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Partial Discharge Simulation for a High Voltage Transformer Winding Using a Model Based on Geometrical Dimensions

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Introduction

Partial discharge (PD) is a common phenomena which may occur in high voltage equipment especially in power cables and high voltage transformers. It may occur as a result of ageing processes, electrical overstressing or presence of defects introduced during manufacture. PD might occur anywhere inside a transformer particularly along the transformer winding and the discharge signal can propagate along windings to the bushing and neutral to earth connections. Therefore, the identification of a PD source as well as its location are essential to ensure that PD monitoring allows evaluation and maintenance processes to be carried out effectively .

Various methods and analytical models have been proposed and discussed thoroughly in the literature which allow the study of transient phenomena inside a transformer winding. More recent research is focussed on trying to use models in order to study PD activities inside a transformer winding and particularly for identifying the location of the PD source. There are three different model structures which can be categorised as either black box or physical or hybrid models and each one has its own properties and capabilities which suit different types of investigation and study.

However in this case, the need is to develop an accurate physical model of a transformer winding which can then be used to investigate PD signal propagation and the simplest solution is to use a lumped parameter network approach. An experiment has been developed in the Tony Davies High Voltage Laboratory that can be used to create PD data over hundreds of cycles of applied voltage in order to produce data which can then be used to verify the accuracy of the model using a least mean square error approach.

Lumped Parameter Network

A transformer winding may be represented as a large coil covered with paper insulation and immersed in mineral oil which results in a structure of several elements which can be represented using a RLC transmission line network. Fundamentally, the transformer consists of the copper coils surrounding with insulation systems around the core bar. Typically, the coil windings are represented as a series connection of equivalent inductors and the insulation system surrounding the winding is represented using equivalent capacitors. The losses can be included to the network as resistors in series with the inductors. The complete lumped parameter network system to represent a winding is shown in Figure 1.

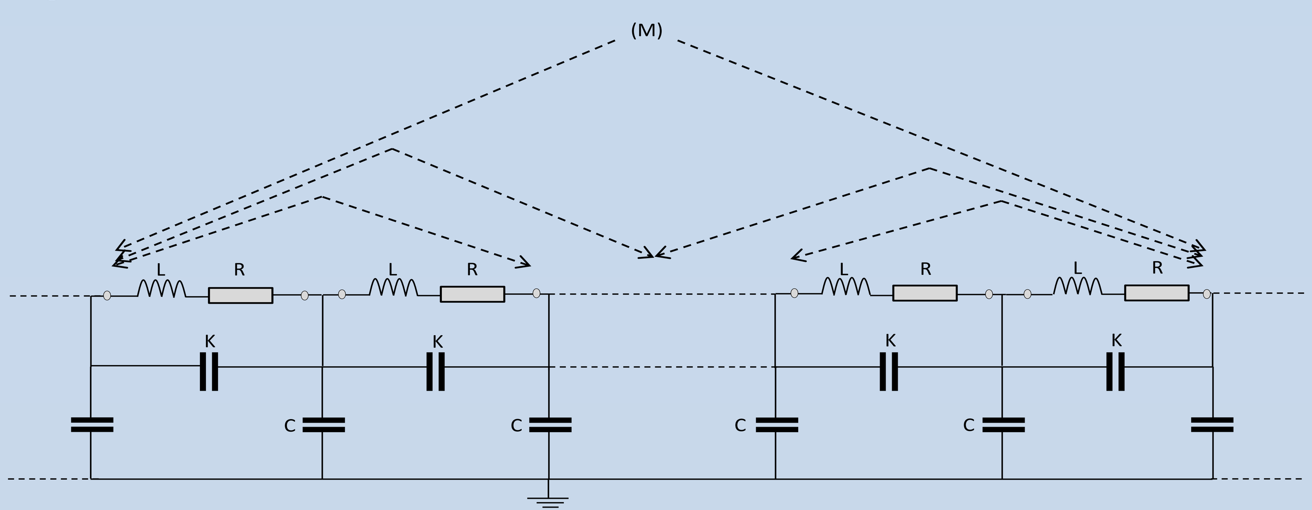

Figure 1: A lumped parameter network model for a high voltage transformer winding.

Equivalent Model

The simulation model represents an interleaved disc type winding which consists of eight sections having internal winding series resistances (R), inductances (L), series and shunt capacitances (K,Cg), including the effect of their mutual inductances while the magnetic losses have been ignored as shown in Figure 2. These parameters are derived using analytical calculations from the geometrical dimensions and the model has been implemented using a circuit simulation package (PSPICE OrCAD) and also MATLAB Simulink which was ultimately used for further analysis due to its flexibility.

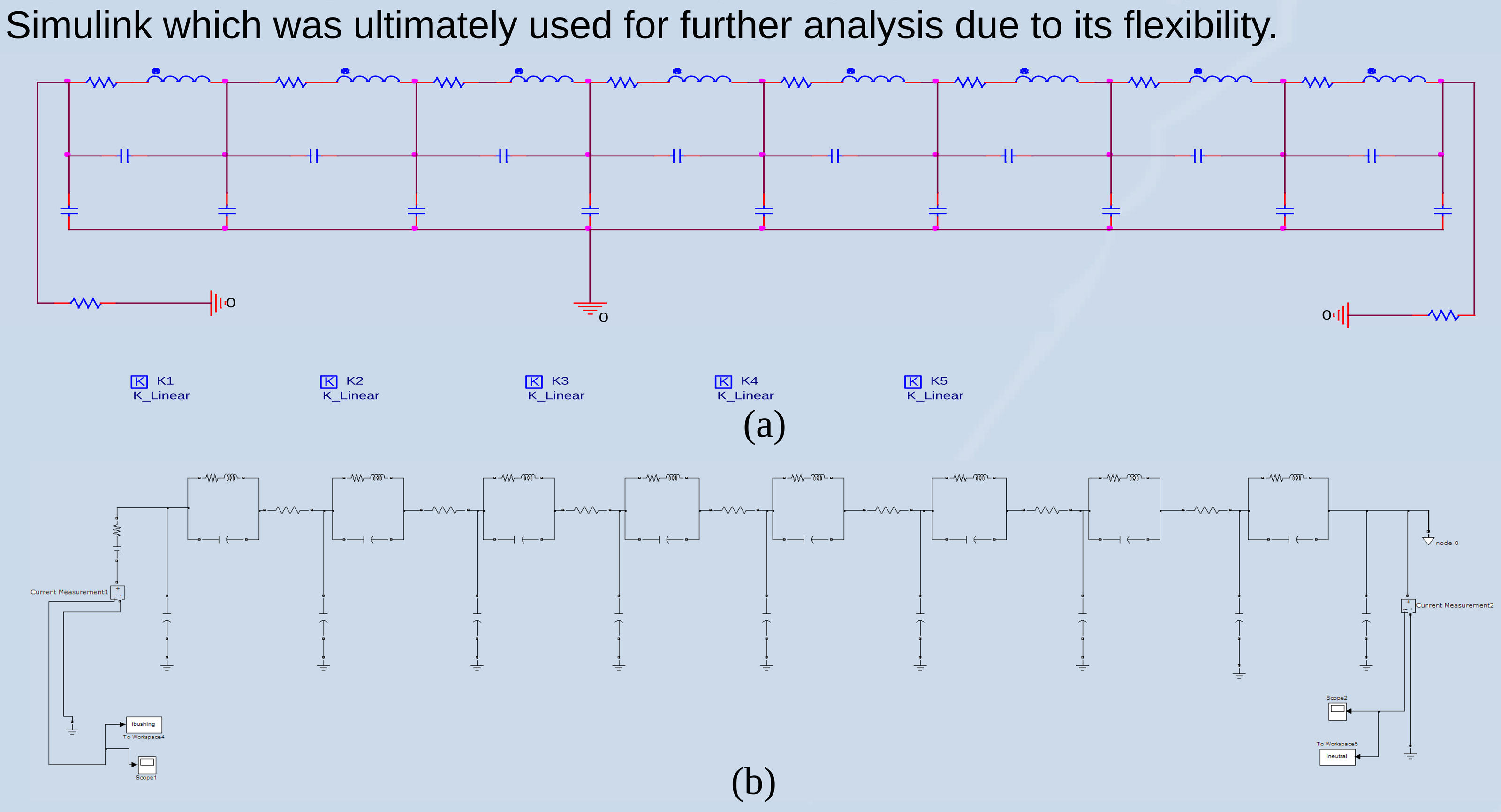

Figure 2: Equivalent model for high voltage transformer winding a) PSPICE OrCAD b) Matlab Simulink

The parameters of the winding section can be calculated individually depending on their configurations inside the transformer. The inductance (L) for connecting the two sections inside the winding is 1.2 mH. For the capacitance of the winding to ground (Cg), the capacitance of 81 pF was divided equally between the number of discs, given each a capacitance to ground of 5.1 pF. The series capacitance (K) is 930 pF for the interleaved winding. The input to simulation circuit which acts as a transient pulse is generated using a function generator, providing a pulse with a duration of a few nanoseconds. The simulation results are captured via both ends of the winding at terminal 1 and terminal 8 which are grounded through a small capacitive and resistive element to represent the bushing end and neutral to earth connection respectively.

Experiment

The experiment is based on high voltage transformer winding model BS148:1998 class 1 and 60 kV transformer bushing 60HC755 in order to simulate the PD activity using signal generator inside transformer winding. The transformer has 2 type of windings, interleaved disc and plain disc winding, in this case the PD signal source was generated using a signal generator to inject into the interleaved disc winding whilst the plain disc winding remains grounded. The interleaved winding consist of eight terminals, terminal one of the winding is connected to the bushing core bar while the last terminal was grounded. The pulses from signal generator were injected at each terminal of the winding and the pulse current from the signal generator is measured at measurement points. There are two PD measurement points in this case due the signal from the signal generator can travel to both directions, first point is located at the bushing tap and the other is at neutral to earth connections as shown in Figure 3. The current flowing to the both ends can be measured by using a radio frequency radio transducer (RFCT). The RFCT used in this experiment is the clamp-type split core RFCT EMCO model 93686-5, serial model 9802-50174 which has a measurable frequency range from 10kHz to 200MHz. A digital storage oscilloscope, Tektronix DPO7254 with a bandwidth of 2.5 GHz and sampling rate 40 Gs/s was used to display, analyse and store the obtained output signals from both ends.

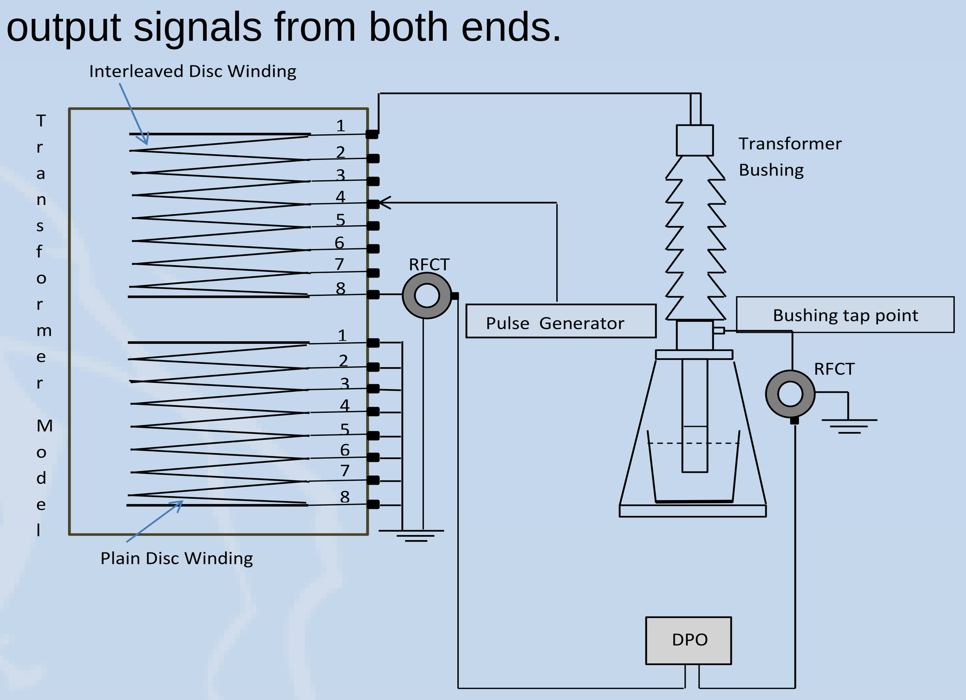

Figure 3: Experiment diagram for measuring transient pulse within transformer winding.

Results and Discussion

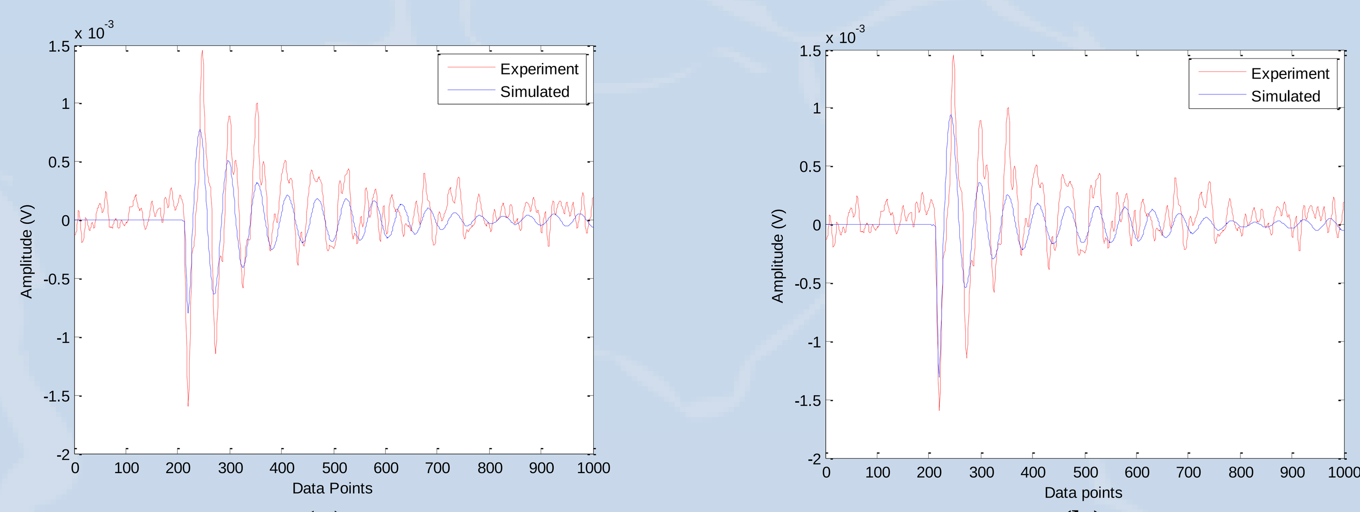

Figure 4: Transient signals from a transformer winding. a) Bushing tap point b) Neutral to earth connection

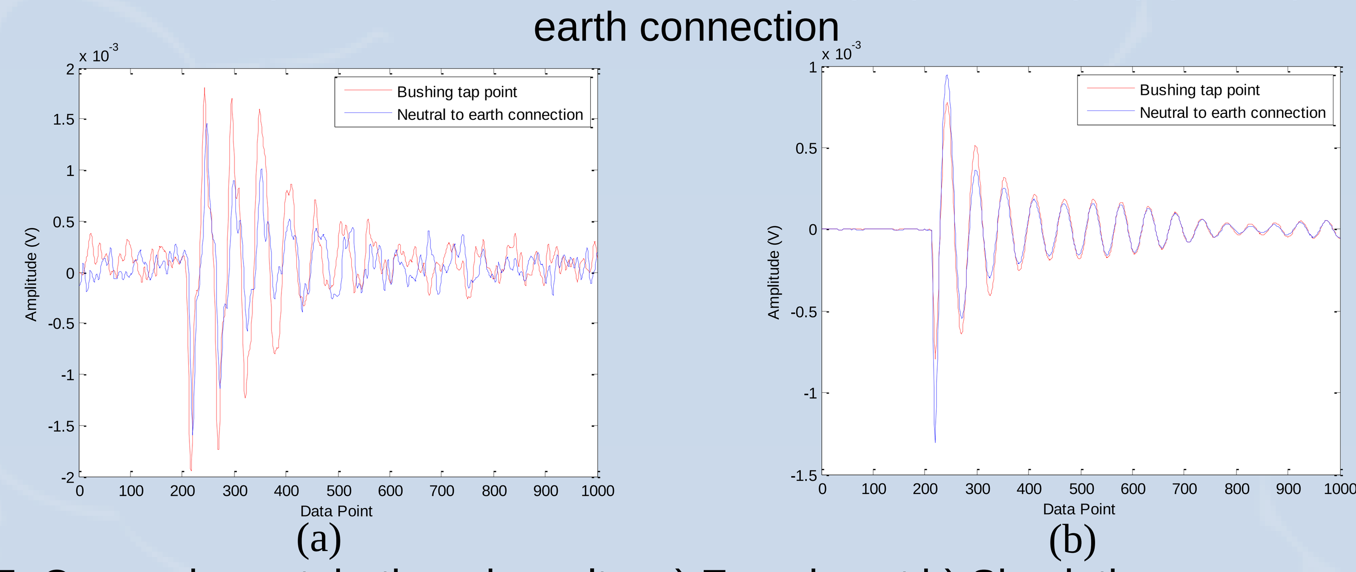

Figure 5: Comparison at both end results. a) Experiment b) Simulation

Figure 4 (a and b) show the comparison of simulation results and the results from the experiment when the signal from the signal generator was injected at the same location inside the winding. The signals show a similar pattern and duration although the magnitude of the experimental signal is almost double that of the simulated one as shown in Figure 5. These results indicate that this model might be useful to simulate the PD activity inside the transformer winding. However, if the results from the simulation model are compared to experimental data using a real PD source, the limitations of this approach may be established.

Conclusions

A model for simulating PD propagation inside the transformer winding based on the lumped parameter model has been presented. The analytical solutions which are used to estimate the parameters of the model based on limited knowledge of the geometrical dimensions of the winding provide good accuracy when the simulation result is compared to the experiment results obtained using a signal generator as a PD source.

The model can be used to investigate the sensitivity to variation of the physical parameters on simulation performance by altering a single parameter such as thickness of paper insulation, permittivity of paper insulation or permittivity of the oil.

The true limitation of assuming the winding can be represented by a LTI model for PD source location may be discovered from the comparison of these results.

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