The analysis of the deforming regime in the electric traction railway

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Abstract. The paper presents the results of measurements of electric power quality analyzer CA8334 on an electric locomotive equipped with continuous power engines. Determinations were made of the arrangements of current and voltage related to a motor of a locomotive 5 MVA. The data measured by the analyzer were transferred to a computer system using the Qualistar program and further processed in Excel that allows graphical representation of the characteristic quantities of power quality.

1. Introduction
The consumer’s sensitivity to the received power quality is varied even for certain specified load. This is due to the impossibility of the task to work correctly under supply voltage variations in which are not within the limits prescribed and of course the compensation measures against malfunction tasks will certainly have repercussions on costs [1].

Power quality depends on the supply network topology, and on the amount of polluting harmonics injected into the network by non-linear loads [2], [3].

To have some security in the proper functioning of a power system, some specific rules were imposed for a range of sizes that are operating in these systems [4].

Comply with the limits prescribed by rules or standards of quality is not a simple in practical cases [5].

The set standards are generally different for different voltage levels and often in practice, certain tasks need to assure for themselves the optimal supply voltage [1].

This obviously involves solving the problem of unwanted external energy to compensate for load disturbances, the effect is obvious to extend the life of the load.

Power quality is determined by using qualitative indicators whose values are standardized for all supply lines, low voltage, medium voltage and high voltage [6].

Failure to comply with certain rules or standards of parameters will inevitably lead to the dramatic fall in life equipment or to oversize them to meet new operating conditions [7].

The most important imbalances are produced by industrial single-phase high power consumers, connected to the electrical network of medium or high voltage among which are the transformer stations for the railway electric traction supply.
2. Problem formulation

Electricity supply systems in electric traction, are a vital part, and their development has enabled the development of technologies used in the field. The types of power systems are direct current, alternative single-phase and three-phase current.

The single-phase voltage of 25kV and frequency of 50Hz was imposed in most European countries, with the convenience of national networks and cruising speeds achieved [1]. Mathematical formulas used to compute the various parameters [8].

Half-period voltage and current RMS values.

Single RMS voltage half-period $i+1$ phase:

$$V_{dem}(i) = \sqrt{\frac{2}{N} \sum_{n=0}^{N} V(i,n)^2}$$  \hspace{1cm} (1)

Compound RMS voltage half-period $i+1$ phase:

$$U_{dem}(i) = \sqrt{\frac{2}{N} \sum_{n=0}^{N} U(i,n)^2}$$  \hspace{1cm} (2)

RMS current half-period $i+1$ phase:

$$A_{dem}(i) = \sqrt{\frac{2}{N} \sum_{n=0}^{N} A(i,n)^2}$$  \hspace{1cm} (3)

1 sec RMS values for voltage and current:

Single RMS voltage $i+1$ phase:

$$V_{rms}(i) = \sqrt{\frac{1}{N} \sum_{n=0}^{N} V(i,n)^2}$$  \hspace{1cm} (4)

Compound RMS voltage $i+1$ phase:

$$U_{rms}(i) = \sqrt{\frac{1}{N} \sum_{n=0}^{N} U(i,n)^2}$$  \hspace{1cm} (5)

Courant efficacy phase $i+1$:

$$A_{rms}(i) = \sqrt{\frac{1}{N} \sum_{n=0}^{N} A(i,n)^2}$$  \hspace{1cm} (6)

Neutral RMS current:

$$A_{rms}(3) = \sqrt{\frac{1}{N} \sum_{n=0}^{N} (A(0,n)+A(1,n)+A(2,n))^2}$$  \hspace{1cm} (7)

$N$: Number of samples in a second;

Calculation of the total harmonic distortion factor (THD):

$$V_{thd}(i) = \sqrt{\sum_{n=2}^{50} \frac{V_{harm}(i,n)^2}{V_{harm}(i,1)^2}}$$  \hspace{1cm} (8)
\[ U_{\text{thd}}(i) = \sqrt{\sum_{n=2}^{50} U_{\text{harm}}(i,n)^2} / U_{\text{harm}}(i,1) \]  
(9)

\[ A_{\text{thd}}(i) = \sqrt{\sum_{n=2}^{50} A_{\text{harm}}(i,n)^2} / A_{\text{harm}}(i,1) \]  
(10)

i: phase (0; 1; 2)  
n: rang (2…50)

Different power levels 1 sec.

Active power i + 1 phase:

\[ W(i) = \frac{1}{N} \sum_{n=0}^{N-1} V(i,n) \cdot A(i,n) \]  
(11)

Apparent power i + 1 phase:

\[ VA(i) = V_{\text{rms}}(i) \cdot A_{\text{rms}}(i) \]  
(12)

Reactive power i + 1 phase:

\[ VAR(i) = \frac{1}{N} \sum_{n=0}^{N-1} VF(i) \left( n - \frac{N}{4} \right) \cdot AF(i,n) \]  
(13)

Power factor i + 1 phase:

\[ PF(i) = \frac{W(i)}{VA(i)} \]  
(14)

Based on these relationships the power quality analyzer provides a range of sizes characteristic of electricity depending on which the state of the electric transport power line rail is determined [8].

The paper shows the waveforms of current and voltage measured over a period or a longer period of time.

The voltage measurements were performed with descending transformer voltage because the input of the analyzer that does not support a higher voltage of 500 V. The transformation ratio was 25:1 for the reason that some values read directly from the analyzer are lower. For the other graphs corrections were made, proper size were purchased in the analyzer’s memory and then downloaded to a computer and represented using Excel.

\[ \text{Figure 1. Harmonic voltage values determined for an engine} \]
Figure 1 represents the values of harmonic voltage on the screen; it are presented up to the 25th order, but the calculation factor of harmonic distortion (THD) is done for a number of harmonics up to the 40th order [9], [10]. It is discovered a quite high distorting factor. The values of the current harmonics (Figure 2) are more pronounced, as expected, and the THD factor is very high, so measures are necessary to reduce these values.

![Figure 2. Harmonic current values determined for an engine](image)

The differences between the values of voltage and current harmonics are obvious in Figure 3 where the two types show of variation in the size range on one period, the current having a much more distorted shape than the voltage. The phase shift difference between the two sizes (Figure 4) is of 18° with inductive character and which didn’t exceed in most of the time the value of 25° throughout the measurement.

![Figure 3. Wave forms from period for voltage and electric current on a motor](image)

Next is presented the variation measurements determined on a longer period of time. The samples are acquired at intervals of 1s, the memory of the analyser doesn’t allow a large volume of data and the measurement’s time exceed 3 hours. Following the obtained waveforms one can find a current variation (Figure 5) around 500A and the effective value of the voltage (Figure 6) a fluctuation around 400V.
Figure 4. Phase shift between voltage and current for the locomotive engine.

Figure 5. Time variation for the actual value of the current absorbed by a motor.

From the presentation of the current THD factor (Figure 7) or to the voltage (Figure 8) a value is found, most of the time more than 30% and around 15% variation in the voltage THD. These values require taking measures to reduce these values, especially for electricity.

Figure 6. Time variation for the actual value of the voltage at the terminals of a motor.
Figure 7. Time variation for the value of the harmonic distortion factor (THD) for current

Figure 8. Time variation for the value of the factor (THD) of voltage at the terminals of a motor

Analysing the variation of powers, active (Figure 9), reactive (Figure 10) and apparent (Figure 11) an increase of the reactive power can be seen to the same extent and with the increasing of active power, in the first part to an active power with a variation around 150kW we have a reactive power variation around 50kVAR and in the final part of the measurement the values are preserved, at 250 kW we have around 150 kvar values that are found in the chart of apparent power.

Figure 9. The variation in time corresponding to the active power of an engine
Figure 10. Variation in time for the reactive power

Figure 11. Variation in time for the apparent power

The variation of the power factor based on the actual value (Figure 12) is kept nearly constant around 90%, and the power factor based on the fundamental DPF (Figure 13) is maintained at a value of about 95%.

Figure 12. Variation in time for the power factor

Figure 13. Variation in time for the value of the deviation factor
From the above presented it can be seen that the need for a compensation of the existing deforming regime, this involves greater studies, to highlight the optimal placement of the compensation circuits. The location of these devices on the locomotive shows a type of compensation equipment and their location in the substation traction other equipment.

To emphasize some effects in reducing harmonic voltage it is presented a variant that uses a number of passive filters that connect to the supply line of the locomotive. Using simulation software PSCAD / EMTDC in which data from the measurement was used and then adapted to conform with the file of the simulation program. Passive filter of LC type were calculated and given to the odd harmonics’ frequencies and connected to the supply line of the locomotive [9].

By performing simulations it was noted that a too low number of filters (one or two) or too high (over 9) does not bring a significant gain in terms of harmonic reduction [10]. The most obvious effects are obtained for a number of 3-5 passive filters which correspond to low order harmonics (3-13). One example is shown for the current and also for the voltage use of 5 passive filters in the power supply circuit using a resistive load. The representation of the current waveform (Figure 15a, b) highlights the form acquired from the power supply circuit from the substation voltage but also the two current waveforms, unfiltered Ia and filtered Ia. A considerable reduction can be seen of the deforming regime for the output current which is observed also from the comparison of the calculated harmonics with the FFT block up to the 19th harmonic order.

For the voltage waves (Figure 14 a, b) a conclusive effect is not obtained anymore, the voltage form is less deformed and then the filters don’t have a pronounced character as the one for current, but differences can be observed from the comparison of the calculated harmonics with the FFT block. Analysing the two graphs it can be seen that there are situations when some harmonics filtered to be bigger than the unfiltered one, but on the whole it can be concluded that the introduction of filters improves the harmonic regime.
Figure 14. Waveforms and voltage harmonic filters values of the order 3, 5, 7, 9, 11
3. Conclusions

From everything presented it can be noted the existence of a strong deforming in the fuel system of locomotives equipped with direct current motors. Using the passive filters is the simplest method of reducing the harmonics values, but for a considerable reduction of the deforming regime introduced by electric traction equipment it was discovered the need of a bigger number of filters, for each harmonic a filter.

This makes it almost impossible to use only passive filters, so they have to be merged with other methods of reducing the deforming regime.

From the results obtained with the simulation program PSCAD / EMTDC it was noted an important reduction in the values of the harmonics by introducing passive filters. Simulations were made with a resistive load, in order not to introduce any additional harmonics, since both the current and the voltage sources are given actual values measured in the substation traction, acquired and processed to be recognized by the simulation program. At the increase in the number of filters is found that some harmonics have a value slightly increased as against to the situations discussed above with a smaller number of filters. This is found especially in the current harmonic and to a less extent to the voltage, within the meaning of their values’ percentage change.

It is thus emphasized the limiting of the number of used passive filters whether they are connected to the traction vehicle or in the substation traction.

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