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3-PHASE MV/LV DISTRIBUTION TRANSFORMER INTERFACIAL FREQUENCY CHARACTERISTICS DURING SURGE CONDICTIONS

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Abstract – In MV/LV lightning surges come from medium voltage side to the low voltage side respectively. Major task of this paper is to present transformers surge frequency characteristics. In measurements, as the source of surges, voltage surge generator Upp=6kV and shape 1,2/50us was used. In calculations, characteristics were computed by Discrete Fourier Transform functions (DFT).
The result from measurements and calculations will be transformer interfacial characteristics. They describe frequency relationship between phases. They will be used for future MV/LV distribution substation model which will base on the mutual frequency characteristics and convolution functions.

1 INTRODUCTION

The MV/LV substation takes major part in electric power distribution system. High reliability of system requires knowledge of the surge propagation in neuralgic points of it. This problem appears simultaneously with growing number of electronic equipped MV/LV substations. Disturbances make danger especially for electronically controlled substations. They can result in incorrect work or they can even damage some very sensitive equipment. Black-out can provide financial damage.
Major part of MV/LV substation is distribution transformer and the purpose of this paper is to provide knowledge about interfacial frequency characteristics of typical MV/LV transformer during surge conditions.
Interfacial frequency characteristics were obtained as the calculation results. Conception of new kind of transformer model will be presented as well.
This model bases on the frequency characteristics, circular convolution calculation and Fast Fourier Transform.
Additionally transformer frequency characteristics measurements results will were presented in the lightning surge conditions.

2 ANALYZED TRANSFORMERS

All presented characteristics base on measurements, which were made in Polish Transformer Service on distribution transformers. These transformers were survey there and measurements possibility appears then.
Three different types of MV/LV distribution transformer was examined for three different voltage levels and same winding configuration.
All details are presented in table 1.

Table 1: Examined MV/LV distribution transformers.

No.	1	2	3
Transformer manufacturer	Elta Poland	Elta Poland	Elta Poland
Type	TAOb 400/15h	TAOFn 630/20	TAOb 400/20h
Nominal power	400 kVA	630 kVA	400 kVA
Year of manufacture	1985	1984	1979
MV voltage	6300 V	15750 V	21000 V
LV voltage	400 V	400 V	400 V
Short circuit voltage	4,61 %	6,16 %	4,57 %
Nominal MV current	36,7 A	23,1 A	11 A
Nominal LV current	577 A	910 A	577 A
Winding configuration	Dyn5	Dyn5	Dyn5

3 MEASUREMENT SETUP

In the investigations, the surge were produced by the high-voltage impulse generator – UCS 500M6B. The UCS 500M6B is generator to cover transient and power fail requirement according to international standards with voltage capability of up to 6.6kV.
Apart from the IEC 61000-4-5 standard for surge testing it also complies to ANSI/IEEE C62.41 for surge and ringwave testing. Having a built-in CDN for single phase EUT it can be extended for testing three- phase EUT's by means of an automatically controlled external coupling network.
Some generator parameters are listed below [1]:

- voltage (open circuit) 250-6600V
- pulse front time 1,2µs +/- 30%
- pulse time to half value 50µs +/- 20%
- current (short circuit) 125-3300A
- polarity positive/negative/alternating
- direct output Via HV-coaxial connector, Zi=2Ω
- coupling mode Line to line, Line(s) to ground (PE)

During measurements also were used:

- digital oscilloscope Tektronix TDS3032B 300MHz, 2,5GS/s,
- high voltage probe with 100x attenuation. Tektronix P6009 4kV, 180MHz, input capacitance 2.5pF, input resistance 10MΩ, cable length 9ft,
- MV transformer side matching impedance (characteristic impedance of the line is normally in the range 400-650Ω) we took the 620Ω value,
- high voltage coaxial cable Zo=50Ω,
- external power supply for the surge generator (UPS).

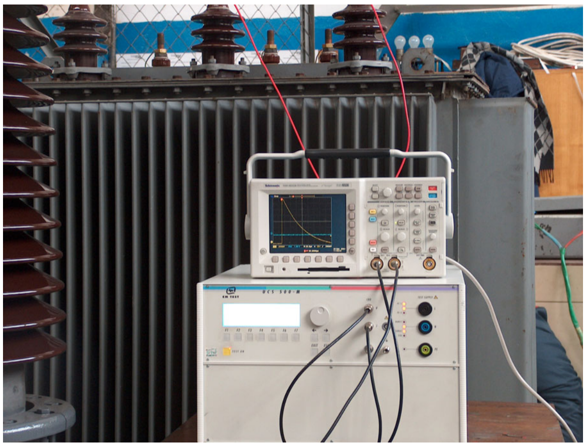

Fig. 1 - Photo of the test set-up for direct measurements.

Surge generator was connected to the one of the primary transformer terminals.

Different combinations were examined for different terminals configurations.
One of examined combinations presents figure 2. On the transformer secondary side digital oscilloscope record measurements results also in different combinations. For safety reasons transformer neutral terminal was grounded.

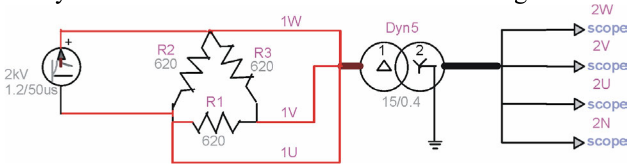

Fig. 2 - Circuit diagram of test set-up.

4 MEASUREMENT RESULTS

The surge generator is high voltage unit. This provides real values of voltages transferred through distribution transformers. Voltage waveform on the generator output presents figure 3.

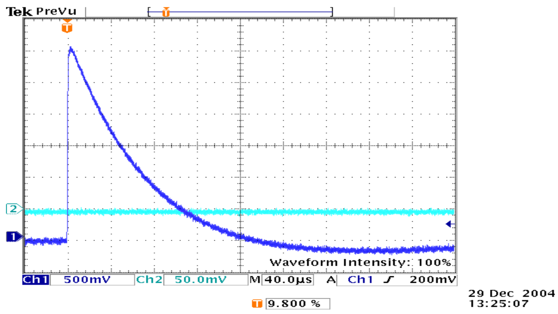

Fig. 3 - Surge generator output voltage – Upp=2kV, 1.2/50µs.

It was recorded by voltage probe described above.
Figure 4 presents voltage on the transformer secondary side when a surge comes to the 1W-1V terminals.

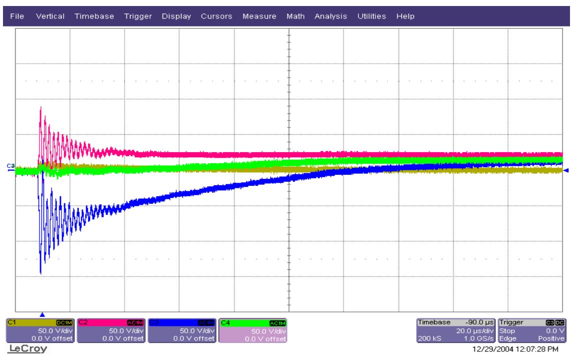

Fig. 4 – Voltage transferred from MV do LV voltage side. Surge input: MV voltage side, phase 1W to 1V, Upp=2kV. Recorded voltage waveform: LV voltage side, phase 2W-2N (blue line), 2V-2N (red line), 2U-2N (yellow line). Transformer number 1.

It simulates induced voltage in MV line caused by lightning strike. Next figure presents frequency spectrum of voltage transferred to the transformer secondary side.
Sampling time is constant and equal 400us.
Spectrum was computed by Orgin 7.5 DFT functions (computer calculation program – similar to MatLab).
Noise reduction methods aren't used. Number of points used to analysis was equal 250000.
These two values provide some limitations on the frequency spectrum range and resolution. All presented measurements results are for transformer number 1 – see details in table 1.
Figures 5, 6, 7 present different frequency spectrums for different transformer terminals (surge still connected to 1W-1V).

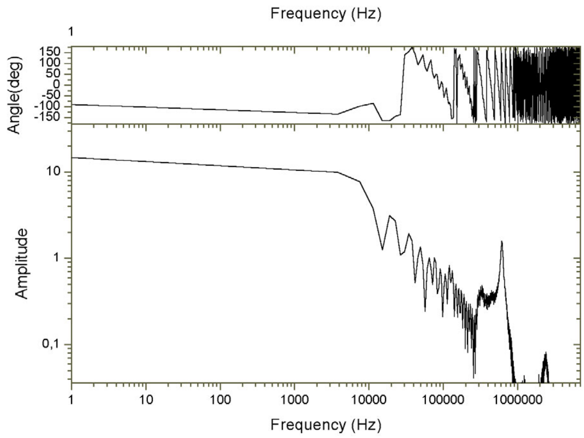

Fig. 5 – Frequency spectrum of the transformer winding phase 2W-2N. Surge input (Upp=2kV): MV voltage side, phase 1W to 1V.

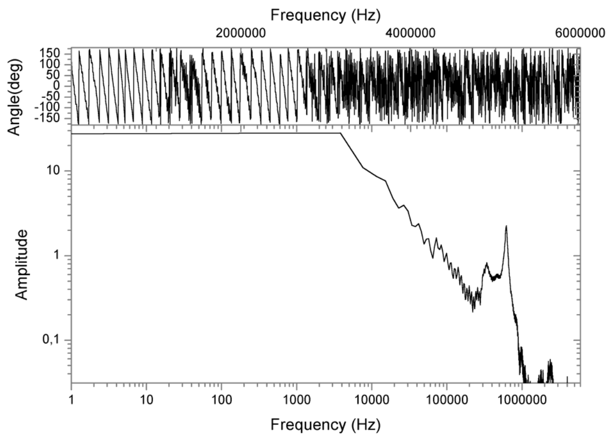

Fig. 6 – Frequency spectrum of the transformer winding phase 2V-2N. Surge input (Upp=2kV): MV voltage side, phase 1W to 1V.

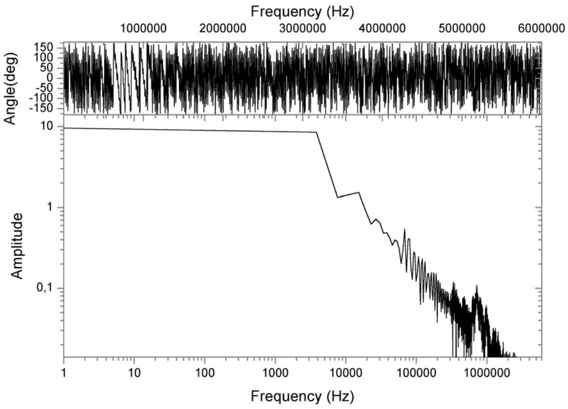

Fig. 7 – Frequency spectrum of the transformer winding phase 2u-2N. Surge input (Upp=2kV): MV voltage side, phase 1W to 1V.

5 INTERFACIAL FREQUENCY CHARACTERISTICS

The DFT can calculate a signal's frequency spectrum and also can find a system's impulse response from the frequency response – fig. 8.

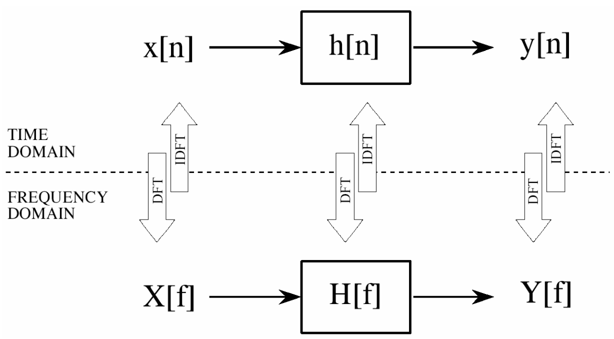

Fig. 8 – Comparing system operation in the time and frequency domains. In the time domain, an input signal is convolved with an impulse response, resulting in the output signal [2].

The equations presented below describes idea of convolution:

$$x[n] * h[n] = y[n] \quad (1).$$

$$X[f] \times H[f] = Y[f] \quad (2).$$

where:
x[n] – system's input signal in time domain,
h[n] – system's impulse response in time domain,
y[n] – system's output signal in time domain,
X[f] – system's input signal in frequency domain,
H[f] – system's impulse response in frequency domain,
Y[f] – system's output signal in frequency domain.

The convolution in the time domain corresponds to multiplication in the frequency domain. Interfacial frequency characteristics are convolution of real transformer's impulse response and typical transformer model's impulse response. This is new idea of improving any existing transformer model by real measurements for exactly precise frequency range. This operation will provide demanded transformer model in specific frequency range by frequency spectrum modification in frequency domain – fig. 9.

$$X[f] = \operatorname{Re} X[f] + j \operatorname{Im} X[f] \quad (3).$$

$$H[f] = \operatorname{Re} H[f] + j \operatorname{Im} H[f] \quad (4).$$

$$Y[f] = \operatorname{Re} Y[f] + j \operatorname{Im} Y[f] \quad (5).$$

$$\operatorname{Re} H[f] = \frac{\operatorname{Re} Y[f] \operatorname{Re} X[f] + \operatorname{Im} Y[f] \operatorname{Im} X[f]}{\operatorname{Re} X[f]^2 + \operatorname{Im} X[f]^2} \quad (6).$$

$$\operatorname{Im} H[f] = \frac{\operatorname{Im} Y[f] \operatorname{Re} X[f] - \operatorname{Re} Y[f] \operatorname{Im} X[f]}{\operatorname{Re} X[f]^2 + \operatorname{Im} X[f]^2} \quad (7).$$

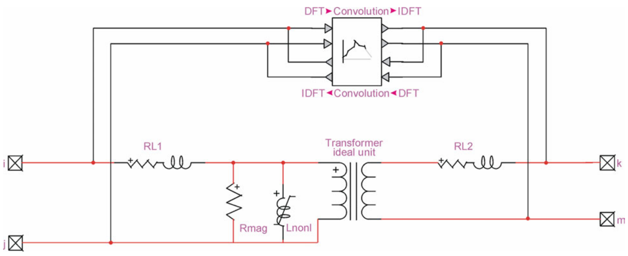

Fig. 9 – Typical transformer model modification by convolution in frequency domain. [2].

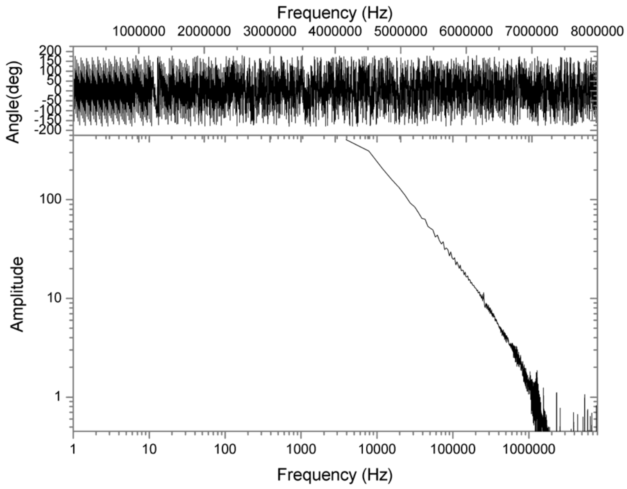

Fig. 10 – Input signal (X[f]) frequency spectrum for phase 1W-1V.

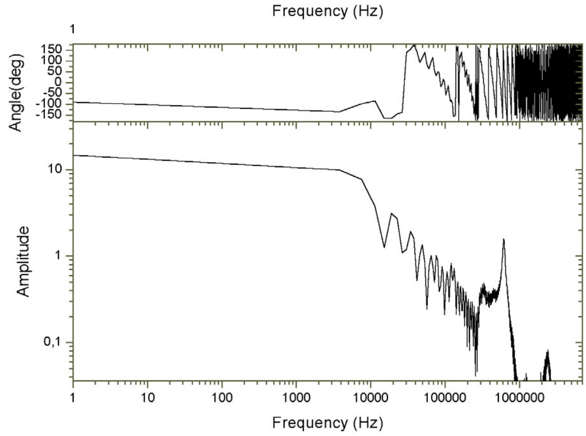

Fig. 11 – Output signal (Y[f]) frequency spectrum for phase 2W-2N.

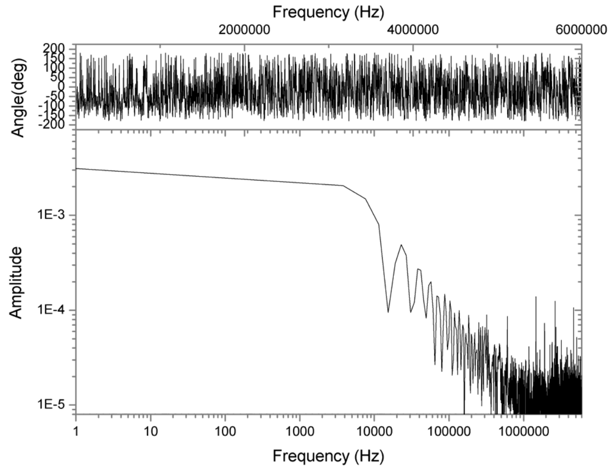

Fig. 12 – Transformer no 1 interfacial frequency characteristics (H[f]) for phase W.

6 CONCLUSION

Real transformer frequency spectrum can be multiplied with standard transformer model frequency spectrum in frequency domain. This characteristic overlaps and corrects typical transformer model for measured spectrum range. In our case it's make high frequency transformer model especially corrected for 1,2/50μs surge. This kind of modelling is in the first stage of investigation. Future research takes into account interfacial between phases, transformer tub etc.

7 REFERENCES

[1] *"UCS 500M6B instruction manual"*, EM Test 2002.

[2] Steven W. Smith, "The Scientist and Engineer's Guide to Digital Signal Processing", *California Technical Publishing*, pp. 178, USA 1998.