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Protection of 3-Phase Induction Motor Fed from 3-Phase Inverter Using Rogowski Coil Transducer

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Abstract - *This study presents a technique for protecting a field-oriented control (FOC) system using a Rogowski coil. The proposed method depends on measureing the current that pass through switches inverter (IGBTs) using a Rogowski coil to protect switches for over current. This technique describes the theory and design of Rogowski coil ,as well as the Rogowski coil protection of IGBTs. The obtained experimental results give another evidence for the validity and efficacy of the proposed Rogowski coil design in protecting the system from high impulse currents An evaluation of the proposed measurement process was theoretically carried out using power simulation program (PSIM).*

Key Words: *induction motor (IM);Field oriented control (FOC); Rogowski coil; current transducer*

1. INTRODUCTION

Induction motors are pre_ferred for most of the industry applications due to the limitations of commutation and rotor speed in DC drives. The induction motor is brushless and may be controlled using simple ways that do not require a shaft position transducer. Because there is no shaft position feedback, the motor is only stable if the load torque does not exceed the breakdown torque. It is conceivable for oscillatory instabilities to occur at low speeds. To solve these constraints, field-oriented or vector control has been developed, in which the phase and amplitude of stator currents are adjusted in order to maintain the optimal angle between stator mmf and rotor flux. This control works by converting a three-phase time and frequency dependent system into a two-coordinate (d and q axis) time invariant system. These projections result in a configuration that resembles that of an independently stimulated DC motor control. Field orientation, on the other hand, necessitates the use of either a shaft position encoder or an in-built control model with motor-specific characteristics. In general, there are two types of field oriented control methods. 1. Field-oriented direct control 2. Control of an indirect field.

The field Oriented Control was previously developed for high-performance motor applications that must work smoothly over the whole speed range, generate full torque at zero speed, and have great dynamic performance including quick acceleration and stopping. Nevertheless, due to FOC's advantage in motor size, cost, and power consumption discount [7],[4], it is becoming increasingly appealing for lower performance applications as well. The downside of this system (FOC) is the lack of a protective mechanism against overcurrent due to mistakes, hence the Rogowski coil is recommended as the best solution for this problem. The Rogowski coil is the ideal choice for high current measurement in high-power laboratories because it is highly reliable as a current sensor for power system protection and monitoring [10]. Walter Rogowski invented it in the nineteenth century, and it is still frequently utilised in a variety of applications today. Some applications include measurements of pulsed and impulsive currents [7], power frequency current, and monitoring of insulated gate bi-polar transistors (IGBTs), diodes, and capacitors in power electronic converters. The Rogowski coil is widely used because of its benefits over other measurement devices such as current transformers (CTs). Because there is no core saturation, the Rogowski coil offers the benefit of linearity. As a result, it is made of turns twisted around a non-magnetic core. It is generally understood that core saturation is a significant drawback in CTs, causing difficulties in determining fault distances in electric power systems when utilised with distance protection relays [6], [8]. Further advantages of Rogowski coils over CTs are their small weight, low cost, and decreased size [8].

In fact, the design of the Rogowski coil has piqued the curiosity of many experts in recent years. As a result, the Rogowski coil design is tailored to a specific purpose. One of these breakthroughs is the design of a Printed Circuit Board (PCB) Rogowski coil [18]-[21]. As a result, to be more appropriate for such applications, a PCB Rogowski coil is built to monitor currents for IGBTs and capacitors of power electronic converters [15], [16]. To monitor currents through a switch inverter (IGBT), typical Rogowski coils should be utilised.

To measure current through a switch inverter (IGBT), a typical Rogowski coil should be utilised. As indicated in Figure 1, each coil is wrapped around the switch inverter where the current is to be measured. In reality, protecting switching inverters introduces other challenges, such as the expensive cost of protective equipment. Also, it cannot sustain indefinite short-circuit currents. Hence, in our research, we present a low-cost Rogowski coil design that may be utilised to detect currents across switches inveter without the need for costly sensing devices. Additionally, the same coil may be used to measure currents ranging from few amps to hundreds of kiloamps. Rogowski coils do not measure direct currents, but unlike CTs, they can accurately measure currents when a large dc component is present, can be used to measure current distributions in circuits with very small impedances without affecting the circuits, and can be very small to measure currents in restricted areas where other techniques cannot be used. It is so tiny that it can monitor currents in places where other approaches cannot be employed. It is so tiny that it can monitor currents in places where other approaches cannot be employed.

In this paper, We present a Rogowski coil design for monitoring currents across switching inverters (IGBTs). The Rogowski coil is made up of different coils twisted around a circular non-magnetic core. A current reconstruction approach for measuring currents using IGBTs is presented. The induced EMFs of Rogowski coils when installed around IGBTs are used in the current reconstruction approach. The proposed Rogowski coil design, as well as the existing reconstruction approach, are theoretically validated in terms of accuracy and efficacy. PSIM software was used to implement the Rogowski coil and the current reconstruction approach.

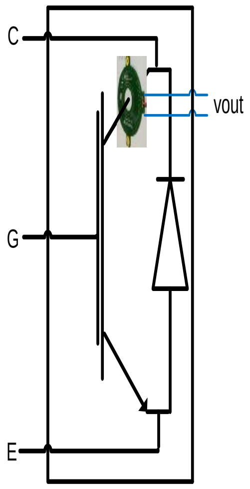

Figure (1): A Rogowski coil built-in inverter switch(IGBT)

2. Protection of IGBTs Using Rogowski Coil

In this section, Rogowski coil Basics is introduced .In additoin to, Equivalent circuit of Rogowski coil is presented. Also, the principle of operation in current measurement and Protection of switches inverter (IGBTs) are explained.

2.1 Rogowski coil Basics

Figure 2 shows a Rogowski coil coiled around a conductor. The equation for the current that flows through the conductor is:

$$i(t) = \mathrm{Im}\sin(wt \pm \theta) \qquad (1)$$

Where i(t) denotes the instantaneous current in A, Im the current amplitude in A, w the angular frequency in rad/sec, is the phase angle in rad, and t the time in sec.

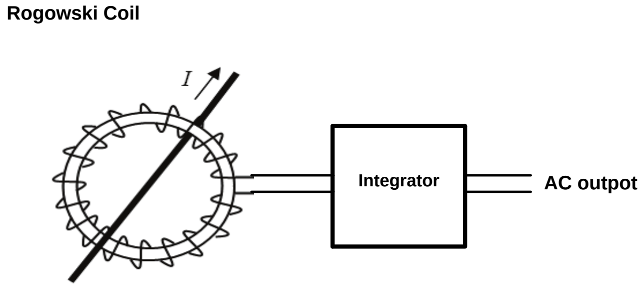

Figure 2. A current-carrying conductor encircles a Rogowski coil.

When a Rogowski coil is put on a current-carrying wire, it creates a voltage e_{in} proportional to the coil's mutual inductance M and the current , $di(t)/dt$ as shown by equations (2):

$$e_{in} = M\frac{di(t)}{dt} \qquad (2)$$

where e_{in} represents the induced EMF in the coil(V) and M represents the mutual inductance (H). As a result, the coil's equivalent circuit, as described in several studies in the literature, depicts the coil with the equivalent circuit depicted in Figure 3. Hence, equations (3) may be used to represent the induced EMF at the coil terminals:

$$e_{in} = L\frac{di}{dt} + Ri + Vo \qquad (3)$$

Indeed, the amplitude and phase angle of the output voltage at the coil terminals varies from the induced EMF, especially at higher frequencies. This is because of the combined effects of coil self-inductance (Lc), coil resistance (Rc), and coil stray capacitance (Co). Equations (4) can be used to represent the output voltage at the coil terminals:

$$Vo = \frac{1}{c}\int i(dt) \qquad (4)$$

From equation (3), the current is derived using the relationship

$$i = c\frac{d(vo)}{dt} \qquad (5)$$

Where i is the current passing through the Rogowski coil winding. Substituting (2) into (4), the induced EMF can be computed from:

$$e_{in} = LC\frac{d^2(vo)}{dt^2} + RC\frac{d(vo)}{dt} + vo \qquad (6)$$

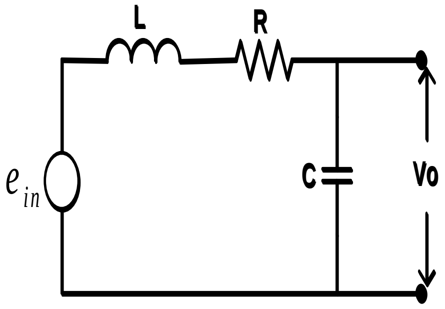

Figure 3. A Rogowski coil's equivalent circuit

2.2 Protection of IGBTs

Figure 2 depicts a control circuit that employs a Rogowski coil to safeguard the FOC system from excessive currents that might cause system damage. Consider the distorted current going through the conductor in figure 4 to clearly explain the selected current reconstruction approach. Hence, when current passing through the conductor induces an EMF in the coil and a voltage at its terminals. Therefore ,through terminals of Rogowski coil we can measure Root main square value (RMS) of the output voltage, where (Vrms) is used as an expression of the current. Hence, fed (Vrms) into the comparator block to compare the actual value of the voltage and reference value, the error signal from this projection feds NOT Gate , so if the output gate is one. It means that the actual value is lower then the reference value, thus the Field Oriented control system continues to work normally, but if the gate output is zero, it means that there is a high in current, so the control circuit will separate the pulses Gates switches inverter.

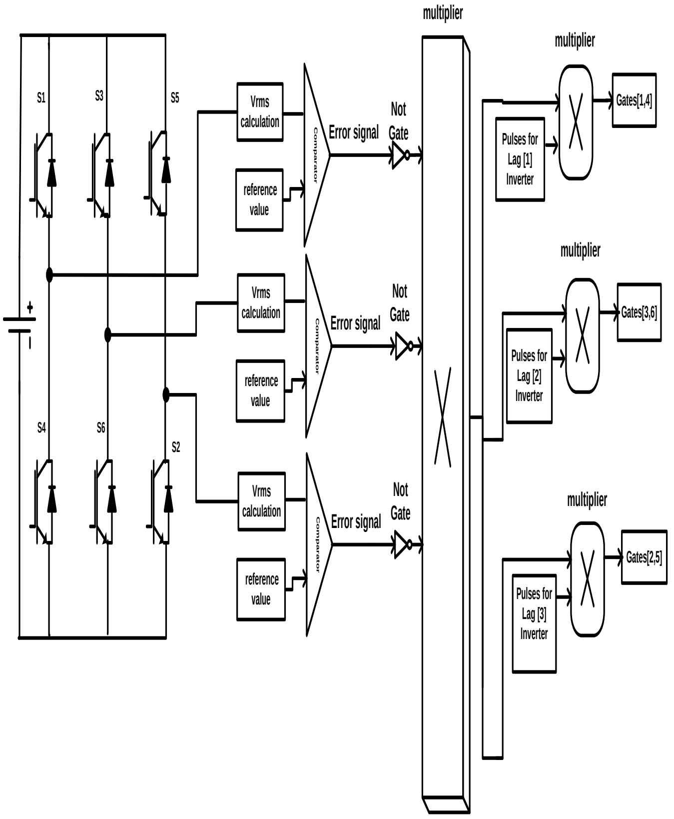

Figure (4): Protection of IGBT by Rogowski coil

3.Simulation and Analysis

The power simulation programme (PSIM) was utilised to conceptually validate the suggested measuring technique. The Rogowski coil was modelled using the analogous circuit depicted in Figure 3 and the accompanying equations(2) and (3). (6).

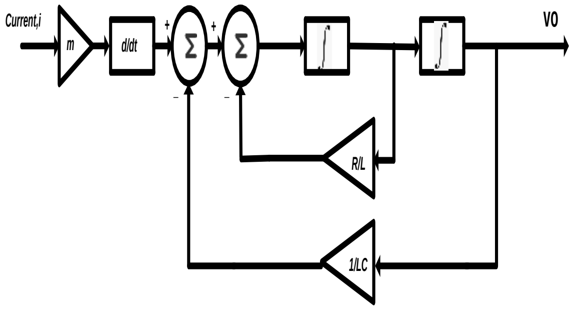

Figure 5: A Rogowski Coil Model in PSIM .

Figure 4 depicts a schematic representation of the modelling and simulation of Equations (2) and (6). Table 1 displays the specifications of the Rogowski coil.

Table 1.
Parameters of the Simulated Rogowski Coil

Parameter	Value	Unit
Coil Resistance(Rc)	4	Ω
Coil Self Inductance (Lc)	5	mH
Mutual Inductance (M)	86.3	μH

The whole FOC system simulation model, and the parameters of induction motor are tabulated in Table II.

Table II
PARAMETERS OF SIMULATED THREE-PHASE INDUCTION MOTOR

symbol	Quantity	Value
Rs	Stator phase resistance	0.294 Ω
Ls	Stator phase self-inductance	0.00139 H
Rr	Rotor phase resistance	0.156 Ω
Lr	Rotor phase self-inductance	0.00074 H
Lm	Magnetizing inductance	0.041 H
P	Number of poles	6
Moment of inertia		0.002 $Kg.m^2$

The simulation examination was carried out to validate the correctness of the drive system's control strategy. The findings were obtained at various operating points, including drive responsiveness due to load variations and speed command step adjustments. Figure 6 depicts three-phase current. Figure 7 depicts the waveforms of the motor phase and current. Figure 8 depicts the 1.5-second step shift in speed from 1000rpm to 800rpm. It is demonstrated that the rotor is smoothly accelerated to obey the speed reference command with virtually zero steady state error. Figure 9 depicts the torque created by the motor. The torque increases and decreases in proportion to the step variations in the reference speed caused by the dynamic states.

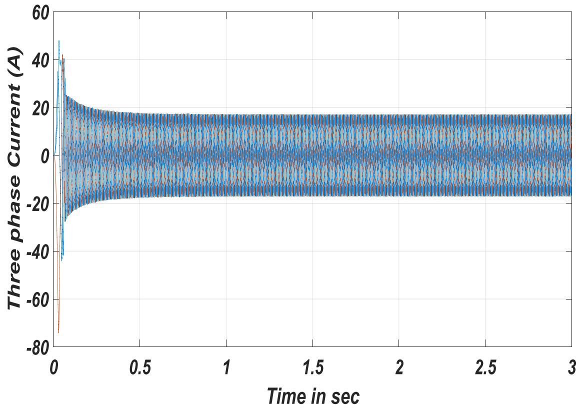

Figure (6) Three-phase currents at 0-3s

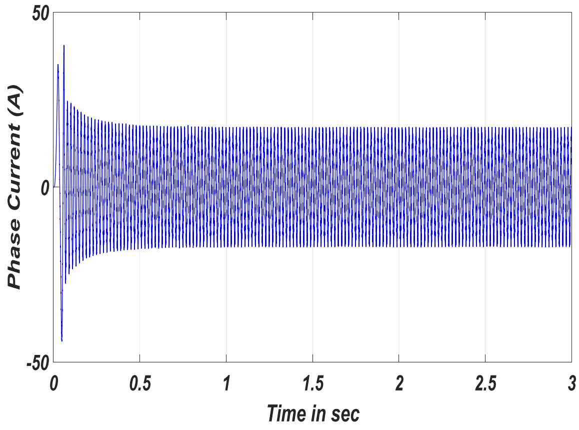

Figure (7) A phase current at 0-3s

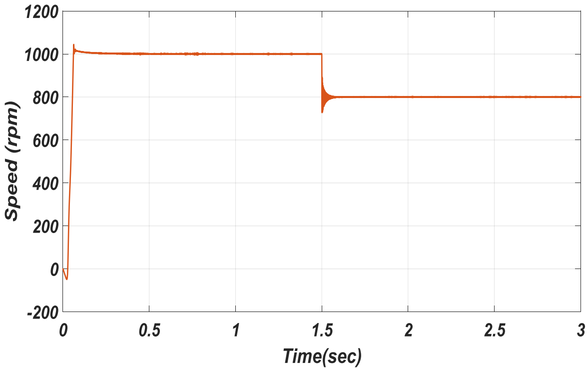

Figure (8) Rotational speed at 0-3s

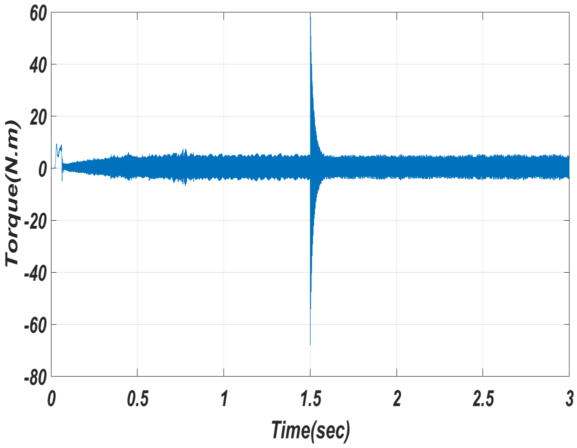

Figure (9) Torque at 0-3s

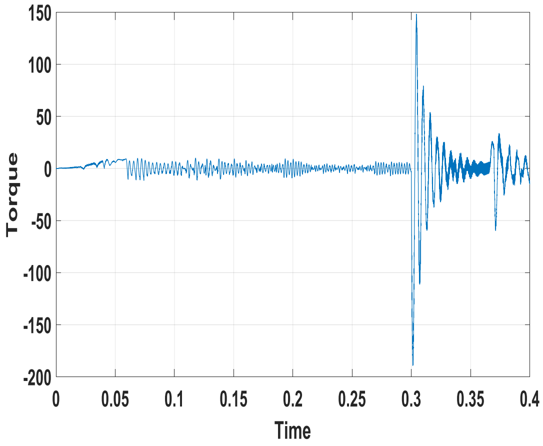

Figure (11) Torque at 0-0.3s

Fig.10. Simulation drive response for FOC with Rogowski coil at full load: Fig.10. shows speed response at 0.3s the speed changes from 1000 to zero cause high current circuit, wherefore the control circuit for the Rogowski coil disconnects the system due to high current occurrence greater then reference current.The torque response shown in Fig.11. at 0.3s, the torque increase and decrease during the change decrease speed due to the dynamic states. Fig.12. shows the motor phase current . the control cicuit will continue to provide IGBT gate pulses from 0-0.3s,but at 0.34s,the pulses will be disconnected from the gates, as shown in Fig.13.

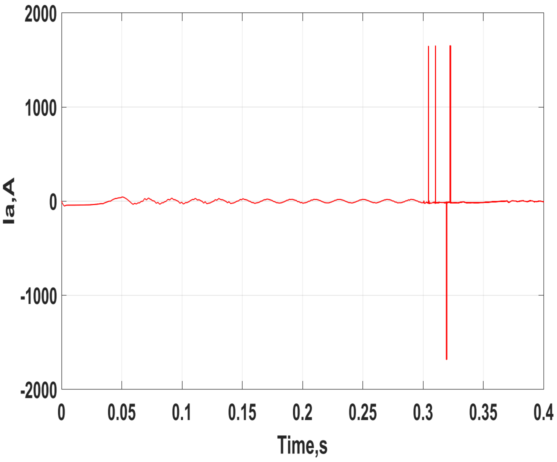

Figure (12) A phase current at 0-0.4s

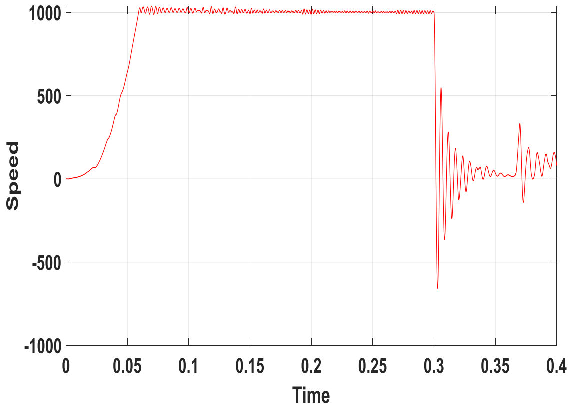

Figure (10) Rotational speed at 0-0.4s

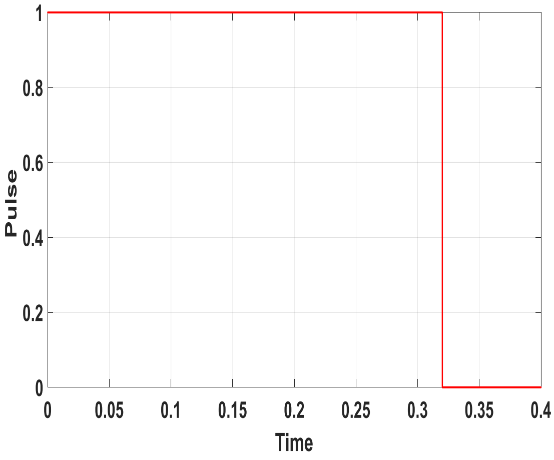

Figure (13) pulses gates at 0-0.4 s

4. CONCLUSIONS

To detect power frequency AC currents, a measurement approach based on the usage of a Rogowski coil with a field oriented control system is proposed. PSIM software was used to conceptually assess the suggested measuring technique. The proposed measurement process's efficacy was thus validated. In general, it is possible to conclude from this research that Rogowski coils are frequently employed for protection. It has been demonstrated that the Rogowski coil has a high capability for high current measuring or sensor such as fault current detection, high impulse current detection, and so on. Furthermore, the modelling findings reveal that the Rogowski coil is well suited to the system (Foc).

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