Investigation of Inter-turn Fault in Transformer Winding under Impulse Excitation

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ABSTRACT
Power Transformers are the most critical component of power system. This work investigates the pattern of the fault currents contain a typical signature of the nature and type of the fault for a given winding. It determines the reliability of equipment and facilities used in a power system is an essential precondition of the energy transmission security. This dissertation aims at investigating the behaviour of dynamic insulation failure in transformer under impulse excitation like standard impulse and switching impulse. Major faults like series and shunt fault in transformer are considered for analysis. In this proposed work, the fault can be diagnosed by winding current waveform of transformer, where the equivalent circuit of transformer winding model is developed by using ORCAD PSPICE software.

General Terms
Modeling and simulation, High voltage engineering.

Keywords
Transformer winding, standard impulse, Switching impulse, shunt fault and series fault.

1. INTRODUCTION

As major apparatus in electric power system, power transformers are the important for stable and reliable operation for power supply in the power system. Being essential equipment, the failure of power transformer might cause the severe damage in power system. The insulation failure has been considered as the major cause for the failure of the power transformer, thus it need cautious attention during winding insulation design. As per IEC 60076 [1], insulation strength of the transformer is assessed. The insulation failure may cause during impulse testing of the transformer. This failure may classify into two types, viz. Static and dynamic [2-3].

The fault created due to the defects which are already present in the insulation before to the application of impulse sequences, i.e. the defect which do not develop with the propagation of impulse voltage wave are referred as static insulation failure. On the other side, failure that may arise along the winding due to propagation of impulse voltage wave during testing are referred as dynamic insulation failure.

Recently, as the result of advancement in technology the transformer insulation defects are reduced during manufacturing. So the probability of occurrences of static insulation failure is reduced during impulse test and majority of the insulation failure that may arise are dynamic in nature. Hence, the analyses of dynamic insulation failure during impulse test are more important.

In this approach the insulation failure are identified by analysing the winding currents acquired by current during impulse test. In addition to the static and dynamic fault, the fault may be classified into series faults and shunt faults. Thus the transformer winding model is simulated using ORCAD PSPICE.

2. MODELING

2.1 Modeling of Transformer

According to the theory of electromagnetic, a transformer winding is equivalent to a linear bilateral passive network. It consists of inductance and capacitance (the resistance is usually ignored). The character of this network can be described by transfer function [4-5]. Equivalent circuit and simulated transformer winding model is shown in fig. 1 and fig. 2. Table I and II shows the basic design parameter and value, basic design details of the transformer respectively.

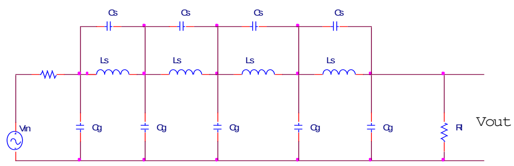

Fig 1: Equivalent circuit for transformer winding

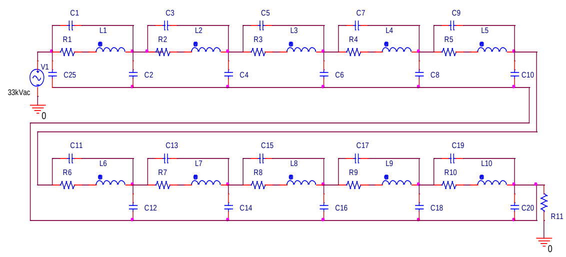

Fig 2: Simulated transformer winding model

Table 1. Basic design parameter and value

Rated Power	16MVA
Number of Phases	3
Rated frequency	50Hz
Connection (HV/LV)	Star/ Delta
Rated Voltage(HV/LV)	33/11Kv
Type	Core type transformer
Construction	Disc winding
Dielectric	Mineral oil
Approximate Overall dimension	1100*155mm

Table 2. Basic design details of transformer

Parameters	Symbols
Series Inductance (mH)	La
Ground Capacitance(nF)	Cg
Series Capacitance(pF)	Cs
Input resistance(ohm)	Ri
Output Resistance	Ro
Bushing Capacitance(pF)	Cb

2.2 Impulse Generator

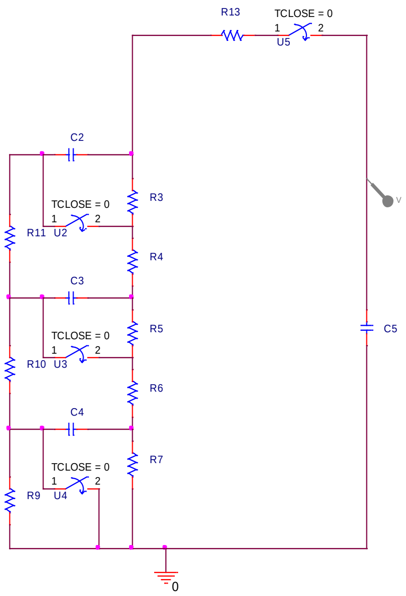

Fig 3: Impulse generator circuit

The generator capacitance C2, C3 and C4 is to be first charged and then discharged into the wave shaping circuits. For producing very high voltages, a bank of capacitors are charged in parallel and then discharged in series. This was produced by Marx so it is called Marx circuit. Impulse generator circuit is shown in fig.3. Standard impulse voltage is defined, both by the Indian Standards and the IEC, as 1.5/50 μs wave [6].

2.3 Switching Impulse

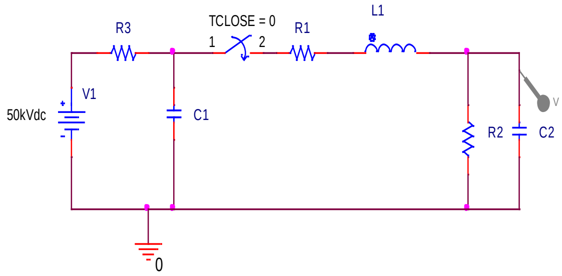

Fig 4: Switching impulse circuit

In extra high voltage transformer and power systems, switching surge is an important factor that affects the design of insulation. A switching surge is a short duration transient voltage produced in the system due to a sudden opening or closing of a switch or circuit breaker or due to an arcing at a fault in the system and its waveform is not unique. The transient voltage may be an oscillatory wave or a damped oscillatory wave of frequency ranging from few hundred hertz to few kilo hertz. It may also be considered as a slow rising impulse having a wave front time 0.1 to 10 ms, and tail time of one to several milliseconds. Switching impulse circuit is shown in fig.4. Switching surges contain larger energy than the lightning impulse voltages. Standard switching impulse voltage is defined, both by the Indian Standards and the IEC, as 250/2500 μs wave.

3. FAULT ANALYSIS

3.1 Transformer under Impulse Excitation

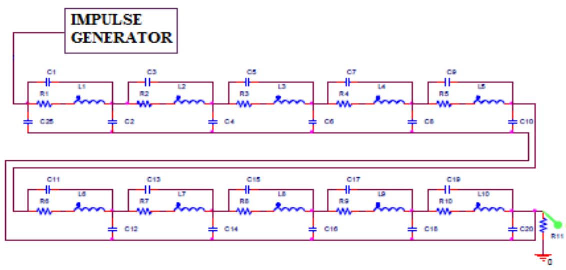

Fig 5: Transformer with impulse excitation circuit

In this work transformer winding is subjected to the impulse excitation without any fault condition in the winding. Transformer winding with impulse excitation circuit is shown in the Fig.5

3.2 Transformer Winding with Shunt Fault and Series under Lightning Impulse

Standard lightning impulse of 1.2/50 μs is applied to the transformer winding with the shunt and series fault, circuit is shown in Fig.6 and Fig.7 respectively.

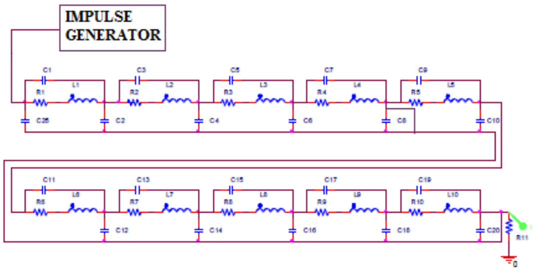

Fig 6: Transformer winding with shunt fault under lightning impulse

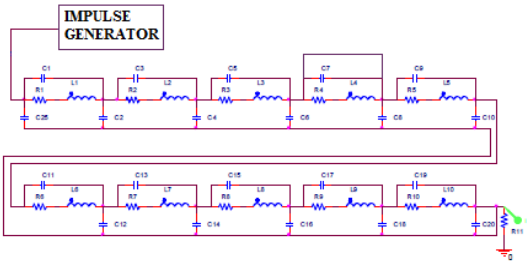

Fig 7: Transformer winding with series fault under lightning impulse

3.3 Transformer Winding under Switching Impulse Excitation

Switching impulse of 250/2500μs is applied to the transformer winding under the un-faulted Transformer winding, circuit is shown in Fig.8

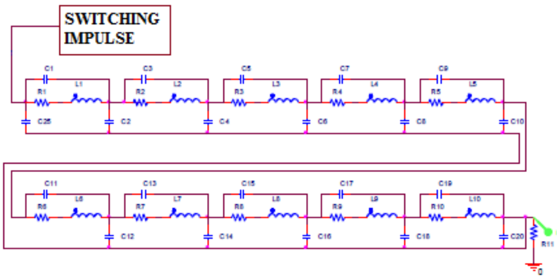

Fig 8: Transformer winding under switching impulse

3.4 Transformer Winding with Shunt and Series Fault under Switching Lightning Impulse

Transformer winding is subjected to switching impulse excitation under shunt and series faulted condition, circuit is shown in Fig.9 and Fig.10 respectively.

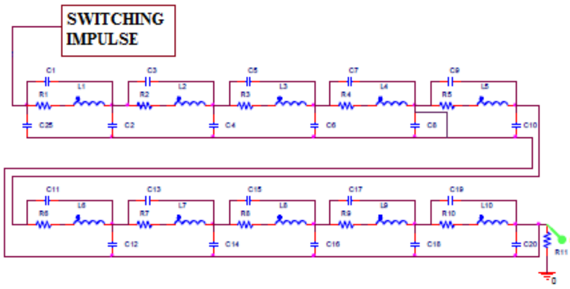

Fig 9: Transformer winding with shunt fault under switching impulse

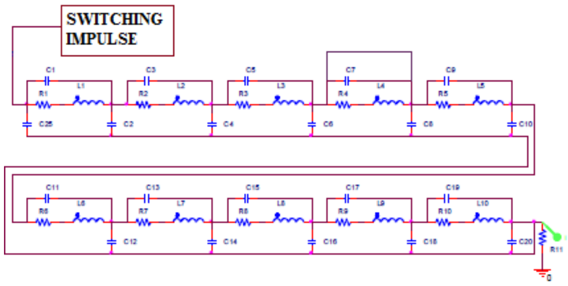

Fig 10: Transformer winding with series fault under switching impulse

In this fault analysis, transformer winding is applied to the standard impulse wave form of 1.2/50μs [7] and switching impulse of 250/2500μs. For each transformer windings, series and shunt faults are created in the fourth winding as shown in the figs. (6, 7, 9 and 10).

4. RESULT AND DISCUSSION

4.1 Shunt Fault

This fault may be occurs due to aging of insulation material. Lightning or over voltage causes breakdown in the aged insulations such as craft paper, press board and mineral oil (transformer oil). Shunt fault may me any one of the following,

- Insulation breakdown between winding and earth.
- Insulation breakdown between different phases.
- Transformer core fault.

Due to the shunt fault, there is a severe increase in current through the transformer winding.

Waveforms for the standard impulse with shunt fault for each winding is shown in the Fig.13. The switching impulse with shunt fault for each winding is shown in the Fig 14.

4.1.1 Impulse excitation with shunt fault

Peak current value, 10% of peak current value, 50% of peak current (tail) value and 90% of peak current value and their corresponding time are obtained from the shunt fault waveforms. The values are tabulated in Table 3 for shunt fault under standard impulse.

4.1.2 Switching impulse excitation with shunt fault

Peak current value, 10% of peak current value, 50% of peak current (tail) value and 90% of peak current value and their corresponding time are obtained from the shunt fault waveforms. The values are tabulated in Table 4 for shunt fault under switching impulse.

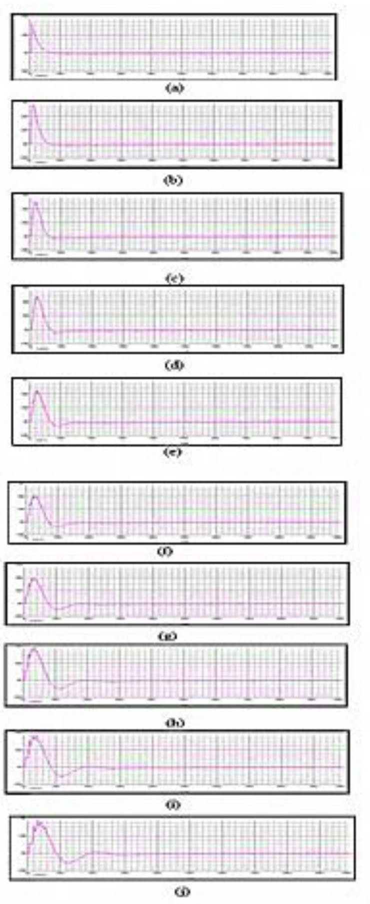

Fig 11: Transformer winding with shunt fault under lightning impulse excitation (current vs. time)

4.2 Series Fault

When there is an insulation breakdown between adjacent phase (i.e.) inter-turn faults occurs in transformer windings is series fault. This is one of the internal fault in power transformer, here insulation of the winding get damaged due to lightning and overvoltage it causes short circuit between the inter-turn winding.

4.2.1 Impulse excitation with series fault

Waveforms for standard impulse with series fault for each winding is shown in the Fig 13. Peak current value, 10% of peak current value, 50% of peak current (tail) value and 90% of peak current value and their corresponding time are obtained from the series fault waveforms. The values are tabulated in Table 5 for series fault under standard impulse.

4.2.2 Switching impulse with series fault

The switching impulse with series fault for each winding is shown in the Fig 14. Peak current value, 10% of peak current value, 50% of peak current (tail) value and 90% of peak current value and their corresponding time are obtained from the series fault waveforms The values are tabulated in Table 6 for series fault under standard switching impulse respectively.

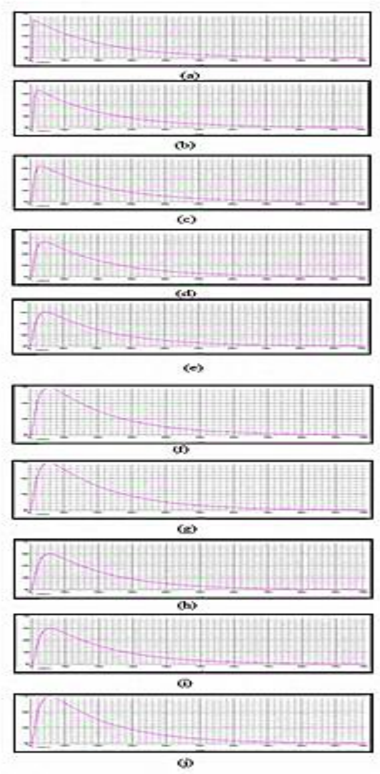

Fig 12: Transformer winding with shunt fault under switching impulse excitation (current vs. time)

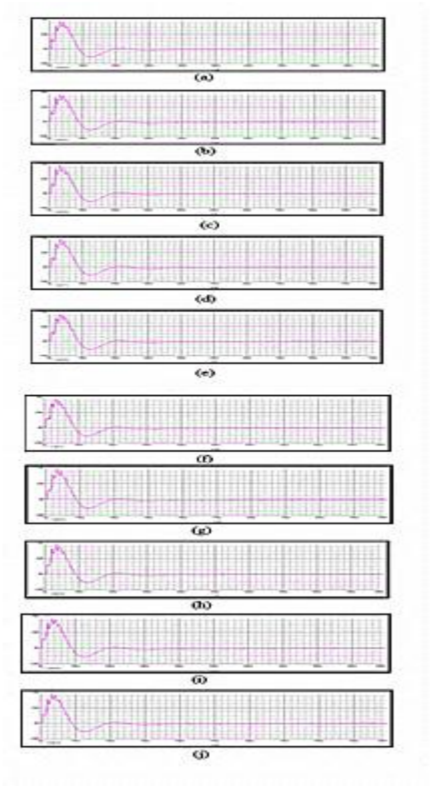

Fig 13: Transformer winding with series fault under lightning impulse excitation (current vs. time)

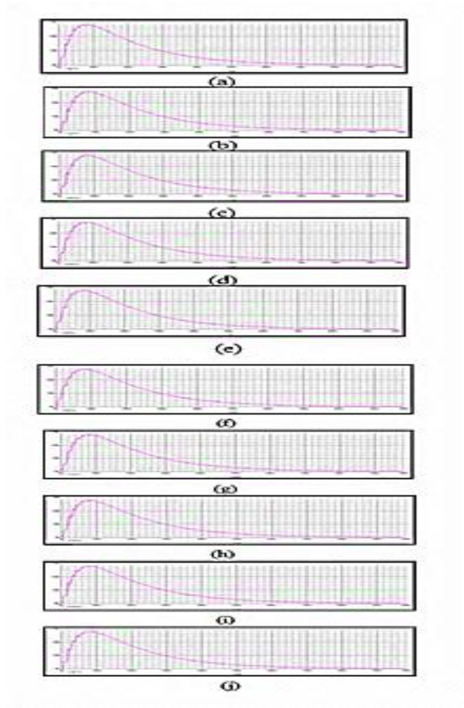

Fig 14: Transformer winding with series fault under switching impulse excitation (current vs. time)

Table 3. Transformer winding with shunt fault under impulse excitation

WINDING NUMBER	Peak value of current		10% of Peak value of current		50% of Peak value of current		90% of Peak value of current	
	Amplitude (A)	Time (µs)	Amplitude (A)	Time (µs)	Amplitude (A)	Time (µs)	Time (µs)	Amplitude (A)
1	56.21	1.24	5.621	0.46	23.105	2.87	50.589	0.98
2	50.45	1.73	5.045	0.46	25.225	3.54	45.405	1.30
3	46.62	1.98	4.662	0.458	23.31	4.12	41.958	1.49
4	44.85	2.34	4.485	0.455	22.425	4.59	40.365	2.12
5	42.38	2.682	4.238	0.449	21.19	5.05	38.142	2.45
6	40.22	3.09	4.022	0.440	20.11	5.36	36.198	2.79
7	38.92	3.57	3.892	0.446	19.46	5.79	35.028	3.10
8	37.36	2.90	3.786	0.446	18.93	6.25	34.074	2.67
9	37.72	3.15	3.772	0.440	18.86	6.59	33.943	2.96
10	36.97	3.39	3.697	0.450	18.48	6.32	33.048	3.16

Table 4. Transformer winding with shunt fault under switching impulse excitation

WINDING NUMBER	Peak value of current		10% of Peak value of current		50% of Peak value of current		90% of Peak value of current	
	Amplitude (A)	Time (μs)	Amplitude (A)	Time (μs)	Amplitude (A)	Time (μs)	Time (μs)	Amplitude (A)
1	34.44	1	3.44	0.41	17.21	15.16	30.99	0.72
2	33.55	1.99	3.35	0.51	16.77	16.12	30.19	1.3
3	32.23	3.13	3.22	0.54	16.17	17.33	29.11	1.9
4	31.32	4.1	3.13	0.54	15.66	18.14	28.18	2.43
5	30.59	4.93	3.59	0.53	15.29	19.38	27.53	2.95
6	29.97	5.71	2.99	0.53	14.985	20.32	26.97	3.41
7	29.42	5.84	2.94	0.53	14.71	20.12	26.47	3.90
8	29.00	6.61	2.90	0.53	14.50	21.93	26.10	4.37
9	28.66	7.17	2.86	0.52	14.33	22.52	25.70	4.76
10	28.24	7.79	2.82	0.52	14.12	23.49	25.40	5.29

Table 5. Transformer winding with series fault under impulse excitation

WINDING NUMBER	Peak value of current		10% of Peak value of current		50% of Peak value of current		90% of Peak value of current	
	Amplitude (A)	Time (μs)	Amplitude (A)	Time (μs)	Amplitude (A)	Time (μs)	Time (μs)	Amplitude (A)
1	37.65	3.15	18.825	6.73	3.765	0.43	33.885	2.97
2	36.98	3.20	18.49	6.72	3.698	0.444	33.282	2.98
3	37.94	3.37	18.97	6.31	3.794	0.43o	34.146	3.10
4	38.36	3.26	19.18	6.30	3.836	0.448	34.524	3.11
5	36.57	3.41	18.285	6.42	3.657	0.444	32.913	3.05
6	36.48	3.24	18.24	6.44	3.648	0.444	32.830	3.05
7	38.72	3.26	19.36	6.20	3.872	0.447	34.848	3.12
8	37.91	3.36	18.955	6.32	3.791	0.446	34.119	3.11
9	37.30	3.23	18.65	6.66	3.730	0.446	33.57o	2.97
10	37.71	3.15	18.86	6.60	3.772	0.445	33.948	2.96

Table 6. Transformer winding with series fault under switching impulse excitation

WINDING NUMBER	Peak value of current		10% of Peak value of current		50% of Peak value of current		90% of Peak value of current	
	Amplitude (A)	Time (μs)	Amplitude (A)	Time (μs)	Amplitude (A)	Time (μs)	Time (μs)	Amplitude (A)
1	28.19	7.82	2.81	0.49	14.095	23.54	25.371	5.28
2	28.17	8.04	2.817	0.51	14.085	23.54	25.353	5.30
3	28.17	8.30	2.817	0.51	14.085	23.54	25.353	5.4
4	28.18	7.33	2.818	0.5	14.09	23.54	25.362	5.46
5	28.15	7.29	2.815	0.5	14.075	23.54	25.335	5.60
6	28.17	7.29	2.817	0.5	14.085	23.54	25.353	5.58
7	28.20	7.29	2.82	0.5	14.10	23.54	25.38	5.43
8	28.28	7.07	2.82	0.5	14.14	23.45	25.45	5.45
9	28.29	8.05	2.80	0.5	14.14	23.46	25.46	5.27
10	28.24	7.90	2.80	0.5	14.12	23.46	25.41	5.25

5. CONCLUSION

In this work method of modelling and simulation of the transformer under normal and fault condition, various impulse voltages (1.2/50µs, 250/2500µs) is applied to transformer winding and analysed using ORCAD SPICE software.

- As the result of series insulation failure there is small increase in winding current of 1.8%.
- In shunt insulation failure, winding current exceeds 52% of the applied impulse level.

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