element concept described has been practically implemented in new ABB distribution transformers providing a superior protection against high dU/dt transients. The SmartChoke element is integrated within the transformer bushing and thus the filtering of the high dU/dt transient takes place before it reaches the winding. Experiments performed showed that reduction in dU/dt resulting from the use of the special bushing with integrated SmartChoke device exceeds a factor of 2 with respect to the standard transformer bushing. Also, a significant reduction in peak voltage was recorded.

The transformer comprising the SmartChoke bushing has been certified according to the SFS 2646 Standard at the HV Laboratory of the Helsinki University of Technology, Espoo, Finland.

References
1 K. C. Agrawal, „Industrial Power Engineering and application handbook”, Newnes2001, p. 577
2 FINNISH STANDARDS SFS 2646, 1987-06-29, „Pole mounted substation”.

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