TESTING METHODS AND ANALYSIS OF THE MAIN ELECTRICAL PROPERTIES OF MODERNIZED LOCOMOTIVES

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Abstract: In the Laboratory of Traction and Rolling Stock systematic research into the methods of testing a traction drive, using the real models has been conducted. The aim of this research was to completely define all elements of the system for testing the main electrical and mechanical properties which include the selection of measuring transducers, the selection and implementation of the system for conditioning and transmitting signals to processing methods and analysis by using application software. This kind of approach has made it possible for a target test of an electric locomotive on the field to be performed in a reliable manner and without failure.

Key words: electric locomotive, testing, currents, voltages.

1. Introduction

The modernization of electric locomotives represents one of the noticeable methods of engine stock renewal with corresponding economic effects observed in the maintenance cost reduction and increased operational reliability.

In the last decade, electric locomotives were modernized in the Czech Republic, Croatia, Romania, Bulgaria, Bosnia and Herzegovina, and Serbia. Research and testing methods of electric locomotives, following the modernization, have been defined within the IEC 61133 standards by principle (IEC, 2003).

The modernization of the 441 electric locomotive performed by Končar is the most notable feature in the converter units of a traction power circuit and auxiliary drive. The degree of modernization is such that it demands the revision of the 441 original locomotive's track record. This can be achieved through simultaneously executed detailed testing of traction and operating characteristics of the 444 modernized and original 441 locomotives. An important part of an electric locomotive test is current and voltage measurement in the power subsystem of the locomotive.

2. Current-Volatge Measurement in the Primary Circuit of the Traction Transformer

This type of measurement is necessary due to the following reasons:

- Determining the degree of current and voltage distortion in the overhead contact line which is a result of the rectifier's equivalent load and traction motors' nonlinearity
- Determining the mean value of the power the locomotive takes from the

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network as a function of time, distance and track parameters.

- Knowing the basic elements of the current and voltage waveform range of its change and possible transient phenomena represent a precondition for selection the elements of a measurement system which will be reliable and accurate.

Alternating current in a high-voltage side is distorted as a consequence of multiple dependent quantities, the ones exerting the greatest influence being:

- Equivalent nonlinear load of the rectifier with inductors, traction motors involving effects of commutations of the switching elements

- Line leakage inductance on the high-voltage side.

In a cutting edge case which presupposes a smoothed current on the direct side of the traction circuit I_d, ideal switching, and distortion free supply voltage,the input current is composed of rectangular alternating segments (Radojkovic,1969), and has the following Fourier's expansion, Eq. (1):

$$i(t) = \sum_{n=2k+1} \frac{4I_d}{\pi n} \sin\left(n\frac{\pi-\alpha}{2}\right)\cos\left(100n\pi t - n\frac{\alpha+\pi}{2}\right) \quad (1)$$

Where $0 \leq \alpha \leq \pi$ stands for the control angle of the rectified voltage.

Alternating voltage of the overhead contact line has a waveform which deviates from the sinusoidal. In the simplest case when the overhead contact line is modeled using the lumped parameters L_k, and the substation is modeled as an ideal source of alternating voltage, the voltage on the pantograph is, Eq. (2):

$$u(t) = \left(U_m \sin(100\pi t) - \sum_k L_k \frac{di_{1k}}{dt}\right) - \sum_k L_k \frac{di_{hk}}{dt} \quad (2)$$

Where is:

U_m- maximum voltage of the secondary of the substation's transformer

L_k- inductance of the k-th current sector

i_{1k}- instantaneous value of the main electric current harmonic of the k-th electric current sector

i_{kh}- instantaneous value of the electric current distortion of the k-th electric current sector.

The purpose of this paper is not to provide a detailed analysis of these quantities. On the other hand, an accurately selected system, which enables the above-mentioned quantities to be determined from the results of the measurement with a high degree of accuracy, is based on the knowledge of physical characteristics we research by measurement.

3. The Elements of the Measurement System on the High-Voltage Side

The main elements of the measurement system for measuring the current in the primary high-voltage circuit are:

- Current transformer with secondary load

- Voltage measuring transformer with secondary load.

The selection of measuring transformers is made based on a number of elements which are outlined in the standard (IEC 60044). Considering the application on the traction vehicle, the following have to be analyzed:

- Characteristic of the secondary transformers load

- Transient characteristic and magnetic saturation of the transformer's magnetic circuit.

Having analyzed all factors with traction applications, it was concluded that for an accurate measurement of the alternating current in the high-voltage electric circuit it is necessary to select the current transformer of a nominal current of 300/5 A, and 0.2 accuracy class, which guarantees accurate measurement between 15 A and 360 A of primary current, at secondary load 15VA, cosø=0.8(15VA, coswhich was formed due to the terminals being connected to a low inductive shunt which ensures both the amplitude and phase signal accuracy.

For a voltage level of 25 kV, inductive voltage measuring transformers are used, the selection of which includes the elements already mentioned when selecting a current transformer.

The transformer's measuring circuit which guarantees the accuracy of the signal reproduction of the pantograph's high voltage calls for low consumption since the operating mode of the voltage transformer is close to no load conditions. If the apparent nominal power of the secondary is 1.3-1.5 times greater than the apparent load power of the coupled instrument, the best results are obtained regarding accuracy(ABB,2006).

The most probable magnitude of change in the voltage of the overhead contact line of 22.5 kV to 27.5k V rms value ensures the relative error to be below 0.5 % in case we select the measuring voltage transformer of 0.5 accuracy class with a nominal load of 25 VA and an equivalent apparent instrument load between 16 VA and 20 VA.

4. The Elements of the Measurement System in the Traction Power Circuit

During the current and voltage measurement, it is necessary to use measuring transducers which are immune to electromagnetic effects and have dynamic characteristics (bandwidth and time of response) within acceptable limits.

When selecting the measuring points, it is important that the values of current and voltage are invariant regarding the transition of the traction mode into braking mode and vice versa.

While selecting measuring transducers it is not enough to know the range of currents and voltages that are being measured. Measuring transducers have to fulfil a series of other conditions which presuppose safe measurement and accurate results. The most important include:

- the insulation of the measuring signal in respect to the measuring point within the electric traction power circuit
- insensitivity to the external interference
- linear dependence of the measuring signal in relation to the actual measuring quantity
- an optimal time of the output response to the measuring value change
- a large scale frequency range.

Measuring transducers have been used for quite some time now in our Laboratory. These transducers are based on the Hall Effect with feedback whose characteristics have been carefully selected to meet the requirements of accurate, precise and safe measurement of direct, alternating and impulse currents and voltages in the electric traction power circuit. Since recently, similar measuring transducers, based on the same principle, have been used as transducer in traction control circuits on modernized locomotives of type 444.

The main principle of operation of measuring transducers with feedback could be seen in Fig. 1.

According to the Hall effect, the voltage on the terminals of the plate in the magnetic field is proportional to the magnetic field in the air gap, that is, it is proportional to magneto-motive force $N_p I_p$. This voltage was used to generate the compensating current I_s which would compensate for the magnetomotive force in the air gap due to the primary current. When the magnetic flux is compensated for, the following relationship applies: $N_P I_P = N_S I_S$

Thus, the secondary current is an exact image of the primary current that is being measured. Inserting the measuring resistance R_M into the secondary circuit, the output voltage signal is obtained which is the image of the current in the primary. Fig. 1 clearly shows that the primary and secondary circuit are galvanically isolated which is precondition for the further processing of electric current and voltage signals(Mohan,2003).

Measuring transducers LEM LT 2000-S were used for the traction current measurement and LEM LV 100-800 for voltage measurement.

Fig. 2 shows motor currents and armature voltage while the 444 electric locomotive is running with a gradient of 14.5 ‰, the curve of radius of R=300 m and the traction of the freight train of 900 tonnes.

5. Determining Active Power and the Factors of Current and Voltage Distortion

In order to calculate active power, it is necessary to make three steps:

1. Simultaneously sampling the quantities of current and voltage
2. Perform the multiplication of corresponding quantities
3. Perform the averaging on a corresponding period.

Instead of the standard formula which is used for the sinusoidal waveforms of current and voltage we use the definitional formula, Eq. (3):

$$P = \frac{1}{T}\int_0^T i(t)\cdot u(t)\cdot dt \qquad (3)$$

Since calculating power is a post-processing operation the main attention should be paid to the simultaneous sampling of voltage and current during the measurement itself in order to make the phase error, due to asynchronous moments of sampling, under 5'.

The main elements which determine the quality of power conversion and its impact on the primary power supply system are:

- Current and voltage factors of distortion, Eq. (4):

$$THD_i = \left[\left(\frac{I_{rms}}{I_1}\right)^2 - 1\right]^{0.5};$$

$$THD_u = \left[\left(\frac{U_{rms}}{U_1}\right)^2 - 1\right]^{0.5} \qquad (4)$$

where I_{rms} and U_{rms} denote the rms values of current and voltage at the entrance of the transformer, and I_1 and U_1 are the rms values of the fundamental harmonic, when it comes to alternating quantities, that is, the mean values in the case of directed quantities.

- Power factor, Eq. (5):

$$PF = \frac{P}{U_{eff} I_{eff}} \tag{5}$$

They can be determined by using some application software which includes programming modules of Fourier's discrete analysis.

6. Elements of Analogue/Digital Conversion of Current and Voltage Signals

Even though Fourier's expansion includes an infinite number of harmonics, an actual signal is represented, quite accurately, by a limited number of harmonics.

By analysing expression Eq. (1) it can be concluded that it is sufficient to consider trigonometric polynomial which is formed when all the harmonics above seventh are neglected. In this way, we reach the possability of defining the frequency of sampling a measurement signal in the process of A/D conversion.

According to the the sampling theorem, a periodic signal of the limited frequency content can be accurately reproduced if the number of samples N within the main period is higher than twice the value of the highest harmonic n. Since in our case T=0.02 s and N>14 it follows that for the minimum sampling period the inequality applies, Eq. (6):

$$T_s < \frac{T}{N} \tag{6}$$

In the tests which were performed on the 441 locomotive, the sampling rate of f_s = 2000 Hz was used, for which the above inequality was met. In addition, the sampling frequency makes it possible for us, via moving averaging procedure to three points filtering of the signal which cause removing the noise effect and extracting the usable signal (Golten,1997).

Conditions in the overhead contact line are characterized by frequent commutation overvoltages which lead to the deviation of the rms values of voltage in relation to the nominal value. These transients last between 20 ms and 2 s. These phenomena must be taken into consideration even with the selection of the sampling rate in the process of A/D conversion. Following the recommendations of the international standard EN 50163, the sampling rate must not be below 2000 Hz.

Finally, it follows that the voltage-current measurements require the measurement equipment which has the possibility of simultaneous sampling of two quantities at a frequency no lower than 2000 Hz.

7. Conclusion

The tests on traction vehicles following the modernization or following the main overhaul represent an important step in assessing the quality of new or modified technical solutions in the electric traction power circuit. The purpose of the conducted analysis is to further elaborate research approaches and methodologies envisaged by contemporary standards and international regulations in the field of electric traction. The principles outlined in this paper were practically implemented during the test of the 461 locomotive's power consumption and

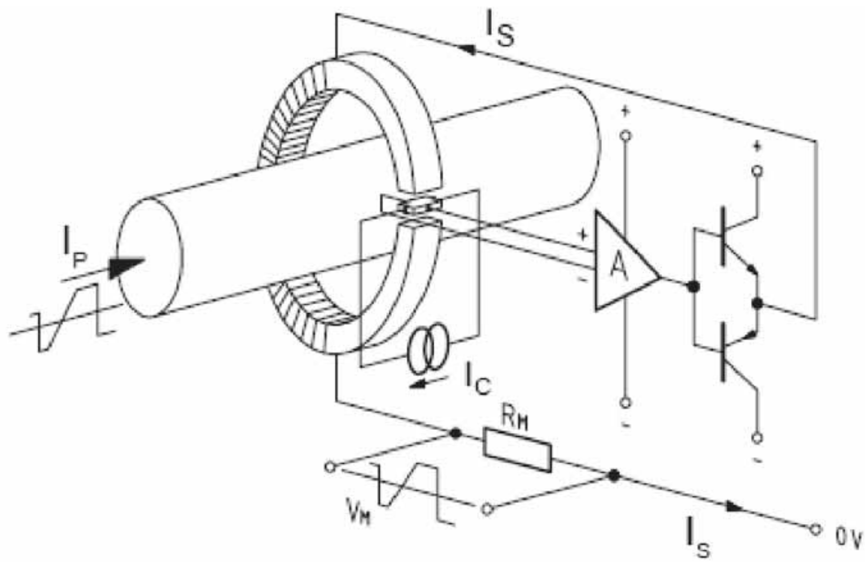

Fig. 1.
The Principle of Operation of a Measuring Transducer With Feedback

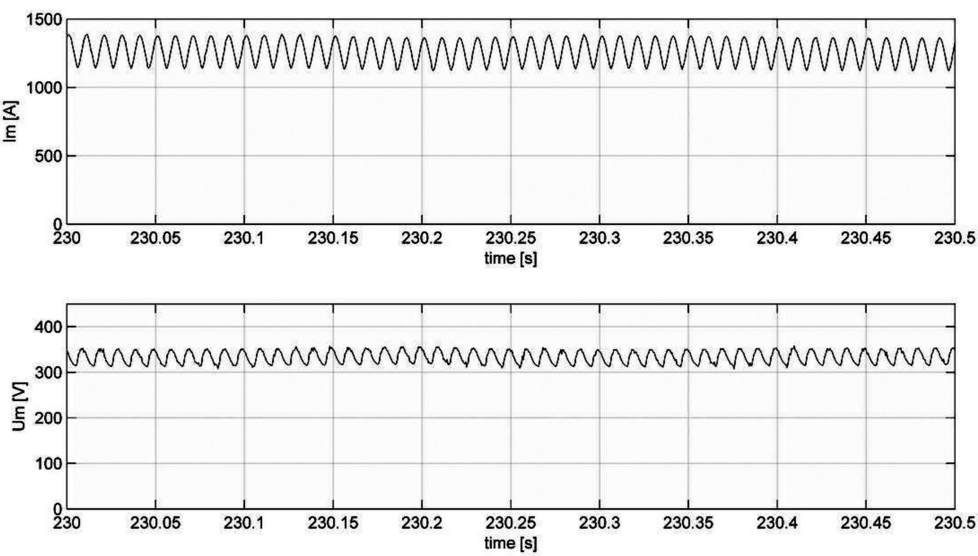

Fig. 2.
The Display of the 444 Locomotive's Current and Voltage

while conducting a specialized test of the 444 modernized electric locomotive.

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METODE ISPITIVANJA I ANALIZE GLAVNIH ELEKTRIČNIH VELIČINA KOJE ODREĐUJU EKSPLOATACIONE KARAKTERISTIKE LOKOMOTIVE NAKON MODERNIZACIJE

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Sažetak: U okviru laboratorije za vuču i vozna sredstva vršena su dugogodišnja istraživanja metoda testiranja vučnog vozila na realnim modelima vučnog pogona. Cilj ovih istraživanja bio je da se potpuno definišu svi elementi sistema za ispitivanje glavnih električnih i mehaničkih veličina koji uključuju izbor mernih transduktora, izbor i implementaciju sistema za kondicioniranje i prenos signala do metoda obrade i analize rezultata ispitivanja primenom aplikativnog softvera. Ovakav pristup omogućio je da se jedno ciljano ispitivanje električne lokomotive u eksploatacionim uslovima obavi pouzdano i bez otkaza.

Ključne reči: električna lokomotiva, testiranje, struje, naponi.