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Design of Differential Protection Scheme Using Rogowski Coil

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ABSTRACT

The following article presents brief information regarding 'Differential protection scheme of power transformer using Rogowski Coil'. The basic intention of this article is to create a general awareness concerning the concept of Rogowski Coil Technology. The first section introduces you to the concept of Rogowski coil and Differential protection Scheme, the second section emphasises the designing and constructional features of Rogowski coil. The last sections covers the difference between the conventional CT's and modern flexible Rogowski coil. The reader is encouraged to go through the references listed in the last section if further information is required pertaining to the article.
Keywords: RC (Rogowski coil), CT(Current Transformer), Power Transformer, Differential Protection

I. INTRODUCTION

Rogowski coils, also called air-cored coils, evolved from a simple solenoid structure. Early applications of the technology were restricted because the low output voltage was inadequate to drive the measuring equipment. As the sensitivity of measuring equipment improved, Rogowski coils began to be used in a variety of specialized ac current monitoring applications.

Rogowski coils can overcome many of the limitations of conventional iron core CT's. The new flexible Rogowski coil allow the users to easily install and measure the current in the tight spaces that may be inaccessible with conventional iron core CT's. Since these coils come up with variety of diameters and current ranges it allows the user to carry only one lightweight flexible probe for a wide range of applications. Because of all these advantages of this coil it is the ultimate replacement of conventional iron core CT's.

This article briefs about advance relay protection systems that incorporate Rogowski Coil current sensors and multifunctional relays. Rogowski coil are accurate and do not saturate, making it possible to set protection level to lower fault current thresholds while preserving high stability of the scheme for through faults. This reduces the stress on the protected equipment during faults. Even though Rogowski Coils are low power sensors, the protection system is immune to external electromagnetic fields. The schemes are simple, user friendly and require less wiring and space than conventional solutions.

The CT is a non-linear element that saturates whenever flux inside the CT core exceeds the saturation level, resulting in distorted and reduced secondary current that may cause relay non operative. However, CTs cannot saturate immediately upon the fault inception. The time that it takes to begin the CT saturation is called time-to-saturation. Manufacturers use different algorithms to achieve proper relay performance during the CT saturation or design relays to operate prior to the CT saturation. Remnant flux in the CT core can also cause relay misoperation. To reduce remnant flux, gapped core CTs have been used. Traditional Rogowski coil consist of a wire wound on a nonmagnetic core. The coil is then placed around conductors whose currents are to be measured. The output voltage is proportional to the rate of change of measured current.

$\left[V(t) = -\mu_0\, n\, S \frac{\mathrm{di(t)}}{\mathrm{dt}} = -\mathrm{M} \frac{\mathrm{di(t)}}{\mathrm{dt}}\right]$----------- (1)

Where μ_0 is the magnetic permeability of air, n is the winding density (turns per unit length), S is the core cross-section area, and M is the mutual inductance.

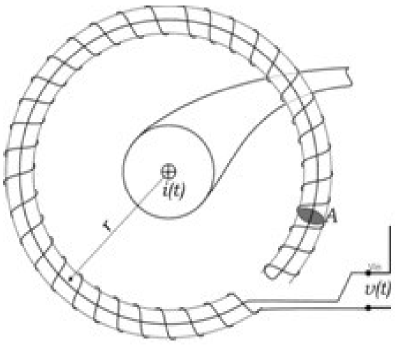

Figure 1. Schematic Representation of Rogowski coil

A Rogowski Coil signal is a scaled time derivative, di(t)/dt of the primary current instantaneous signal. To use such signals with phasor-based protective relays, signal processing is required to extract the power frequency signal. This may be achieved using one of the following methods:

(a)-Integrating the Rogowski Coil output signal or,
(b)-by using a non-integrated signal and perform signal processing to adjust magnitudes and phase shift signals 90^0. For an ideal RC, measurement accuracy is independent of conductor location inside the coil loop (See Figure 2.1). To prevent the unwanted influence of nearby conductors carrying high currents, RCs are designed with two wire loops connected in electrically opposite directions. This cancels electromagnetic fields coming from outside the coil loop. One or both loops can consist of wound wire. If only one loop is constructed as a winding on a non-magnetic core, then the second wire loop can be constructed by returning the wire through or near this winding. If both loops are constructed as windings, then they must be wound in opposite directions. In this way, the RC output voltage induced by current from the inside conductors will be doubled. Rogowski Coils can also be connected in series to increase the output signal.

II. DESIGN OF ROGOWSKI COIL

Rogowski coil current sensors may be design with different shapes such as rectangular, circular, and oval. These coil sensors can also be designed as non- split style or alternatively as split core construction which can be opened alternatively to assemble around a conductor that can't be opened. The sensors may be designed using rigid or flexible materials.

The coil is placed around the conductors whose currents are to be measured as shown in (Figure 2.1). The coil can be designed using PCB's as a non split type of core. In differential protection, two identical RC's are used each PCB contain one imprinted coil wound in opposite directions (clockwise and counter-clockwise) (See fig. 2.2).

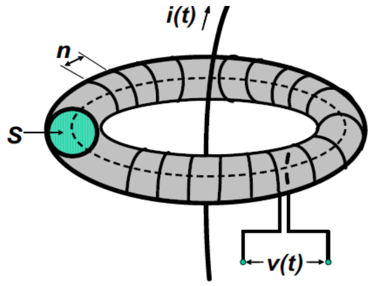

Figure 2. Internal Design of Rogowski coil

The top and bottom sides of each PCB are imprinted to form a coil around the centre of the board. The conductive imprints on the upper and lower sides of the PCB are interconnected by conductive-plated holes. High precision is obtained because the manufacturing process is computer controlled, providing accurate geometry of the coils. New RC designs use multi-layer PCBs, which provides higher accuracy and more proficient manufacturing.

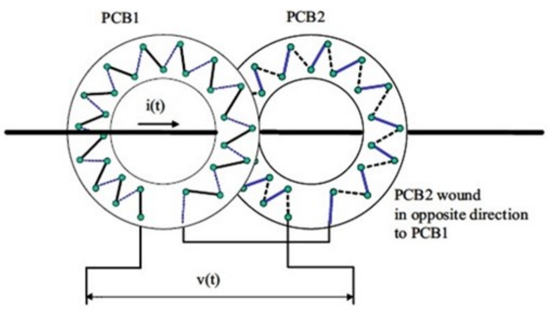

Figure 3. Rogowski Coil embedded on PCB

PCB Rogowski coils can be designed with different shapes to adjust for the application and be designed in split-core styles for installation without the need to disconnect primary conductors. All three phase conductors or parallel conductors that carry heavy currents can be designed in oval shape split core style. It has four PCB half loops in split core style. The Rogowski Coil constructed have two loops imprinted winding in one direction while other two loops in opposite direction.

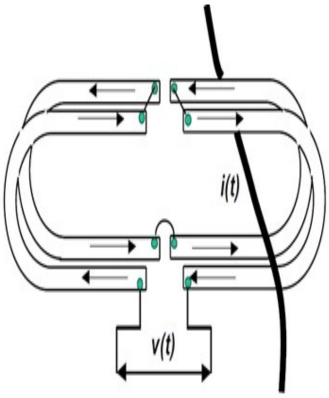

Figure 4. Split Core type of Design by using PCB

For an ideal Rogowski coil, the mutual coupling between the coil and the primary conductor is independent of the conductor location inside the coil loop. To prevent the influence of nearby conductors carrying high currents, Rogowski coils are designed with two wire loops connected in the electrically opposite direction to cancel all electromagnetic fields coming from outside the coil loop. The first loop is formed by the advancing winding pitch. This other loop can be formed by returning the wire through or near the winding or by adding an additional winding wound in the opposite direction over or near the existing one.

Table 1. Performance Type Characteristics of Bushing Type CTS and Rogowski Coil

Characteristic	**Bushing Type CT's**	**Rogowski coils**
Metering	Typically, two CTs are used, one for metering and one for protection	One metering class Rogowski coil can be used for both metering and protection
Saturation	For symmetric currents, saturation starts near 20-times rated current and rated burden. For asymmetric currents, saturation can start at several times rated current depending on the primary system X/R value.	Does not saturate (linear).
High frequency range	Typically, up to 50 kHz.	Up to 1 MHz or greater
Remanence	Remanence is possible	No remanence (No iron core)
Secondary wiring	Requires heavy gauge conductors with shorting type terminal blocks	Shielded twisted pair cable with connectors (no shorting blocks needed)
Size and Weight	Large and heavy	Small and light
Different protection schemes	Several CTs with different V-I characteristics may be required to cover multiple protection schemes.	One RC can be used for multiple protection schemes.
Personnel Safety	Open secondary can generate dangerous voltages.	Safe (open secondary voltages are small)

III. APPLICATIONS OF ROGOWSKI COIL

Rogowski coils may replace conventional current transformers for metering and protection. **IEEE** document **C37-235** provides guidelines for the application of Rogowski Coils used for protective relaying purposes **[3].**

The following section elaborates the applications of Rogowski coil.

1. EAF Power Transformer Protection

In steel facilities, the electric arc furnace **(EAF)** transformer is one of the most critical pieces of electric power equipment in the plant. The differential protection system presented here uses Rogowski coil current sensors, and multifunction relays designed to accept the RC secondary signals. Because of high secondary currents exceeding 50 kA, the EAF transformer secondary has been designed with multiple parallel windings.

2. Power and Power Quality Monitoring

Flexible Rogowski based current probes have gained rapid acceptance in the power monitoring and power quality industry. The advantages of a flexible measurement head and light weight are important factors to those involved in field studies of power and power quality. The advantages of bandwidth and measurement range provide the user with confident measurement of transients and harmonics when used with a range of power quality analyzers, power recorders and data loggers. The applications for power quality measurements range from monitoring office equipment to utility distribution equipment.

3. Rectifier Monitoring

Although Rogowski coils are insensitive to dc they can be used to measure pulse dc current. Rogowski coils have been used in high power rectifiers to measure pulse dc from six phase legs. These currents can then be summed to determine the total rectifier current. Each leg in a rectifier may be constructed of several rectifier elements connected in parallel. Rogowski coils have also been used to determine the current distribution between the parallel paths.

4. Bus Bar Protection

Scheme applied for bus bar protection is similar to the traditional scheme using linear couplers. The protection scheme must meet the criteria that for normal condition and external fault condition, the voltage fed to the relay is small. During fault through the bus bars, the secondary voltage must exceed the pickup value causing the relay to operate.

5. Relay Protection

Microprocessor-based relays do not accept the 1A or 5A signal directly from a CT secondary but require low voltage inputs in the range of 5V. In a typical application the signal from the CT secondary is transformed to the low voltage level by the insertion of scaling transformers. The low voltage output of a Rogowski coil can be connected directly to the relay voltage input eliminating the need for scaling transformers. Any required amplification of the low voltage signal can be done during integration of the signal.

IV. CONCLUSION

Rogowski Coil current sensors are accurate, linear (do not saturate), and immune to external electromagnetic fields. These coils can provide superior differential protection for substation bus bars, transformers, and generators. The physical dimensions and weight of RC are much smaller than conventional current transformers, while providing simpler and more reliable protection.

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