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SIMULATION OF PASSIVE FILTERING PERFORMANCES IN A FEEDING STATION OF THE "SERBIEN RAILWAYS"

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Abstract*. The article deals with harmonics filtration in railway traction transformer substations. In traction transforms substations in the "Serbien Railways" there are filters of* 3rd and 5th *harmonics. In this concrete application, the proposed solution for harmonics mitigation is based on passive power filtering. The simulations carried out under Matlab Simulink environment show that the installation of two single tuned filters for third and fifth harmonics would reduce harmonics levels and harmonic distortion factor to within acceptable limits even in the most unfavourable situations. Explanation of transient effects during short-circuits at the contact line can be considered as the main problem. These effects can arise during a failure in a traction circuit. Therefore, the attention is turned to an adjustment protection design of the traction circuit. Simulation diagrams were created. Simulation diagrams can be used as a main tool for a particular project of railway traction transformer substations of protection settings process from electromagnetic compatibility point of view.*

INTRODUCTION

In Serbia, the electric power generated by power stations is carried to electric railway substations by 110kV three-phase transmission lines.

The electrical supply system of a railway line provides electric power of the desired characteristics (AC, single phase, 25 kV) to the trains from the high-voltage network by single phase 110kV/25kV transformers. Figure 1 displays the configuration of the system. Each transformer is connected to two phases of the three-phase system. Each section of the line (about 50km of length) is independently fed by a traction substation. Therefore, along of about 150km, the main feeding line is balanced.

In the Serbien Railways network, there are two types of electric railway locomotives of different powers (5100 kW and 3500 kW). Each railway locomotive is driven by six or four DC electric motors supplied by diode-based rectifier groups (one group for each traction motor).

Electrical locomotives are usually designed in a way that alternate voltage 25kV is decreased by a transformer, to a value of about 1kV, and rectified. The rectifier can be controlled or not. The other circuits vary depending on whether the locomotive in question is equipped with DC series-wound motors. The most important thing from the perspective of current harmonic distortion is that current is rectified. All types of rectifiers draw harmonically distorted current.

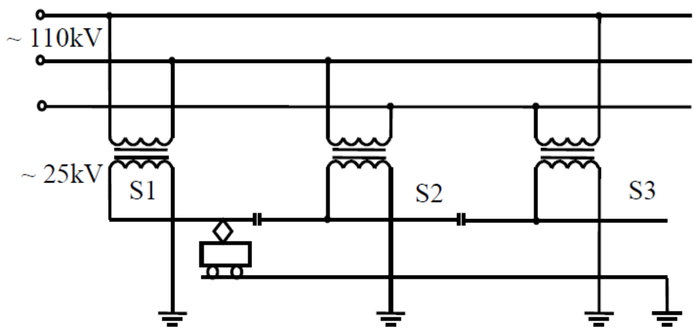

Fig.1 Electrical supply system of the railway line

An 25 kV, 50 Hz electric traction can cause voltage unbalance of more than 2 % allowed by standard EN 50160 [1], mostly during the periods of heavy traction load. A requirement common for both traction current systems is the variability of power taken off the network. Electricity suppliers force Serbian Railway to have as steady load currents as it is possible to cut down the phenomena called flicker. The reason for it is the elimination of the uncomfortableness caused by illumination intensity fluctuations as a result of rapid feeding voltage changes. These changes are here in pursuance of the big variable traction loads, which are specific for electric railways.

During various measurements carried out, the states were not detected when compatible numerical levels valid for flicker given by standard are exceeded. As a matter of fact, the displeasing perceptions of electric bulbs light fluctuations were not observed even in traction substations (where should mostly be expected) during the whole period of electric railways of both current systems operation. Described phenomenon could occur in the point of relatively “soft” supply high voltage network. In that case, increasing the short circuit power at the point of common coupling in distributing network could eliminate flicker.

The unfiltered current and voltage spectrums and time functions can be studied on Figure 2 and 3. In this case a high current distortion could be observed. The locomotive is equipped with DC traction motor and AC/DC converter (semi-controlled bridges of thyristors and diodes), this is the origin of the injection of the harmonic currents. The green columns show the measured loco current spectrum and the red ones the current at the substation. The engine is 10 km far from the substation [2].

Since the rectifier in question is one-phase, current harmonics spectrum includes all the odd harmonics, the most important ones being the low ones, i.e. 3rd and 5th. Harmonic distortion of current taken by traction vehicles is high. It is very common for *THD* (Total Harmonic Distortion) to reach 20-60%, or even more. The total harmonic distortion factors defined with equation:

$$THD = \frac{\sqrt{\sum_{k=2}^{\infty} X_k^2}}{X_1} \tag{1}$$

Where $k = \frac{f}{50Hz}$ harmonic order, X_k – k-th harmonic component of *I* or *U*, X_1 - fundamental frequency component of *I* or *U*.

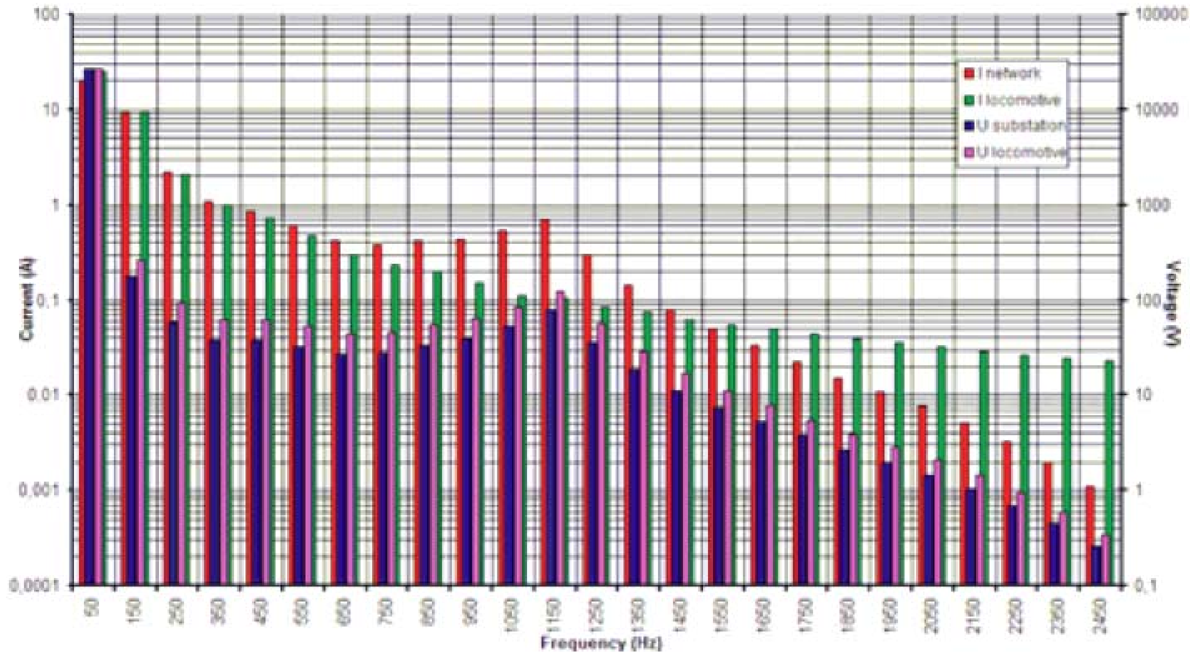

Fig.2 Frequency spectrum of unfiltered current and voltage

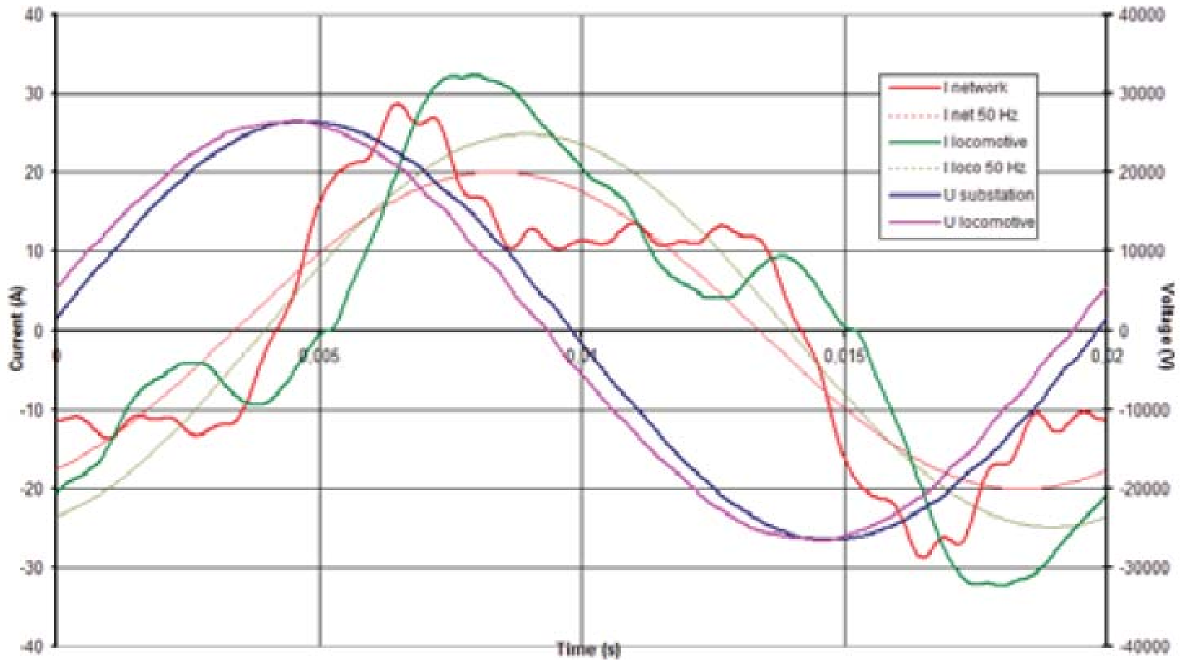

Fig. 3 Time functions of the unfiltered current and voltage

In this paper, we propose the application of passive filters in order to limit the harmonic currents produced by the traction system. The passive filter could be located in substation. Coordination of harmonic of multiple filter units may become a problem since the railway transportation system is characterized by the presence of different types of locomotive from different ages of technology (DC motor with rectifier unit, diode or thyristor). However, in differently from the type of locomotive, the harmonic production needs to be eliminated or limited to a acceptable value imposed by international standards.

SIMULATION DESCRIPTION PASSIVE FILTER IN SUBSTATIONS OF THE "SERBIAN RAILWAYS"

Single tuned passive filter in substations of the "Serbian Railways" consists of two single tuned filters for 3rd and 5th harmonics according as Fig.4.

The device of the feeding station was chosen for a passive filter substitution diagram, see [5]:

1. The 3rd harmonic *LC* branch:
   - The total capacity C_3 = 8,5 μF;
   - The choke inductivity L_3 = 137 mH;
   - The choke resistance R_{L3} = 1.43 Ω;
   - The resonance frequency f_3 = 147,5 Hz.
2. The 5th harmonic *LC* branch
   - The total capacity C_5 =2,4 μF;
   - The choke inductivity L_5 = 169 mH;
   - The choke resistance R_{L5} = 1,77 Ω;
   - The resonance frequency f_5 = 249.9 Hz.

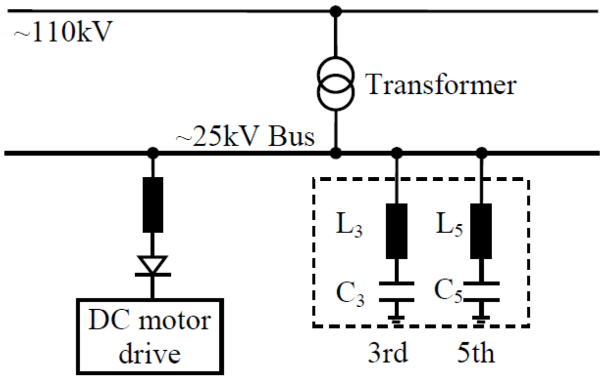

Fig.4 Two single tuned filters in point of common coupling

Transient effects are analyzed at linear systems, which are described by an equations system. Necessarily, building of a physical model has to be avoided due to the high costs, limited process monitoring abilities and the behavior of circuit transient effects. Therefore the simulation program Matlab-Simulink was chosen. PSpice utilizes substitution diagrams of simple connections of a traction circuit as input data. These diagrams are obtained from substitution models of simple elements of a traction circuit.

Now, it is very important to state the main disadvantages of a computer simulation. The program does not work with real elements but it works with models. So, results can be as exact as elements' models and describe only effects which present the used models. A creation of quality models, which represent real devices well, is the most important and the most complicated problem of simulations of electronic circuits.

Parameters of passive filter reactors and capacitors and the traction transformer impedance are known, as well as feeding network impedance. Thus it is possible to simulate the circuit and find out attenuation of the passive filter for individual harmonics. Fig. 4 shows a diagram of the circuit and its parameters. All values are recalculated to voltage level of 27kV. Impedance of the transformer 400/110kV and network 400kV is insignificant, that is why in the simulation it is replaced by short connection. The simulation was carried out in the Matlab-Simulink software.

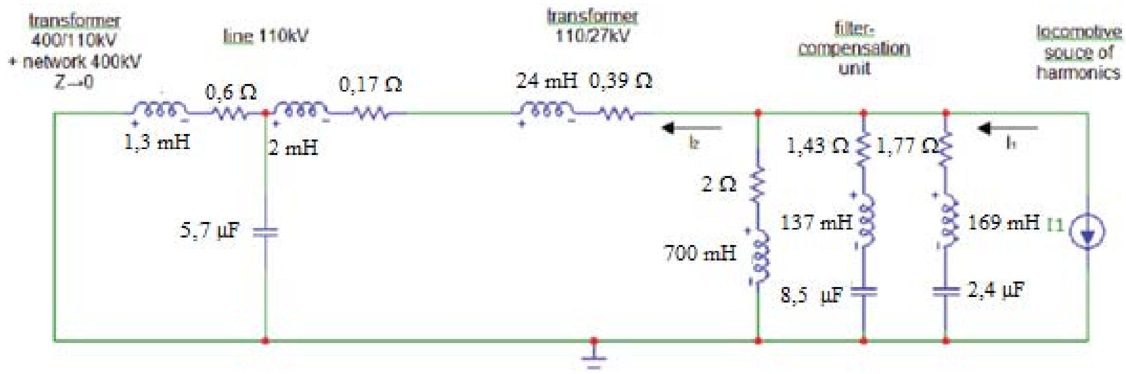

Fig. 5: Circuit diagram created by Matlab - Simulink simulation software

Series RLC circuits were tuned to the 3rd and 5th harmonic orders, and a broadband filter was set to reduce all the harmonic orders above (Fig. 6 and Fig. 7).

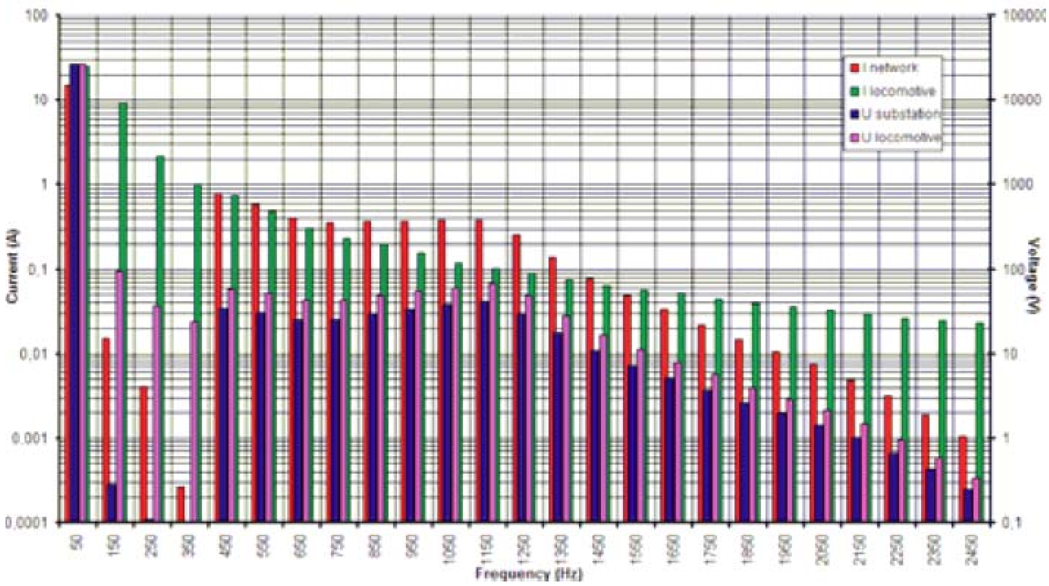

Fig.6: Frequency spectrum of passive filtered current and voltage

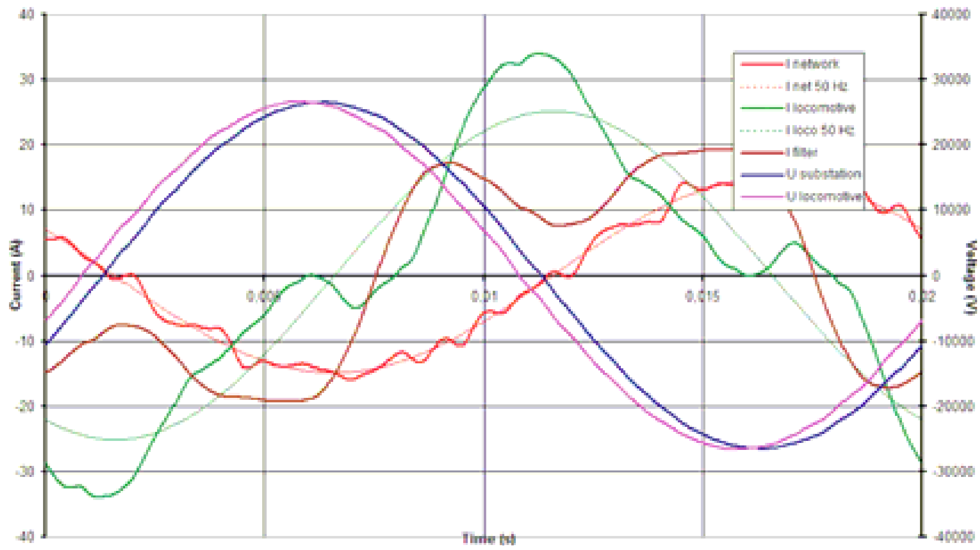

Fig. 7: Time functions of the passive filtered current and voltage

One can conclude, that the effectiveness of the filter is acceptable, the THD value of the current flowing into the HV network is under the recommended limits of the IEEE 519 standard, the voltage THD is low enough, so they comply with the standards.

The results of simulation show that the adopted compensation solution allows respecting the standards even in the worst cases relating to harmonic distortion factor of the load current.

Thus, the harmonic distortion at the points of common coupling would be within the required limits.

It worths mentioning, that this solution has no affect on the fundamental frequency reactive power balance, it means that according to the Serbian tariff system the consumer should pay for reactive power as well.

Table 1 provide the THD values after the previous four calculations. Comparing this case with the unfiltered one, the THD voltage could be reduced by 30-40 % along the whole supply line. The reduction of the HV network current is significant, too.

Table 1 The THD values after the previous four calculations

	$THD_{Inetwork}$	$THD_{Itrac.sub}$	$THDI_{loco}$	THD_{Usubs}.	THD_{Uloco}
Unifiltered	49,10%	49,10%	*38,62%*	*0,88%*	*1,35%*
Passive filter	9,22 %	53,85%	*38,17%*	*0,38%*	*0,74%*

The result of the simulation was attenuation of passive filter as a function of frequency, too. This attenuation in is expressed *as* I_1/I_2 and can be seen in Fig. 8.

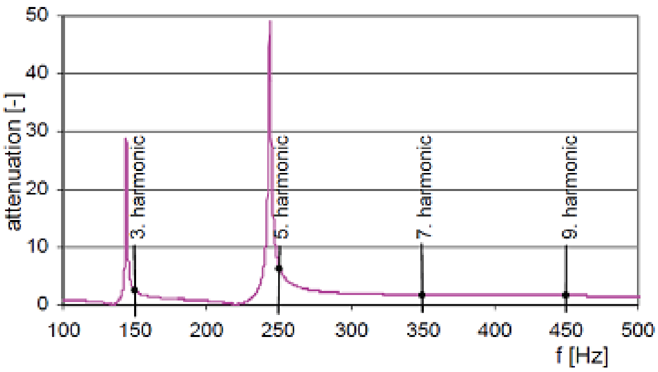

Fig. 8 Attenuation as a function of frequency (from simulation).

Currents harmonics I_1 and I_2 were measured (see Fig.5), and based on these values, attenuation was calculated. To evaluate harmonics and attenuation, it was necessary to use sections with high load, because when the load is low, measurements tend to be less accurate. Thus only sections where current was higher than 100A were evaluated.

Table 2 sums up measurement and simulation results. Attenuation obtained by measurement was evaluated statistically. The mode, i.e. most frequently encountered result, was chosen as a statistical parameter.

Table 2 Attenuation of passive filter - measurement and simulation results

	3rd harmonic	5th harmonic	7th harmonic	9th harmonic
Most frequent measurement result (mode)	1,6 - 1,8	6 - 8	1,4 - 1,6	1,4 - 1,6
Simulation results	2,49	7,04	1,74	1,58

Both measurement and simulation results show that passive filter decreases the values of current harmonics, specifically 3rd and 5th harmonics, for which passive filter is designed, and also further harmonics (7th and 9th). However, the degree to which the individual harmonics were suppressed varies greatly. The highest attenuation is for 5th harmonic, 5th harmonic filter is tuned very close to 5th harmonic frequency. Attenuation for 3rd harmonic is less significant because 3rd harmonic filter is not tuned so accurately.

The attenuation is even less significant for 7th and 9th harmonics (approx. 1.5), which means that current of each of these harmonics is decreased by approx. 1/3. Given the fact that this is only a side effect of 3rd and 5th harmonic filters, it can be considered a relatively good result.

As far as the differences between measurement results and simulation results, the most significant ones are for 3rd and 7th harmonics (simulation was more favorable than reality). These differences can be caused by a number of factors:

- measurement error,
- influence of thyristor regulation of current in the decompensation reactor (not taken into account in the simulation),
- voltage distortion in the feeding network.

CONCLUSIONS

This paper presents a study into harmonic pollution in the railway connection of a traction substation at the 25 kV Serbien distribution network. This connection poses the problem of filtering line current harmonics.

The proposed solution for harmonics mitigation is based on passive power filtering. The analysis of passive filtering performances was made by simulation under Matlab Simulink environment.

Two filtering installations based on single tuned filters were taken into consideration in order to reduce the individual harmonics and the harmonic distortion factor of the current under the recommended limits of the IEEE 519 standard.

The results of simulation show that the adopted compensation solution allows respecting the standards even in the worst cases relating to harmonic distortion factor of the load current. Thus, the harmonic distortion at the points of common coupling would be within the required limits.

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СИМУЛАЦИЯ НА ПАСИВНО ФИЛТРИРАНЕ НА ТЯГОВИ ПОДСТАНЦИИ НА ЖЕЛЕЗОПЪТНИЯ ТРАНСПОРТ В РЕПУБЛИКА СЪРБИЯ

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Ключови думи: *- Железопътни системи, пасивни филтри, преходен ефект, късо съединение*

Резюме. *Статията разглежда проблемите на филтриране на хармоници в тягови подстанции на железопътния транспорт. В тяговите подстанции на сръбските железници има филтри за хармоници от 3ти и 5ти ред. В това конкретно приложение е предложено решение за намаляване на хармониците чрез пасивно филтриране. Симулациите, извършени под Matlab Simulink показват, че монтирането на два теснолентови филтри за хармоници от 3ти и 5ти ред ще намали нивата на хармоници и коефициента на хармониците до приемливи граници дори и в най-неблагоприятните ситуации. Като основен проблем може да се раглеждат преходните ефекти по време на късо съединение в контактната линия. Тези ефекти могат да възникнат по време на повреда в тяговата верига. Следователно, вниманието е обърнато към дизайна на настройките за защита на тяговата верига. Създадени са диаграми от симулациите. Симулационните диаграми могат да се използват като основен инструмент за специфичен проект на процеса на защита на настройките на тягови подстанции в железопътния транспорт от гледна точка на електромагнитната съвместимост.*