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Modelling and Implementation of Long Duration Impulse Current Measurement Circuit

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Abstract

The aim of the project is to model and implement impulse current measurement circuit using Rogowski coil. It is a winding located on the toroidal core, which is made by non-magnetic materials. The coil is not connected directly to the impulse current generation (ICG) circuit. Hence the current generation circuit does not affect the measuring system. Rogowski coil is a transducer which converts current to an integral of induced voltage. The induced voltage is proportional to the rate of change of measured current. Simulation of different configurations of integrator circuit was carried out using MATLAB-SIMULINK. Simulated output of all the configurations of integrator was compared and efficient configuration has been identified. Then the prototype of the long duration impulse current measurement circuit with integrator and Rogowski coil was implemented.

Keywords: *Impulse current, Impulse current generation (ICG) Rogowski coil, Integrator*

1. Introduction

Impulse current is the one which occur with very large magnitude for a short duration of time. The standard impulse current duration is 4/10 micro seconds and 8/20 micro seconds. Long duration impulse current can be obtained by increasing the duration from microseconds to milliseconds. The long duration impulse current can be generated by a transient ladder LC circuit. An attempt has been made to measure the long duration impulse current using Rogowski coil with passive integrator.

The wave shape should be nominally rectangular in shape. The rectangular waves generally have durations of the order of 0.5 to 5ms, with rise and fall times of the waves being less than ±10% of their total duration. The tolerance allowed on the peak value is ± 20% and 0% (The peak value may be more than the specified value but not less.) the duration of the wave is defined as the total time of the wave during which the current is atleast 10% of its peak value.

There are many ways to measure impulse current. The impulse current can be measured by various methods such as,a non-inductive shunt resistor, a current transformer ,a Rogowski coil, Hall sensor. One uses a non inductive resistor for impulse current measurement. The disadvantage of using non inductance resistor is that the damage on the low voltage recording system can be occurred when the breakdown or flashover is occurred on a test object during the test.

A Rogowski coil with an integrator is one of the better choices for impulse current measurement. The Rogowski coil is not connected directly to the impulse current generation circuit. Therefore, there exists an electrical isolation between ICG and impulse current measurement circuit. Also the low

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voltage recording system is prevented from the accident from breakdown and flashover in tests.

The aim of this research it to design the Rogowski coil for long duration impulse current measurement circuit and also to simulate the various configurations of integrator circuits using MATLAB-simulink Then the efficient configuration can be identified by analyzing the waveforms of integrator. Then the prototype of the identified efficient configuration of integrator with the Rogowski coil can be made.

2. Rogowski Coil

Figure 1 depicts Rogowski coil with conventional RC integrator

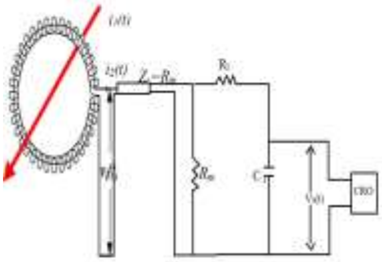


Fig..1 The Rogowski coil with a conventional RC.integrator.

Where $v_i(t)$ = induced voltage in the coil

$i_1(t)$= Current to be measured

$i_2(t)$= Current in the Rogowski coil

R_m=Matching resistor

$v_0(t)$=output voltage

The Rogowski coil, is a kind of a transducer which converts current to voltage, is normally employed for the high impulse current measurement. One of the most advantages of the Rogowski coil in current measurement over the shunt resistor is that it is not connected to generation circuit .The Rogowski coil is made of an air core placed around with the conductor in a toroidal form. The current waveform can be measured from an integral of induced voltage in the coil. The current measuring system is composed of an induced voltage coil and an integrator as illustrated in Fig 1. The induced voltage is proportional to the rate of a change of the measured current. Thus, the integral waveform of induce voltage is the same as the measured current waveform as shown in (1) and (2), when initial current $i_1(0)$ is zero.

$$v_i(t) = \frac{M di_1(t)}{dt} \qquad -(1)$$

$$v_0(t) = \frac{1}{T_i}\int_0^i v_i(t)dt$$

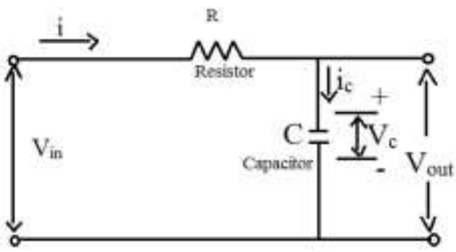
$$= \frac{M}{T_i}\left(i_1(t) - i_1(0)\right)$$

$$= \frac{M}{T_i}\left(i_1(t)\right) \qquad -(2)$$

Rogowski coil with a passive RC integrator is found to have a linear behavior with no saturation effect, having a wide bandwidth, and should be suitable for measuring high impulse current.

3. Integrator Circuit

The basic RC integrator circuit is shown in figure 2



Fig, 2- RC Integrator

The RC integrator is a series connected Resistor-Capacitor network that produces an output signal which corresponds to the mathematical process of integration. For an RC integrator circuit, the input signal is applied to the resistance with the output taken across the capacitor, then V_{OUT} equals V_C. This voltage is proportional to the charge, Q being stored on the capacitor given by: Q = VxC. The result is that the output voltage is the integral of the input voltage with the amount of integration dependent upon the values of R and C and therefore the time constant of the network.

$$i(t)=V_{in}/R=V_R/R=CdV/dt$$

therefore:

$$V_{out}=V_c=Q/C=\int idt/C= 1/C(\int i(t)dt)$$

As $i = V_{IN}/R$, substituting and rearranging to solve for V_{OUT} as

a function of time gives:

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$$V_{out}=1/C(\int(V_{in}/R)dt)=1/RC(\int V_{in}dt)$$

The different configurations of integrator circuit are shown in figures 3, 4 and 5 respectively.

3.1 Configuration 1 of integrator circuit

The configuration 1 of integrator which consists of single RC section is shown in figure 3.

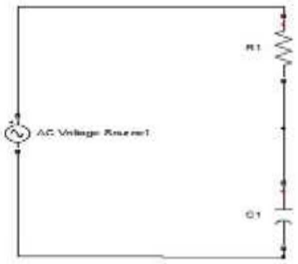

Fig.3 Configuration 1 of Integrator circuit

3.2 Configuration 2 of integrator circuit

The configuration 2 of integrator which consists of single RC section is shown in figure 4.

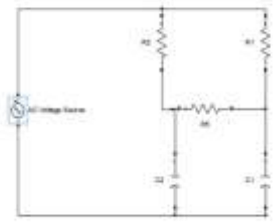

Fig. 4 Configuration 2 of Integrator circuit

3.3 Configuration 3 of integrator circuit

The configuration 3 of integrator which consists of single RC section is shown in figure 5.

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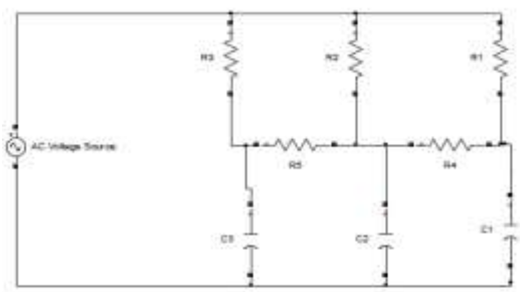

Fig. 5 Configuration 3 of Integrator circuit

4. Design

4.1. Design of Rogowski coil

The specifications of the Rogowski coil includes,

Inner radius of toroidal core (a)= 4 cm

Outer radius of toroidal core (b)= 8 cm

Height of toroidal core (h)=1.5 cm

Number of turns (N)= 40

For circular cross section of Rogowski coil,

Self-inductance $L_o=\mu_0 N^2(a+b-2\sqrt{ab})/2$

Where $\mu_{0,}$ Relative Permeability of the air $=4*\prod*10^{-7}$

$=4*\prod*10^{-7}*(40)^2*(4+8-(2*\sqrt{(4*8)}))*10^{-2}/2$

$=6.89\ \mu H$

Optimal damping resistance ,

$R_s=L_0/\sqrt{((2L_0C_0)-(R_0^2C_0^2)}$

$=6.89*10^{-6}/(2*6.89*10^{-6}*0.375*10^{-9}-[3^2*(0.375)^2*(10^{-9})^2])^{1/2}$

$=95\ \Omega$

Self- resistance $R_0=3\Omega$

Stray capacitance $C_0=0.375$ nF

4.2 Design of Integrator Circuit

The bode diagrams for the integrator circuit with different RC values have been plotted using MATLAB-Simulink. These plots were compared with respect to their bandwidth. The corresponding R and C values of higher bandwidth are chosen.

Figure 6 illustrates the bode plot for R=100Ω,C=0.1μF

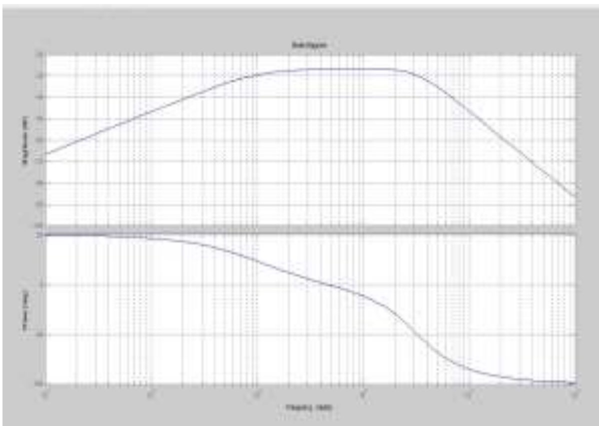

Fig.6 Bode plot for R=100 Ω,C=0.1μF

Figure 7 illustrates the bode plot for R=100Ω,C=1µF

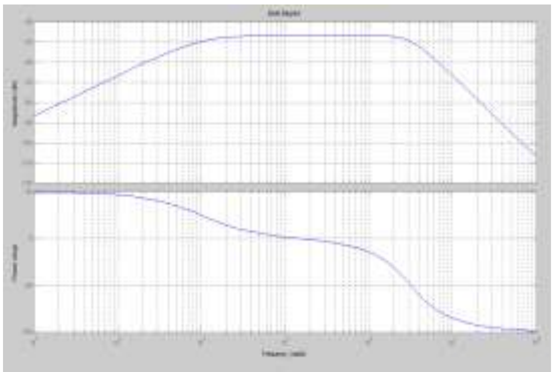

Fig.7 Bode plot for R=100Ω,C=1µF

Figure 8 shows the bode plot for R=1000Ω,C=0.1µF

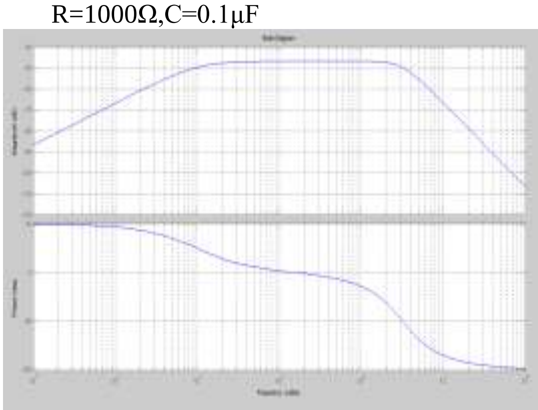

Fig. 8 Bode plot for R=1000Ω,C=0.1µF

Thus the design of Rogowski coil has been carried out and also the values of R and C was selected from the bode diagrams of different cases of integrator

5. Results and Disucssions

5.1 Software Implementation of impulse current measurement circuit

5.1.1 Simulink model of configuration 1 of integrator circuit : [R_1=100Ω,C_1=1µF]

Figure 9 and 10 illustrate the circuit diagram and output waveform for configuration 1 of integrator for 30 V AC input.

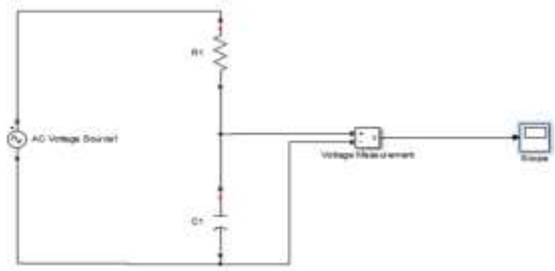

Fig.9 Circuit diagram for configuration 1 of integrator.

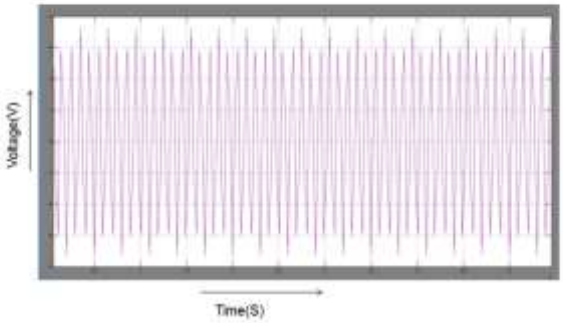

Fig.10 Output waveform for configuration 1 of integrator for 30V AC input

5.1.2 Simulink model of configuration 2 of integrator circuit: [R_1,R_2,R_5=100Ω,C_1,C_2=1 µF]

Figure 11 and 12 illustrates the circuit diagram and output waveform for configuration 2 of integrator for 30 V AC input.

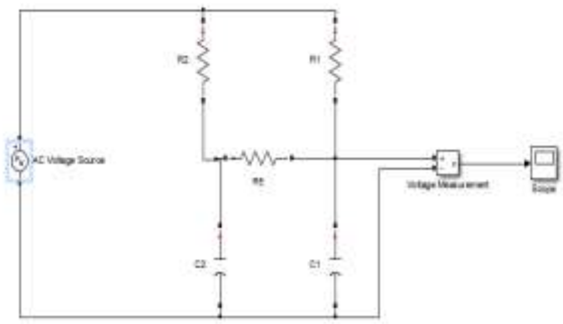

Fig.11 Circuit diagram for configuration 2 of integrator

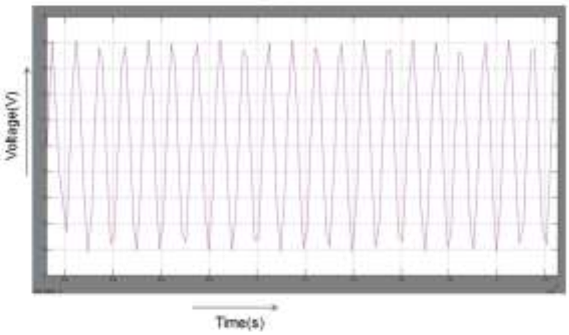

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Fig.12 Output waveform for configuration 2 of integrator for 30V AC input

5.1.3 Simulink model of configuration 3 of integrator circuit: [R_1,R_2,R_3,R_4,R_5=100 Ω,C_1,C_2,C_3=1μF]

Figure 13and 14 illustrates the circuit diagram and output waveform for configuration 3 of integrator for 30 V AC input

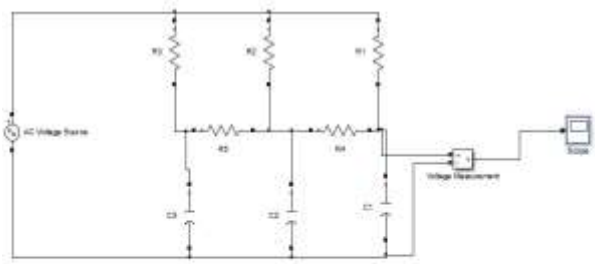

Fig.13 circuit diagram for configuration 3 of integrator

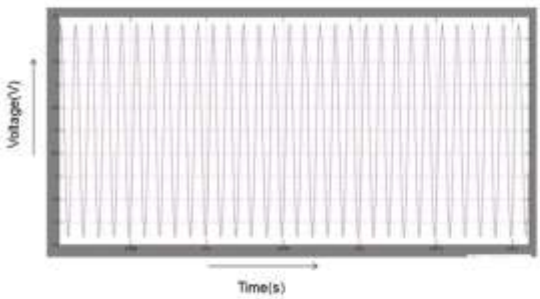

Fig.14 output waveform for configuration 3 of integrator for 30 V AC input

5.2 Simulation of lumped paramaeter model of rogowski coil

The Rogowski coil can be considered as a lumped element model. The lumped parameter model of Rogowski coil with RC integrator is shown in figure 15. This circuit was simulated using MATLAB Simulink. The input current waveform and the output voltage waveform are shown in figure 16 and 17 respectively.

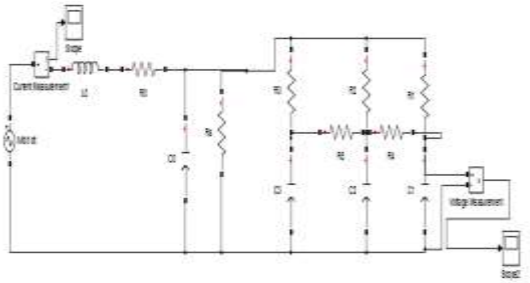

Fig.15 Lumped parameter model of Rogowski coil with a RC integrator

Where L_0=Lumped inductance of coil
C_0=Lumped capacitance of coil
R_0=Lumped resistance of coil
R_s=Damping resistance terminating the coil.
R,C = Integrator circuit

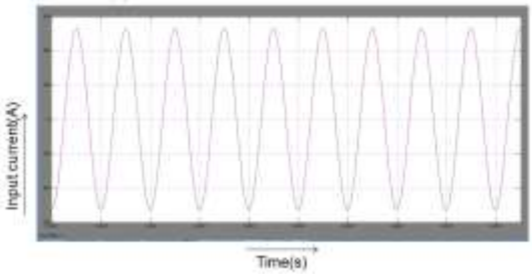

Fig.16 Input current waveform of the lumped parameter model circuit

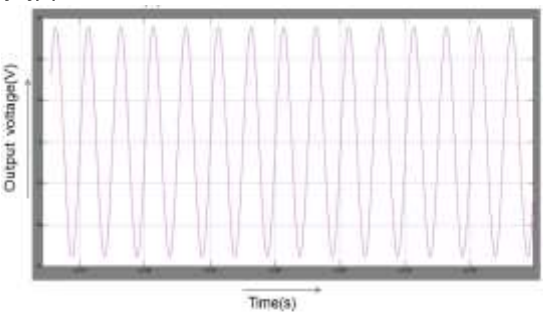

Fig.17 Output voltage waveform of the lumped parameter model circuit

Table 1 illustrates the simulated output of three different configurations of integrator circuit.

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Table 1: Comparison of output of three different simulated configurations of integrator

Configuration of Integrator	R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	C_1 (uF)	C_2 (uF)	C_3 (uF)	O/P (v)
1	-	-	100	-	-	1	26
	-	-	1000	-	-	0.1	27
	-	-	1000	-	-	1	27
2 (R_5=100Ω)	-	100	100	-	1	1	20
	-	1000	1000	-	0.1	0.1	27
	-	100	1000	-	0.1	0.1	26
3 (R_4,R_5=100Ω)	100	100	100	1	1	1	17
	1000	1000	1000	1	1	0.1	8
	100	1000	1000	1	1	1	6

From the figures 10,12 and 14, it can be inferred that distortion was less in configuration 3 when compared to configuration 1 and 2 for fixed R and C values. Hence it was identified as an efficient configuration of integrator to measure long duration impulse current.

5.3 Hardware Implementation of impulse current measurement circuit

5.3.1 Integrator Circuit

Comparison of output of three different hardware configurations of integrator is shown in table 2

By comparing the output waveforms of different configurations, configuration 3 was identified as efficient. Hardware circuit of efficient configuration of integrator circuit is shown in figure 18.

Table 2: Comparison of output of three different hardware configurations of integrator

Configuration of Integrator	R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	C_1 (uF)	C_2 (uF)	C_3 (uF)	O/P (v)
1	-	-	100	-	-	1	24
	-	-	1000	-	-	0.1	26
	-	-	1000	-	-	1	27
2 (R_5=100Ω)	-	100	100	-	1	1	18
	-	1000	1000	-	0.1	0.1	26
	-	100	1000	-	0.1	0.1	26
3(R_4,R_5=100Ω)	100	100	100	1	1	1	14
	1000	1000	1000	1	1	0.1	5
	100	1000	1000	1	1	1	4.8

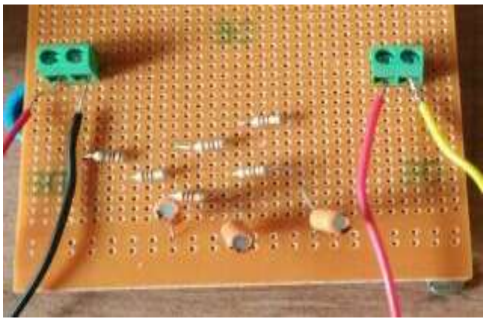

Fig. 18 Hardware circuit of efficient configuration of integrator circuit

5.3.2 Rogowski coil

The Rogowski coil is shown in Figure 19.The long duration impulse current from the impulse current generation circuit was given as input to the Rogowski coil . The output of the coil was connected to the input of integrator circuit.

Fig.19 Rogowski coil

5.3.3 Overall circuit

The overall circuit of long duration impulse current measurement with Rogowski coil and integrator is shown in Figure 20.

A CRO is connected across the last capacitor of the integrator circuit to get the output waveform. Output waveform of Rogowski coil and integrator circuit is shown in figures 21 and 22 respectively.

Fig. 20 Overall circuit of long duration impulse current measurement

Fig. 21 Output of Rogowski coil

Fig. 22 Output of integrator

Thus the long duration impulse current was measured using the Rogowski coil with passive integrator circuit.

6. Conclusions

Three different configurations of integrator circuit were simulated in MATLAB Simulink. By comparing the output of these three configurations of integrator, configuration with three parallel RC sections was identified as an efficient one. And a prototype model of the efficient configuration of integrator with the Rogowski coil was designed and developed. Thus the developed impulse current measurement circuit using Rogowski coil with integrator can be used to measure long duration impulse current.

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