Accurate Current Measurement Transducer for Relaying Purpose

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ABSTRACT:- *The power system monitoring and protection normally makes use of different type of relays. These relays basically operate with signals drawn from system such as voltage and current those are sensed in the current practice by using transducers like current & voltage transformer. These devices suffer a problem of saturation & affect the desired performance of relay & hence fail to operate. Also capacitive voltage transformer suffers the problem of transients. This limitation can be overcome by using a rogowski coil having an air core system.*

This paper while addressing problems associated with current transformer & CVT also presents the effectiveness of rogowski coil as an advanced solution for relaying system by using MATLAB & PSCAD software.

Keywords:- Capacitive Voltage Transformer, CT Saturation, Current Transformer, Rogowski coil etc.

I.   INTRODUCTION

Traditional relaying equipment are provided with signals from iron cored voltage and current transformers (CT) having non-linear magnetizing reactance. CT primary currents can change from load currents to high fault currents. To avoid saturation, CTs are designed to operate at load currents on the lower portion of the magnetizing branch of V-I curve's linear region. It is desirable that CT's operate on the linear region without exceeding the saturation voltage even for fault currents. [3][7]

Capacitive Voltage Transformers (CVTs) are the predominant source of voltage signals for monitoring, protection relays and control application at transmission voltage level. Due to transient conditions in power system, the CVT output waveform may not follow closely to its input waveform due to internal storage elements such as capacitive, inductive and non-linear components (saturable magnetic core) as in steady state. They take time to dissipate their stored energy. [2-4][8-9]

Rogowski coils are linear and provide advanced solutions for applications in multifunctional protective relaying. These schemes require fewer relays and current sensors than conventional designs, response times to faults are faster and adjustments to load and/or power system configuration changes can be easily made. The rogowski coil system is immune to external magnetic fields. It is simple, user friendly, requires less wiring and space and can provide metering class accuracy. [10]

So, its use can be made for the power transmission lines. The topics in the paper address the problem of CT & CVT; it also mentions the effectiveness of rogowski Coil for relaying function.

II.   CONVENTIONAL TRANSDUCERS

2.1 CURRENT TRANSFORMER

In an electrical power system current transformer & voltage transformers are most commonly used as a transducer. The Fig.1 (a) is related to the resistive burden. Fig.1 (b) is with respect to non saturated transformer. [3]

Also two main errors are present inside the current transformer as follow [5],

1.   **Ratio error**   2.   **Phase angle error**

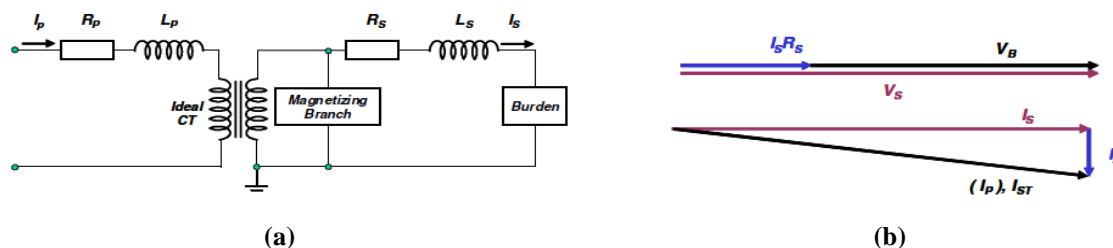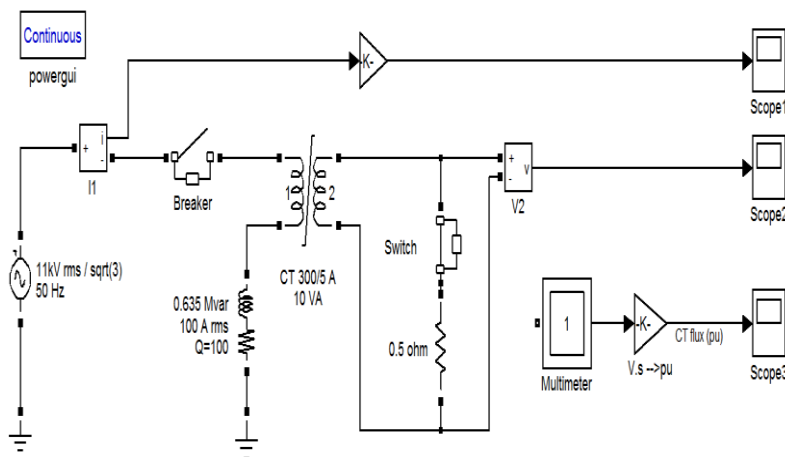(a)   (b)

Fig.1 (a) Equivalent circuit diagram of current transformer, (b) Vector diagram of current transformer
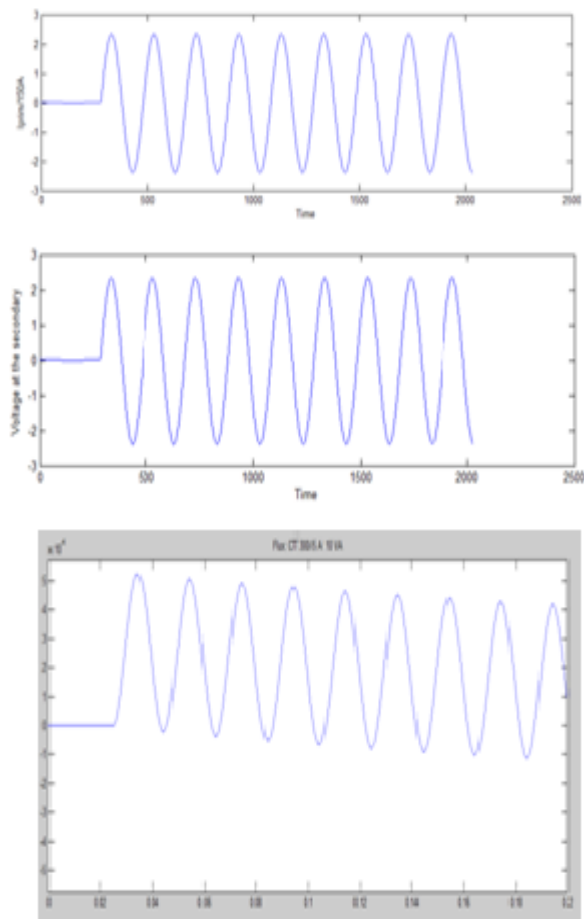
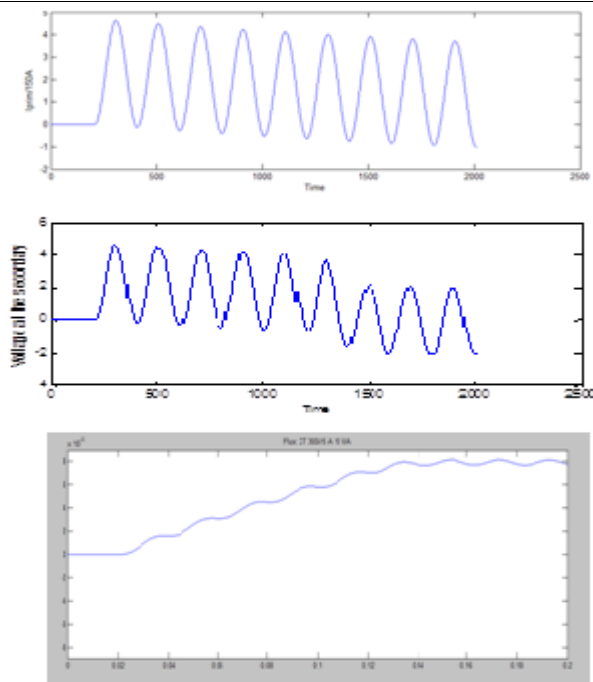The simulation diagram can be drawn using MATLAB software [6] as in Fig.2

Fig.2 Simulation of current transformer saturation

2.1.1 Normal operation:-

In this test, the breaker is closed at a peak of source voltage (t = 1.25 cycle). This switching produces no current asymmetry as shown in Fig.3 (a). Also the flux waveform can be shown as in Fig.3 (c).
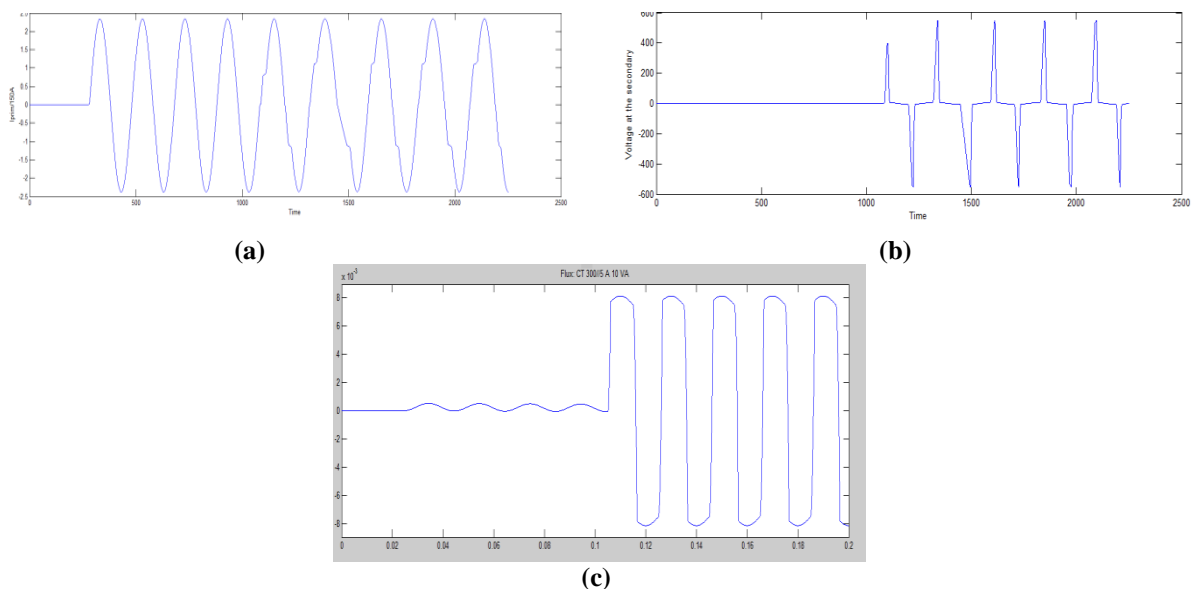
Fig.3 (a) I_{prim}/150 (A), (b) Voltage at secondary side V_2(V), (c) CT Flux
Fig.4 (a) I_{prim}/150 (A), (b) Voltage at secondary side V_2(V), (c) CT Flux

2.1.2 CT saturation due to current asymmetry:-
Now, change the breaker closing time in order to close at a voltage zero crossing, t = 1/50 s is used. This switching instant will produces full current asymmetry in the shunt reactor as shown in Fig.4 (a). Also the flux waveform can be shown as in Fig.4 (c).

2.1.3 Overvoltage due to CT secondary opening
After reprogramming the primary breaker closing time at t = 1.25/50 s (no flux asymmetry) and changing the secondary switch opening time to t = 0.1 s. After starting the simulation the large overvoltage is produced when the CT secondary is opened as shown in Fig.5 (a). The flux has a square wave shape as shown in Fig.5 (c).


(a)

(b)

(c)
Fig.5 (a) I_{prim}/150 (A), (b) Voltage at secondary side V_2(V), (c) CT Flux

2.2 CAPACITIVE VOLTAGE TRANSFORMER

Capacitor voltage transformer is used for protective relaying purpose and monitoring purpose. The monitoring equipment is required low voltage to operate. In purpose to achieve power supply requirement for monitoring equipment, capacitor voltage transformer is used to step down the high voltage to low voltage. The high voltage of transmission line is converted to standard low voltage for metering, protection and controlling high voltage network [4] [8] [9]

The system model of 132 kV, 50 Hz is developed as in Fig.6 whereas the results are shown in Fig.8 & 9. It can be seen from Fig.7 voltage & current is sensed by CVT & CT. From the results in Fig.8 & 9 transient behaviour of CVT & CT can be seen. These transients can affect the performance of protective devices such as relays. So as to avoid the malfunctioning of the devices rogowski coils are proposed as the solution to magnetic core transducers like CT & CVT in the next section.
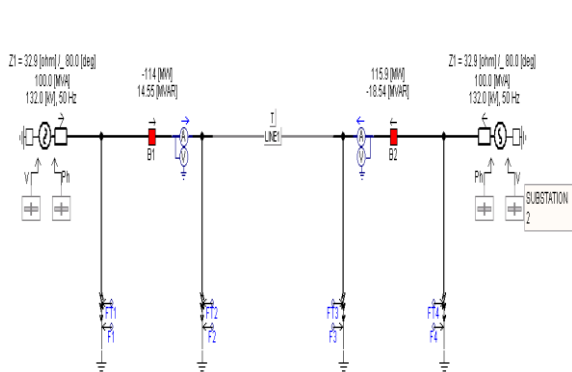
Fig.6 Simulation of 132 kV 50 Hz system model system
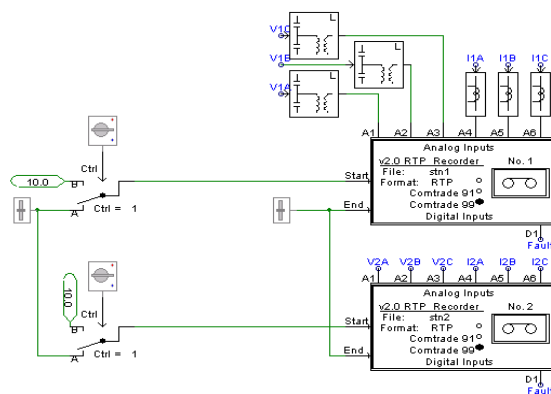
Fig.7 Transducer scheme applied for simulation

III. ROGOWSKI COIL

Generally rogowski coils are torroidal 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. [10][12]
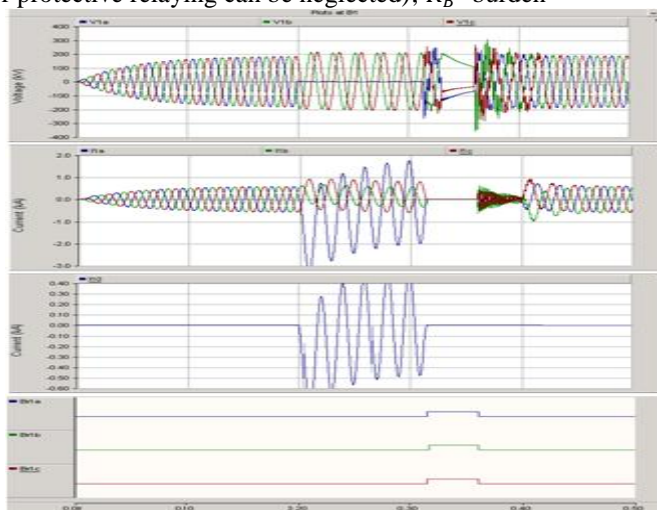
The circuit diagram & vector diagram of rogowski coil is as shown in Fig.10 [3],

Where,
Rs, Ls= secondary winding resistance and self inductance
M= mutual coupling
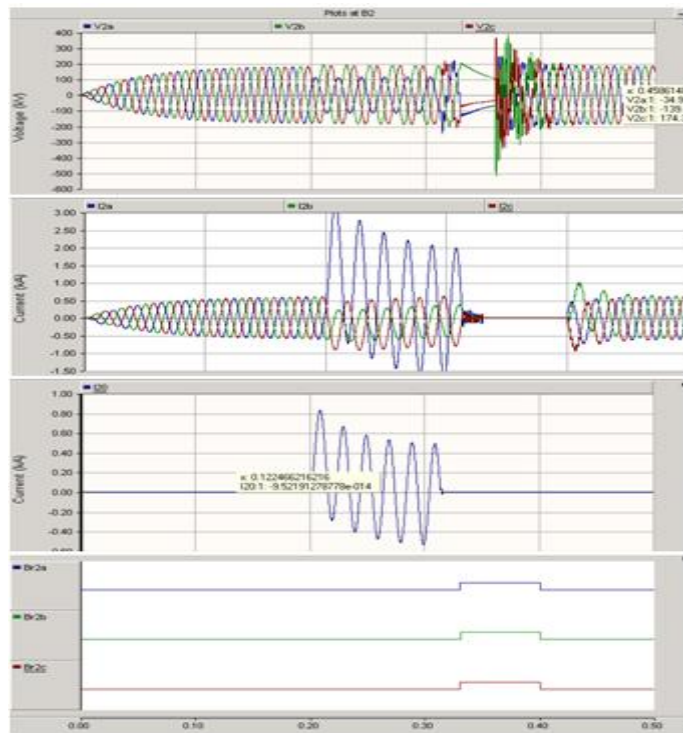C_s= stray capacitance (for protective relaying can be neglected), R_B=burden

Fig.8 Plots at Breaker B1
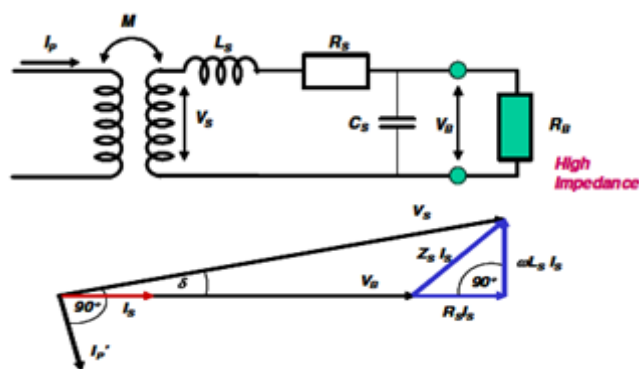**Fig.9 Plots at Breaker B2**

Fig.10 Circuit & Vector diagram of rogoeski coil

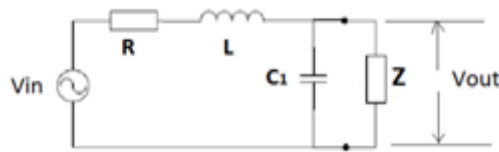To prevent the effect of nearby conductor which is carrying high current, the windings are placed in opposite direction. This cancels electromagnetic fields coming from outside the coil loop.
The output of the rogowski coil can be given by the equation (1):

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

Where,
'i' is the current which is to be sensed.
The model of the rogowski coil can be shown as in Fig. 11 [11]

Fig.11 Equivalent model of rogowski coil

From the above model in Fig.11, the transfer function can be calculated as in equation (2): [13-15]

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

3.1 SIMULATION OF ROGOWSKI COIL IN MATLAB SOFTWARE
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).
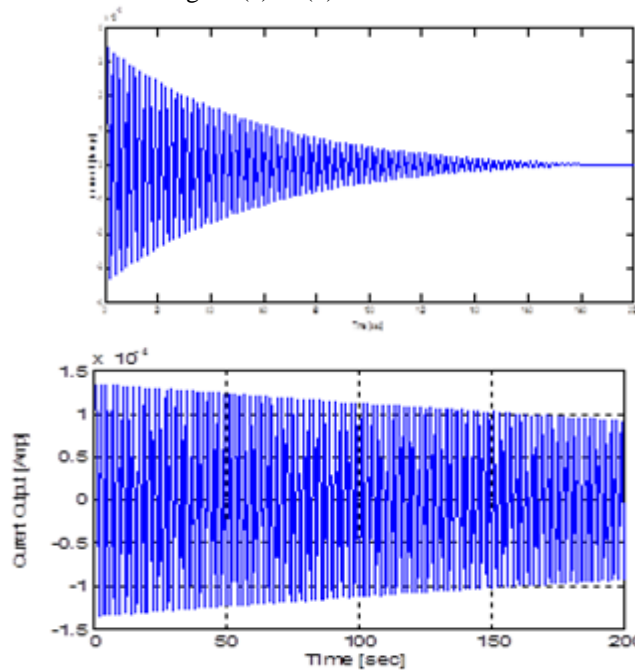
(a) Rogowsk coil output without integrator   **(b) Rogowsk coil output without integrator**
Fig.12 Effect of Integrator

3.2 COMPARISON OF CURRENT TRANSFORMER & ROGOWSKI COIL
Table-1 compares the current transformer & rogowski coil [12].

Table-1- Comparison between current transformer & rogowski coil

	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

IV.   CASE STUDY OF ROGOWSKI COIL

In practice two analog outputs are available across the output terminals of rogowski coil (provided from manufacturer), [13-15]
1.   Standard AC output carrying out instantaneous value with 3Vrms full scale.
2.   An optional DC output carrying out the RMS value of measured current.

The output of the converter is available in two ranges 0-20mA (standard) & 4-20mA (on request). In this work 4-20mA range converter is used which can be observed in Table-2.

PERFORMANCE OF ROGOWSKI COIL AT 50 Hz:-

Table-2 Results of Rogowski coil

Sr No.	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

4. APPLICATION OF ROGOWSKI COIL IN POWER SYSTEM

        From Table-2, it is shown that how the output of rogowski coils can be coupled with the distance relay in Fig.13. 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.
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. [1][15]
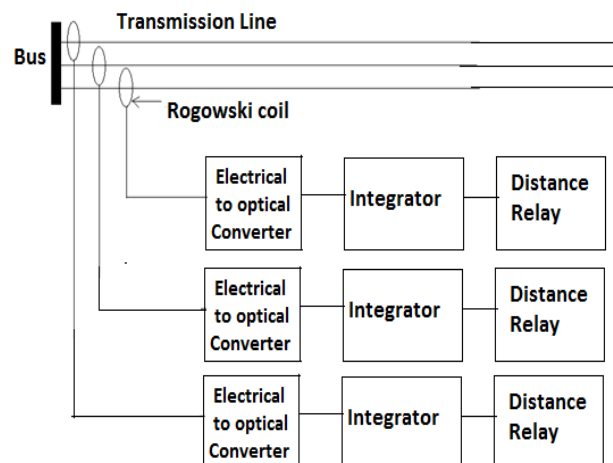
Fig.13 Block diagram of application of rogowski Coil for protection

        The converter along with rogowski coil acts as a transducer. The converter coupled to rogowski coil shown in Fig.14 is as in Fig.15 respectively.
        The installation of the converter needs the input supply of 230V AC. From the manufacturer the resistances are provided along with the rogowski coil & converter. These resistances are generally called as damping resistances.
        From the above mentioned explanation, 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.

Fig.14 application of rogowski coil for induction heating   **Fig.15 Converter installation at the site**

V. CONCLUSION

The well known application of rogowski coil to the arc furnace, induction heating can be similarly applied around the transmission line conductor. This work is mainly related to show the effectiveness of the rogowski coil for the accurate current measurement application. The advantage of air core is the main concern in the case of rogowski coil. Also as it is not magnetising core so it may not have errors like in CT & CVT.

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