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MV/LV SUBSTATION HIGH FREQUENCY PATCH MODEL

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Abstract: In MV/LV substation lightning surges may come from medium voltage side to the low voltage side respectively. Major task of this paper is to present conception of new kind MV/LV substation model. New idea improves existing transformer model by correction patch model. This patch model bases on real measurements, frequency characteristics, circular convolution and Fast Fourier Transform. This operation will provide demanded MV/LV substation model in specific frequency range by it frequency spectrum modification in frequency domain. Real MV/LV substation was investigated. This paper presents measurement results of lightning overvoltages propagation across MV/LV substation and co-existent grounding system. Real substation which supply television broadcaster was used for tests. It’s one of few which work for TV Broadcasting Centre. On the TV area 30m high transceiver tower is placed. The risk of direct lightning strike is high.

Keywords: MV/LV substation, model, high frequency, overvoltage, lightning.

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. The purpose of this paper is to create substation model which will base on well-known transformer model.

2. MV/LV SUBSTATION USED FOR TESTS

Analyzed MV/LV substation is situated on the TV Broadcasting area. There is also located sending-receiving tower – 30 meters high. This substation supplies all television transmitters on 6kV voltage level. Rest of electric power devices are supply on 0,4kV voltage level. All objects are interconnected by grounding system and comprehensive data telecommunication network. Major part of MV/LV substation is distribution transformer 630kVA, 6/0.4kV, Dyn5 with middle tap position (no. 4) [1]. There were no modifications during measurements in typical MV/LV configuration. All typical substation equipment was present (for example: control devices). Substation is supply by 6kV underground cable line. Capacitor bank was installed on the low voltage bus bar - 3x39, 30μF, 7.5kVar. During measurements substation was disconnected from electric power system. Cable line was disconnected from transformer windings.

Middle voltage windings were loaded with typical matching impedance – 620 Ω. Low voltage bus bar was disconnected from load. No overvoltage protection was present.

The lightning overvoltages 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 [2]:

• 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 Z_o =50Ω,
- external power supply for the surge generator (petrol generator).

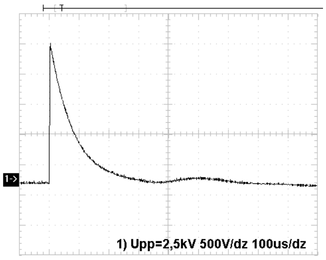

Fig. 1. Voltage waveform on HV generator output (Upp=2,5kV).

Fig. 2. 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: phase-phase, phase-transformer tub. One of examined combinations presents figure 2 (phase-phase). On the transformer secondary side digital oscilloscope record measurement results also in different combinations:

- load and no load on LV side,
- symmetrical and no symmetrical load on LV side,
- different voltage surge peak value.

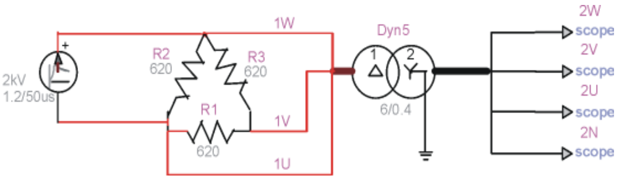

Fig. 3. Circuit diagram of test set-up (selected part of analyzed MV/LV substation).

For safety reasons transformer neutral terminal was grounded. To avoid over coupling digital oscilloscope by high-voltage generator and grounding system external power supply was used (petrol generator). Petrol generator supplies digital oscilloscope and high-voltage generator.

3. MEASUREMENT RESULTS

The surge generator is high voltage unit. This provides real values of voltages transferred through distribution transformers. All waveforms were recorded through voltage probe described above. Figure 4 presents voltage on the substation LV side bus bar. Surge comes between 1W transformer terminal and transformer tub. Measured voltage waveforms are almost identical for this case (fig. 4a, 4b, 4c). Some different appears for interfacial voltage waveforms (fig. 4d, 4e, 4f). Figure 5 presents voltage waveforms for surge incoming on 1V-1U transformer terminals. This time for different observation point different voltage was measured.

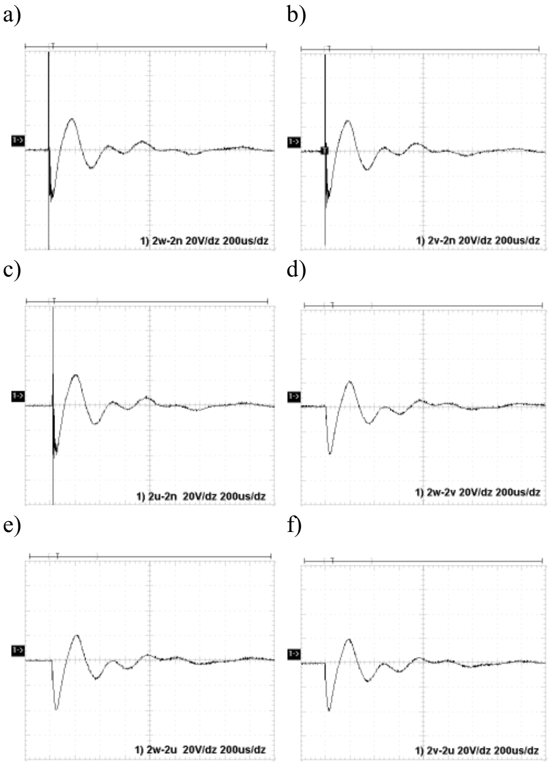

Fig. 4. Voltage waveform measured on the LV bus bar. Surge 1,2/50µs, Upp=2,5kV incoming for 1W-transformer tub terminals. a) 2W-2N, b) 2V-2N, c) 2U-2N, d) 2W-2V, e) 2W-2U, f) 2V-2U (20V/div, 200µs/div).

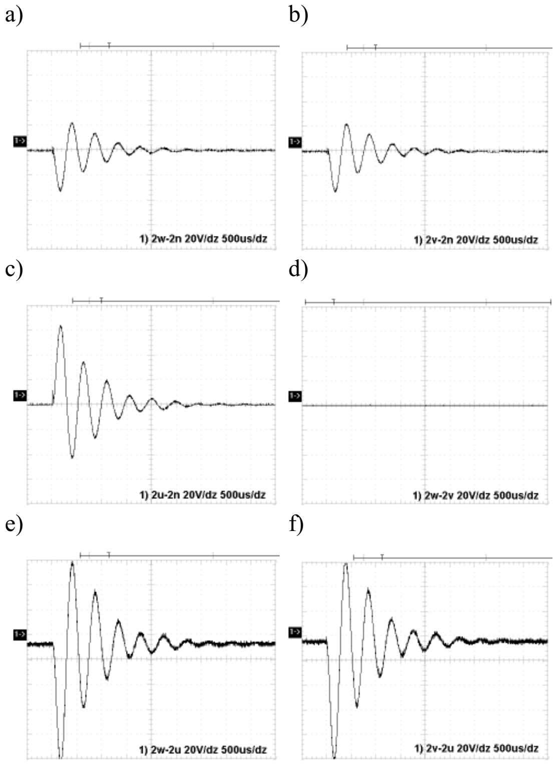

Fig. 5. Voltage waveform measured on the LV bus bar. Surge 1,2/50µs, Upp=2,5kV incoming for 1V-1U transformer terminals. a) 2W-2N, b) 2V-2N, c) 2U-2N, d) 2W-2V, e) 2W-2U, f) 2V-2U (20V/div, 500µs/div).

Big different was observed in phase 2U (amplitude difference) and between phases 2W-2V (no voltage waveform). These differences are caused by internal transformer structure. Surge peek value influence on measured waveforms is presented on figure 6a, 6b, 6c. For higher voltage levels different shape appears.

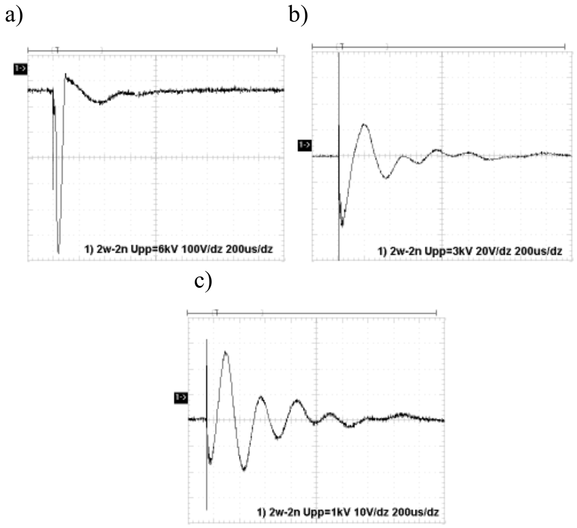

Fig. 6. Voltage waveform measured on the LV bus bar. Surge 1,2/50µs incoming for 1V-transformer tub terminals. a) Upp=6kV, b) Upp=3kV, c) Upp=1kV (100V/div, 200µs/div).

4. MV/LV SUBSTATION PATCH MODEL

New proposed model bases on the frequency characteristics, circular convolution calculation and Fast Fourier Transform (FFT). By the Discrete Fourier Transform (DFT) can be calculated a signal's frequency spectrum and also can be found a system's impulse response from the frequency response– fig. 7.

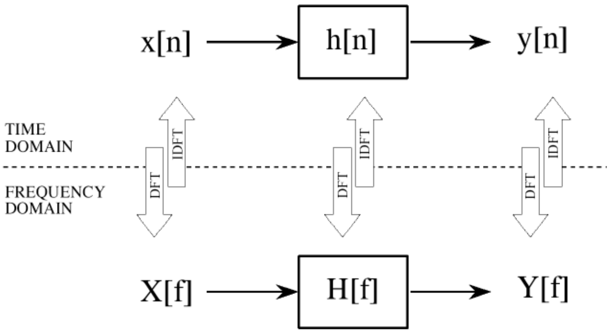

Fig. 7. Comparing system operation in the time and frequency domains. In the time domain, an input signal is convolved with an impulse response, resulting in the output signal [3].

The equations presented below describes idea of convolution:

$$x[n] * h[n] = y[n] \tag{1}$$

$$X[f] \times H[f] = Y[f] \tag{2}$$

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 [4, 5, 6, 7] 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. 8.

$$X[f] = \operatorname{Re} X[f] + j \operatorname{Im} X[f] \tag{3}$$

$$H[f] = \operatorname{Re} H[f] + j \operatorname{Im} H[f] \tag{4}$$

$$Y[f] = \operatorname{Re} Y[f] + j \operatorname{Im} Y[f] \tag{5}$$

$$\operatorname{Re} H[f] = \frac{\operatorname{Re} Y[f] \operatorname{Re} X[f] + \operatorname{Im} Y[f] \operatorname{Im} X[f]}{\operatorname{Re} X[f]^2 + \operatorname{Im} X[f]^2} \tag{6}$$

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

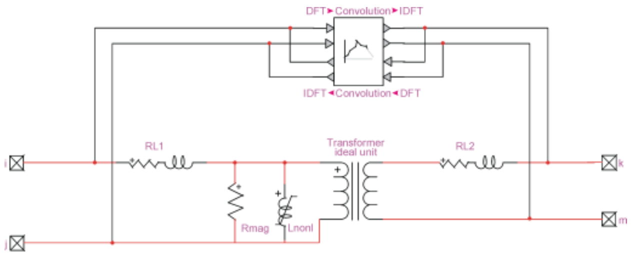

Fig. 8. Typical transformer model modification by convolution in frequency domain.

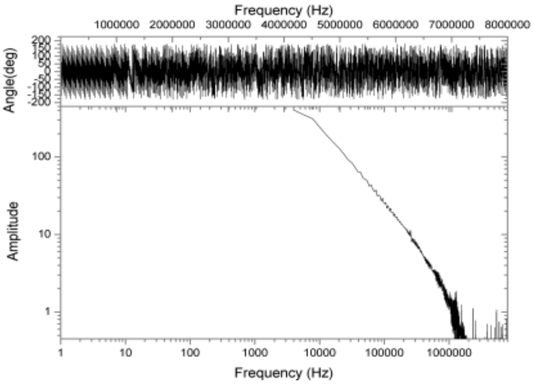

Fig. 9. Input signal (X[f]) frequency spectrum for phase 1W-1V.

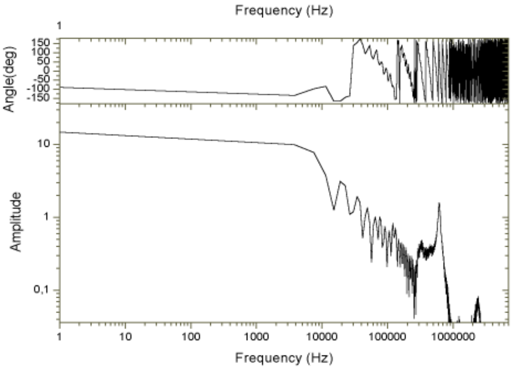

Fig. 10. Output signal (Y[f]) frequency spectrum for phase 2W-2N.

For this case sampling time is constant and equal 400µs. A noise reduction method wasn't used. Number of points used to analysis was equal 250000. These two values provide some limitations on the frequency spectrum range and resolution. For analyzed window 400µs results of simulation and measurement are identical. New patch model give results when is used as a correction factor during normal transient analyze.

5. CONCLUSIONS

The results of these measurements were used to create transformer patch model. It base on measured frequency spectrum of MV/LV substation and circular convolution in frequency domain.

Typical model of transformer was improved by created patch model. As a typical model it can be used any well-known transformer model. 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.

Created model was implemented to ATP/EMTP simulation program. This kind of modelling is in the first stage of investigation. Future research takes into account interfacial between phases, transformer tub etc.

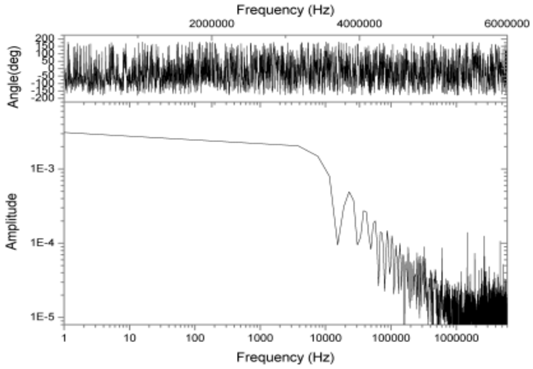

Fig. 11. Transformer frequency characteristics (H[f]) for phase W.

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BIOGRAPHICAL NOTES

Jarosław M. Wiater received the M.Sc. degree in Electric Power Systems from Białystok Technical University in 2002 - Poland. Since 2002 he has been with Białystok Technical University. His main research area is application of computer technology in damage analysis at electric power substation during direct lightning strikes.