LIGHTNING SURGES TRANSFER THROUGH A DISTRIBUTION TRANSFORMER - A CASE STUDY

W.G.N. Jayaweera, N.P. Kariyawasam, D.M.C.S. Senevirathne, W.M.A.R. Wijesinghe and M.A.R.M. Fernando

Department of Electrical and Electronic Engineering, University of Peradeniya

Introduction

In electrical distribution systems, due to lower basic insulation level, the low voltage (LV) networks are frequently affected by lightning surges coming from transmission and distribution networks through the distribution transformers. The surges may enter to the power system characterized by different coupling mechanisms namely from direct strikes to the systems or from induced voltages from nearby strikes. In general, the distribution network consists of a step down transformer together with a radial distribution network towards the consumer end and therefore surge transfer through the distribution transformer has become very crucial. This paper presents an estimation of transfer surge through 33/0.4 kV distribution transformers by using a case study conducted near the Engineering Faculty in Peradeniya.

Distribution Transformer Model

Due to simplicity, a simple single phase high frequency transformer model was used to study the surge transfer through the transformer [1]. The model consists of winding impedances (from R_P, R_S, L_P and L_S), shunt elements (R_C and L_X), capacitances (C_{HL} - between LV to High Voltage (HV), C_{LG} - between LV to ground, C_{HG} - between HV to ground and C_S – inter windings). A 160 kVA, 33/0.4 kV distribution transformer was selected for the analysis and the equivalent circuit of the transformer is shown in Figure 1.

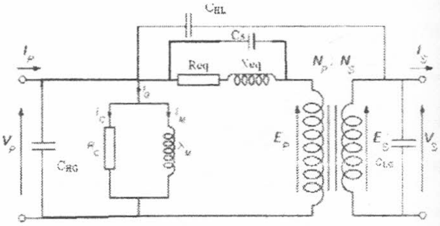

Fig. 1. Transformer Equivalent circuit

By referring the parameters to secondary side the corresponding transfer function was obtained by the Laplace transform as given below.

$$\frac{\left[(C_{HL}L_{eq}L_{M}R_{C}a)S^{3}+(C_{HL}L_{M}R_{C}R_{eq}a)S^{2}+SL_{M}R_{C}\right]/a}{\left[(C_{HL}+C_{LG})L_{M}L_{eq}R_{C}\right]S^{3}+L_{M}\left[(C_{HL}+C_{LG})R_{C}R_{eq}+L_{eq}\right]S^{2}+\left[(R_{C}+R_{eq})L_{M}+R_{C}L_{eq}\right]S+R}$$

Here R_{eq} and L_{eq} are equivalent resistance and inductance and ‘a’ is the turn ratio of the transformer.

Model Verification

The model was verified experimentally by an impulse test. A standard lightning impulse (1.2/50 μs) was applied to the primary side of the transformer (all primary connected together) and the secondary side (all phase windings connected together) waveform was obtained on a two channel digital oscilloscope (600

MHz) screen. The applied voltage was 20 kV from a 400 kV, 20 kJ impulse generator. A resistive voltage divider of HV arm = 6 Nos of 1 MΩ resistors and LV arm of 50 Ω was used to reduce the voltage to measure in the oscilloscope. In comparison, secondary side wave forms were also obtained from the transformer model i.e. theoretically from the transfer function and from PSCAD simulations. For theoretical analysis, the R and X components (R_{eqv}, R_c, X_{eqv} and X_m) of the transformer were calculated from no-load and full load test reports. The capacitances (C_{HG}, C_{LG} and C_{HL}) were measured using Insulation Diagnostics Analyzer (IDA200) as C_{LG}= 354 pF and C_{HL}= 600 pF.

The observed waveforms (theoretical, and experimental) were in oscillatory form confirming the coupling of surge with inductive and capacitive components of the transformer. The peak values of the waveforms decayed due to the contribution from shunt resistance Rc. The Table 1 shows the comparison of results.

Table 1. Model verification

	E	T	S
1st peak	7.2	6.4	6.4
Time to peak	1	1	1
2nd peak	6.0	4.3	4.2
Time to peak	3	3	3
3rd peak	2.0	2.1	2.1
Time to peak	5.5	5.5	5.5

E- Experimental, T – Transfer function, S – PSCAD simulation

The experimental and theoretical waver forms have a good agreement especially in terms of the frequency despite slight variations in the magnitude.

The Case Study

A 33 kV distribution line consist of five distribution transformers was selected to analyze the surge transfer under lightning transient conditions. The selected distribution systems (1 km) lies between the Engineering Faculty (Peradeniya) and Kurunduwatte junction along the Gampola road. It supplies tot he water board by 2 Nos of 1 MVA and domestic consumers by 2 No of 160 kVA and 1 No of 100 kVA. (see Figure 2).

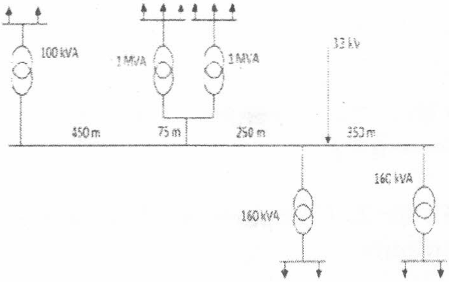

Fig. 2. 33 kV distribution system

The output at the LV sides of transformers was obtained using PSCAD simulations. The RLC parameters for 1 MVA and 100 kVA were calculated from test reports. The corresponding capacitances were calculated according to transformer dimensions. Three different lightning surges (i) standard (1.2/50 μs), (ii) fast (0.5/50 μs) and (iii) long (1.2/1000 μs) were used for the analyses to cover the typical lightning surges under direct and induced lighting strikes. For fast surges rise time varied from 0.5 to 2 μs and it was found that 0.5 μs as the verse case. For long surges, time to half value varied from 50 to 1000 μs and

1000 μs was selected as the extreme case. The selected surge voltage was taken as 100%. Two cases were considered: (i) lighting surge appearing at the primary sides of transformers and (ii) surge in the middle of the distribution line.

Results and Discussion

Fig. 3 (in simulations) shows the surge voltages at transformer secondary for fast surges. Table 2 shows the comparison of three surges on different transformers.

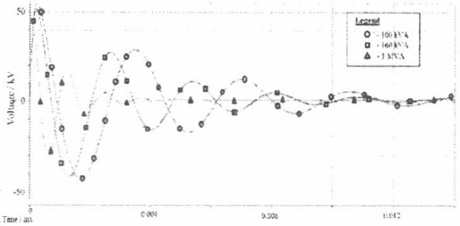

Fig. 3. Surge voltaes at transformer secondary

Table 2. Comparison of secondary outputs

kVA		100	160	1000
	dV/dt [kV/μs]	69.2	71.4	75.0
ST	V_{Peak} [kV]	33.9	30.0	16.5
	dV/dt [kV/μs]	213	229	311
Fast	V_{Peak} [kV]	53.2	50.3	37.3
	dV/dt [kV/μs]	125	132	124
Long	V_{Peak} [kV]	43.7	39.5	24.7

The peak value (V_{peak}) and the gradient (dV/dt) were used for the analysis. In general, the peak value increases for fast surges confirming the effect of surge steepness to the LC coupling. For higher power ratings i.e. 1 MVA, the peak value drops. However, the peak values of the wave form is high so that one could get significant surges at the consumer end after propagating through the 400 V LV network. Attention should be taken to protect the secondary side in LV system for such surges.

Summary and Conclusions

A single phase transformer model was used and verified to estimate the surges appearing on the low voltage side of the transformer. A significant surge voltage even up to 40% may appear at the secondary side depending on the surge steepness and transformer power rating. It is suggested that attention must be paid for such cases to protect the secondary side consumers.

References

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