EMC – CAPACITIVE COUPLING

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ABSTRACT

The paper is dealing with some electromagnetic compatibility (EMC) problems of converters and inverters, which are utilized for feeding of electric machines and its analyzing by PSPICE program. The main attention is focused on implications of parasitic capacitance and capacitive coupling existence.

Keywords*: *EMC, converter, PSPICE simulation, parasitic capacitances, capacitive coupling

1. INTRODUCTION

During the EMC problem investigation we can often eliminate the laborious theoretical analysis and economical expensive realization by numerical computer simulation, which can also disclose the startling facts concerning of this problem.

2. CONVERTER'S PARASITIC CAPACITANCE CALCULATION

Capacitive coupling is typical for galvanically separated circuit nodes, between which exists a mutual influence represented by individual intensity vectors $\overline{E}_i$ of electrostatic field, figure Fig. 1. In such case the influence value is given by the rising or decreasing slope of potential in the described nodes, electrode area dimensions, space dielectric property and wire geometrical ordering in the described nodes.

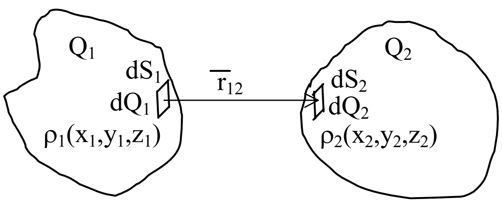

Fig. 1 Capacitive coupling

For the predictive investigation of the capacitive coupling implications we will begin with the well-known Maxwell's equations valid for electrostatic field:

$$rot\ \overline{E} = 0 \tag{1}$$

$$div\ \overline{D} = \rho \tag{2}$$

where the vector of electric induction $\overline{D}$ is given as

$$\overline{D} = \varepsilon.\overline{E} \tag{3}$$

Based on our knowledge of physics, we can determine, the force acting between two elementary charges Q1 and Q2.

$$\overline{F} = \frac{1}{4\pi\varepsilon_0}\int_{S_1}\int_{S_2}\frac{\overline{r}_{12}}{r_{12}^3}.\rho_1.dS_1.\rho_2.dS_2 \tag{4}$$

where $\rho_1 = dQ_1/dS_1$ and $\rho_2 = dQ_2/dS_2$. One element $\overline{E}_{1i}$ of electrostatic intensity vector $\overline{E}_1$ can be expressed as:

$$\overline{E}_{1i} = \frac{\overline{F}_{1i}}{Q_{2i}} = \frac{\frac{Q_{2i}}{4\pi\varepsilon_0}\int_{S_1}\frac{\overline{r}_{12}}{r_{12}^3}.\rho_1.dS_1}{Q_{2i}} = \frac{1}{4\pi\varepsilon_0}\int_{S_1}\frac{\overline{r}_{12}}{r_{12}^3}.\rho_1.dS \tag{5}$$

The total electrostatic intensity vector $\overline{E}$ at the investigated position will be given as the sum of vectors $\overline{E}_1$ and $\overline{E}_2$ induced by both charged volumes. It is possible to express the value of the voltage between these volumes by the following equation.

$$U_{12} = \varphi_1 - \varphi_2 = \int_1^2\left(\overline{E}_1 + \overline{E}_2\right).d\overline{r}_{12} = \\ = \int_1^2\left(\frac{1}{4\pi\varepsilon_0}\int_{S_1}\frac{\overline{r}_{12}}{r_{12}^3}.\rho_1.dS_1 + \frac{1}{4\pi\varepsilon_0}\int_{S_2}\frac{\overline{r}_{21}}{r_{21}^3}.\rho_2.dS_2\right).d\overline{r}_{12} \tag{6}$$

If we suppose that Q1 = Q and Q2 = - Q, we can write such equation for the created capacitance.

$$C_{12} = \frac{Q}{U_{12}} \tag{7}$$

In many cases the engineers must state mutual parasitic capacitance of two wires, which have optional routing, as it is shown in figure Fig. 2. In such case the analytical expression of resulting capacitance is very difficult and due to the utilization of analytic-numerical methods consisting of differential form utilizing is more advantage. For all that, the following basic assumption must be done.

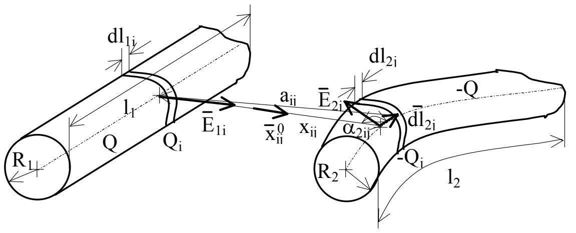

Fig. 2 Capacitive coupling

$$l_1 = \sum_{i=1}^{m\to\infty} dl_{1i}\ ,\quad l_2 = \sum_{j=1}^{k\to\infty} dl_{2j} \tag{8}$$

The potential at the second wire position we can express by the next equation.

$$\varphi_2 = \sum_{i=1}^{m} \frac{Q_i}{2\pi\varepsilon dl_i}.\ln\frac{x_{ij}-R_2}{R_1}.\sin(\alpha_{2ij}) = \\ = \sum_{i=1}^{m} \frac{Q_i}{2\pi\varepsilon dl_i}.\ln\frac{x_{ij}-R_2}{R_1}.\sqrt{\left(1-\left(\frac{x_{ij}^2+\left(\frac{dl_{2j}}{2}\right)^2-a_{ij}^2}{x_{ij}.dl_{2j}}\right)^2\right)} \tag{9}$$

Similarly, we can state the potential for the position of the first wire.

$$\varphi_1 = \sum_{j=1}^{n} \frac{-Q_j}{2\pi\varepsilon dl_j}.\ln\frac{x_{ji}-R_2}{R_1}.\sin(\alpha_{1ji}) = \\ = \sum_{j=1}^{n} \frac{-Q_j}{2\pi\varepsilon dl_j}.\ln\frac{x_{ji}-R_2}{R_1}.\sqrt{\left(1-\left(\frac{x_{ji}^2+\left(\frac{dl_{1i}}{2}\right)^2-a_{ji}^2}{x_{ji}.dl_{1i}}\right)^2\right)} \tag{10}$$

The voltage between both wires will be given as:

$$U = \frac{Q}{2\pi\varepsilon}\left(\sum_{i=1}^{m}\frac{\ln\frac{x_{ij}-R_2}{R_1}.\sqrt{\left(1-\left(\frac{x_{ij}^2+\left(\frac{dl_{2j}}{2}\right)^2-a_{ij}^2}{x_{ij}.dl_{2j}}\right)^2\right)}}{dl_{1i}} + \sum_{j=1}^{n}\frac{\ln\frac{x_{ji}-R_2}{R_1}.\sqrt{\left(1-\left(\frac{x_{ji}^2+\left(\frac{dl_{1i}}{2}\right)^2-a_{ji}^2}{x_{ji}.dl_{1i}}\right)^2\right)}}{dl_{2j}}\right) \tag{11}$$

The searched value of parasitic capacitance is possible to express according to Coulomb's law.

$$C_{12} = \frac{2\pi\varepsilon}{\left(\sum_{i=1}^{m}\frac{\ln\frac{x_{ij}-R_2}{R_1}.\sqrt{\left(1-\left(\frac{x_{ij}^2+\left(\frac{dl_{2j}}{2}\right)^2-a_{ij}^2}{x_{ij}.dl_{2j}}\right)^2\right)}}{dl_{1i}} + \sum_{j=1}^{n}\frac{\ln\frac{x_{ji}-R_2}{R_1}.\sqrt{\left(1-\left(\frac{x_{ji}^2+\left(\frac{dl_{1i}}{2}\right)^2-a_{ji}^2}{x_{ji}.dl_{1i}}\right)^2\right)}}{dl_{2j}}\right)} \tag{12}$$

It is possible to express the individual equation members for 3-D Cartesian system shown in figure Fig. 3 that we search for, by the following equations.

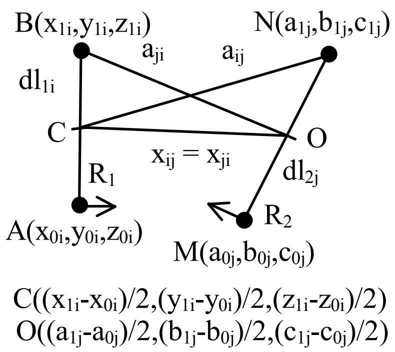

Fig. 3 3-D Cartesian system

$$dl_{1i} = \sqrt{(x_{1i}-x_{0i})^2+(y_{1i}-y_{0i})^2+(z_{1i}-z_{0i})^2} \tag{13}$$

$$dl_{2j} = \sqrt{(a_{1j}-a_{0j})^2+(b_{1j}-b_{0j})^2+(c_{1j}-c_{0j})^2} \tag{14}$$

$$a_{ij} = \sqrt{(a_{1j}-(x_{1i}-x_{0i})/2)^2+(b_{1j}-(y_{1i}-y_{0i})/2)^2+(c_{1j}-(z_{1i}-z_{0i})/2)^2} \tag{15}$$

$$a_{ji} = \sqrt{(x_{1i}-(a_{1j}-a_{0j})/2)^2+(y_{1i}-(b_{1j}-b_{0j})/2)^2+(z_{1i}-(c_{1j}-c_{0j})/2)^2} \tag{16}$$

$$x_{ij} = x_{ji} = \sqrt{\left(\frac{(a_{1j}-a_{0j})}{2}-\frac{(x_{1i}-x_{0i})}{2}\right)^2+\left(\frac{(b_{1j}-b_{0j})}{2}-\frac{(y_{1i}-y_{0i})}{2}\right)^2+\left(\frac{(c_{1j}-c_{0j})}{2}-\frac{(z_{1i}-z_{0i})}{2}\right)^2} \tag{17}$$

Only such wire length elements dl_{1i} and dl_{2j} must be considered for total parasitic capacitance calculation, which have to fulfil the following conditions.

$$x_{ji}^2+\left(\frac{dl_{1i}}{2}\right)^2 = (x_{1i}-(a_{1j}-a_{0j})/2)^2+(y_{1i}-(b_{1j}-b_{0j})/2)^2+(z_{1i}-(c_{1j}-c_{0j})/2)^2 \tag{18}$$

$$x_{ij}^2+\left(\frac{dl_{2j}}{2}\right)^2 = (a_{1j}-(x_{1i}-x_{0i})/2)^2+(b_{1j}-(y_{1i}-y_{0i})/2)^2+(c_{1j}-(z_{1i}-z_{0i})/2)^2 \tag{19}$$

The verification of correctness of obtained results can be done by simulation and measuring. For this purpose, it is possible to utilize the connection of DC impulse converter shown in figure Fig. 4.

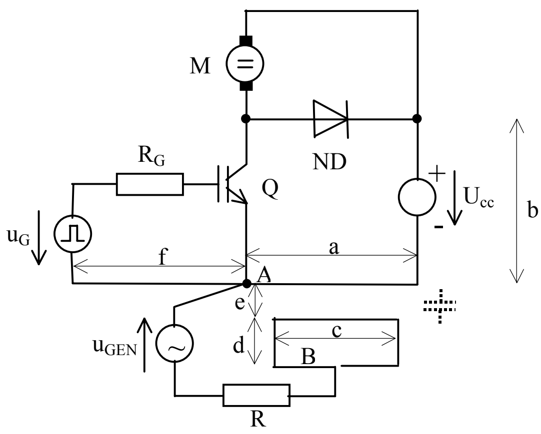

Fig. 4 Investigated circuit

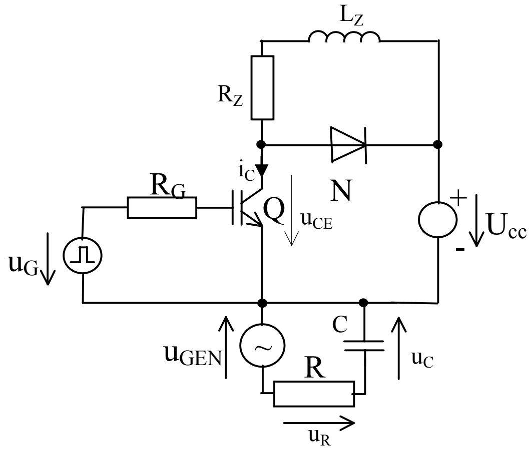

Fig. 5 Simulated circuit

We will try to state the value of parasitic capacitance between the node A of impulse converter and node B of the sense loop. Space dielectric material is created by air. The geometrical dimensions of investigated circuits are a = f = 0,2 m, b = 0,3 m, c = 0,1 m, d = 0,05 m, e = 0,00135 m. Wires are made of copper, with the radius R = 0,0006 m. Based on the above mentioned parameters, it is possible to calculate the individual partial parasitic capacitances.

$$C_{ace}=\frac{1}{\frac{1}{2\pi\varepsilon_0 a}\ln\frac{e-R}{R}+\frac{1}{2\pi\varepsilon_0 c}\ln\frac{e-R}{R}}=16{,}63\,pF \tag{20}$$

$$C_{aced}=\frac{1}{\frac{1}{2\pi\varepsilon_0 a}\ln\frac{(d+e)-R}{R}+\frac{1}{2\pi\varepsilon_0 (c-0{,}001)}\ln\frac{(d+e)-R}{R}}=0{,}8306\,pF \tag{21}$$

$$C_{fce}=\frac{1}{\frac{1}{2\pi\varepsilon_0 a}\ln\frac{\sqrt{e^2+a^2}-R}{R}+\frac{1}{2\pi\varepsilon_0 c}\ln\frac{\sqrt{e^2+a^2}-R}{R}}=0{,}6391\,pF \tag{22}$$

$$C_{fced}=\frac{1}{\frac{1}{2\pi\varepsilon_0 a}\ln\frac{\sqrt{(d+e)^2+a^2}-R}{R}+\frac{1}{2\pi\varepsilon_0 (c-0{,}001)}\ln\frac{\sqrt{(d+e)^2+a^2}-R}{R}}=0{,}6314\,pF \tag{23}$$

$$C_{bda-c}=\frac{1}{\frac{1}{2\pi\varepsilon_0 \frac{b}{2}}\ln\frac{\sqrt{\left(\frac{b}{4}+e+\frac{d}{2}\right)^2+\left(\frac{a}{2}-\frac{c}{2}\right)^2}-R}{R}+\frac{1}{2\pi\varepsilon_0 d}\ln\frac{\sqrt{\left(\frac{b}{4}+e+\frac{d}{2}\right)^2+\left(\frac{a}{2}-\frac{c}{2}\right)^2}-R}{R}}=0{,}3989\,pF \tag{24}$$

$$C_{bda+c}=\frac{1}{\frac{1}{2\pi\varepsilon_0 \frac{b}{2}}\ln\frac{\sqrt{\left(\frac{b}{4}+e+\frac{d}{2}\right)^2+\left(\frac{a}{2}+\frac{c}{2}\right)^2}-R}{R}+\frac{1}{2\pi\varepsilon_0 d}\ln\frac{\sqrt{\left(\frac{b}{4}+e+\frac{d}{2}\right)^2+\left(\frac{a}{2}+\frac{c}{2}\right)^2}-R}{R}}=0{,}3658\,pF \tag{25}$$

$$C=C_{ace}+C_{aced}+C_{fce}+C_{fced}+2.C_{bda-c}+2.C_{bda+c}=20{,}26\,pF \tag{26}$$

Based on the calculated capacitance, the simulation analysis in PSPICE program is possible to do now. The connection of simulated circuit is shown in figure Fig. 5.

Parameters of individual elements are U_{CC} = 70V, R_Z = 11,66 Ω, L_Z = 400 μH, R = 1 MΩ, u_{GEN} = 2 sin (ωt) V. Simulation results for frequency f = 10kHz are pictured in figure Fig. 6.

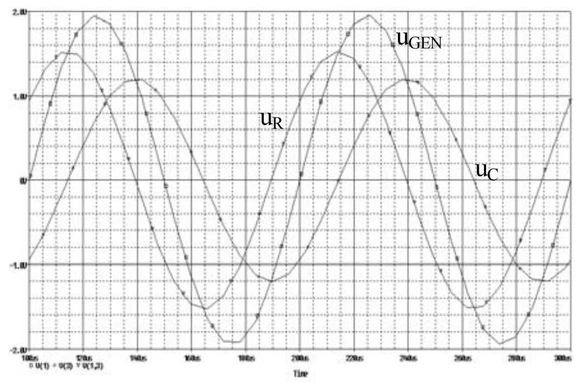

Fig. 6 Simulation results for f = 10 kHz

The same output values obtained by simulation, but for the frequency f = 50 kHz are shown in figure Fig. 7.

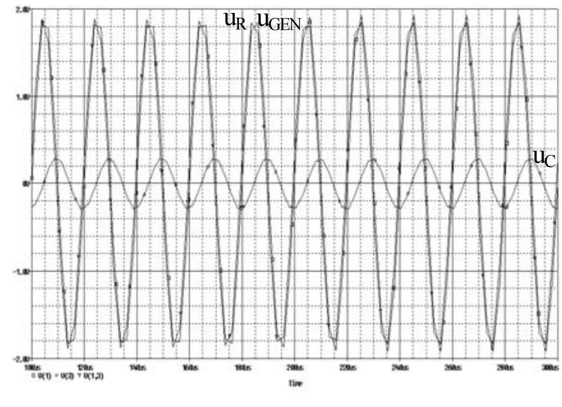

Fig. 7 Simulation results for f = 50 kHz

The measured values of u_{CE}, u_{GEN} and u_C are shown by next figures Fig. 8 to Fig. 11.

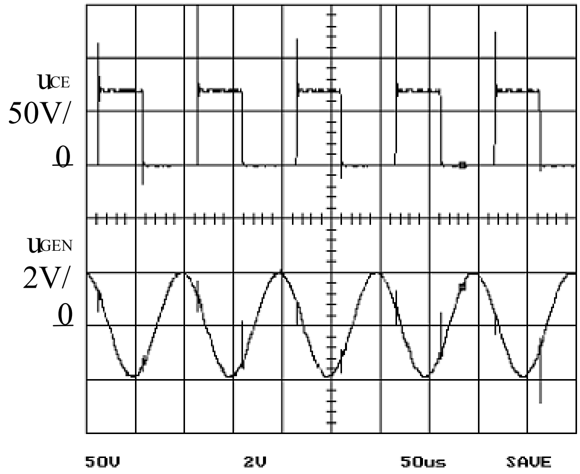

Fig. 8 The measured results for f = 10 kHz

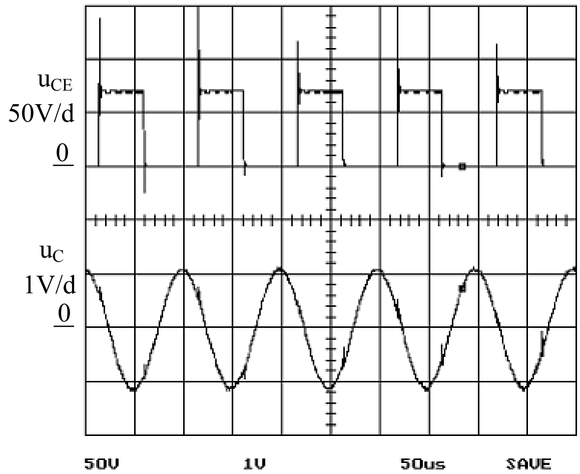

Fig. 9 The measured results for f = 10 kHz

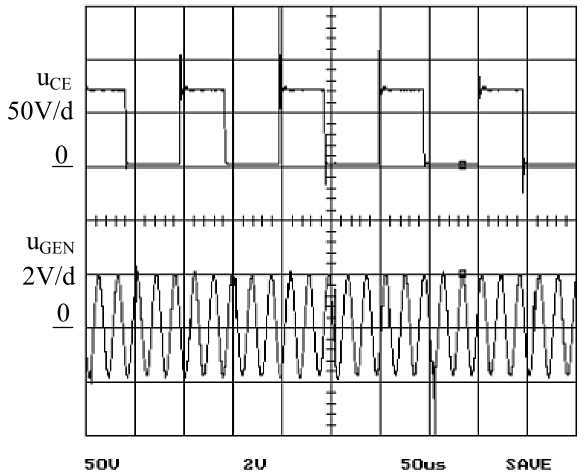

Fig. 10 The measured results for f = 50 kHz

By comparing the simulated and measured results one can see that, the obtained results are identical and it means that the derived analytical formula for parasitic capacitance calculation is valid.

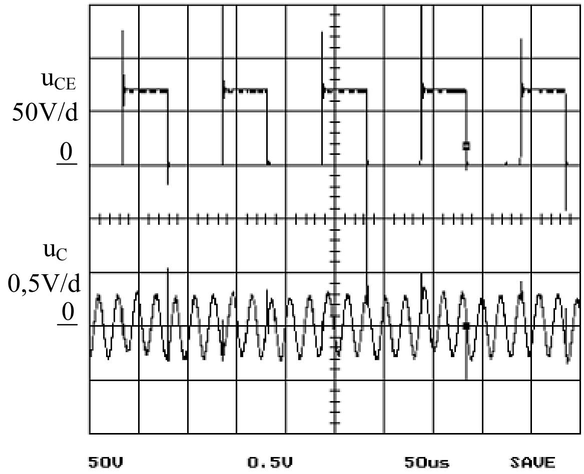

Fig. 11 The measured results for f = 50 kHz

Due to an additional verification requirement, it is possible to analyze the same problem also numerically, by finite element simulation method of electrostatic field. The obtained result is shown in figure Fig. 12.

From the data window, it is possible to state, that the value of the electrical flux between both nodes is $5,4357.10^{-12}$ C. Based on the program property we must multiply this value by the value of wire perimeters $l = 2.\pi.R = 2.\ \pi.0,6 = 3,76$ mm. The total electrical flux is then 20,4382 C. Due to the fact that the voltage between nodes has value 1V, the resulting parasitic capacitance is C = 20,4382 pF.

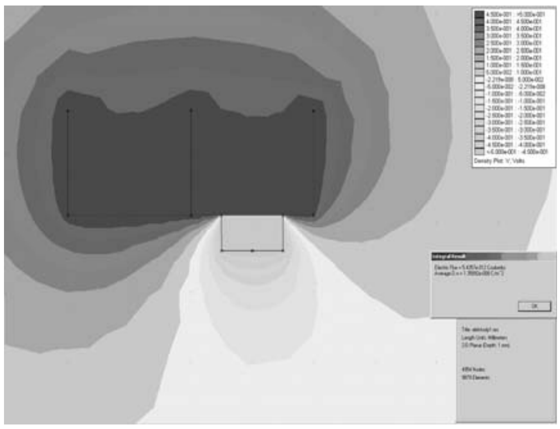

Fig. 12 The finite element method simulation

By comparing all the results, we can state that difference is only 0,879% and it means that the correctness of the derived formula for parasitic capacitance calculation is satisfactory.

3. CONCLUSION

The performed analyzes indicate that not only the large current switching frequency have the main influence on the converter's EMC, but also their switch off state with small parasitic resonant load current is equally important.

The obtained formula for parasitic capacitance calculation is enabling the predictive EMC investigation. Although such converter capacitances seem to be negligible, as the performed analyzes show us, they can have important influence. Mainly in the case when the switching frequency is high, or one of the nodes belongs to the circuit with great impedance. It is obvious in the case of capacitive coupling existence between CMOS integrated circuits and power converter circuit, when EMC quality can be fundamental for the right equipment operation.

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REFERENCES

[1] Carpenter, D. J.: EMC Emissions Certification for Large Systems – A Risk – Management Approach. BT Technology Journal, Springer Science + Bussines Media B. V. Vol 21, 2003, No. 2, pp. 67-76.

[2] Kováč, K., Lenková, A.: Electromagnetic Compatibility. Bratislava 1999.

[3] Electromagnetic Compatibility. Schaffner Elektronik GmbH, Germany 1997.

[4] Kováč, D., Kováčová, I.: Influence of Utilizing Static Power Semiconductor Converters on Quality of Electrical Power Line Parameters. Quality Innovation Prosperity, No.1, 2001, pp. 74-84.

[5] Gallová, Š.: Tools to Model Uncertainty in Knowledge-based System. Transactions of the Universities of Košice, No. 2, 2001, pp. 1 - 4.

[6] Bigoš, P., Sinay, J., Ritók, J.: Nutzung des Steuerungs Systems eines Automatikkranes fur die Bestimmung seines technischen Zustandes. In: 7. Kranfachtagung´99, Magdeburg 1999, pp. 30 – 39, ISBN 3-930385-22-8.

[7] Šimko, V., Kováč, D., Kováčová, I.: Bacic circuits I. Elfa s.r.o. Publisher, 2000, 168 Pages, ISBN 80-89066-27-5.

[8] Mayer, D., Ulrych, B., Škopek, M.: Electromagnetic Field Analysis by Modern Software Products. Journal of Eletrical Engineering, Vol. 7, No.1, 2001.

[9] Gallová, Š.: Reasoning Using Entropy Inference in Machinery System Diagnostic. Proceeding of International Congress MATAR, Prague 2004, pp. 131 – 135.

[10] Rybár, R., Kudelas, D., Fischer, G.: Alternative sources of energy III – Winding energy. Textbook, Košice, 2004.

[11] Trebuňa, F., Bocko, J., Ritók, J.: Analysis of Conventor Working Malfunctions. Acta Mechanica Slovaca, Vol. 5, No. 1, 2001, pp. 5 – 12.

[12] Sinay,J., Bigoš,P., Ritók,J.: Betriebsfestigkeit im Spiegelbild der Richtlinie 89/392/EU. GÉP, IL. évfolyam, 1997/6, pp. 14-19, ISSN 0016-8572.

[13] Gallová, Š.: A Progressive Manufacturing Operation. International Congress MATAR, Prague 2004, pp.141 – 146.

[14] Kováčová, I.: EMC of Power DC Electrical Drives. Journal of Electrical Engineering, Vol. 5, No. 1, 2005, pp.61-66.

[15] Gallová, Š.: Numerical Control Programming Approach. Transactions of the Universities of Košice, No. 1, 2004, pp. 48-52.

[16] Kudelas, D., Rybár, R.: Pneumatic - accumulated system enabling of small potential winding energy utilizing for electrical energy supplying. AT&P Journal, Bratislava, No. 5, 2005, pp. 113-114.

[17] Kováčová, I., Kováč, D.: EMC Compatibility of Power Semiconductor Converters and Inverters. Acta Electrotechnica et Informatica, No.2, Vol. 3, 2003, pp. 12-14.

[18] Kováčová, I., Kováč, D: Converter`s EMC – Paracitic Capacitantes. Electornics Letters, Vol. 5, No. 1, 2005, 6 pages, ISSN 1213-161x.

[19] Kováčová, I., Kováč, D.: Safeguard Circuits of Power Semiconductor Parts. Acta Electrotechnica et Informatica, No.3, Vol. 3, 2003, pp. 44-45.

[20] Göksu, H., Wunsh, D. C: Neural Networks Applied to Electromagnetic Compatibility Simulations. Lecture Notes in Computer Science, Springer - Verlag GmbH, Vol. 2714, 2003, pp. 1057-1063

[21] Ruddle, A. R., Parmantier, J. P., Ferrieres, X., Ward, D. D.: Experimental Varidation of Time – Domain Electromagnetic Models for Field Coupling Into the Interior of a Vehicle from a Nearby Broadband Anntena. Proceedings of IEE International Conference on Comunication in Electromagnetic CEM 2004, Stratford- Upon-Avon, 2004, pp. 133-134

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Dobroslav Kováč - He finished his studies in 1985 at the Technical University of Košice, Department of Electrical Drives, area - Power electronics with excellent evaluation. Then he worked as a research worker at the Department of

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