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Lowering of EMI Noise in Boost Type PFC by the use of Spread Spectrum

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Introduction

Today's electrical energy problems include not only its availability and efficiency of use but the demand for sufficient power quality (PQ) as well. Standard of perfection for PQ is clean power – the ideal single-frequency sine wave of constant amplitude and frequency. PQ aspects are of prime importance for electronics in many cases but especially for highly sensitive loads (data storage equipments, low noise and high speed units, etc.). Taken by their power supply the majority of electronics equipment is common alternating current (AC) supply system powered so the PQ problems first of all need to be solved within the utility service – AC mains. At the transmission level the inherent PQ problems of power grid (system transients, low-frequency inter-area oscillations, voltage collapses, momentary interruptions, a.o.) are being solved by app system control [1]; imperfections at line level (voltage sags, surges, transients, a.o.) are mitigated by the use of Custom Power devices [2].

Additional PQ problems arise on customer side since the majority of electronics units, as offline loads are pronouncedly non-resistive and non-linear today. These loads create a less than unity power factor (*PF*) - the factor which involves two components [4]: displacement power factor (*DpPF*, showing that the current either leads or lags the voltage by the angle *φ: DpPF=cosφ*) and distortion or purity [5] factor (*DtPF*, disclosing the harmonic content of current):

$$PF = DpPF \cdot DtPF = \cos\varphi / \sqrt{1+THD^2}\ , \quad (1)$$

where *THD* – the total harmonic distortion. Thus the aspects of PQ governed by loads in the area covered by the displacement (manifesting itself in poor overall efficiency) and waveform distortions can be characterized by *PF*. The waveform distortions are of especial concern in electronics since they can be the reason of considerably extended electromagnetic interferences (EMI).

PQ looked in the light of PF is of growing importance over last decades. Already in the past nineties there were set the harmonic limits for 50/60 *Hz* power supply recommended by IEC 555-2; later, in 2001, the European Union put into effect the regulation IEC/EN61000-3-2 that limits level of harmonics injected by load into power supply system as high as 39th. Now there is a huge amount of switch-mode converters powering different electrical and electronic units. The first stage of these converters very commonly is typical input stage (TIS) - the full wave diode bridge rectifier with a capacitive output filter.

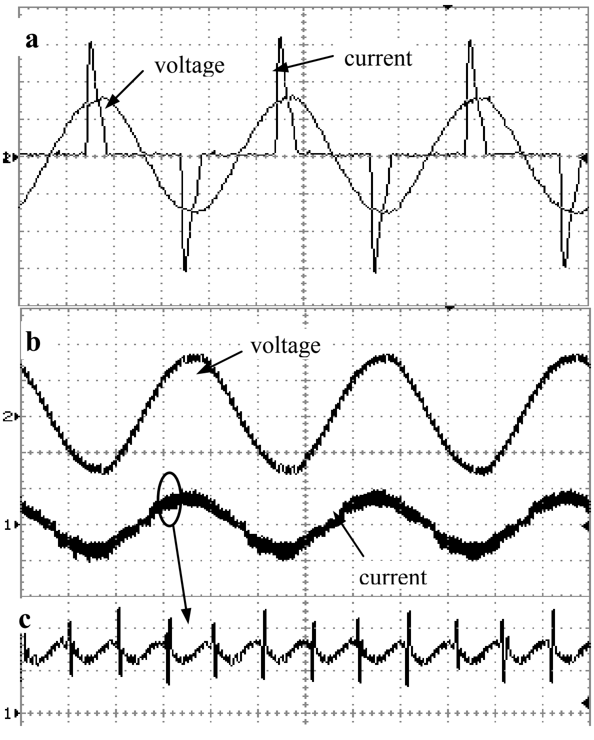

Fig. 1. Input current and voltage waveforms for resistive load of 100…110 *W* powered through TIS: a) directly and b) with PFC added. Scale: (a, b) current (1A/div; 5ms/div); voltage (200V/div; 5ms/div); (c) current (500mA/div; 10µs/div)

Operation of this stage results in substantially non-sinusoidal current from the mains (Fig. 1, a).

To alike the current waveform with that of the voltage (Fig.1, b) power factor correctors (PFC) are used – by this *PF* may come very close to unity.

However, active PFC themselves as a rule are switch mode power supply (SMPS) devices and as such are creating marked EMI noise (Fig.1,c). Thus, by the use of PFC we get rid of low, power grid frequency harmonics (and so improve the grid use efficiency) at the sacrifice of the introduction of high frequency harmonics of switching frequency (typically near 100 *kHz*) bringing into being high frequency EMI problems. To contribute in the solving of these problems, the potentialities of one particular method – spread spectrum technique [6,7] implemented in most commonly used active boost topology PFC for reduction of their EMI level is unveiled in this study on the basis of experimental and computer simulation results.

Experimental setup

In principle, there are two alternatives in the design of PFC – they may be either passive or active. Passive ones used before TIS allow to reach, at best, $PF \approx 0.85$; they can be more effective only for linear loads in rather fixed conditions (especially, current and frequency), they are bulky but don't produce extra EMI.

More opportunities offer TIS transformed in the form of active PFC. They are switch mode devices typically of a boost topology ensuring *PF* values close to unity, are volume and weight effective but they are adding extra EMI. In the following the potential of spread spectrum technique used in such PFC for EMI reduction is studied.

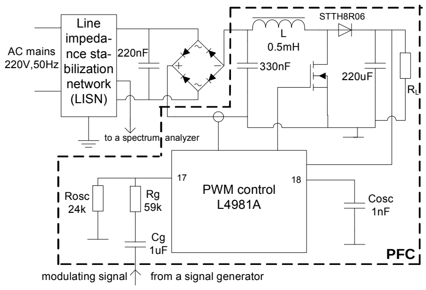

Fig. 2. Simplified schematic diagramm of the experimental setup

The hart of the experimental setup developed is PFC based on the boost converter topology operating in continuous conduction mode that, as such, generates lower EMI noise as compared with discontinuous one. The switching frequency f_{sw} of PFC is 100 *kHz*, the rated output power 360 *W* and regulated DC output voltage up to 400 *V*. The control loop of PFC is built with STMicroelectronics L4981A PWM controller, which simultaneously allows the control of sinusoidal shaping of the input current as well as the value of output voltage.

To perform the frequency modulation of f_{sw} (for the conversion of its discrete spectrum in the spread one), the modulating signal from a signal generator is fed into pin 17 of the controller via *RC* circuit *RgCg* (Fig.2). Value of f_{sw} can be calculated by [8] (f_{sw} - *Hz*; R_{osc} - *Ω*; C_{osc} – *F*):

$$f_{sw} = 2.44/(R_{osc} \cdot C_{osc}), \quad (2)$$

where R_{osc} – an external resistor of the controller oscillator, which programs the charge and the discharge currents that pin 18 forces to the external capacitor C_{osc} – the one that fixes the rise and fall time of the sawtooth oscillator of the controller [8].

After simple derivations the deviation Δf_{sw} of f_{sw} can be estimated by:

$$\Delta f_{sw} = \frac{2.44}{U_{osc}C_{osc}}\left(U_{osc}/R_{osc} + U_m/\left(R_g + \frac{1}{2\pi f_m C_g}\right)\right), \quad (3)$$

where U_{osc} – the regulated reference voltage at the pin 17 (U_{osc}=1.25 *V*); f_m, U_m – the frequency and the amplitude of modulating signal (from signal generator) respectively.

Experimental results

The PFC shown in Fig. 2 was tested with active load R_L of 102 *W*. In the experiments only sinusoidal frequency modulation with different modulation parameters (Δf_{sw}, f_m) was used. EMI of PFC – conducted noises were analyzed in the frequency range 50-340 *kHz* by the use of a spectrum analyzer (Agilent E4402B) connected to LISN (Hameg 6050-2). In Fig. 3 as the examples are shown two conducted EMI spectra both for unmodulated and modulated f_{sw} of PFC for different sets of modulation parameters. The spectrum peak envelope attenuation A_{env}.

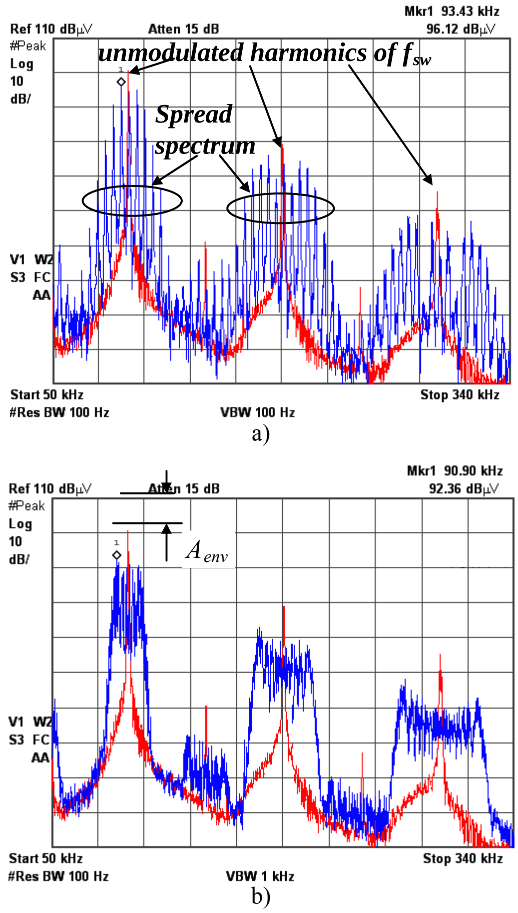

Fig. 3. Experimental power spectra of conducted EMI for unmodulated and modulated f_{sw} of PFC: (a) Δf_{sw}=10 *kHz*, f_m=5 *kHz*. (b) Δf_{sw}=10 *kHz*, f_m=1 *kHz*.

(Fig.3, b) of modulated f_{sw} as a function of Δf_{sw} and f_m based on measured values is shown in Fig.4.

Simulation results

The previous research [3] shows that the SIMULINK is one of the most useful and flexible tools for investigating the implementation of spread spectrum in SMPS. In order to broaden area of this investigation, SIMULINK model of the boost PFC under study was designed. The power stage of the virtual PFC was created using specialized SimPowerSystems blockset elements that in addition allow take into account different circuit component typical parasitic effects to make the designed model more accurate and correspond to real system parameters.

The input current shaping and the stability of output voltage, when the input voltage or the load is changed, is ensured by appropriate current and voltage control loops, that where designed by means of common SIMULINK elements. The current control loop provided (similar with one employed in the actual IC L4981A, Fig.2), ensures the average current control. To implement the spread spectrum technique to the switch of this PFC, specific reference sawtooth generator block (that defines the switching frequency f_{sw} of PFC) was designed, using simple SIMULINK elements and embedded Matlab function block. This virtual generator block allows to modulate the frequency of generated sawtooth, accordingly to the signal values of any optional modulating signal. During the simulation only the sinewave modulating signals with different f_m and Δf_{sw} were used in order to evaluate their influence on the spectra of PFC. The simulation data - A_{env} along with the experimental ones are represented in Fig.4. The comparison of these data allows to ascertain some important points: SIMULINK model provides the spreading of spectrum of PFC as well, and reveals the attenuation of the peaks of harmonics like to that of real experiments; thus SIMULINK model designed may be considered as well-founded and the simulation data as convincing. This conclusion allows to use the simulation data along with experimental ones for further analysis. Besides, the use of this model incorporates several advantages of the simulation in comparison to real experiments:

- designed simulation model provides the feasibility to control the spectrum of input current (EMI noises) directly without introducing any measurement errors or added noise sources (inherent in real practice);
- SIMULINK allows to generate the modulating signal of any complexity (even those hard to generated by laboratory signal generators) and to feed this signal to the virtual reference generator block.

Thus the designed SIMULINK model could be used as a widely available complimentary tool for study of different effects of spread spectrum in boost PFC as well as a verification tool for experiments.

Analysis of the results

As it can be seen from Fig. 3 and Fig. 4 there is achieved appreciable attenuation A_{env} (defined as the difference between maximum values of the highest components of unmodulated and modulated spectrum) of conducted EMI by spreading the spectrum by the use of sinusoidal frequency modulation. Furthermore, the general trait is that the attenuation increases as f_m decreases. In principle, the attenuation can be assessed from frequency modulation theory (FMT) viewpoint as well [6]:

$$A_{env}[dB] = 20\lg\left|J_k(\Delta f_{sw} / f_m)\right|_{\max}, \quad (3)$$

where $\left|J_k(\Delta f_{sw} / f_m)\right|_{\max}$ is the maximum absolute value of the kth order Bessel function of the argument $\Delta f_{sw}/f_m$.

However, there are marked differences between A_{env} gained from (3) used for our frequency modulated square waveform and the ones from experiments and simulations (Fig. 4). Firstly, the experimental and the simulated attenuations are lower than calculated ones for the same Δf_{sw} and f_m. This is mainly due to spread spectrum distortions characterized by their asymmetry (with respect to the unmodulated f_{sw} harmonics), as it can be observed, e.g., from Fig. 3.

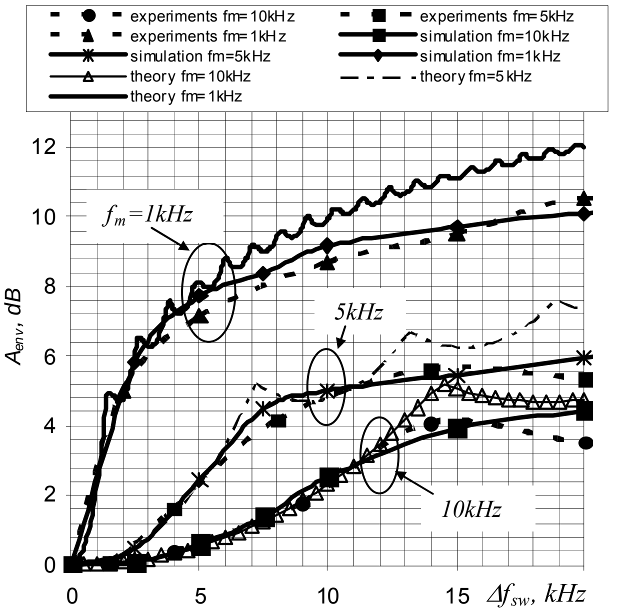

Fig. 4. Obtained attenuation A_{env} of EMI noise versus Δf_{sw} for different f_m resulting from the experiments, the simulations and FMT.

This distortion, that is not present in the modulated control signal of the power switch, results from the fact that there are power inductor current ripples that cause the input current to depend on instantaneous switching frequency, that causes amplitude modulation of the input current. Secondly, the experimental and the simulated results show that A_{env} is growing up rather steeply until Δf_{sw}=10…15 *kHz* (Fig.4), unclearly maximizes near 20 *kHz*, and distinctly decreases after 35 *kHz* (not shown in Fig.4). This is inconsistent with FMT, within which A_{env} is the increasing function of Δf_{sw} for constant f_m. This can be explained by the fact that the increase of Δf_{sw} causes the increase of inductor current ripples. Therefore, the growth of A_{env} by the increase of Δf_{sw} is compensated with the decrease of A_{env} by additions from inductor current ripples. It should be noted that for small Δf_{sw} and consequently small modulation indexes ($m= \Delta f_{sw}/f_m$) the increase of A_{env} is faster than that for higher m. That is why the experimental A_{env} increases significantly with Δf_{sw} up to frequency of about 15 *kHz*.

In order to examine possible adverse effects of frequency modulation, the efficiency of the PFC was measured for different f_m and Δf_{sw}. The efficiency for unmodulated PFC (77,8% at *Pout*=102*W*) slightly decreases when increasing Δf_{sw} up to approximately 25 *kHz*. For higher Δf_{sw} (>40 *kHz*) the decrease of efficiency was significant (more than 10%).

Conclusions

During the investigation it has been ascertained that the proper implementation of spread spectrum technique within the boost PFC can lead to substantial EMI noise attenuation. The true attenuation is governed by the parameters of modulation (spreading) – frequency and deviation. Thus, both the experiments as well as SIMULINK simulations prove that the increase of frequency deviation causes the attenuation of switching frequency harmonics (EMI noise) firstly to grow, then gradually to become almost constant near the border (over the area of 20 *kHz* regardless of modulating signal's frequency) with the still further tendency to ramp down.

The results obtained by two methods: experimental and SIMULINK model are in close agreement. In its turn the difference between the calculations according to FMT and the experimental data for slight deviations is small, but the difference is increasing as the deviation grows up. The reason for this is the input current distortion due to its parasitic amplitude modulation initiated by the triangular-wave ripple currents in the inductor of PFC. The overall performance of PFC from the efficiency point of view decreases when the deviation is increased. So the deviation with properly selected modulating frequency need to be high enough to maintain the acceptable EMI attenuation and low enough not to deteriorate the efficiency significantly.

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J. Jankovskis, D. Stepins, D. Pikulins. Lowering of EMI Noise in Boost Type PFC by the use of Spread Spectrum // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 6(94). – P. 15–18.

The implementation of spread spectrum technique within the boost type power factor corrector (PFC) for its EMI reduction is studied. The study involves the experimental measurements, SIMULINK simulations and the calculations of attenuation of harmonics of switching frequency spectrum. The results show that appreciable EMI attenuation can be achieved by the use of spread spectrum gained with sinusoidal frequency modulation. The modulating signal's frequency and the deviation manifest themselves as the main factors that influence the degree of EMI attenuation. Some adverse affects of frequency modulation are also discussed. It has been proved, that the efficiency of PFC under study slightly decreases with the increase of frequency deviation. SIMULINK model of boost PFC was also designed. The fact that the simulation data and the experimental ones are almost identical proves that the model is relatively precise and could be used as the tool for analysis and for further investigation in order to examine other types of modulating signals and their effects. Ill. 4, bibl. 8 (in English; abstracts in English, Russian and Lithuanian).

Я. Янковский, Д. Степин, Д. Пикулин. Уменьшение ЭМП в корректоре коэффициента мощности методом распределенного спектра // Электроника и электротехника. – Каунас: Технология, 2009. – № 6(94). – С. 15–18.

Статья посвящена исследованию применения техники распределенного спектра в активном корректоре коэффициента мощности на основе повышающего преобразователя для уменьшения электромагнитных помех (ЭМП). Исследования включают экспериментальные измерения, моделирование и теоретический расчет ослабления гармоник спектра частоты коммутации. Показано, что при использовании метода распределенного спектра, путем синусоидальной модуляции работы ключа, достигается значительное ослабление ЭМП. Установлено, что факторами, влияющими на эффективность подавления гармоник входного тока, являются частота и девиация модулирующего сигнала (МС). При рассмотрении негативных эффектов применения частотной модуляции доказано, что коэффициент полезного действия уменьшается при увеличении девиации частоты МС. Тот факт, что данные, полученные в ходе моделирования, совпадают с экспериментальными данными, доказывают, что разработанная модель достаточно точна и может быть использована для дальнейших исследований при изучении других типов МС. Ил. 4, библ. 8 (на английском языке; рефераты на английском, русском и литовском яз.).

J. Jankovskis, D. Stepins, D. Pikulins. Elektromagnetinių trikdžių silpnėjimo paplatintame spektre tyrimas įvertinant galios koeficientą // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 6(94). – P. 15–18.

Ištirta metodika, paplatintame spektre mažinanti elektromagnetinius trikdžius ir įvertinanti galios koeficientą aktyviuosiuose korektoriuose. Atliktas besikeičiančio dažnio spektro susilpnėjusių harmonikų modeliavimas ir skaičiavimas, taip pat eksperimentiniai matavimai. Nustatyta, kad pastebimas elektromagnetinių trikdžių susilpnėjimas pasiekiamas taikant paplatintą spektrą, suformuotą atlikus sinusinio signalo moduliaciją. Moduliuojančiojo signalo dažnis ir nuokrypis yra pagrindiniai parametrai, lemiantys elektromagnetinių trikdžių silpnėjimą. Il. 4, bibl. 8 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).