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DIGITAL MEASURING OF TRACTION AND RECUPERATIVE CURRENT IN THE SERBIAN RAILWAYS ELECTRO-TRACTION SUBSTATIONS

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Abstract: *This paper deals with construction of device for real-time analysis of traction and recuperative current. The sensing device constructed through utilization of modern microprocessor unit and thus representing full digital system for real time analysis of current spectrum of power semiconductor converter. Content of higher harmonics in these currents must not exceed limits specified in international standard EN 50160, so exact measurement and analysis of this harmonics is necessary. Proposed device uses microprocessor for real time measurement and analysis of traction and recuperative currents. The paper suggests one of the possible modern solutions to the measurement and supervision of traction and recuperative currents in railways electro-traction substations of "Serbian Railways".*

INTRODUCTION

The AC regenerative braking is possible if the "locomotive" is based on dedicated equipment able to operate the traction motors in generator mode, on one hand, and the traction electrification system – with the most important element, the traction power substations (TPSS) – gives the possibility to recover electrical energy back into the national grid, to be used by other trains in motoring mode of operation.

The locomotive equipment is based on the main step-down transformer with more secondary windings the four quadrant line side AC/DC converter, a DC – link circuit and more DC/AC three phase inverters which supply the induction traction motors. In motoring mode of operation, the electrical power is transferred from the national grid, through step-down transformer to the AC/DC converter which is operated as controlled rectifier and the DC/AC converters, typically operated as inverters.

By regenerative braking, the induction machine operates as generator, the DC/AC converter – the motor side converter - becomes "rectifier" using the voltage of the DC – link. The AC/DC converter - the line-side converters – becomes inverter and transfers the electrical power to the distribution point.

Content of higher harmonics in traction and recuperative currents must not exceed limits specified in international standard EN 50160, so exact measurement and analysis of this harmonics is necessary.

Values of individual higher harmonics (h) in traction and recuperative current at the location of transmission to the 25th higher harmonic with a percentage of the nominal traction current according to the EN 50160 standard showed in Table 1.

Table 1

Odd-numbered higher harmonics not divisible by 3		Odd-numbered higher harmonics divisible by 3		Even-numbered higher harmonics	
Number of a Harmonic	I_h in % of I_1	Number of a Harmonic	I_h in % of I_1	Number of a Harmonic	I_h in % of I_1
5	6.0	3	5.0		
7	5.0	9	1.5	2	2.0
11	3.5	15	0.5	4	1.0
13	3.0	21	0.5	6 to 24	0.5
17	2.0				
19	1.5				
23	1.5				
25	1.5				

According to the EN 50160 standard, the total harmonic distortion of traction and recuperative currents (THD) can be calculated using the formula:

$$THD = \sqrt{\sum_{h=2}^{40} \left(I_h\right)^2} \qquad (1)$$

In this paper we will describe construction of device for online, real-time analysis of traction and recuperative current. The sensing device will be constructed through utilization of modern microprocessor unit (TMS320F28335 from Texas Instruments), and thus will be representing full digital system for real time analysis of current spectrum of power semiconductor converter. In the first part of paper, the current sensor and digital filter are described. Then the computation algorithm is being presented. Last part of paper shows implementation in microprocessor and experimental verification of proposed solution.

1. SYSTEM FOR REAL TIME ANALYSIS OF CURRENT'S SPECTRUM

Our proposal of system for real time analysis of current's spectrum is primarily indented for use in railway applications. But this system can be normally used in every application where exact measurement of traction and recuperative current is necessity. As we previously mentioned, according to standard EN 50160, the traction and recuperative current which is flowing through rail back into power network cannot affect signal devices and other equipment which could be potentially safety risk for railway system.

Whole analysis of traction and recuperative current must be done in real time. It means that if analysed current contains specific harmonic content, or if content of higher harmonics is above allowable limit, then the proposed system has to perform certain measurements. Control system and control algorithm will prevent distorted current from flowing back into the distribution point and power network.

Fig. 1 shows block scheme of proposed system. It consists from current sensing device, and from microprocessor (in our case we have been working with TMS320F28335). Analog to digital conversion and all functions of filters and computational algorithms which are necessary for measurement and analysis of harmonic content in traction and recuperative currents are in digital - in software form.

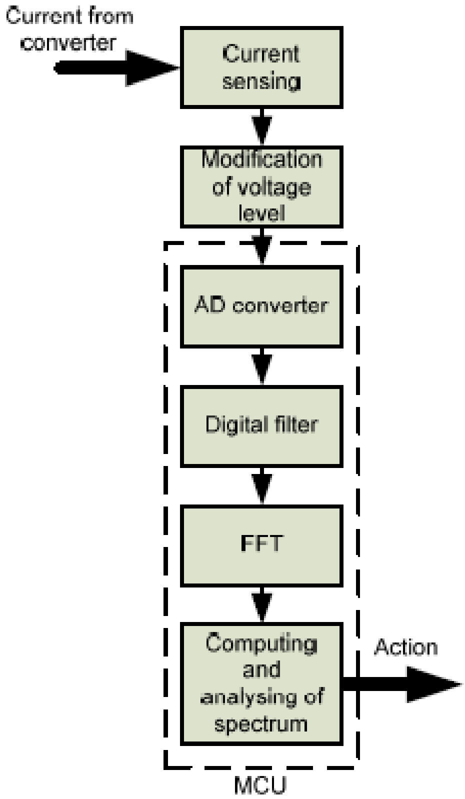

Fig. 1. Block scheme of system for analysis of traction and recuperative currents.

We have selected Honeywell CSNF161 sensor configured in closed loop for current measurements with amplitude of 300 A. This sensor contains Hall circuit with closed loop and enables to sense alternating, direct as well as pulsed waveforms.

Due to fact, that hall sensor is equipped with current output, the transformation from current to acceptable voltage level for A/D converter (microprocessor) is necessary. A/D converter is operating with input voltage level between 0 VDC - 3 VDC.

Algorithms for filtering, computing and analysis of measured signal are realized in software form in microprocessor. For this purpose a 32 bit float-point microprocessor TMS 320F28335 Delfino is used. This 150MHz microprocessor contains float-point C2000 core and powerful peripherals, from which a 12bit A/D converter was used for measurement of signal from Hall sensor. Maximum frequency of analysed signal is up to 20kHz, so the sampling frequency of 192kHz was chosen, which means, that Shannon criteria was observed.

Digital filter in device for real time measurement and analysis of traction and recuperative currents from electric locomotive acts like antialiasing filter, which is basically low pass filter.. For sampling frequency fs=192307.69 Hz, a low pass filter with cut-off frequency fc=26kHz was designed. Digital filter do not affect amplitude frequency spectrum from 0 to 26kHz, but all higher frequencies will be damped. Main criterion for filter design is its stability that means that all poles of transfer function must belong to internal part of unity circle line.

For computing of discrete Fourier transform the FFT algorithm with "in place computing" was used. In program, two fields each with 512 samples were used. Both fields were in 16b floating point form. For realization of FFT function, standard MATLAB function - void fft(float32*p_real, float32*p_imag) was used. Input to the function is array of real numbers, but computing of imaginary numbers is also possible. Generally, output from the discrete Fourier transform is sequence of complex numbers. From above mentioned function, the output is array of real parts of numbers and array of imaginary numbers. Hence, the input values are overwritten with output values. Advantage of this algorithm is in low memory usage and relatively short time necessary for computing of this function. For application in real time, computing time of algorithms has big impact on performance of whole device. Time necessary for computing of all algorithms was 6.8μs, whereby single precision 32b floating point operands were used for variables.

For amplitude spectrum computing, function „void Spectrum_Amp(float32 *p_real, float32 *p_imag)" was used. This function reconstruct the frequency axis and compute amplitudes of each harmonic component by:

$$A[n]=\frac{2}{N}\sqrt{X_{real}^{2}[n]+X_{imag}^{2}} \qquad (2)$$

where n - is n-th component of Fourier transform, X_{real} is real part and X_{imag} is imaginary part.

Function, which resolution is determined by number of samples N, assign the value of amplitude to each frequency from frequency range, whereby identify the spectrum of analysed signal, in our case the current from converter.

3.. SIMULATION AND EXPERIMENTAL VERIFICATION

For verification of proposed algorithm - digital filter and its accuracy, the simulation in MATLAB environment was made. Input to the simulation was signal, which contains 20 harmonic functions. Each function has amplitude equals to 1 and frequencies were in range from 5 kHz to 100 kHz. Sampling frequency was 192 kHz.

Fig. 3. shows amplitude spectrum of filtered signal. From figure it is clear to say, that frequencies of each harmonic component are clearly identified, but due to spectral leakage, some frequencies are still present also above range of 26kHz. But this problem has only minor impact on application of real time measuring device. Results from simulations also show good accordance with standard MATLAB function fft().

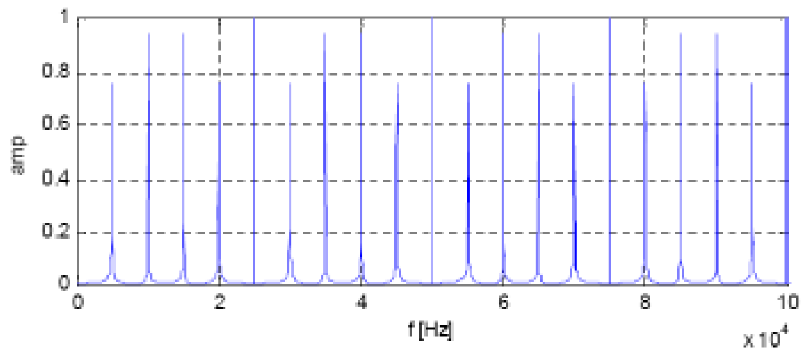

Fig. 2. Amplitude spectrum of original input signal.

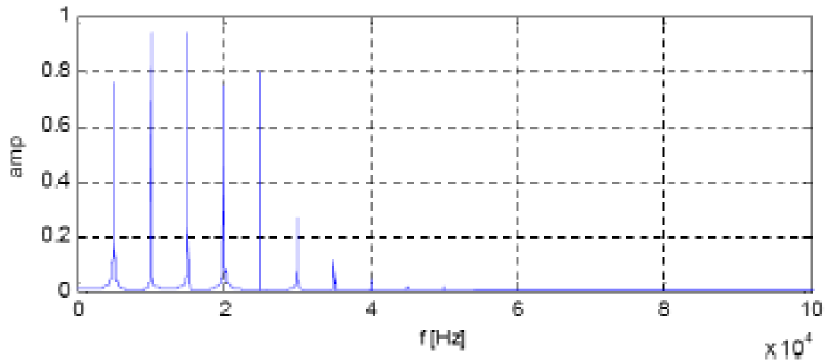

Fig. 3. Amplitude spectrum of filtered signal.

For the experimental verification of functionality of proposed device we have first connected function generator. Then we have been analysing triangular waveform. All signals had frequency of 200 Hz with amplitude ± 1.2 Vdc, and as evaluation software the graphical interface of Code Composer Studio v3.3 have been utilized.

Fig. 4. is showing simple triangular waveform which was trial verification of proposed device for real time analysis.

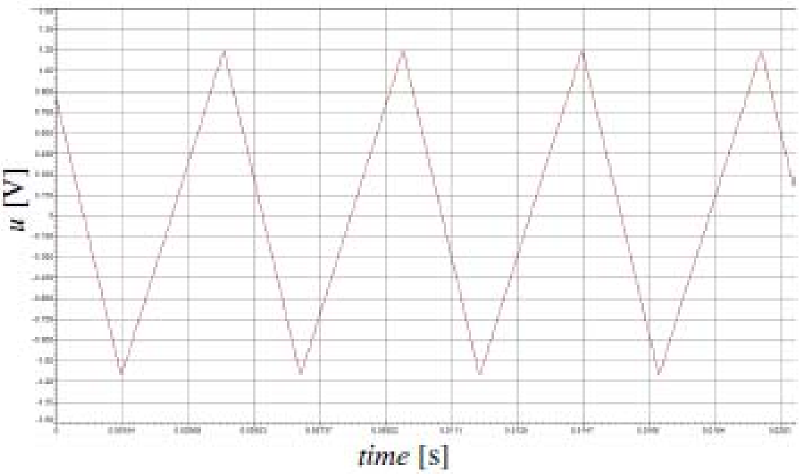

Fig. 4. Triangual waveform for real time analysis.

Fig. 5 is showing amplitude spectrum of triangular waveform, where we can see first harmonic and its three multiples (3rd, 5th, 7th harmonics).

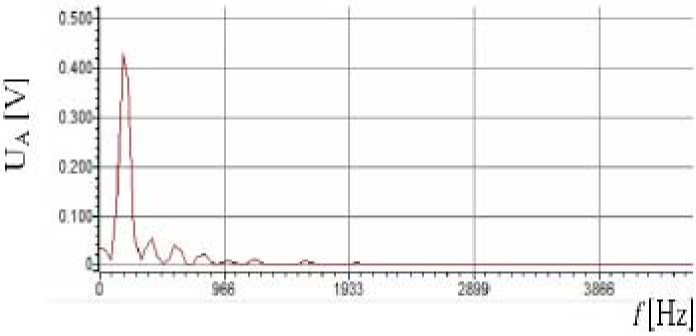

Fig. 5. Amplitude spectrum of triangual waveform.

For calculation of this type of signal we need to use next formula, which describes sum of infinite series:

(3) $$u(x) = \frac{8 \cdot A}{\pi^2} \sum_{k=1}^{\infty} \frac{1}{k^2} sin(k \cdot x),$$ k=1,3,3,5,7,…,

where A is amplitude of triangular waveform, whereby for this type of signal it is the same as in previous case ± 1.2 $V_{dc.}$

4. CONCLUSIONS

In this paper the device for analyzing of spectrum of current was proposed. This device is used for measurement and analysis analysis of spectrum of traction and recuperative current in railways electro-traction substations of "Serbian Railways". All system, except the current sensor is in digital form. First, proposed digital filter and computing algorithm for determination of higher harmonic components, shows good results for application as system for monitoring the traction and recuperative currents from converter in electric locomotive. Performance and resolution is limited due to used current sensor, but for proposed application in railway electric locomotive is sufficient. For other application, a processor with higher amount of RAM memory and more accurately current sensor should by used. Final optimization works will be focused on accuracy increase during measurements on target application. Anyway, such solution presents very perspective, low-count design for real time analysis of spectrum of traction and recuperative current.

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ЦИФРОВО ИЗМЕРВАНЕ НА ТЕГЛИТЕЛНАТА СИЛА И РЕКУПЕРАТИВНИЯ ТОК В СРЪБСКИТЕ ТЯГОВИ ПОДСТАНЦИИ

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Ключови думи: *микропроцесор, изчислителни методи, пробно изследване*
Резюме: *Настоящият доклад представя опит за създаване на устройство, с помощта на което да се извършва анализ в реално време на теглителната сила и рекуперативния ток в железниците. Устройството е конструирано като микропроцесорна единица и дава възможност за пълен анализ на мощността на полупроводниците. Изследването на рекуперативния ток е съобразено с изискванията на международния стандарт EN 50160. Представеното устройство може да се използва при измерване на теглителната сила и рекуперативния ток в железниците. В разработката устройството е представено като съвременен метод за измерване на теглителната сила и рекуперативния ток в тяговите подстанции на Сръбските железници.*