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Comparative Performance of Conventional Transducers & Rogowski Coil for Relaying Purpose

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ABSTRACT— *The power system monitoring & protection normally makes use of different types of relays. These relays basically operate with signals drawn from system such as voltage & current those are sensed in the current practice by using current transformer & capacitive voltage transformer. These devices suffer problems such as ratio & phase error along with saturation which affects the performance of relay & hence fail to operate. This limitation can be overcome by rogowski coil having air core.*

This paper while addressing the problems related to current transformer & capacitive voltage transformer using PSCAD software also presents effectiveness of rogowski coil by experimental validation.

Keywords— Current Transformer, Capacitive Voltage transformer, Ratio error, Saturation, Rogowski Coil etc.

1, INTRODUCTION

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.

Therefore Rogowski coil can be used as a transducer which provides advantages such as air core, linear output, less expensive, over conventional CT. [1][3][9]

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. [6-8]

Theoretically, the output waveform of a CVT should be an exact replica of the input waveform under all operating system conditions. This requirement can easily be satisfied under steady-state condition. However, electric power systems are subjected to many types of disturbances that results in electric transients due to lightning, system fault, line energization and deenergisation, switching of inductive or capacitive load. Under such transient conditions, 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) of the CVT. They take time to dissipate their stored energy. Electromechanical relays can cope with unfavorable CVT transients due to their natural mechanical inertia at the expense of slower operation. Digital relays are designed for high-speed tripping and therefore they face certain CVT related transient problem. [6][10]

This paper addresses the issue of CT saturation & CVT transients using PSCAD software package while analyzing CVT ratio error using experimental case study.

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

2, CONVENTIONAL TRANSDUCERS

2.1 Current Transformer

The circuit diagram of CT can be shown as in Fig.1 [1]

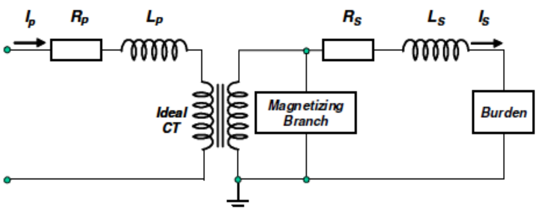

Fig.1.Equivalent circuit diagram of current transformer

Two main errors are present inside the current transformer because of magnetising branch [1] [5]

1. Ratio error
2. Phase angle error

The magnetisation curve of conventional CT can be plotted taking the overvoltage test on the respective specimen.

Table-1 provides the results of the 2000/1 A CT from which magnetisation curve can be plotted as in Fig.2.

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		

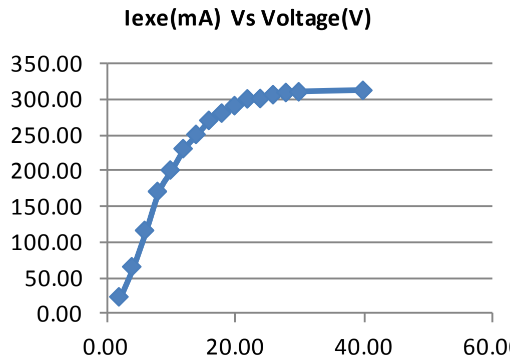

Fig.2. Magnetisation curve of 33kV, 2000/1A CT

From Table.1 & Fig.2, the saturation of conventional CT can be observed. The saturation of CT leads to the malfunction of relays. [2][3]

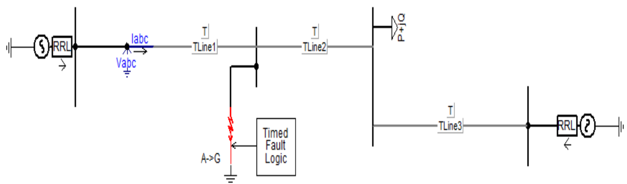

Fig.3. AC System model

In Fig.3 PSCAD software model of 220kV, 200km, 50 Hz is developed to show the effect of saturation.

The following can have a significant impact on CT saturation and should be given due consideration in a simulation study [2]:

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]

The saturation behaviour of CT can be analysed for above mentioned conditions with the help of flux waveforms as shown in Fig.4.

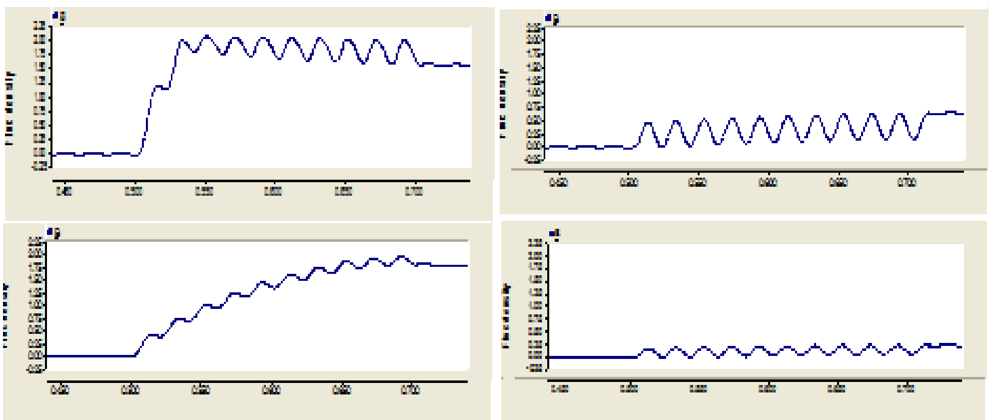

Fig 4 Waveforms of CT flux for (a) DC offset present condition (b) DC offset absent condition (c) Impact of secondary burden of 2.5 Ω (d) Impact of secondary burden of 0.5 Ω

2.2 Capacitive Voltage Transformer

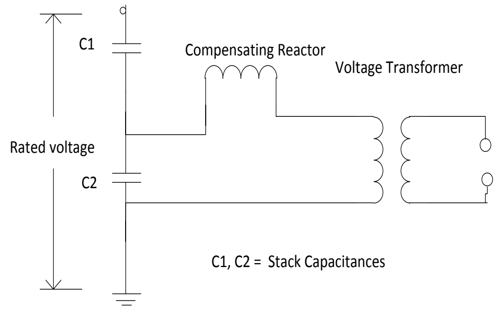

Fig.5.Equivalent circuit diagram of Capacitive voltage transformer

Basically, the CVT model as shown in Fig.5 is composed of Capacitive Voltage Divider (C1 and C2), Step-down Transformer (SDT), and Compensating Series Reactor (SR). It also includes Ferro resonance Suppression Circuit (Cf, Rf, Lf), and Overvoltage Protection devices (Vgap, Rgap).[6][7]

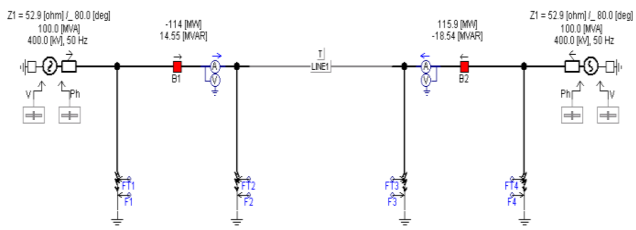

Fig.6 400 kV system model using PSCAD

The system model shown in Fig.6 is simulated to show the effect of CVT transients. In this model CT & CVT are used as transducers using fault conditions at four different locations.

Details of the CVT used for the simulation:

(i) Lower stack capacitance- 91252 pF (ii) Upper stack capacitance- 4583 pF

(iii) Compensating Reactor- 1.1 H

2.2.1 Fault applied at F1, F2, F3, F4 location-

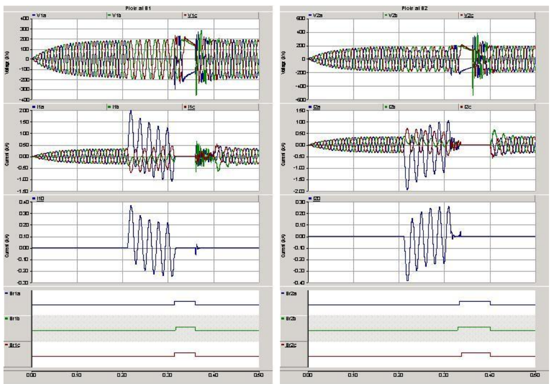

Fig.7 Output waveforms of CVT & CT at F1 location for A-G

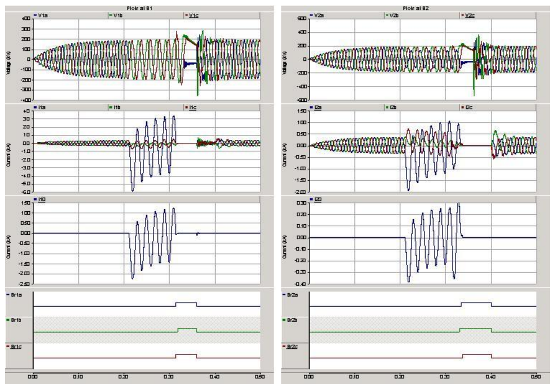

Fig.8 Output waveforms of CVT & CT at F2 location for A-G fault

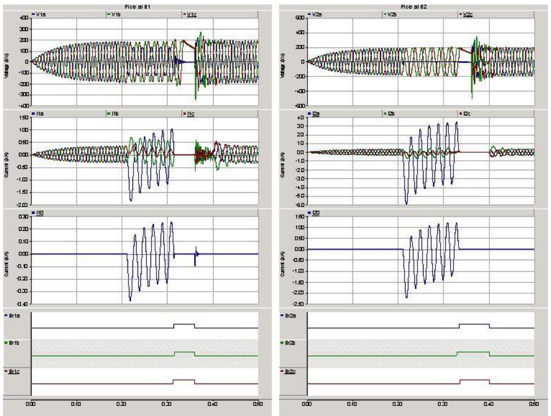

Fig.9 Output waveforms of CVT & CT at F3 location for A-G fault

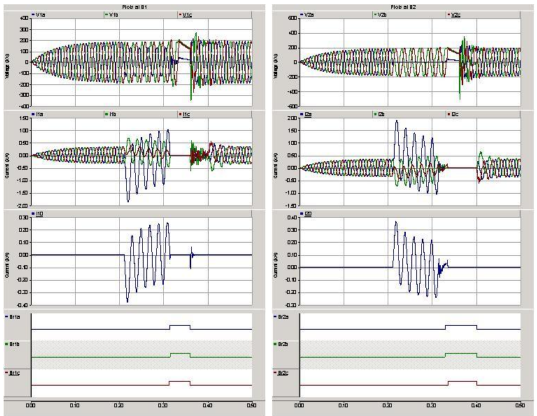

Fig.10 Output waveforms of CVT & CT at F4 location for A-G fault

From Fig. 7, 8, 9, 10, the severity of the CVT transients can be observed at different fault locations which may lead to malfunctioning of relay.[8][10]

2.3 Case Study of CVT Ratio Error

According to the calculation of CVT ratio,

$$CVT\ Ratio = \frac{Primary\ Voltage\ CVT}{secondary\ voltage\ of\ VT}$$

$$CVT\ Ratio = \frac{400/\sqrt{3}}{\frac{110}{1000}/\sqrt{3}} = 3636.36$$

For the purpose of testing 1kV input to the CVT was applied which must result an output of 275 mV. If it deviates from the standard value it may affect the performance of protective devices too.

The results obtained as per the ratio error formula for the line under consideration have been shown in above table. The results show that the ratio error of CVT exceeded the limits. Such kind of error may occur due to stack capacitor element failure & internal short circuit due to internal flash over may be due to ageing effects.

Therefore for the calculation of ratio error, it can be tabulated as in Table-2

Where

V_{prim}= Primary voltage

V_{sec} = Secondary Voltage

Table-2 Ratio error of CVT

V_{prim} at CVT (kV)	V_{sec} at VT (V)	Ratio	Specified Ratio Error (%)	Specified V_{sec} of CVT for 1 kV (mV)	Actual V_{sec} of CVT for 1 kV	Actual ratio error at the field (%)
400	110	3636.36	5	275	291	5.81
400	110	3636.36	5	275	292	6.18
400	110	3636.36	5	275	295	7.27
400	110	3636.36	5	275	294	6.91
400	110	3636.36	5	275	292	6.18

400	110	3636.36	5	275	293	6.55

3, 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 as shown in Fig.11. [1][3][4]

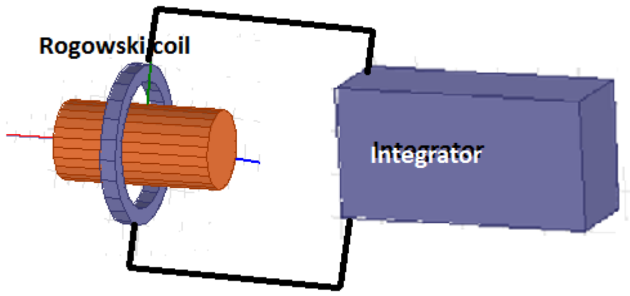

Fig.11 Model of Rogowski Coil

The output of the rogowski coil can be given by the equation, [1]

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

Where,

'i' is the current which is to be sensed.

3.1 Case Study of Rogowski Coil

In practice two analog outputs are available across the output terminals of rogowski coil (provided from manufacturer), [11][12]

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

3.2 Application of Rogowski Coil in Power System

The application of rogowski coil for the induction heating application is coupled at the site as shown in Fig.12.

The converter along with rogowski coil acts as a transducer.

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.

Fig.12 Application of rogowski coil for induction heating

3.3 Performance of Rogowski Coil at 50 Hz:

Table-3 provides results of the prototype installation for induction heating conductor application

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

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. 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 & CVTs. 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. The application of rogowski coil is proposed for the over-current relay in upcoming research.

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6,BIOGRAPHY

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