Current transition time decrease in contour antenna of mineral electrical prospecting system

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Abstract. The new circuit design has been considered to reduce current setting time after switching in a low-dimension contour antenna applied in an electrical mineral prospecting system. Such circuit is a bridge of IGBT transistors with an inductive load. It has been shown that switching time for the circuit with a shunt and damping dissipative elements is 10 times less than that for the circuit with a resistive shunt.

1. Introduction

Electric impulse prospecting of minerals means generation of high-power periodic electromagnetic impulses acting on the investigated ground surface. Then response parameters are measured [1-2]. Contour antennas are usually placed on the ground surface or attached to a helicopter [3-6]. A measurement system implementing such method consists of the following parts: accumulator, current switch, generator contour, receiving countour and voltage analyzer (Fig. 1).

Fig. 1. A block-diagram of the measurement system for electrical impulse mineral prospecting

The field of the generator contour probe is produced by a stepwise current change in the contour from maximum to zero. The transient process should finish until the reflected signal applies to the receiving contour.

The purpose of the paper is the analysis of transient processes in a current switching bridge with respect to generator contour electrical parameters and analysis of circuit design methods that help to reduce transient process duration in the generator antenna.
2. Investigation of the generator contour operating mode
The generator contour magnetic antenna is a rectangular loop made of the GPMP wire. The rectangular loop equivalent circuit together with a resistive shunt and current switch is shown in Fig. 2. The current switch is designed according to the circuit applied in reactive power compensation systems [7-8]. Usually pulse-width modulation is used in such systems to support output sine current and voltage. The principle of the demanded current generation is stated in [9-10].

\[
L_g = 4 \cdot 10^{-7} \left[ 0.434 \left( a \cdot \ln \frac{2ab}{r_0 \cdot (a + d)} + b \cdot \ln \frac{2ab}{r_0 \cdot (b + d)} \right) + 2d - 1.75 \cdot (a + b) \right],
\]

(1)

where \(a, b, d\) are correspondingly the rectangular loop length, width and diagonal; \(r_0\) is the wire radius.

The rectangular loop active resistance is:

\[
R_g = 2R_0(a + b),
\]

(2)

where \(R_0\) is the GPMP wire specific resistance per meter.

The current impulse switch in the measurement system is a full-bridge made of IGBT transistors (Fig. 2). The resistive shunt \(R_s\) is connected in parallel with the generator contour antenna. The transistors VT1 and VT4 generate the current drop from some positive value to zero while the transistors VT2, VT3 form the reverse current drop from some negative value to zero. When the positive voltage drop is generated, the generator current flows through the contour antenna and shunt. Such mode corresponds to the transient mode when the current in the contour antenna has the form:

\[
I_g = I_0 \cdot \exp \left( -\frac{t}{r_g} \right),
\]

(3)
where \( I_0 \) is the initial current value.

The time constant in (3) is calculated as:

\[
\tau_g = \frac{L_g}{R_g + R_s}.
\]  
(4)

If the rectangular loop size is 2 x 4 m, then the inductance is \( L_g = 15\mu\text{H} \) and the active resistance is \( R_g = 0.01 \text{ Ohm} \). As it follows from the analysis above, the shunt resistance is \( R_s = 18 \text{ Ohm} \) and the time of current drop from maximum to zero is about 10 µs.

3. Transient process time decrease in a contour antenna

To reduce transient process duration, it is proposed to use the additional damping \( R_dC_d \) circuit connected through the semiconductor diode VD1 together with the parallel resistive shunt (Fig. 3). The minimal current drop time is provided by the capacity \( C_d \) which should correspond to the generator contour mode which is close to critical one.

\[
\begin{align*}
\text{Figure 3. A generator contour with the resistive shunt and damping RC circuit}
\end{align*}
\]

When the damping circuit \( C_dR_d \) occurs, the current-time function for the generator contour in the switching-off mode has the form:

\[
I_g(t) = A \cdot \exp(-p_1t) + B \cdot \exp(-p_2t).
\]  
(5)

where

\[
\begin{align*}
A &= I_0 \cdot L_g \cdot (1 + (R_g + R_s) \cdot C_d \cdot p_1 / (2 \cdot L_s \cdot C_d \cdot (R_g + R_s) p_1 + R_d(R_g + R_s) \cdot C_d + L_g),
\end{align*}
\]  
(6)

\[
\begin{align*}
B &= I_0 \cdot L_g \cdot (1 + (R_g + R_s) \cdot C_d \cdot p_2 / (2 \cdot L_s \cdot C_d \cdot (R_g + R_s) p_2 + R_d(R_g + R_s) \cdot C_d + L_g),
\end{align*}
\]  
(7)
\[
I_{t,2} = \frac{-(R_s + R_i)R_oC_d + L_o \pm \sqrt{(R_s + R_i)R_oC_d + L_o}^2 - 4L_o \cdot C_d \cdot (R_s + R_i) \cdot (R_s + R_o)}}{2L_o \cdot C_d \cdot (R_s + R_o)}
\]

4. Simulation of the current drop in the contour antenna

Fig. 4 shows the simulated current drops in the contour antenna for different damping circuit and shunt parameters. The curve 1 describes the case when there is no damping circuit and the current drop time becomes too long. The curve 2 shows that if the capacity \( C_d \) is too high, the current drop time significantly reduces, however there is the negative overshoot. The curve 3 corresponds to the minimum contour current drop from 10 A to 0.05 A with duration about 1 \( \mu \)s. To provide good heat sink, high reliability, high-power thin-film resistors on beryllium ceramic are preferable.

![Graph of current drop](Image)

**Figure 4.** Generator contour current: 1- \( R_s = 18 \) Ohm, \( C_d = 0 \), \( R_o = \infty \); 2- \( R_s = 18 \) Ohm, \( C_d = 100 \mu \)F, \( R_o = 40 \) Ohm; 3- \( R_s = 18 \) Ohm, \( C_d = 0,01 \mu \)F, \( R_o = 50 \) Ohm.

The analysis of other damping circuits structures and their elements parameters has shown that the proposed version of the current switch based on the full bridge provides minimum current drop in the generator contour. Further decrease of the current drop duration is possible if an IGBT double bridge is used.

5. Conclusion

The analysis, research and simulation of the switch with the generator contour in the mineral prospecting system have shown that the proposed current switch structure and its elements parameters optimization permit to reduce the current drop time value about 10 times. Further decrease of the current drop time is possible because of additional compensation circuit and corresponding received signal processing.
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