Determination of the Voltage Fluctuations and Distortions in Transformer Station Supplying Nonlinear Load with 12-pulse Converter

Wiesław Brociek, Robert Wilanowicz

***Abstract* — The paper presents the results of the analysis of voltage fluctuations (flickers) and distortions in the transformer station 110/15kV on the 15kV side. This transformer supplies the 3kV DC traction substation containing 12-phase converters. The level and the instantaneous waveform on the 15kV side voltage and loading current have been registered and used for the investigation of the influence of the converters on the parameters of the energy of the supplying system. Additional registration has been done of the low voltage side of the transformer 15/0.4kV. The correlation coefficients between the load current and parameters of the voltage have been calculated. These coefficients illustrate the mutual influence of the investigated variables. The presented results of the measurements of higher harmonics, voltage fluctuations and distortions are presented and discussed.**

I. Introduction

Asymmetry of voltage, voltage and frequency fluctuations (flicker), voltage harmonics, voltage distortion coefficient (Total Harmonics Distortion - THD) are the fundamental parameters describing quality of electrical energy [1].

At present there are the requirements in the field of experimental researches and the new research simulations programs based on the real parameters witch gives us possibilities describing chosen parameters of electrical energy quality in nonlinear systems. It is the results of applications of low and high power nonlinear loads. Also very important problems concern on electromagnetic compatibility (EMC) of installed devices. The paper shows results of measurements and numerical calculations concerning distortions and fluctuations of voltage. Measurements have been carried out in transformer station 110/15kV. This transformer supplies the 3kV DC traction containing 12-pulse converter [5].

Simultaneously with measurement on high voltage side, measurement of low voltage side of the transformer has been provided.

The aim of the measurements was determination of influence of 12-pulse converter on chosen parameters of electrical energy quality of both sides of the transformer (15kV and 0.4kV). Based on the measurement and the correlation coefficient of the load current and chosen voltage parameters have been determined.

The paper shows the example results of measurements (THD and flicker).

II. Description of the Analysing Circuit

Supply circuit of transformer substation is presented in fig. 1.

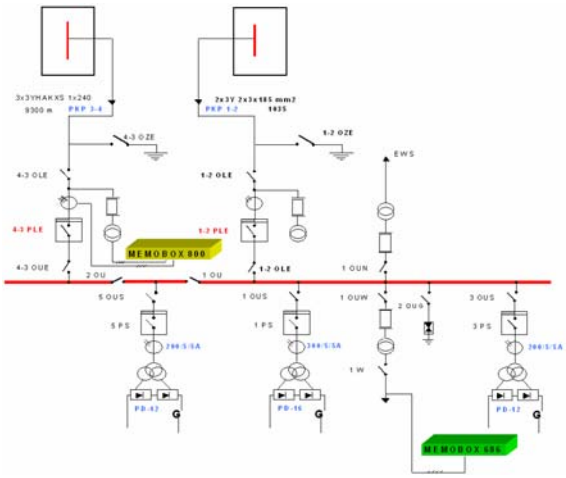

Fig. 1. Schematic diagram of measuring system

15kV bus bars are supply from 110kV bus bars trough cable line and transformer of power S=25MVA (connection Ynd11, 115kV/16.5kV). There are equipped with two separate bus bars 3kV DC in traction substation. Each section is supply by two rectifiers (parallel connection) type PD 12 plus PD16. Each rectifier are supply by 3-winding transformer TOZ-4400/15 with nominal power S=4.4/2.2/2.2MVA (connection Y/y0-d11). Schematic diagram is presented on fig. 2.

Analyzing substation as each nonlinear load generated typical distortion. Distortions generated by 12-pulse rectifier are sources of *k*-harmonics

$$k = 4n \pm 1 \text{ where } n = 3,6,9\ldots \qquad (1)$$

and fluctuation of voltage. In this case 11^{th} and 13^{th} harmonic have dominated values. In the papers [2,3] results of experimental research and numerical calculation of the traction substation equipped with 6-pulse rectifiers have been presented. Distortions generated by 6-pulse rectifiers are sources of *k*-harmonics

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$$k = 2n \pm 1 \text{ where } n = 3,6,9\ldots \quad (2)$$

In this case 5th and 7th harmonic have dominated values.

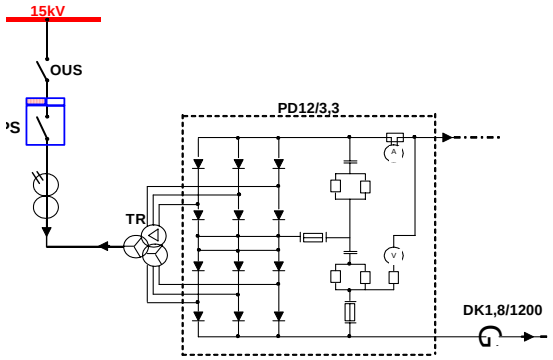


Fig. 2. Schematic diagram of 12-pulse rectifier PD-12

According to EN-50160 standard permissible values of chosen electric power quality parameters (defined for 95% of measuring time) for low and mean voltages equals:

- percentage value of 11th harmonics

$$U_{11\%} = \frac{U_{11}}{U_1} 100\% \le 3.5\% \quad (3)$$

- percentage value of 13th harmonics

$$U_{13\%} = \frac{U_{13}}{U_1} 100\% \le 3\% \quad (4)$$

- THD_V coefficient

$$THD_V = \sqrt{\sum_{k\ge 2}^{n} \left(\frac{U_k}{U_1} \cdot 100\% \right)^2} \le 8\% \quad (5)$$

where:
k – number of harmonics,
n – number of considered harmonics,
U_k – rms value of k^{th} harmonic,
U_1 – rms value of 1^{st} harmonic;

- asymmetry coefficient

$$k_{u\%} = \frac{U_2}{U_1} \cdot 100\% \le 2\% \quad (6)$$

where
U_1 – symmetrical component of positive phase sequence,
U_2 – symmetrical component of negative phase sequence;

- voltage fluctuation coefficient

P_{ST} (Short Term Probability) depends on changes of RMS voltage and visual sensation. It averages the measuring results within 10 minutes.
P_{LT} (Long Term Probability), is determined for period of two hours (12 ten minutes periods) according to formula:

$$P_{LT} \le \sqrt[3]{\sum_{1}^{12} \frac{P_{ST}^{\ 3}}{12}} \quad (7)$$

$$P_{ST} \le 1$$
$$P_{LT} \le 1 \quad (8)$$

III. Influence of the work of 12-pulse rectifier on distortions and fluctuations of the voltage

Example change of load current I_{ob} values of converter and 15kV voltages are shown on fig. 3.

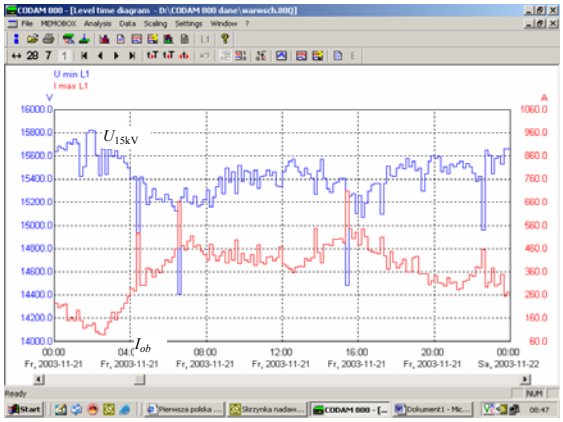


Fig. 3. Changes of current and voltage values in 15kV line

Exceeding of permitted levels of voltage distortion is caused by to low value of short circuit power on 15kV bus bars in comparison with power of converter systems (impedance of supply circuit is to high).

Changes of load current have significant influence on voltage changes. Based on measurements it was find, that 5th and 7th harmonics appears in 15kV voltage. They are transmitted by electroenergetic system from 110kV line and generated by converters.

The example changes of THD_V and 5th harmonics on 110kV bus bars during 24 hours is shown on fig. 4.

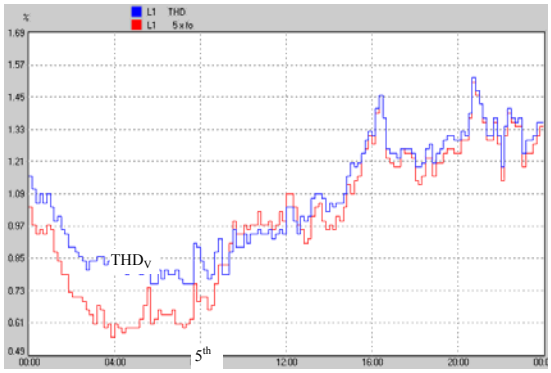


Fig. 4. Changes of THD_V and 5th harmonic in 110kV of voltage

Parameters describing quality of energy depend on distortion caused by electroenergetic system and by nonlinear loads.

Based on curves mentioned in fig. 4 it can be find, the distortion level of voltage 110kV line changes

according to 24 hours load. The minimal value (during the night) is calculated on 0.6÷0.8% and maximal value (during the evening) is calculated on 1.3÷2.3%.

Changes of THD_V i THD_V' on 15kV bus bars are presented on fig. 5.

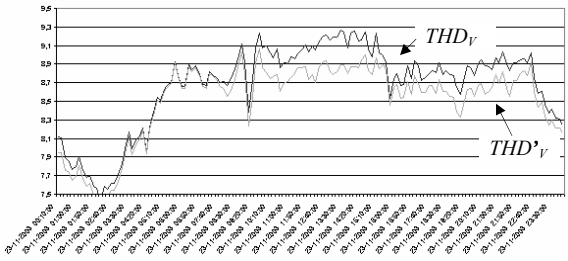


Fig. 5. Changes of THD_V and THD_V' coefficients on 15kV bus bars

THD_V coefficient is determined by formula (5). Coefficient THD_V' is described by formula (9).

$$THD_V' = \sqrt{THD_V^2 - U_5^2 - U_7^2} \qquad (9)$$

THD_V' coefficient gives information about distortion caused by converters, ignoring 5th and 7th harmonics generated by electroenergetic system.

Proper way to describe mutual influence of both values is correlation coefficient defined by formula (10).

$$\rho_{I_{15kV},THD_V} = \frac{\mathrm{cov}(I_{15kV},THD_V)}{\sigma_{I_{15kV}} \cdot \sigma_{THDV}} \qquad (10)$$

where

$$\mathrm{cov}(I_{15kV},THD_V) = \frac{1}{n}\sum_{j=1}^{n}\left(I_{j\,15kV} - I_{śr15kV}\right)\cdot\left(THD_{V\,j} - THD_{V\,śr}\right) \qquad (11)$$

and

$$\sigma^2_{I_{15kV}} = \frac{1}{n}\sum_{j=1}^{n}\left(I_{j\,15kV} - I_{śr15kV}\right)^2 \qquad (12)$$

$$\sigma^2_{THDV} = \frac{1}{n}\sum_{j=1}^{n}\left(THD_{V\,j} - THD_{V\,śr}\right) \qquad (13)$$

Correlation coefficient is a statistical measure of the interdependence of two or more variables. Fundamentally, the value indicates how much of a change in one variable is explained by a change in another.

Table 1 contains values of correlation coefficients between load current I_{ob} of converter and chosen parameters of voltage (15kV and 230V).

Table 1. Values of correlation coefficients between load current I_{ob} of converter and chosen parameters of voltage (15kV and 230V).

Correlation coefficient	Fri.	Sat.	Sun.	Mon.	Thu.
I_{15kV} / $U_{5\,230V}$	-0,17	0,19	0,17	-0,41	-0,19
I_{15kV} / $U_{11\,230V}$	0,82	0,93	0,88	0,79	0,70
$I_{15kV}/U_{THD230V}$	0,65	0,89	0,83	0,95	0,56
I_{15kV}/ U_{15kV}	-0,61	-0,79	-0,75	-0,82	-0,81
$I_{15kV}/U'_{THD15kV}$	0,88	0,91	0,86	0,93	0,90
$I_{15kV}/U_{THD15kV}$	0,86	0,86	0,79	0,91	0,89

Changes of load current I_{ob} of converter and chosen parameters of quality of energy on 15kV side:

- THD_V coefficient (fig.6)
- 11th and 13th harmonics (fig. 7)
- P_{LT} and P_{ST} (fig. 8)

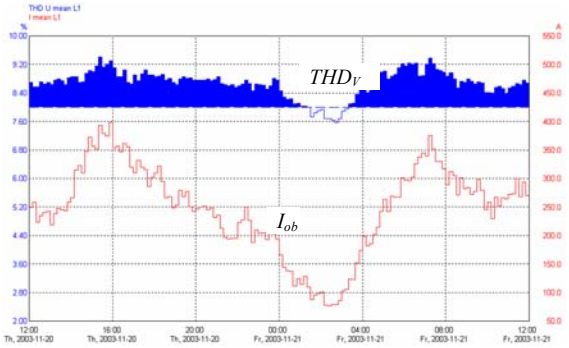


Fig. 6. Changes of load current I_{ob} of converters and THD_V coefficient on 15kV side

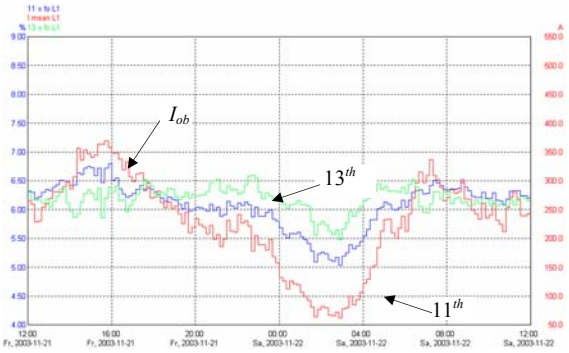
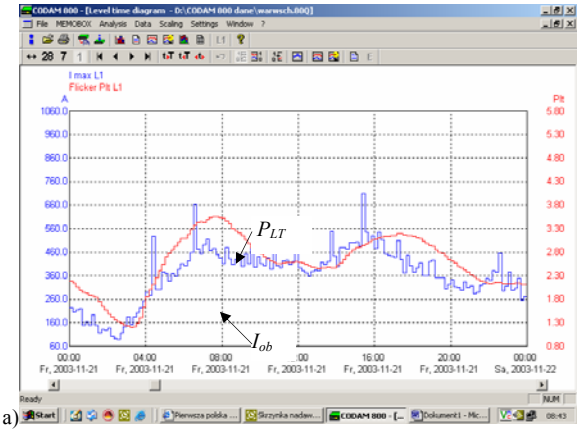
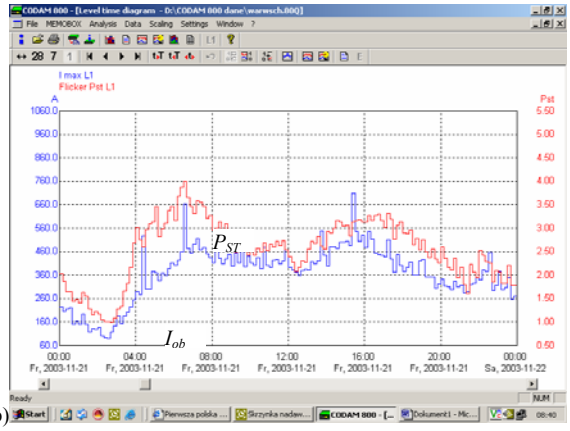


Fig. 7. Changes of load current I_{ob} of converters and 11th and 13th harmonics on 15kV side



a)



b)

Fig. 8. Changes of load current Iob of converters and a) P_{LT} and b) P_{ST} on 15kV side

Total value of the load of the current of converters and participation of 11th harmonic during 24 hours is shown on fig. 9.

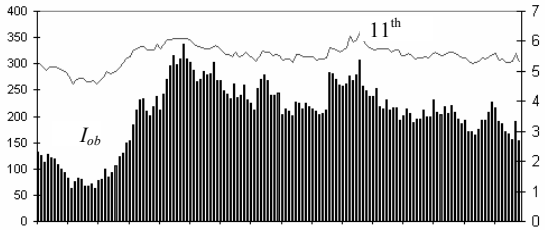


Fig. 9. Total value load current of converters I_{ob} and participation of 11th in 230V durning 24 hours

The exemplary changes of THD_V and 5th and 11th harmonics during 24 hours (on 230V bus bars) is shown on figures 10 and 11.

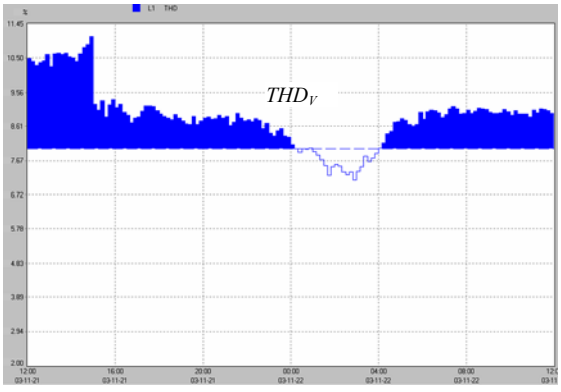


Fig. 10. Changes of THD_V on 230V bus bar

The results presented in Fig. 5 and 10 show that THD_V coefficient exceeds the permissible value (8 %).

Fig. 8 presents the changes of P_{ST} and P_{LT} on 15kV bus bars. Analysis of P_{ST} and P_{LT} coefficients changes lead to the conclusion that during the registration period, values of the mentioned above coefficients have exceeded permissible values.

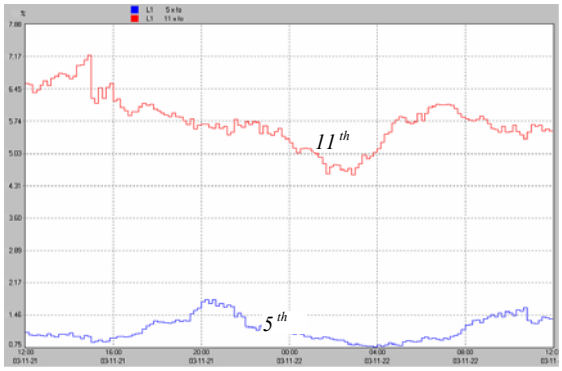


Fig. 11. Changes of 5th and 11th harmonics on 230V bus bar

IV. Conclusion

The parameters of electric energy depend on the disturbances introduced by the power system which stands for the "background", and the disturbances following from the nonlinear load, especially of high power.

Measurements carried out on low voltage side of transformer 15/0.4kV show, that harmonics generated by converted are not limited by this transformer (Fig. 9). These harmonics have big influence on THD of phase voltage 230V (Fig. 10 and 11).

Based on measurements carried out in traction substation with 12-pulse converters the following conclusion have been work out:

- distortion of voltage, caused by work of substation is proportional to the load,
- 11th and 13th harmonics have the main influence on THD_V on 15kV bus bars,
- in registered 15kV voltage additional harmonics generated by electroenergetics system have been appear,
- P_{ST} and P_{LT} coefficients have exceeded permissible values on bus bars 15kV.

Presented results of measurements allow to simply defined of generation higher harmonics by nonlinear loads and their influence on electroenergetic system

Taking into consideration that the measurement has been carried out in the typical supply system of traction sub-station the obtained results are representative for majority of traction sub-stations.

References

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