NON-HARMONIC POWER MEASURING

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ABSTRACT
The paper deals with the basic mathematical and computer simulation models of Hall probe. This probe is possible to utilize for converter's non-harmonic signal measuring very easy. The benefits of such construction solution consist in galvanic isolation of evaluated signals and also in non-delaying signal processing. Functionality of the designed simulation model is confirmed by presented computer simulation results.

Keywords: *Hall sensor, non-harmonic power measuring*

1. INTRODUCTION

An electric current produces a magnetic field, which can be guided by a magnetic yoke to a linear Hall sensor. A Hall probe is a device used for measuring the magnetic flux density of a specific place within a magnetic field. This is based on a small integrated circuit that produces an output voltage proportional to the magnetic field strength. The output of the probe is then proportional to the electric current.

2. BASIC PRINCIPLE OF HALL EFFECT

Over 100 years ago E. H. Hall discovered that when a magnetic field is applied perpendicular to the direction of a current flowing through a metal a voltage is developed in the third perpendicular direction as show Fig. 1. This is well understood and is due to the charge carriers within the current being deflected towards the edge of the sample by the magnetic field. Equilibrium is achieved when the magnetic force is balanced by the electrostatic force from the build up of charge at the edge. This happens when $E_y = v_x B_z$.

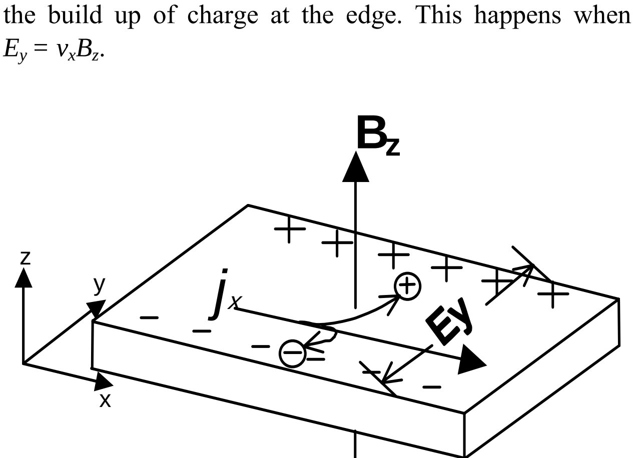

Fig. 1 Basic principle of Hall effect

In the Drude's theory of the electrical conductivity of a metal, an electron is accelerated by the electric field for an average time τ, the relaxation or means free time, before being scattered by impurities, lattice imperfections and phonons to a state which has average velocity zero. The average drift velocity of the electron is [1],

$$\overline{v_{dx}} = -q\overline{E_y}\tau / m \tag{1}$$

where $\overline{E}$ is the electric field and *m* is the electron mass. The current density is thus

$$\overline{j}_x = -nq\overline{v_{dx}} = \sigma_0 \overline{E_y} \tag{2}$$

where

$$\sigma_0 = nq^2\tau / m \tag{3}$$

and *n* is the electron density.

In the presence of a steady magnetic field, the conductivity and resistivity become tensors

$$\sigma = \begin{pmatrix} \sigma_{xx} & \sigma_{xy} \\ \sigma_{yx} & \sigma_{yy} \end{pmatrix}$$
$$\rho = \begin{pmatrix} \rho_{xx} & \rho_{xy} \\ \rho_{yx} & \rho_{yy} \end{pmatrix} \tag{4}$$

and $\overline{j_x} = \sigma \cdot \overline{E}_y$, $\overline{E_y} = \rho \cdot \overline{j}_x$. Still assuming that the relaxation time is τ, the Lorentz force must be added to the force from the electric field in Eq. 1.

$$\overline{v_{dx}} = -q\left(\overline{E_y} + \frac{\overline{v_{dx}} \times \overline{B_z}}{d}\right)\frac{\tau}{m} \tag{5}$$

In the steady state, $\overline{j_x} = -nq\,\overline{v_{dx}}$. If the magnetic field is in *z* direction, then in *xy* plane is valid

$$\begin{aligned} \sigma_0 E_x &= \omega_c \tau j_y + j_x \\ \sigma_0 E_y &= \omega_c \tau j_x + j_y \end{aligned} \tag{6}$$

where σ_0 is defined in equation 3 and

$$\omega_c = \frac{qB_z}{md} \tag{7}$$

is the cyclotron frequency. From equation 6, we can easily get:

$$\begin{aligned} &\rho_{xx} = \rho_{yy} = 1/\sigma_0 \\ &\rho_{xy} = -\rho_{yx} = \omega_c \tau / \sigma_0 \\ &\sigma_{xx} = \sigma_{yy} = \frac{\sigma_0}{1 + (\omega_c \tau)^2} \\ &\sigma_{xy} = -\sigma_{yx} = \frac{-\sigma_0 \omega_c \tau}{1 + (\omega_c \tau)^2} \end{aligned} \tag{8}$$

Equation 8 directly leads to the relation between conductivity and resistivity

$$\begin{aligned} \sigma_{xx} &= \frac{\rho_{xx}}{\rho_{xx}^{\;2} + \rho_{xy}^{\;2}} \\ \sigma_{xy} &= -\frac{\rho_{xy}}{\rho_{xx}^{\;2} + \rho_{xy}^{\;2}} \end{aligned} \tag{9}$$

We can see that if $\rho_{xy} \neq 0$, the conductivity σ_{xx} vanishes when the resistivity ρ_{xx} vanishes. On the other hand:

$$\sigma_{xy} = -\frac{nqd}{B_z} + \frac{\sigma_{xx}}{\omega_c \tau} \tag{10}$$

Therefore when $\sigma_{xx} = 0$, $j_x = \sigma_{xy} E_y$, where σ_{xy} is given by the first term in equation 10, i.e. Hall conductivity:

$$\sigma_H = \sigma_{xy} = -\frac{nqd}{B_z} \tag{11}$$

The Hall voltage is then possible to express by equations 2 and 11 as:

$$\begin{aligned} U_{H(y)} &= E_y \cdot y = \frac{j_x}{\sigma_{xy}} \cdot y = \\ &= -\frac{I_x \cdot B_z}{nqd} \end{aligned} \tag{12}$$

The Hall voltage is negative for *n*-type semiconductors and positive for *p*-type semiconductors.

3. SIMULATION MODEL

PSPICE simulation model is based on block diagram displayed in the Fig. 2. It consists from multiplier block, low pas filter and amplifier [2]. The main parameters of such model are possible to state by static and dynamic measuring of the real probe.

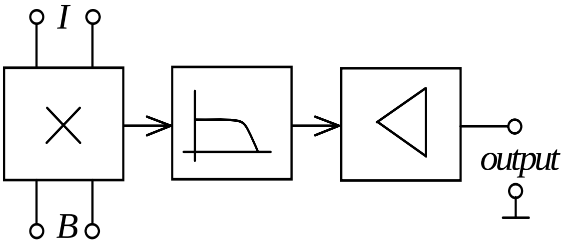

Fig. 2 Block diagram of Hall probe model

The input text file for the designed PSPICE program simulation model subcircuit is given as:

```
Hall sensor
.SUBCKT Hall_sensor 2 100 17 4 31 101
FUO 100 41 VIST 5.E-4
RGUO 100 41 1 TC = 8.E-4
EUO 9 5 41 100 1
FST 100 50 POLY(2) 31 1 71 100 0 0 0 0 1
RST  100 50 1 TC = -4.807E-3
E1 3 11 50 100 4.E-3
E2 13 4 50 100 4.E-3
VIST 2 7 0
VOM 15 3 0
H1 203 100 POLY(1) 31 101 0 0 8.165E-9 6.546E-10
RNON1 203 100 1
FB 100 210 VIB 0.1
ENON 17 15 302 100 1
FRI 100 70 POLY(1) VIB 0 6.E-3
RMAGI 100 70 1 TC = 1.5E-3
HIST 71 100 VIST 1
RIST 71 100 1
EFRI 370 100 POLY(2) 70 100 212 100 0 0 0 0 1
RFI 370 100 1
EV1 7 6 POLY(2) 71 100 370 100 0 0 0 0 -0.5
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EV2 8 100 POLY(2) 71 100  370 100 0 0 0 0 -0.5
FRO 100 80 POLY(1) VIB 0 6.E-3
RMAGO 80 100 1 TC = 1.5E-3
HVOM 81 100 VOM 1
ROM 81 100 1
EFRO 380 100 POLY(2) 80 100 212 100 0 0 0 0 1
RFO 380 100 1
EV3 11 10 POLY(2) 81 100 380 100 0 0 0 0 -0.5
EV4 12 13 POLY(2) 81 100 380 100 0 0 0 0 -0.5
R1 6 5 0.5 TC = 1.5E-3
R2 5 8 0.5 TC = 1.5E-3
RB1 210 100 100K
Q1 212 210 211 QMOD
.MODEL QMOD NPN
RQ1 212 213 10K
VCQ1 213 100 1.0
VEQ1 211 100 -1.0
ENON 100 190 POLY(2) 203 100 212 100 0 0 0 0 -1
RG 190 100 1 TC = -4.807E-3
EMAGC 37 100 31 1 1.E3
CMAG 37 38 1.E-11
RMAG 38 100 0.8753
GX1 301 100 POLY(2) 71 100 203 100 0 -5.E-4 0 0 10
EX2 302 301 38 100 1
RXX1 302 100 1
R3 10 9 0.5 TC = 1.5E-3
R4 5 12 0.5 TC = 1.5E-3
RB 31 1 1
VIB 1 101 0
RDUM 101 100 1.E8
.ENDS

XHall 3 4 0 5 9 10 Hall_sensor
RH 5 0 1k
F1 9 10 Vamp 40
Rpom 9 10 10000
Vz 7 0 SIN(0 1 50 0 0)
Rz 7 8 1
Vamp 8 0 DC 0
Vu 3 4 SIN(3 5 100 0 0 0)
.TRAN 100f 40m 0
.PROBE
.END
```

4. CONVERTER'S NON-HARMONIC SIGNAL MEASURING

At the moment when the constructor of power semiconductor converters should to state the efficiency of the designed equipment it is required to measure the input and output converter's power obviously created by the non-harmonic waveforms with the frequencies up to 100 kHz. This task is possible fulfill very easy by utilizing of Hall probe sensor. If the magnetic induction B_z will be represented by magnetic flux generated inside the magnetic core and given by measured current I and the current I_x will be generated by measured voltage then the output voltage $U_{H(y)}$ of Hall probe will be coressponding to the output power as it is shown in Fig. 3. Such analog output signal is possible to digitalize very simply and consequently to evaluate by numerical computing.

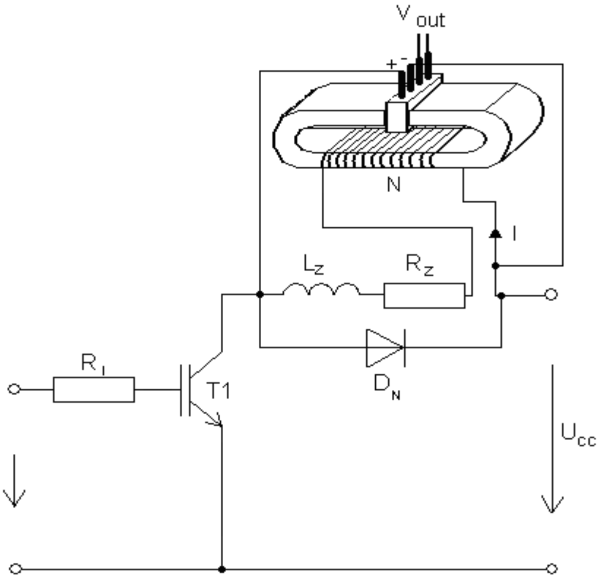

Fig. 3 Non-harmonnic power measuring of one quadrante DC converter

5. CONCLUSION

The designed PSPICE program model of Hall probe was used for power measuring of load represented by serial combination of *R*, *L* elements and fedded by harmonic voltage source, Fig 4.

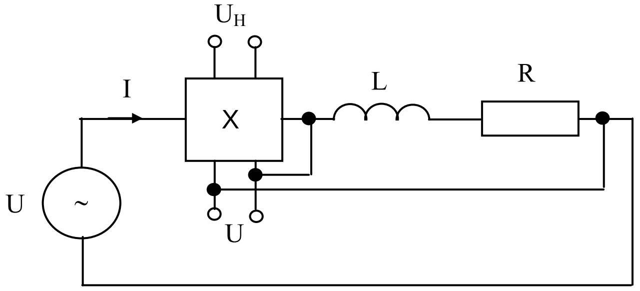

Fig. 4 Simulated circuit

Designed simulation model functionality is confirmed by the output results shown in Fig. 5. The curve V(3,4) shows the shape of measured input voltage (U), the curve I(Vamp) represents the waveform of load current (I) flowing through ampermeter and the curve V(5) represents corresponding output Hall voltage (U_H) and so also the measured non-harmonic power. It is evident that voltage V(5) corresponds to the curve of instantaneous power *p*, which can be also calculated by equation 13.

$$p = u * i \tag{13}$$

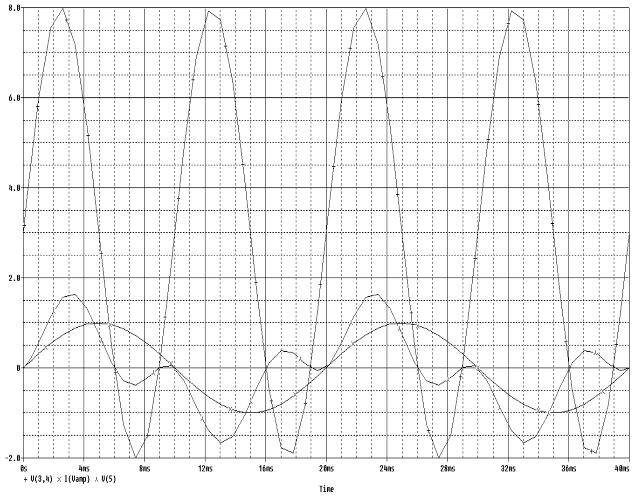

Fig. 5 Input and output waveforms of Hall probe simulation model

The course of this power has typical non-harmonic shape, which is difficulty measurable by classic analog mesurement methods.

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BIOGRAPHIES

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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 Electrical Drives. His research work was focused on the practical application of new power semiconductor devices. In 1989 he got the Award of the Minister of Education for the Development of Science and Technology. From 1991 he has worked as assistant lecturer at the Department of Theoretical Electrical Engineering and Electrical Measurement. He got his doctoral diploma in 1992 for the work on the field of power electronics. From 2000 he has worked as professor and his working interest is now focused mainly on the field of computer simulation of power electronic circuits and automated computer measuring.