Anomalous Rising of Input Current Induced in the Transformer of Inverter

Osamu Ide,
Takao Yamazaki (Ph.D.),
Takashi Maeza,
Takayuki Funabashi, and
Honami Ichinose

Clean Energy Research Laboratory,
3-4-21-601 Mita, Minato-ku, Tokyo, 108-0073, Japan,
03-5442-4746 (fax) daphne@myad.jp (email)

EXPERIMENTAL CIRCUIT

The experimental circuit is shown in Figure 1. When the MOS-transistor is turned on, the current (**Im**) from DC power supply starts to flow into the primary coil of transformer. Then the transient current (**Im**) is measured by current probe and digital oscilloscope with a sampling frequency of 100MHz, and plotted by X-Y plotter.

A simplified circuit of Figure 1 is shown on Figure 2. The circuit equation (1) is well-known to calculate the transient current (**Is**) after the MOS-transistor in Figure 2 is turned on.

$$\text{Is} = \frac{V}{R}\left(1 - e^{-\frac{Rt}{L}}\right) \text{ (A)} \qquad (1)$$

Where, **V** is the voltage of DC power supply, **R** is coil resistance, **L** is the coil inductance, and **t** is the time elapsed after MOS is turned on.

Figure 1: Measuring circuit.
Figure 2: Equivalent circuit.

EXPERIMENTAL RESULTS and CONSIDERATION

The result of the experiment is shown in Figure 3. With the MOS-Transistor is turned on and off, then the red curve shows the input transient current **Im** (A) for the y-axis and the elapsed time **t** (μ sec) for the x-axis. Furthermore, the blue curve of it is the calculated transient current **Is** from equation (1). The element values (**V**, **L** and **R**) are measured at the primary side when the secondary load (30Ω) is connected.

The results show the measured data of the transient current is much larger than the calculated values. In addition, the red curve has some regularity. It is presumed to be beyond the usual error and noise level of the experiment. Especially, in the period within 2～3μsec after MOS-Transistor was turned on, strong rising of the input current was observed. After around 3μsec passed over, the measured current was changed to almost parallel with the calculation.

Figure 3: Input current to the transformer and the time elapsed; measured and calculation.

Author has simulated the measured current during the time of t=0μsec～2.5μsec. Within this window, the equation of the measured current (**Im**) is approximately expressed by the equation (2).

$$\text{Im} = \alpha(1 - e^{-\beta t}) \text{ (A)} \qquad (2)$$

where, **α**=2.5 , **β**= 1.5 are the fixed value by the measuring data, and **t** is elapsed time(μsec). The author has tried to calculate and compare the electrical energy (**Ee**) output from DC power supply and the magnetic energy (**Em**) every 0.2μsec within 2.5μsec. The input electrical energy is calculated by equation (3)

$$\text{Ee} = V\int_0^t Im \cdot dt \quad \text{(J)} \qquad (3)$$

where, **V** is the power supply voltage, and **Im** is the measured current derived from equation (2),

The magnetic energy of the transformer (**Em**) is calculated by equation (4).

$$\text{Em} = \frac{1}{2}L \cdot Im^2 \quad \text{(J)} \qquad (4)$$

where, **L** is the measured inductance of the primary coil with load, and **Im** is the measured current at time (t).

Figure 4: Magnetic energy caused by the input current and electrical energy output from DC power supply.

Figure 4 shows the energy relation of both electric and magnetic in Joules (**Ee** and **Em** on y-axis) at the time **t** μsec (x-axis). The magnetic energy of the transformer caused by the input current is much larger than the electrical energy output from DC power supply. On the other hand, the same calculation is done by the calculated value by equation (1). In contrast, **Ee** and **Em** are almost identical at t < 3μsec. It is quite reasonable, but in the case of this experiment it is presumed the strong positive EMF is induced in the short moment after the current has started to flow. In order to find some characteristic of this positive EMF, the author tried to calculate and check the relation between the positive EMF and 2nd order time derivatives of the input current. Positive EMF (**Vp**) is estimated by the rate of change of the measured current and calculated current by equation (1) at the same time. Therefore **Vp** is calculated by equation (5).

$$Vp = V\left(Im/Is - 1\right) \text{ (V)} \qquad (5)$$

Where, **V** is the DC power supply voltage, **Im** is the measured current, and **Is** is the calculated current at time **t**.

The 2nd order time derivatives of the current (d²Im/dt²) is calculated by equation (6), derived from equation (2).

$$d^2Im / dt^2 = -\alpha \beta^2 e^{-\beta t} \text{ (A/s}^2\text{)} \qquad (6)$$

Where, **α** = 2.5, **β** = 1.5 are the fixed values by the measured data, and **t** is the elapsed time (μsec).

Figure 5: Estimated positive EMF vs. 2nd order time derivatives of the input current.

Figure 5 shows the relation between 2nd order time derivative (d²Im/dt² for x-axis) and positive EMF (**Vp**=Δ**V** for y-axis). This exponential curve is very much like the curve plotted by the relation with the positive EMF and the 2nd order time derivatives of the "inductance L", which is presented in Figure 6 .

Figure 6 is derived from the result of the motor (Ether Engine) test, described in [1], [2]. This motor has unique driving system, runs by the discharging of the capacitors, The original construction of this motor is from EMA motor invented by Edwin Gray, in [5].

Figure 6: Positive EMF vs. 2nd order time derivatives of the inductance.
(From Fig.9 (C) in [2])

While the motor runs (either while the capacitors are discharging in the short time), it occurs the time changing of the inductance of the motor coils by shifting of the coils of rotor and stator each other. Then the abnormal charging of the capacitors occur described in [1], [2]. Recharging voltage of the capacitor exceeds the value of calculation by Faraday's law. The author estimated the cause of the phenomenon is the positive EMF, induced by the high speed changing of the inductance of the motor coils. In the Figure 6, the positive EMF (Vp for y-axis) shows the deviation between the measuring value and the calculated value based on the Faraday's EMF. The x-axis shows the 2nd order time derivatives of the inductance of motor coils. If Faraday's law and the measuring are perfect, the deviation (Vp) should be zero, or the value of Vp distributes positive and negative in random around the x-axis. Generally speaking, the deviation (Vp) is called noise or measurement error. But Figure 6 shows the measuring value is always bigger than the precisely calculated value, and looks to have some rule of an exponential form like Figure 5. The result shows it's not noise, has some physical rule, and is the function of the 2nd order time derivatives of the inductance. This means Vp should be some unknown physical factor of EMF.

Equation (7) is derived from equation (13) in [2]. This is the hypothesis of the extended function of EMF presumed by the author, expressed by series of the time differential of the magnetic flux (Φ).

$$\text{EMF} = K_0 \Phi - K_1 \frac{d\Phi}{dt} + K_2 \frac{d^2\Phi}{dt^2} - K_3 \frac{d^3\Phi}{dt^3} + \cdot \cdot \cdot + (-1)^n K_n \frac{d^n\Phi}{dt^n} + \cdot \cdot \cdot \quad (7)$$

The 1st term of the function is the unipolar induction, generating DC current. The 2nd term is well-known Faraday's EMF. These two terms are generally known by electrical engineers. But the 3rd term and higher terms are not authorized. The 3rd term is the positive EMF, and has opposite direction to Faraday's law.

Equation (8) is the 3rd term of the equation (7), expressed by the time derivatives of inductance (L) and current (I), derived from equation (12) in [2].

$$\frac{d^2\Phi}{dt^2} = L\frac{d^2I}{dt^2} + 2\frac{dL}{dt} \times \frac{dI}{dt} + I\frac{d^2L}{dt^2} \quad (8)$$

Figure 5 predicts the existence of a 1st term of the equation (8). The 2nd term means Faraday's EMF. Figure 6 predicts the existence of a 3rd term of equation (8).
Hence, Figure 5 and Figure 6 predicts a 3rd order term ($+K_3 \, d^2\Phi/dt^2$) of EMF (Eq.13. in [2]) exists. The 3rd ordered term of this equation means positive EMF, induced by quick changing of magnetic flux (Φ) in opposite direction to Faraday's back EMF. [1, 2, 3, 4]
In addition, non-linear exponential curves of Figure 5 and Figure 6 also predict the existence of 4th, 5th and higher terms of the EMF function.

CONCLUSION
The electrical circuit consisted of DC power source, MOS-transistor and coil with magnetic core in series was discussed. In the short moment after MOS was turned on, the transient current of the circuit was examined. Rising of the measured transient current is much larger than the calculated value. As a result, the magnetic energy by the input current might be much larger than the output energy from DC power source.

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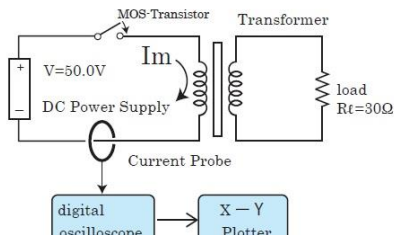6. Ide, O., " INVERTER DRIVING SYSTEM " ; US Patent 8873262; 2014

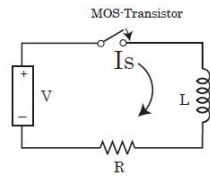Figure 1. Measuring circuit.

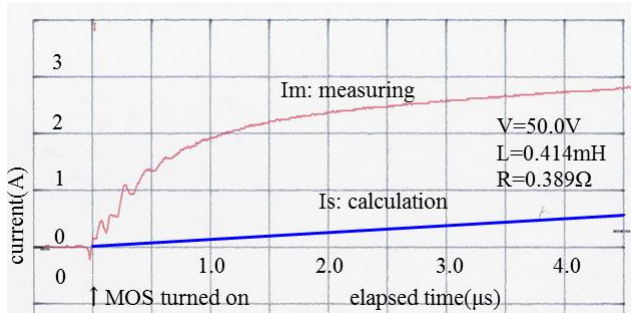Figure 2. Equivalent circuit.

Figure 3. Input current to the transformer and the time elapsed; measured and calculation.
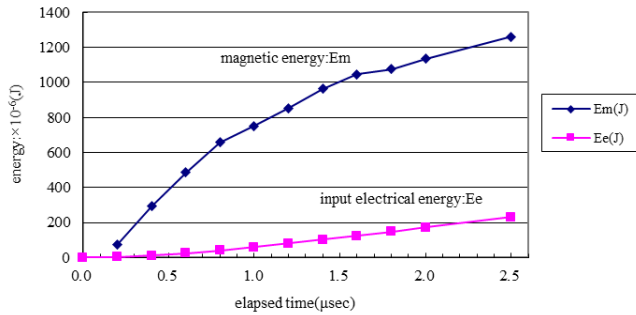

Figure 4. Magnetic energy caused by the input current and electrical energy output from DC power supply
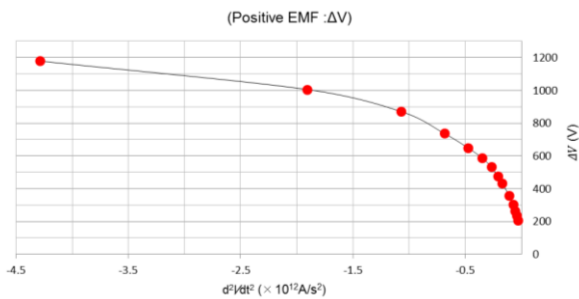

Figure 5. Estimated positive EMF vs. 2nd order time derivatives of the input current.
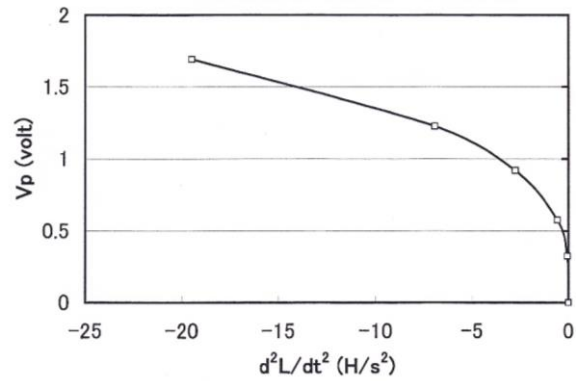

Figure 6. Positive EMF vs. 2nd order time derivatives of the inductance.
(From Fig.9 (C) in [2])