Current Transformer replacement by Rogowski Coil for measurement of current in High Voltage System

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ABSTRACT:

To have adequate protection of electrical power system, the current and voltage signals collected from current and voltage transformer plays an important role. Sometimes conventional current transformer core gets saturated at normal as well as at abnormal conditions. This hampers the quality of the signals fed to different relays used for protection purpose. Nowadays, Rogowski coil can be used for measurement of current, as it is possessing air core which is non-saturable. The saturation of the CT is analysed in this paper using the PSCAD software simulations carried out on 230kV, 200 km, 50 Hz system model. Rogowski coil actual implementation data is used to show its performance as current transducer over current transformer.

***Keywords* – Current Transformer, Saturation, Rogowski Coil**

1. INTRODUCTION

CT's (Current transformers) have been widely used for relay protection and current measurement. For protection applications, CT saturation is a major concern. When CTs saturate, secondary signals become distorted and may affect the performance of protection components of power systems such as relays [1].

In the past, high power output needed for electromechanical equipment's were provided from conventional CTs. Modern relays do not require high power current sensors and allow applications of nonconventional (low power) current sensors, eliminating CT problems such as saturation, size and weight. Therefore, Rogowski coil can be used as a transducer which provides advantages such as air core, linear output, less expensive, over conventional CT. [2]

This paper presents novel current sensors (Rogowski coils) and compares their operating characteristics to those of a conventional CT.

2. CURRENT TRANSFORMER

The circuit diagram of CT can be shown as in Figure1.

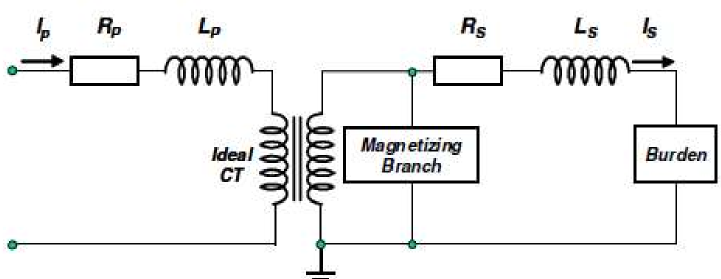

Figure 1.Equivalent circuit diagram of current transformer

Ratio error and Phase angle error are the main errors present inside the current transformer because of magnetising branch [3]. The magnetisation curve of conventional CT can be plotted taking the overvoltage test on the respective specimen.
Table-1 provides the results of the 33kV, 2000/1 A CT from which magnetisation curve can be plotted as in Fig.1 [4].

Table.1 Overvoltage test results of 2000/1A

I_{exe}(mA)	Voltage(V)	I_{exe}(mA)	Voltage(V)	I_{exe}(mA)	Voltage(V)
2.00	23.10	14.00	250.40	26.00	306.00
4.00	65.20	16.00	270.00	28.00	309.00
6.00	116.00	18.00	280.20	30.00	310.00
8.00	170.50	20.00	290.60	40.00	312.00
10.00	200.50	22.00	300.10		
12.00	230.40	24.00	300.60		

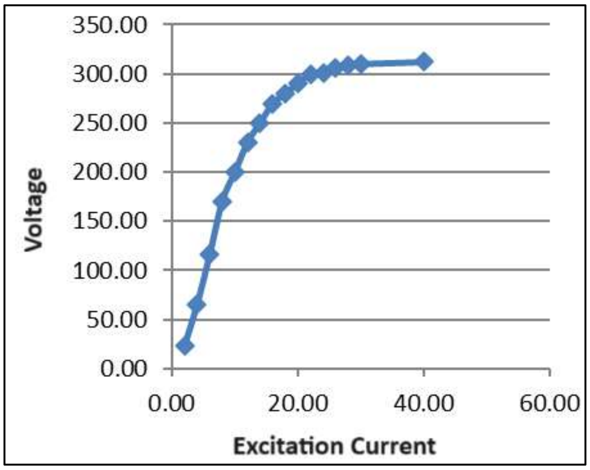

Fig.2. Magnetisation curve of 33kV, 2000/1A CT

From Table.1 & Figure 2, the saturation of conventional CT can be observed. The saturation of CT leads to the malfunction of relays.

2.1 CT SATURATION BEHAVIOUR

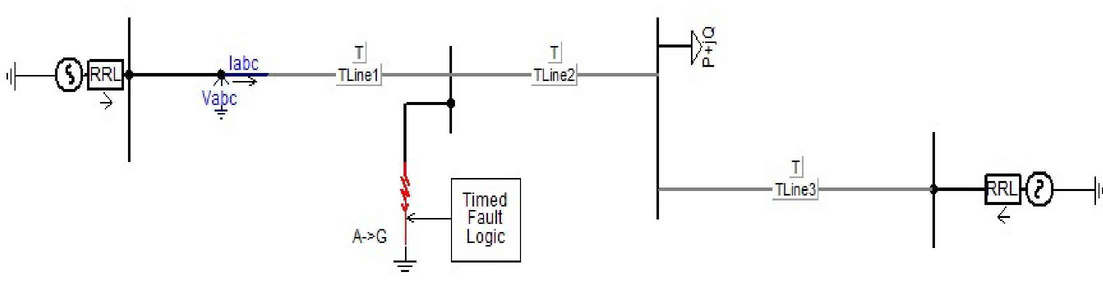

Fig.3. CT saturation using AC System model

In figure 3 PSCAD software model of 230kV, 200km, 50 Hz is developed. Also to show the effect of CT saturation, the model is developed as in figure 4 [5].
The following can have a significant impact on CT saturation and should be given due consideration in a simulation study:

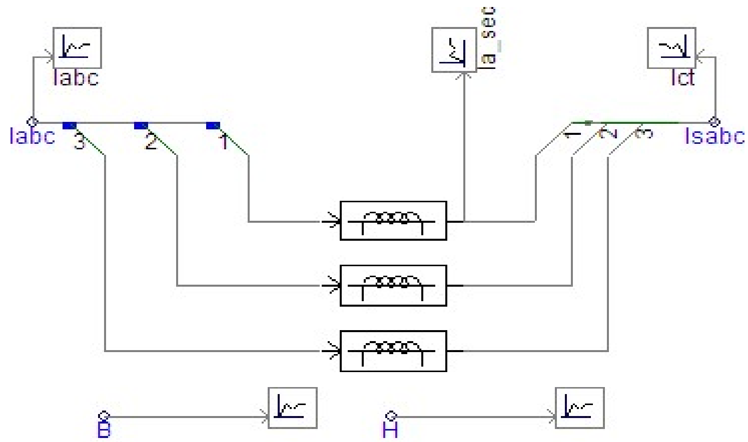

Fig.4. Model of CT in PSCAD software

1. DC offset in the primary side fault current.
2. Remnant flux on the CT prior to the fault (if any).
3. Secondary side impedance including those of the relay, connecting wires and CT secondary impedance - this parameter plays a major role in the level of saturation the CT will be subjected to.

2.2 IMPACT OF DC OFFSET IN THE PRIMARY FAULT CURRENT

The point on the voltage wave form at the instant of the fault determines the level of the DC offset in the primary current. The maximum DC offset will occur when the fault is applied at a voltage minimum (t=0.5 s). The results in figure 5 occurs, when the DC offset is significant.

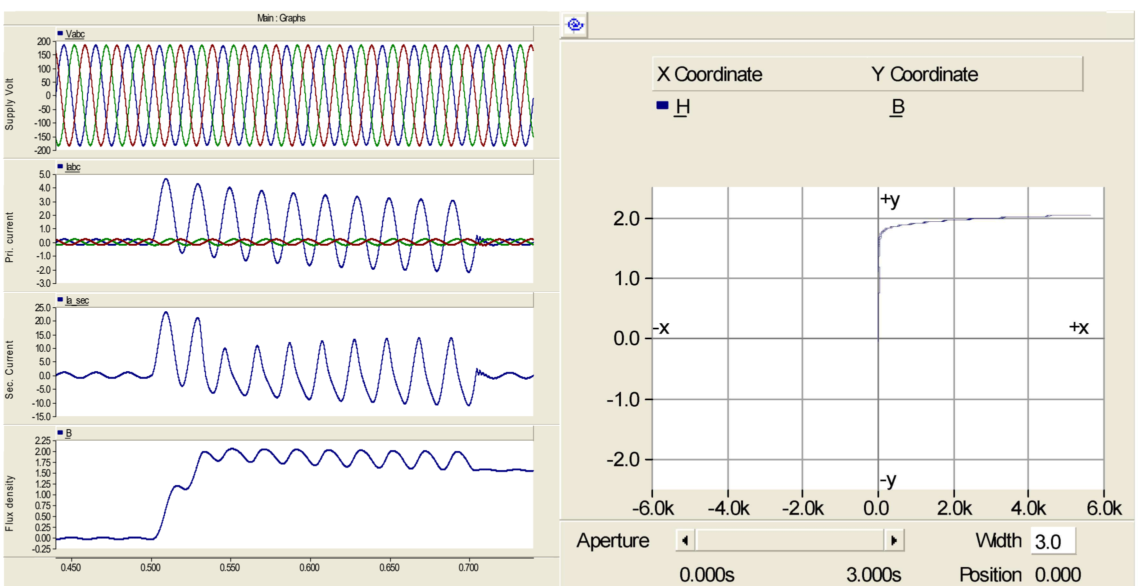

Fig.5 Waveforms for DC Offset present condition of (a) applied voltage (b) Secondary current (c) Primary current (d) flux density (e) B-H curve.

2.3 NO DC OFFSET CONDITION

To achieve the no dc offset condition time of fault is changed to 0.505 sec. As can be seen, the CT does not go into saturation and only a small amount of magnetizing current is required to magnetize the core. Therefore, the secondary current is an exact but scaled down replica of the primary current.

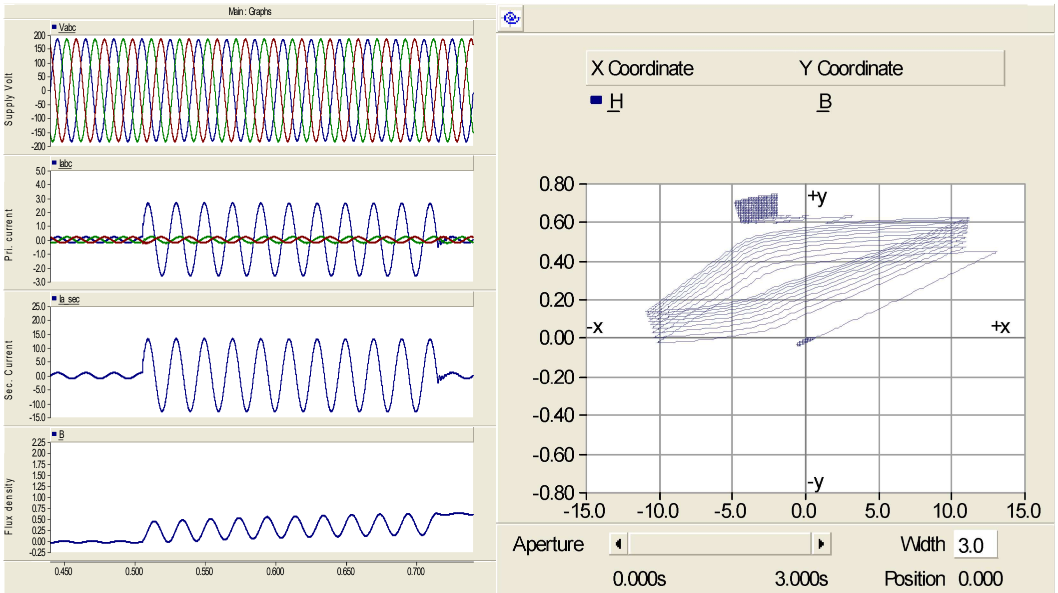

Figure 6 Waveforms for DC Offset absent condition of (a) applied voltage (b) Secondary current (c) Primary current (d) flux density (e) B-H curve

2.4 IMPACT OF SECONDARY BURDEN

The CT secondary side burden impedance has a significant impact on CT saturation. In Case 1, the burden was set to 2.5 Ω. The results are shown in Fig.7

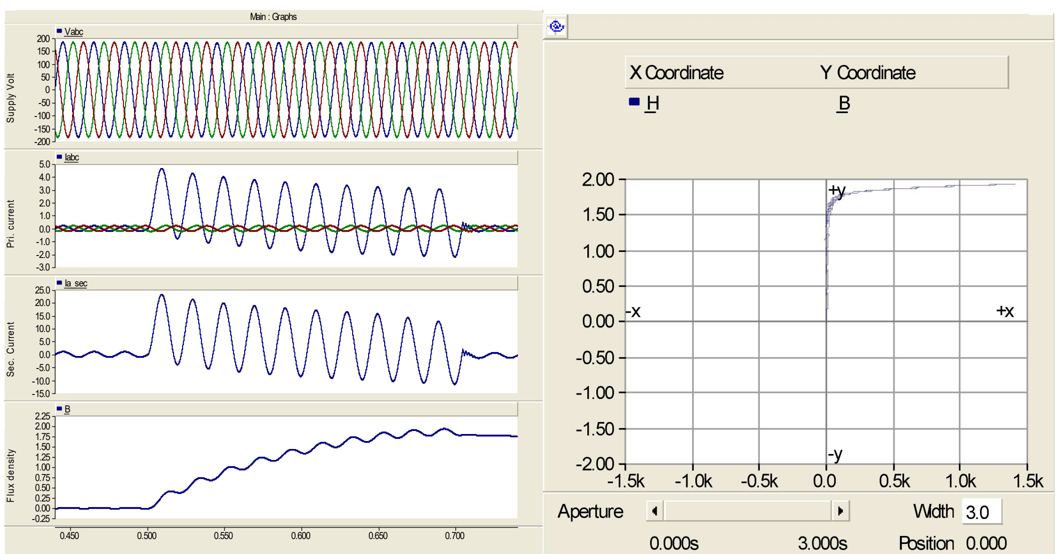

Fig.7. Waveforms for Impact of secondary burden of 2.5 ohm on (a) applied voltage (b) Secondary current (c) Primary current (d) flux density (e) B-H curve

The results shown in figure8 were obtained by reducing the burden to 0.5 Ω in the simulation. As can be seen from the results, the flux is not driven down as far. It also takes a longer time for the CT to become saturated (approximately 6 cycles).

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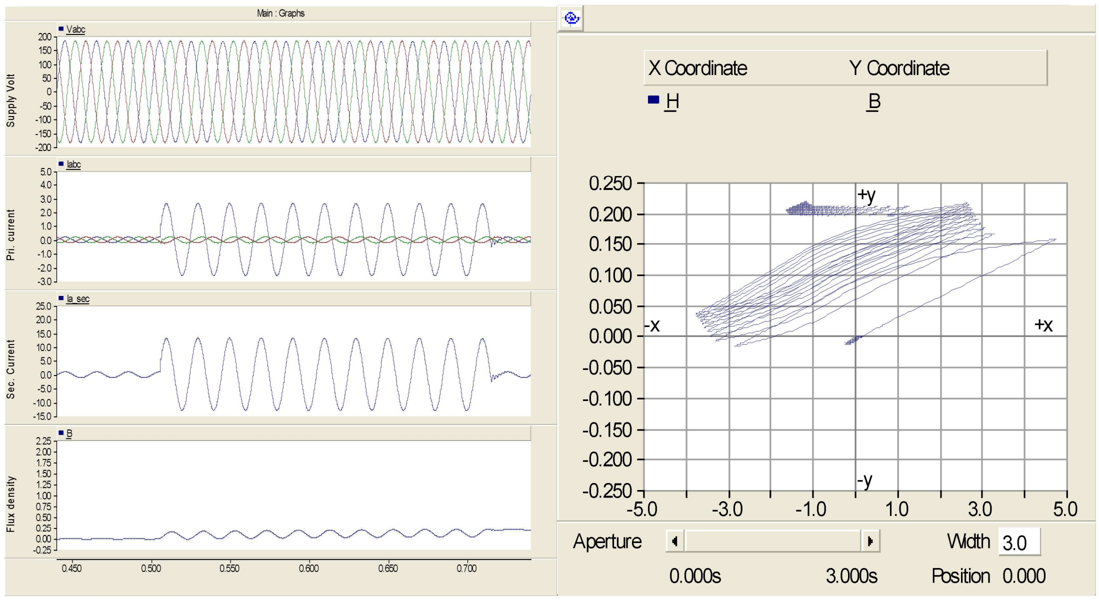


Figure.8. Waveforms for Impact of secondary burden of 0.5 ohm on (a) applied voltage (b) Secondary current (c) Primary current (d) flux density (e) B-H curve

3. ROGOWSKI COIL

Generally, Rogowski coils are toroidal coils with air core (non-magnetic core). The absence of core makes them lighter in weight as compared to current transformer which is having iron core. The air core consideration in the Rogowski coil construction makes the relative permeability as unity ($\mu_r = 1$). Rogowski coil is placed around the current whose current is to be sensed as shown in Fig.9 [6]

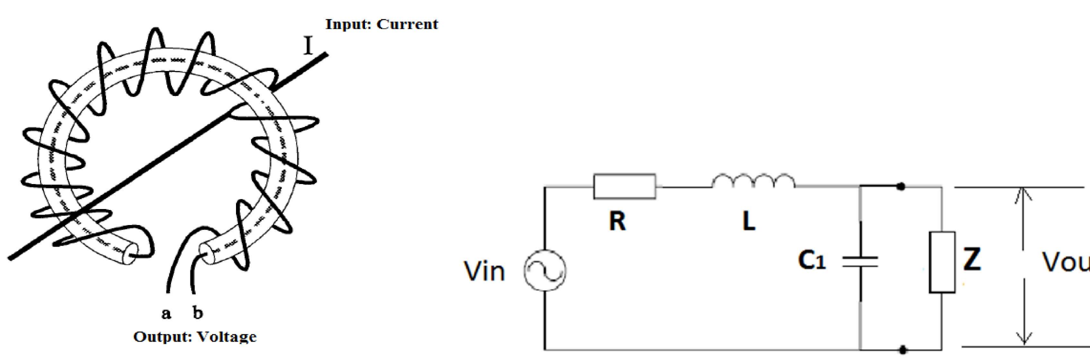


Figure 9. Model of Rogowski Coil with equivalent circuit

The output of the Rogowski coil can be given by the equation,

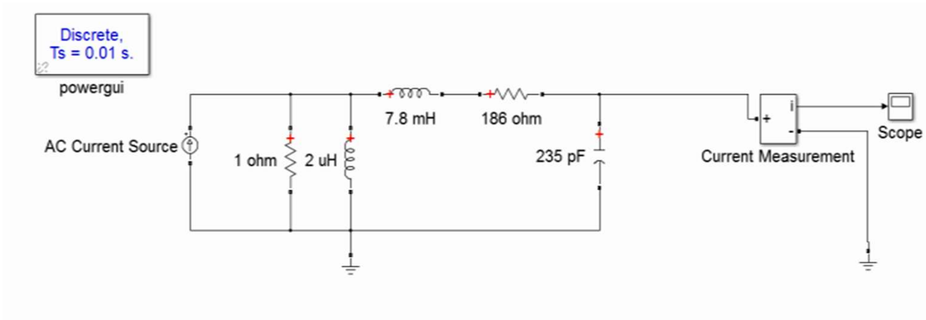
$$V(t) = -M\frac{di(t)}{dt} \quad (1)$$

Where, 'i' is the current which is to be sensed.
The model of the Rogowski coil can be shown as in Fig. 11[6]
From the model in Fig.10, the transfer function can be calculated as [7],

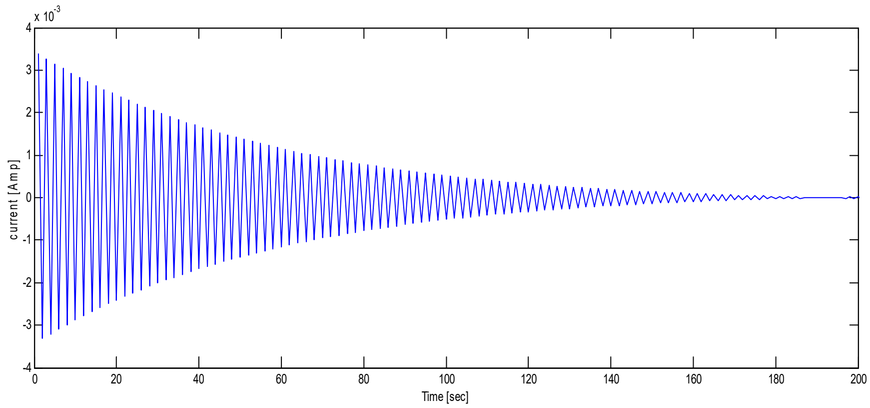
$$H(s) = \frac{V_{out}}{V_{in}} = \frac{Z}{R+sL+sZC_1R+s^2ZC_1L+Z} \quad (2)$$

3.1 SIMULATION OF ROGOWSKI COIL IN MATLAB SOFTWARE

The model of rogowski coil without integrator is shown in Fig.11 with its output.



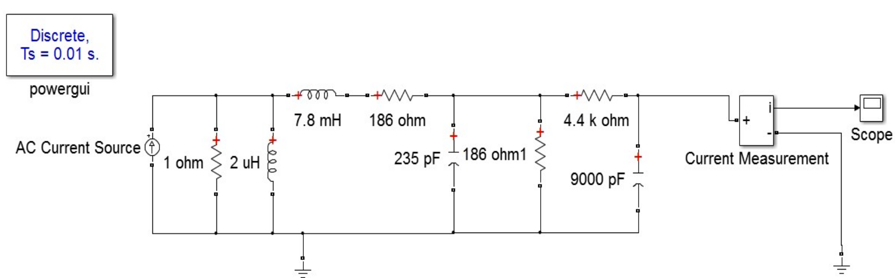
(a)



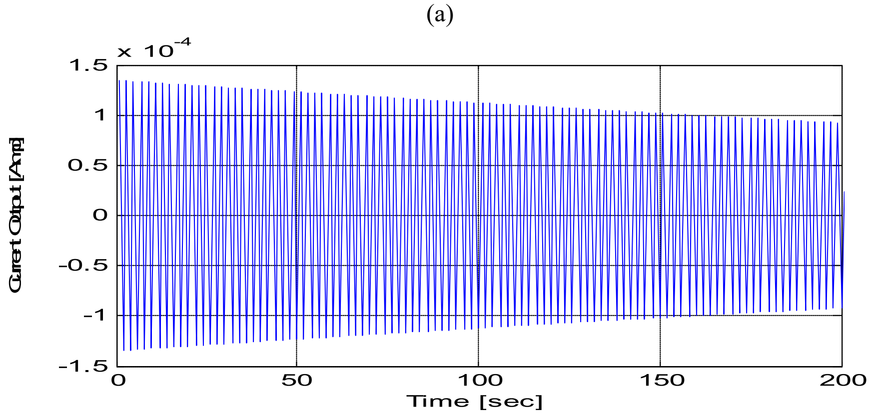
(b)

Figure.11 (a), (b) Rogowski coil circuit without integrator

Integrator circuits are required due to differential input-output relationship of Rogowski coil. The effect of integrator can be shown in Fig.12 (a), (b).



(a)



(b)

Fig.12 (a), (b) Rogowski coil circuit with integrator

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From Fig.11 (b) & 12 (b) the effectiveness of the integrator can be observed.

4. COMPARISON OF CURRENT TRANSFORMER & ROGOWSKI COIL

From the results obtained in Fig. 5,6,7,8 for CT & from Fig. 11 (b) & Fig.12 (b), the comparison of the performance of CT & rogowski coil is shown in Table. 2 [1].

Table.2 Comparison of CT & Rogowski coil

Characteristics	Current Transformer	Rogowski coil
DC response	No	No
Saturation	Yes	No
Weight	High	Low
Robustness	Excellent	Good
External Field Rejection	Excellent	Good
Output	Current	Voltage
Use	Industry Standard	Low
Multiple Loads	Yes	Low

5. CASE STUDY OF ROGOWSKI COIL

In practice two analog outputs are available across the output terminals of Rogowski coil (provided from manufacturer),

1. Standard AC output with an instantaneous value of 3Vrms full scale.
2. An optional DC output with the RMS value of measured current.

5.1 APPLICATION AND PERFORMANCE OF ROGOWSKI COIL IN POWER SYSTEM

In Fig.13 & results in Table.3, it is shown that how the output of Rogowski coils can be coupled with the distance relay. As the fibre optics communication port is provided in the distance relay setup therefore the conversion from electrical to optical signal is needed. Also, the output of Rogowski coil can be directly coupled to distance relay. The formerly mentioned consideration is only the provision.

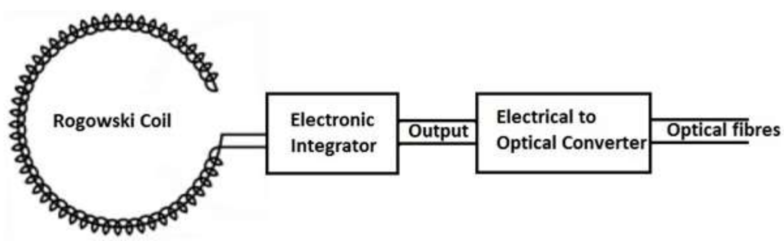

Fig.13 Block diagram of application of Rogowski Coil for protection

Table.3 – Results at the site installed for induction heating application.

	Current Value	Rogowski Output	Integrator Output
1	10KA	10V	20mA
2	7.5KA	7.5V	16mA
3	5KA	5V	12mA
4	2.5KA	2.5V	8mA
5	0A	0V	4mA

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The basis for the above-mentioned consideration is based upon the installed application of Rogowski coil for the induction heating application. It is coupled at the site as shown in Fig.14 (a).

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The converter along with Rogowski coil acts as a transducer. The converter coupled to above Rogowski coil is shown as in Fig.14(b)

The installation of the converter needs the input supply of 230V AC. The relevant parameters such as ratings are normally provided by the manufacturer.
From which it is clear that the same Rogowski coil can be coupled around the transmission line. As the connection of current transformer needs the terminal block, in case of Rogowski coil there is no need of such blocks. It can be directly connected with the help of shielded cable.[8]

(a) (b)

Fig.14 Installation of Rogowski coil and integrator for induction heating

6. CONCLUSION

From the results performance characteristics as shown in respective tables it is apparent that Rogowski coils overcome most of the limitations of the existing devices such as CTs. Further Rogowski coils being air core the problem of saturation doesn't arise. Thus, Rogowski coils are found to give effective devices for sensing the signals to relays.

7. REFERENCES

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