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Measurement of railway traction transformer using by SFRA method

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Anotácia:
Článok popisuje postup merania prototypu trakčného vozidlového transformátora metódou SFRA – Sweep Frequency Response Analyse. Metóda bola použitá prvýkrát na tomto type transformátora. V príspevku sú uvedené referenčné merania ako aj merania po typových skúškach prototypu nového trakčného transformátora.
Annotation:
The paper deals with measurement of railway traction transformer using by Sweep Frequency Response Analysis method (SFRA). It was the first measurement of traction transformer SFRA characteristics. In this paper are given reference measurements as well as measurements after type test of new railway transformer.

INTRODUCTION

Single-phase railway traction transformer consists of a primary winding designed to voltage from 0 to 25 kV and of secondary winding for traction motors power supply. There are also windings for auxiliary locomotive drives power supply and for electrical heating power supply (eventually for air condition) placed on a common magnetic circuit. Traction transformer is exposed during operation of the railroad to frequent mechanical shocks and vibrations. It may cause mechanical breakdowns of transformer windings and core, such as winding displacement (axial or radial), the release of the core and turn-to-turn faults. Detection of these types of failures of traction transformer is possible only by its removal, except the turn-to-turn faults (measurement of winding resistance). Using the SFRA method (Sweep frequency response analyse) to detect those types of traction transformer disorders becomes hot topic, whereas the SFRA method detect the same types of faults on power transformers used in distribution or transmission systems [1]. For frequency characteristics measuring by SFRA method we have chosen a prototype of the traction transformer, developed by EVPÚ a.s., Nová Dubnica in cooperation with ŽOS Vrútky a.s. The measurement of traction transformer by SFRA method has been realised in the Slovak Republic for the first time. There are published only the basic parameters of traction transformer in the article. There is also published the measurement methodology, we designed and implemented as well as the basic reference waveforms of SFRA characteristics.

TRACTION TRANSFORMER PARAMETERS AND MEASUREMENT METHODOLOGY

Tab. 1: Basic traction transformer label data

Power	kVA	4900
Primary. voltage	V	25 000
Secondary. voltage	V	2x1700 / 2x1500
Primary. current	A	196
Secondary. current	A	2x1226 / 2x233
Frequency	Hz	50

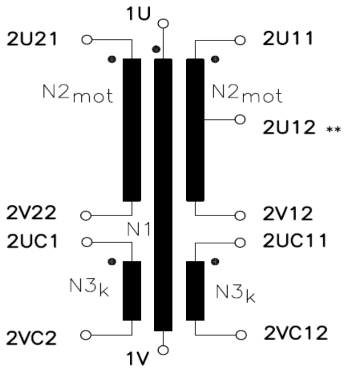

Fig. 1: Winding wiring diagram of traction transformer prototype.

On the basis on the connection of traction transformer windings, as shown in Fig. 1, we set the open circuit and short circuit measurement methodology of all windings. Terminals 1U and 1V are the primary winding, other terminals are the secondary windings specifically windings for motor (2U21 – 2V22, 2U11 – 2U12, 2U12 – 2V12) and windings for heating (2UC1-2VC2, 2UC11-2VC12). Measurements of SFRA reference characteristics were made by measuring system DOBLE M5100 in the traction transformers laboratory at company ZOS Vrutky a.s. The process of the traction transformer measurement is shown in Tab. 2. The future measurement has to be also done according to this process.

Tab. 2: Measurement methodology of traction transformer prototype

Open circuit tests		
Test 1	Test 2	Test 3
1U – 1V (D25 – D0)	2U21 – 2V22 (m1 – m2)	2U11 – 2U12 (m5 – m4)
Test č. 4	Test č. 5	Test č. 6
2U12 – 2V12 (m4 – m3)	2UC1 – 2VC2 (C1 – C3)	2UC11 – 2VC12 (C4 – C5)
Short circuit tests		
Test 7	Test 8	Test 9
D25 – D0 (entire secondary part shorted)	m1 – m2 (primary winding shorted D25 – D0)	m5 – m4 (primary winding shorted D25 – D0)
Test 10	Test 11	Test 12
m4 – m3 (primary winding shorted D25 – D0)	C1 – C3 (primary winding shorted D25 – D0)	C4 – C5 (primary winding shorted D25 – D0)

Note: D25-D0 – primary winding (bushing sign on TT), m1 to m5 – motor groups (bushing sign on TT), C1, C3, C4, C5 – heating (bushing sign on TT).

The measurement procedure (for test No. 1) is based on standard conditions for the power transformers. The reference signal from the device DOBLE is fed to the first (input - D25) bushing together with the connected shielding wire to the bottom of bushing (conductive connected with container). The measured signal is recorded on the second (output - D0) bushing, while the shielding wire is also connected on the bottom of bushing (filtering of interfering signals). Similarly, further measurements are also carried out, however, bushings of other winding terminals are dimensionally small and do not have a type of construction for conductive connection of shielding wires of input and output test loads. This was solved by shielding wires always connected to the nearest transformer container tightening plug to the bushing. Fig. 2 shows a developed prototype of the traction transformer.

Fig. 2: Railway traction transformer prototype. Type T1T-4900-25/2x1700 [2]

Measured reference characteristics

The following figures show the reference waveforms of traction transformer, which was first measured by the method SFRA. These waveforms are part of the prototype tests, which were performed on the transformer.

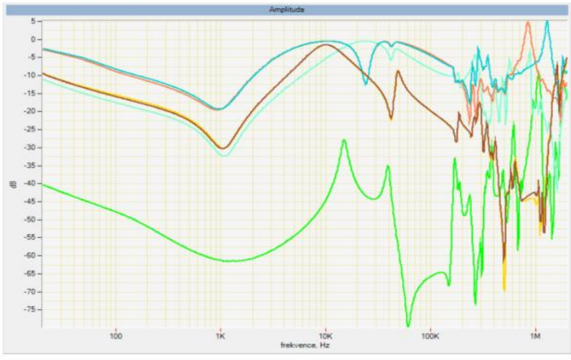

Fig. 3: Measured reference frequency characteristics of traction transformer by SFRA method for open circuit measuring methodology

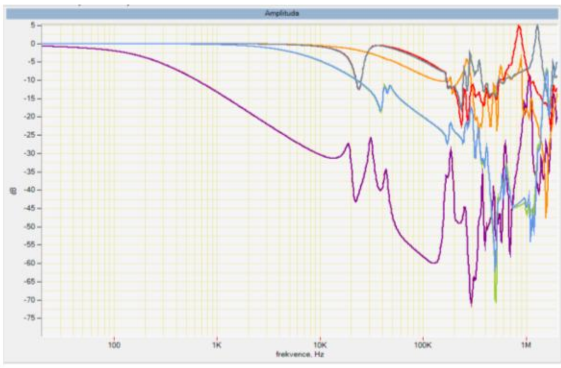

Fig. 4: Measured reference frequency characteristics of traction transformer by SFRA method for short circuit measuring methodology

MEASUREMENT AND ANALYSIS OF SFRA CHARACTERISTICS OF RAILWAY TRACTION TRANSFORMER AFTER TYPE TESTS

The transformer was subjected to all type tests, required for setting them into operation. The tests were made in the laboratory of traction transformers at ŽOS Vrútky a.s. and in laboratory of Electrical Engineering Faculty and Computer Science at Slovak Technical University in Bratislava (SFEI STU Bratislava). After basic measurements like measurement of windings resistance, measurement of insulation, open circuit measurement, short circuit measurement, and so on, the transformer was measured by SFRA method and reference SFRA waveforms were recorded. The bushing on the primary winding D25 was damaged during surge voltage test. It was removed and superseded by a new one, which was subsequently also tested. Transformer was again transferred from laboratory in Bratislava into the laboratory in Vrútky and was again subjected to SFRA tests.

The repeated measurement of SFRA characteristics of traction transformer were realized according to Table 2. Because of the transformer part damage (bushing on primary winding D25) caused during the previous tests, mainly because of surge voltage test, it was necessary to made a measurement of SFRA characteristics again, and find out how it affects waveforms shape as well as to analyse if there could occur mechanical changes on the transformer windings.
Waveforms in Fig. 5 and 6 show the impact of the primary winding bushing D25 exchange on the shape of traction transformer SFRA characteristic. Due to the large number of measured characteristics, we introduce only the reference waveforms and also the waveforms from the primary winding tests D25 – D0 (Test No. 1 and 7).

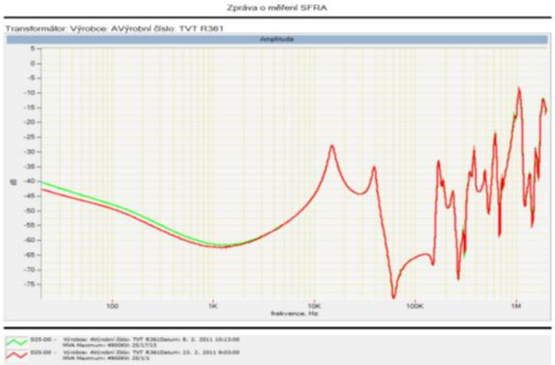

Fig. 5: SFRA characteristics of traction transformer – open circuit measurement (D25-D0)
Reference waveform
Waveform from type tests

Fig. 6: SFRA characteristics of traction transformer – short circuit measurement (D25-D0)
Reference waveform
Waveform from type tests

Fig. 7: Analysis of waveforms D25-D0 (reference and from type tests) for open circuit measurement methodology using cross-correlation coefficient

Fig. 8: Analysis of waveforms D25-D0 (reference and from type tests) for short circuit measurement methodology using cross-correlation coefficient

In Fig. 7 and 8, the waveforms of the primary winding characteristics analysis are shown. The primary winding analysis was realized by cross-correlation coefficients for the reference measurements and for measurements after type tests. The Cross-correlation coefficients (CCFs) are used directly in Doble company´s software and are needed for the exact interpretation of the measured waveforms according to Table 2 with regard to defined values of these coefficients according to Table 3 [3].
CCFs are often used in industry, telecommunications, and where the exact signal analysis is important. Application of Cross-correlation in the SFRA is of importance at two waveforms analysis. If the computed values of coefficients are 1.0, it is an absolute correlation and if values are 0.0, it is an absolute noncorrelation. The negative correlation coefficients are of no importance at assessment by SFRA method [3].

Tab. 3: Explanation of CCFs examples

	CCF
good agreement	0.95 – 1.0
boundary agreement	0.90 – 0.94
bad agreement	< 0.89
discord	<= 0.0

CCFs are defined by equation:

$$CCF = \frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right)}{\sqrt{\sum\left(X_i - \overline{X}\right)^2} \cdot \sqrt{\sum\left(Y_i - \overline{Y}\right)^2}}, \qquad (1)$$

where Xi and Yi are two real series (or graphs in the case of SFRA) compared to every individual frequency "i", X and Y are the axis of values. In the case of mathematical signal processing, which is more complex, the coefficient values are between 1 and -1 still accurate for the necessary conclusions. [3]

CONCLUSIONS

On the basis of the analysis of Fig. 7, 8 and based on automatic cross-correlation coefficient calculation, we can specify that the replacement of damaged bushing D25 had an impact on the reference waveforms shape. However, a major waveform shape change do not occurred and waveforms are within the allowable limits, as set out in Table 3. These measurements confirmed that whatever mechanical change is represented by change in SFRA characteristic shape. In our case, it was an exchange of one bushing, which was recorded as a slight change in the waveform D25-D0 shape. Other measurements also show that during tests there was no other winding or core damage. And we propose to consider the new measurement after tests as a new reference one, which will serve for comparing with other waveforms, measured throughout the whole period of the operation of this traction transformer prototype.

Acknowledgement

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