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Neutral Current and Frequency Response Analysis of Single and Multiple Turn Fault in the Winding of a 315 MVA 500 kV HVDC Transformer

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Abstract - *The paper presents the theoretical simulation of neutral current and Frequency Response Analysis (FRA) of HVDC transformer due to fault in the turns of the winding. The HVAC and HVDC (Valve) windings of the transformer are represented by its self and mutual inductances and capacitances. Using these parameters equivalent electrical network is formed. The windings are subjected to standard lightning impulse voltage at its high voltage terminal and neutral currents are calculated. Single and multiple turn faults are simulated at different Coil Depth (CD) of the winding. The paper presents the comparison of neutral current for different turn faults. The neutral currents are analyzed to determine the magnitude and phase difference between them to relate turn faults. The results are complemented by FRA analysis of each neutral current to examine the faults. Comparison between neutral currents of different turn fault and their frequency response establishes the effectiveness of the technique for the detection of minor faults.*

Key Words: FAR, Transformer, Neutral current, Fault.

1. INTRODUCTION

In accordance with the National and International standards [1] a power transformers is tested for lightning impulse voltage to determine the integrity of the windings. In order to conduct the test, the winding under consideration is subjected to impulse voltage at its high voltage terminal while the neutral is grounded. The current in the neutral winding is recorded for reduced and full voltage. A comparison is done between neutral current at reduced and full voltage which gives an indication of failure status. Even a small deviation between two neutral current is regarded as failure. It is however argued that such a costly transformer should not be rejected merely on the basis of neutral current deviation observed by eye estimation since such deviation may occur due to Partial Discharges (PD) also. Difference in neutral current at reduced voltage during calibration and full test voltage is however not construed as failure in case of occurrence of PD.
In order to differentiate between the success and failure of transformer during impulse test a diagnostic method based on FRA is proposed by several researchers [2-5]. Many other methods based on Wavelet Analysis (WA) [6,7] as well Coherence Function Analysis (CFA) [8,9] have been proposed in literature. FRA method provides useful information on failure of transformer. However, in certain cases where a single turn or part of turn (minor insulation) is involved in short circuit, ambiguous results are obtained. The results are obscured by noise. The method of FRA is considered complementary to neutral current comparison.

2. MODELING OF TRANSFORMER EQUIVALENT CIRCUIT AND TURN SHORT SIMULATION

The HVDC transformer consists of two windings where one is connected to 400 kV transmission line and the other, known as valve winding is connected to HVDC system. The HVAC windings are all-star connected. Fig. 1 depicts the schematic diagram of 400 kV HVAC winding and star (Valve) DC winding.

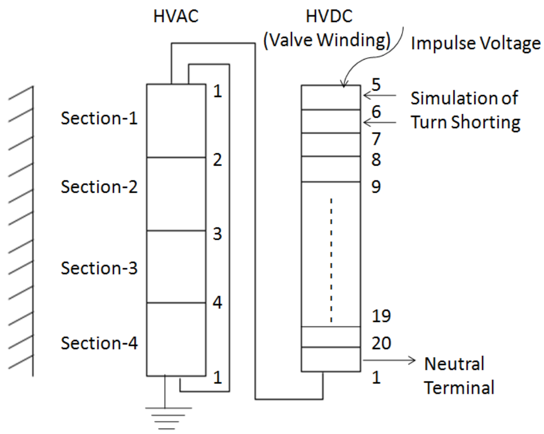

Fig. 1. Schematic diagram of 315 MVA, 500 kV HVDC Transformer

During impulse test the AC winding is fully grounded and other end of the valve winding is grounded in accordance with standard test requirement.

Fig. 2 shows the equivalent electric circuit comprising inductance and capacitance of the two windings of

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transformer. The HVAC winding is divided into 4 sections and valve winding is divided into 16 sections.

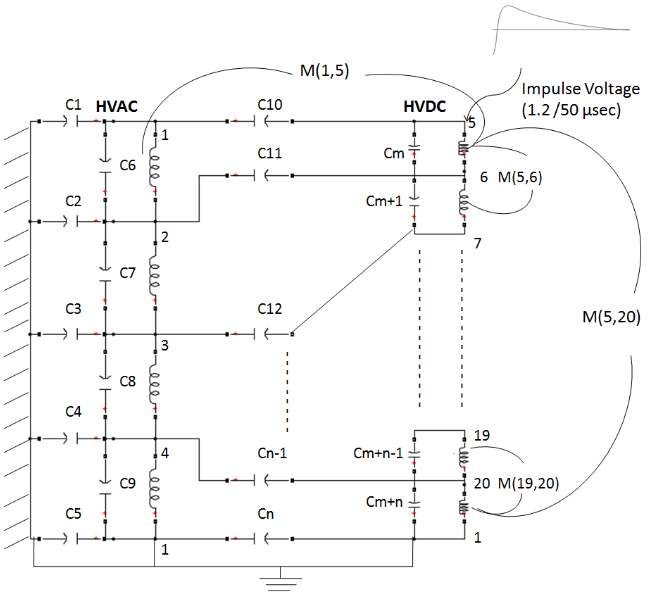

Fig. 2. Equivalent electrical network of 315 MVA, 500 kV HVDC Transformer.

The shorted terminals which are connected to ground are depicted in Fig. 1 and Fig. 2. The self and mutual inductance of the section of each winding and mutual inductances between sections of both the windings are calculated based on the tabulated values [10]. The self capacitance in each section, capacitance between sections and windings to ground are calculated based on standard formula for capacitance. The connections to ground are done as shown in equivalent circuit.

The neutral current is DE convoluted into frequency domain using standard FFT program and frequency response of healthy and faulty neutral current is compared for change in frequencies and respective magnitudes.

3. SIMULATION OF FAULT

Terminal Node 5 is excited with impulse voltage (1.2/50 µsec) of unit magnitude and Node 1 is grounded as shown in Fig. 2. The current in inductance and capacitance between Node 20 and Node1 is added [11] to obtain total neutral current to ground. A single or multiple turn short is created along the height of winding in order to analyze the effect of fault. For each turn short the neutral current is obtained. The neutral currents for healthy winding and winding with turn fault are compared to determine the magnitude and phase difference of the current pulses. The fault is simulated by shorting a) One Turn b) Five Turns c) Ten Turns in the first section of HVAC winding. In other case again a) One Turn b) Five Turns c) Ten Turns short are simulated in Second section of HVDC winding. In each case currents are recorded. Duration of current calculation is limited to about 102 µsec with a discrete time step of 0.1 µsec. The time step is found adequate to obtain accurate transient current for the purpose of this analysis.

4. RESULTS AND DISCUSSIONS

The simulation results of neutral currents for unit impulse voltage are given in Fig. 3 and Fig. 4. Fig. 3 shows the plot of neutral currents due to various faults in first section. Similarly Fig. 4 shows the neutral current due to faults in second section.

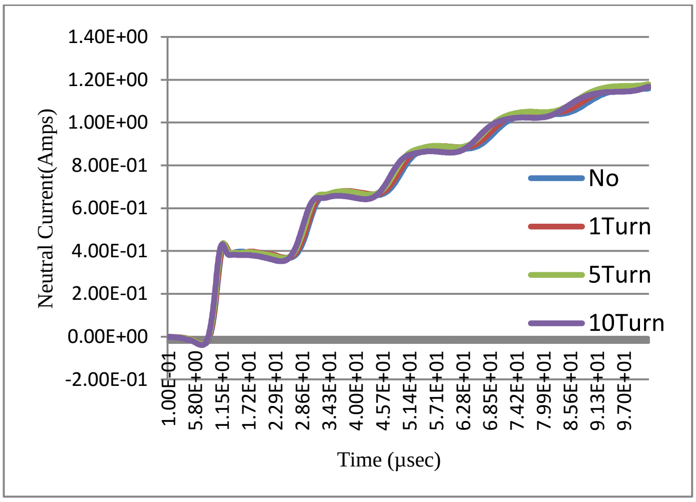

Fig. 3. Neutral Current for Unit Impulse Voltage at HV section-1

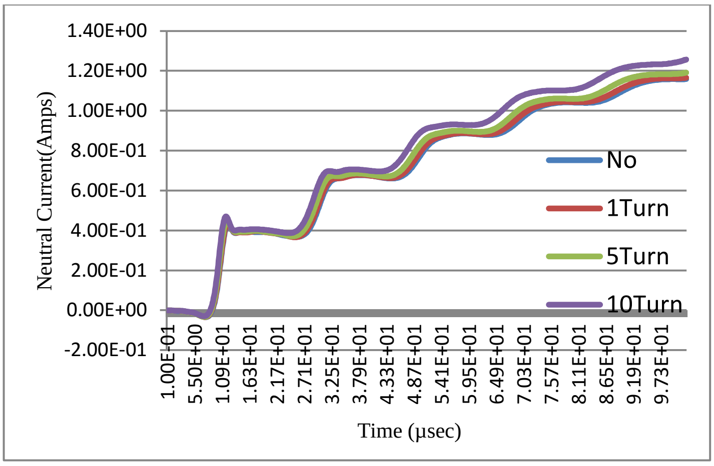

Fig. 4. Neutral Current for Unit Impulse Voltage at HV section-2

A visual observation of neutral currents shows that a difference exists between the healthy neutral current and the current with shorted turns. However the difference is rather small. It may occur since one turn fault out of 246 turns does not significantly alter the inductance and capacitance of the windings. There is marginal difference in currents with five and ten turns fault. Similar neutral current variations are observed where one, five and ten turn faults are simulated in second section.

In view of such small difference between current with healthy and turn shorted it becomes complex to determine the failure of the winding. In this regard several researcher[2-5] reported deconvolution in frequency domain to determine if any additional difference can be located due to changes in frequency. A closer look at FRA of fault in first section is depicted in Fig. 5.

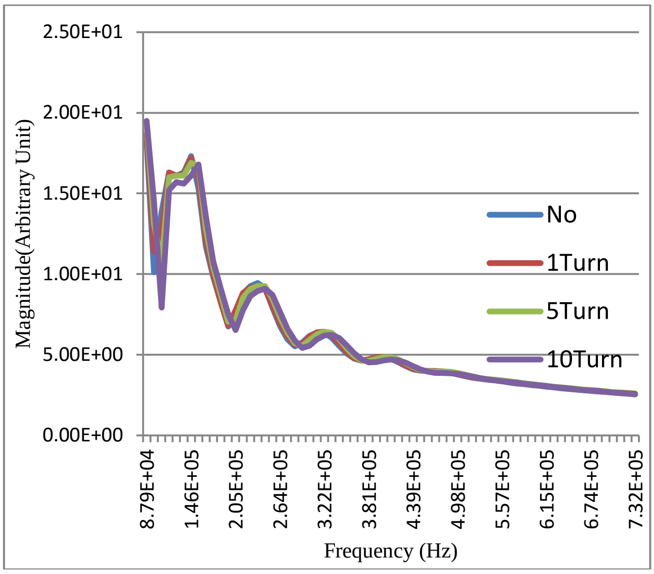

Fig. 5. Frequency Response of the turn fault in sec-1 in 500 kV winding.

It is observed that there is a change in frequencies. However not all frequencies have changed. For example the frequency of 117 kHz has remained same even when a single turn fault occurred, but changed to 127 kHz with ten turn fault. Similar results are seen for other frequencies also. For a single turn fault there is a change in at least one of the eigen frequencies and FRA magnitude as seen in the 4th peak (313 kHz to 322 kHz) in Table 1. Hence change in frequencies for minimum turn faults and their magnitudes can be related to failure. The above fact can be visualized in Table 1 where there is no change in frequency between healthy and one turn fault except in the peak as stated above.

Table -1: Frequency and Peak Magnitude for Turn faults in First Section of Valve Winding.

Turn Fault	1st Peak		2nd Peak	
	Frequency	**Magnitude**	**Frequency**	**Magnitude**
No Fault	1.17E+05	1.63E+01	1.46E+05	1.73E+01
One Turn	1.17E+05	1.63E+01	1.46E+05	1.72E+01
Five Turn	1.27E+05	1.61E+01	1.46E+05	1.69E+01
Ten Turn	1.27E+05	1.57E+01	1.56E+05	1.68E+01

Turn Fault	3rd Peak		4th Peak	
	Frequency	**Magnitude**	**Frequency**	**Magnitude**
No Fault	2.34E+05	9.45E+00	3.13E+05	4.82E+00
One Turn	2.34E+05	9.29E+00	3.22E+05	4.85E+00
Five Turn	2.34E+05	9.27E+00	3.22E+05	4.84E+00
Ten Turn	2.44E+05	9.08E+00	3.32E+05	4.69E+00

5. CONCLUSION

Turn fault in 500 kV HVDC transformer has been analyzed on the basis of neutral current and FRA calculation. It is observed that minor turn fault in the form of single turn does not significantly change the neutral current during the total duration of transient. However, it is observed that there are frequency and magnitude changes in the event of single turn fault also. This change in frequency and corresponding magnitude may be considered as criteria for detection of minor fault.

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