A Novel Initial Rotor-Position Estimation Method for Switched Reluctance Motors Based on Frequency Measurement

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ABSTRACT

This paper presents a novel method which is designed to detect the rotor position at standstill and also low speeds in switched reluctance motor (SRM). In this paper the inductance of phase winding is added as a part in Colpitts oscillator and will cause a change in oscillation frequency according to the rotor position. The phase inductance regularly varies with the rotor position. Experiments were carried out on three phases SRM 6/4, where the measured frequency of colpitts oscillator was converted into a voltage value by the frequency to voltage converter and were then converted into a digital value to be matched with the proposed digital processing. The Experimental results showed high accuracy in determining the values of phase inductance, which produced an estimated rotor position accurately and quickly.

Keywords: Switched Reluctance; sensorless method; position estimation

طريقة جديدة لتخمين موقع الدوار الابتدائي لمحرك المعاوقة الالكتروني بالاعتماد على قياس التردد

الخلاصة

يقدم هذا البحث طريقة جديدة صممت لكشف موقع الدوار عند السكون والسرعة الواطئة لمحرك المعاوقة الالكتروني .تم في هذا البحث اضافة محاثة اطوار المحرك كجزء من مذبذب كولبتس اذ سيؤدي ذلك الى تغير في تردد المذبذب اعتمادا على موقع الدوار .محاثة اطوار المحرك تتغير بأنتظام مع موقع الدوار . نفذت التجارب المختبرية على محرك معاوقة ثلاثي الطور ذو اقطاب 4/6 ,حيث ان التردد المقاس لمذبذب كولبتس يتحول الى قيمة فولتية من خلال محول تردد الى فولتية ثم تتحول الى قيم رقمية تتوافق مع المعالجة الرقمية المقترحة .اظهرت النتائج المختبرية دقة عالية في تحديد قيم محاثات اطوار المحرك,والتي أنتجت تخمينا دقيقا وسريعا لموقع الدوار.

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INTRODUCTION

The switched reluctance motor (SRM) drive system has gotten more attentions because of its excellent characteristics of the firm structure, low cost and flexible control, its application has been limited by the existence of shaft position sensor. The previous schemes of SRD are always equipped with rotor position sensor, which determines the system high speed performance, reliability and cost. Therefore, position sensorless operation of SRM has become an attractive research region. For these reasons, several approaches to eliminate the position sensor have already been proposed [1]-[16]. The various methods suggested have their own merits and demerits depending on their principles of operation, it is desirable to have a sensorless scheme which uses only terminal measurements and does not require additional hardware. The main idea for rotor position detection is to use the relationship between the rotor position, the phase current, and the flux linkage [17]. The SRM is modeled by equations based on some parameters such as flux, current and torque, speed, and inductance, some of the parameters may be obtained directly from the measurement of SRMs but some are undetermined. There are some intelligent control methods based on fuzzy control that has found applications in the detection of the rotor position in switched reluctance motors [18]-[19].

Several indirect position-sensing methods have been patented and published for sensorless control of SRM drives. All of these methods use the instantaneous phase inductance- variation information in some way to detect the rotor position indirectly. This paper proposes a new sensorless method that is based on the frequency measurement method to estimate rotor position.

Overlooking at all of the SRM position estimation methods, all has made use of the stator phase inductance periodically change with changes in rotor position. Rotor position detection in this paper is performed by measuring the frequency variations in the oscillator circuit, where L is the phase inductance of SRM which varies with rotor position. The frequency in a circuit can be determined by the capacitance, and inductance values.

The proposed method is based on inductance variations in each phase of SRM. These variations will change the output frequency of the oscillator circuit which is made up of the phase inductance and a capacitor as colpitts oscillator and the rotor position is detected by measuring frequency variations. Experimental results on a 0.25 kW SRM and drive are presented in this paper.

SWITCHED RELUCTANCE MOTOR CONFIGURATION

Figure 1 shows a cross section of the three-phase 6/4 poles SRM considered in the present study, Figure 2 shows a photograph of the tested SRM. The SRM has a doubly salient pole structure in which the stator and the rotor have salient poles. The SRM considered here has a stator with six poles and a rotor with four poles. The stator poles have windings for excitation. In the 6/4-SRM, the windings on stator poles A and A' are connected in series and are dealt with as phase-*a* windings. Accordingly, the windings on poles B and B' are dealt with as phase-*b* windings and the windings on poles C and C' are dealt with as phase-C windings. Let us define the position in which pole A and pole X are perfectly aligned as rotor position $\theta = 0$ deg.

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and define the rotor position as increases in the clockwise (CW) direction. Assume that the rotor position is
−45 deg. < θ < 0 deg. and that current flows into a phase-*a* winding. Then, the electromagnetic force is generated, and, accordingly, rotor poles X and X' are attracted to stator poles A and A'. The electromagnetic force generates the rotation torque in the CW direction and the rotor rotates until poles A and A' and X and X' are perfectly aligned = 0 deg.
As the rotor pole moves from the unaligned position to the aligned position, with a stator pole, the inductance of the stator coil varies from a minimum value to a maximum value. The values of L_{max} and L_{min} of the tested motor are 11.8 mH and 4.9mH, respectively.

PROPOSED SYSTEM DESCRIPTION

The basic idea of the system is to detect the rotor position very accurately by proposing a new method capable of to determining the rotor position perfectly.
In this paper the oscillator method is proposed which detects the rotor position by adding a phase winding of SRM to the oscillator circuit to produce a frequency value which refers to the value of phase inductance. Colpitts oscillator has been chosen for this application [20, 21].
A motor winding is connected to the colpitts oscillator through analog switches sequentially. Therefore, each phase inductance is inserted separately to the oscillator.
The oscillator frequency value varies according to the value of phase inductance which is varying according to the rotor position. Therefore, three frequency values can be obtained with respect to phase inductances. For simplicity and to get high resolution, the values have been converted to voltage values by using frequency to voltage converter. Voltage value is converted to a digital value and fed to the computer to store in a temporary file until the completion of the three values. The three digital values are compared and the least value is chosen as indication of large inductance in order to energize the first phase of the SRM.

HARDWARE AND SOFTWARE SYSTEM MODEL

In this paper, the proposed system model for rotor position estimation based frequency measurement is arranged in steps as shown in the block diagram of Figure 3.
Analog Switch: The switch generally provides good isolation between the control signal and the input/output signals. It is used to connect between the winding of the SRM and the circuits of the proposed system to transfer information motor to the system.
Colpitts Oscillator Circuit: The classical Colpitts oscillator is commonly used to generate sinusoidal signals. However with special settings of the circuit parameters, the oscillator includes a bipolar junction transistor as the gain element, two resistors, and a resonant network consisting of an inductor (phase inductance) and two capacitors used to feedback the output signal as it is depicted in Figure 4. In this circuit it is assumed that the values of resistance and capacitance are fixed but the inductance varies between L_{min} (11.8 mH) and L_{max}. (4.9 mH) and the fundamental oscillation frequency is given by:

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$$f = \frac{1}{2\pi\sqrt{LC}} \qquad \text{….. (1)}$$

Where: $C = \frac{C1.C2}{C1+C2}$

L is the phase inductance of motor

Frequency to Voltage Converter: The frequency to voltage converter circuit is illustrated in Figure 5. This circuit produces a 10 V output for 10 kHz full scale input, and has a good linearity, from 10 kHz down to 500 Hz. .The output voltage is given by:

$$V_{out} = f_{IN} \times \left(\frac{R_L}{R_S}\right) \times (1.9V) \times (1.1R_tC_t) \qquad \text{….. (2)}$$

Analog to Digital Convertor A/D: This circuit converts continuous output signals of frequency to voltage converter into discrete digital signals, so it can be measured and processed using digital equipment. The ADC0804 shown in Figure 6 is CMOS 8-Bit, successive approximation A/D converters are used. The differential analog voltage input has good common mode-rejection and permits offsetting the analog zero-input voltage value. In addition, the voltage reference input can be adjusted to allow encoding any smaller analog voltage span to the full 8 bits of resolution.

Interface Data and Control Port: The circuit presented in Figure 7, shows that PC is connected to the A/D converter to enter the digital data into PC.

PC: Is the main part, where the digital processor is located. The overall system under fully digitalized control is realized by personal computer, as the master controller. All the sensed signals after isolation are sent to individual analog-to-digital converters (ADCs), they are then sent to the PC for mathematical calculation so as to obtain the Phase, which is trigger to drive the power switches. The flow chart of DSP program is arranged in the following steps as shown Figure 8.

1-Read the values of inductors by sequential connection to the colpitts oscillator.

2- Storage inductors values after conversion to digital values.

3-Compare the values of inductors and choose the least value of inductance.

4-Generate the firing pulses of the three phases.

5-Trigger the phase of least inductance.

6-Trigger the next phase and continue to cascade trigger phases.

EXPERIMENTS AND RESULTS

In order to demonstrate the validity and practicality of the proposed sensorless control method, the 6/4 poles three phase SRM has been tested.

The proposed controller has been implemented using a high-performance digital signal processor. The DC link voltage of the half wave inverter is 12 V. Figure 9 shows experimental setup of the proposed system. The data of the measuring the instantaneous value of the phase inductance which correspond to an instantaneous value of the phase current are performed via a proposed circuit described in [17].

In Figure 10, the aligned inductance versus current is plotted. From this figure, note that, as current increases, the machine is becomes increasingly saturated resulting in a decreasing inductance. The inductance versus phase current of the unaligned position is also plotted in Figure 10. It is observed that the inductance does not change with respect to the phase current due to the dominating reluctance of the large air gap.

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Figures 11, 12 and 13 represent the output signal of frequency to voltage circuit and the output of oscillator circuit of phases A, B and C respectively.
The results show a high accuracy in determining the values of motor phase inductances, where the experimental results of phase inductance measured for the rotor position when the inductance is 5.7 mHµµ the frequency measured is 8.2 kHz for first phase in Figure11.When the inductance is 8.10 mH, the frequency measured is 7 kHz for second phase Figure12, and for third phase shown in Figure13, the inductance is 19.6 mH the frequency is 9 kHz. It can be noticed this results, we note that the frequency difference between the larger and smaller inductance is 2 kHz which confirms the accuracy of choose triggering phase to be first. There are no chances of getting an error on choosing the correct phase because of the great difference between the frequencies.

CONCLUSIONS

A new SRM rotor position sensing schemes based on frequency measurement relating to phases inductances is presented in this paper. The technique uses the colpitts oscillator design. This technique has been tested successfully on 0.25 HP three phase 6/4 SRM over a wide range of speed, as well as to a standstill. The advantage of this method is that there is no need for precise knowledge of machine parameters, and the algorithm will operate across a wide range of operating conditions. Experimental results show that the proposed method is more effective and robust to detect the rotor position.

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Figure (1) cross section of a 6/4 SRM structure

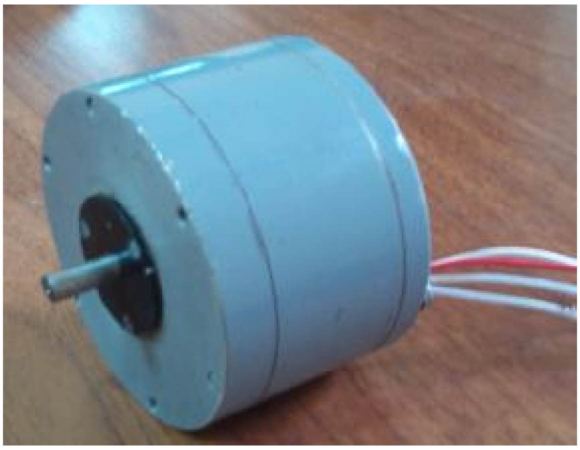

Figure (2) photograph of tested SRM

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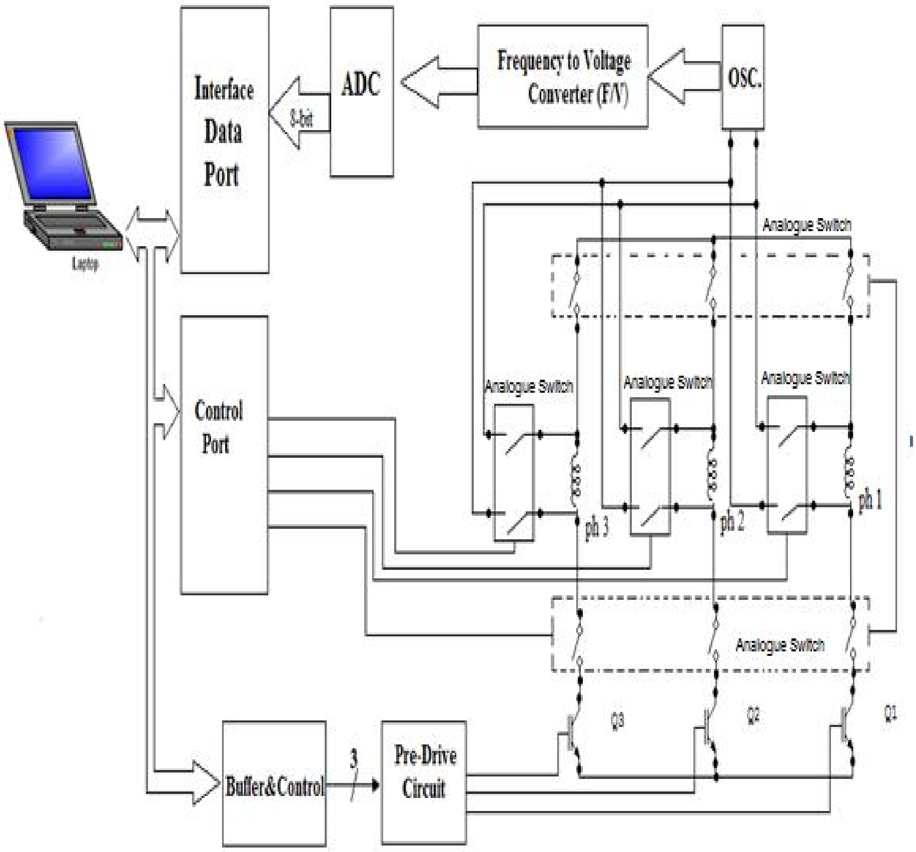

Figure (3) the block diagram of implemented system

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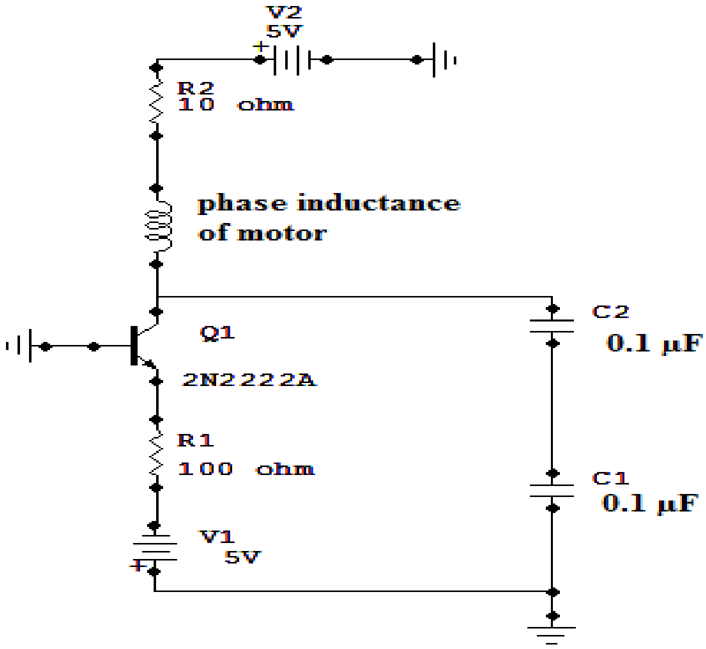

Figure (4) Colpitts oscillator circuit

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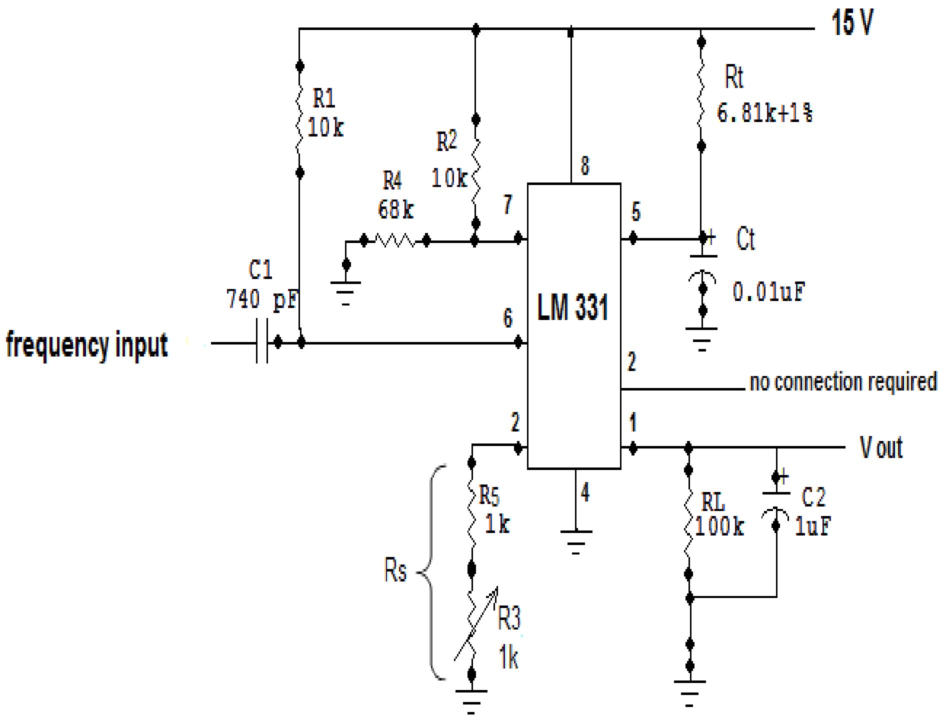

Figure (5) Frequency to Voltage Converter

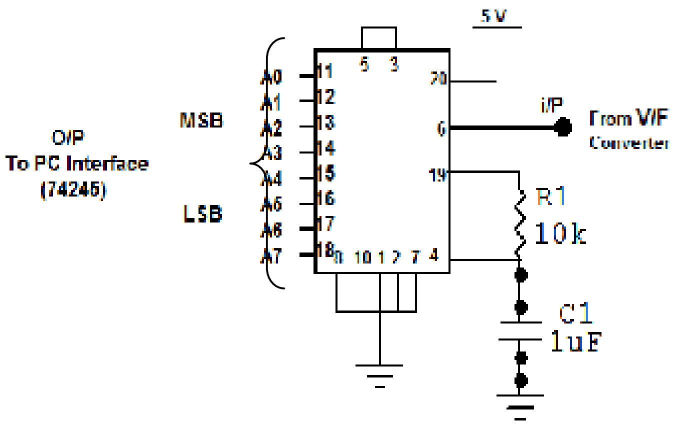

Figure (6) Implemented circuit of A/D

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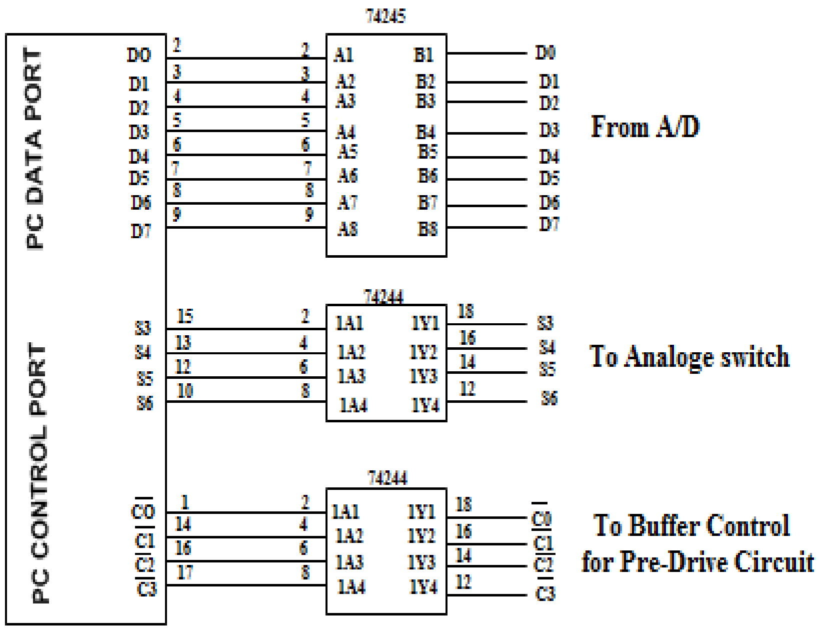

Figure (7) **Hardware Interface Circuit**

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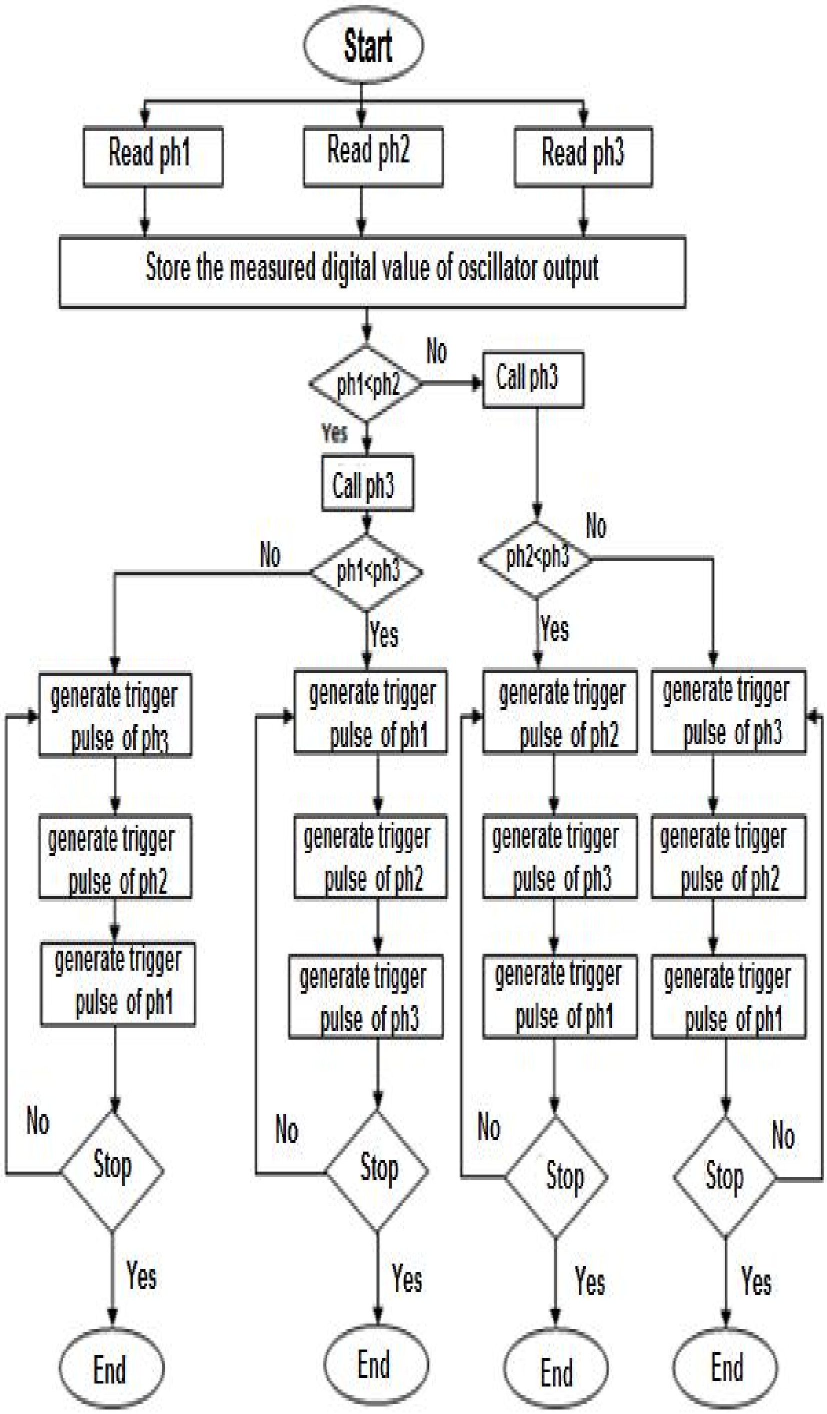

Figure (8) Flow chart of the proposed sensorless scheme.

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Figure (9) Experimental setup of proposed system

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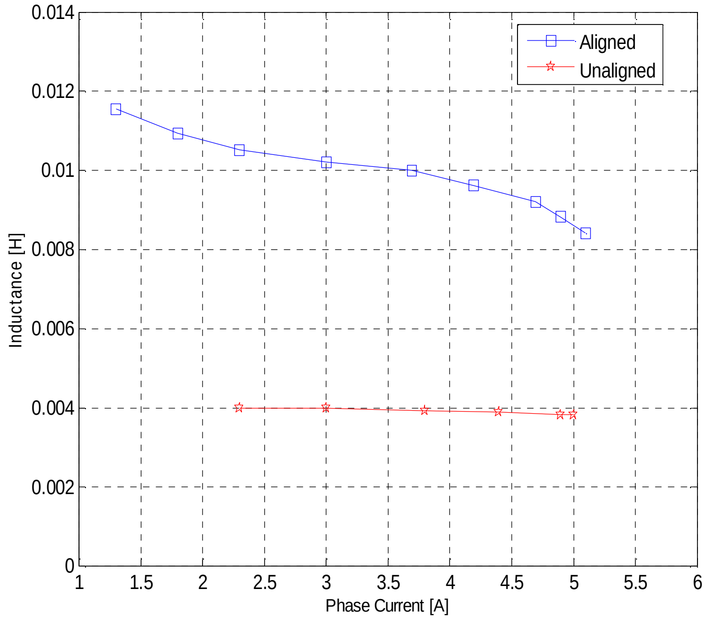

Figure (10) Inductance at aligned position, and unaligned position (as a function of the phaseCurrent).

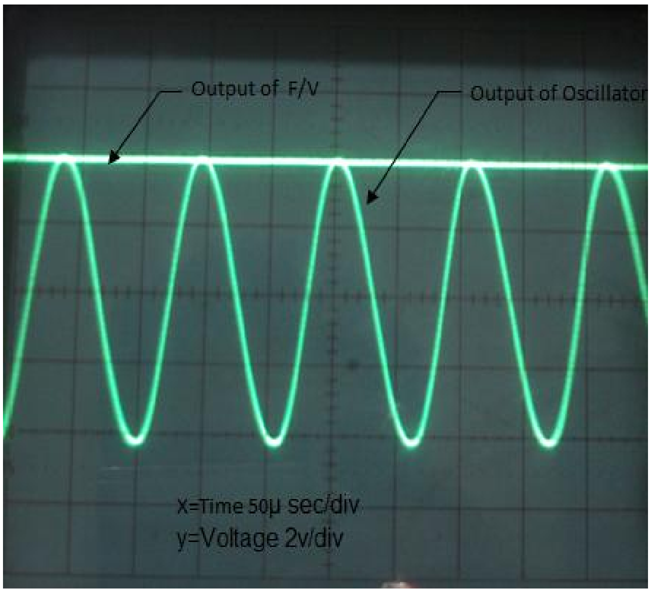

Figure (11) output waveform of f/v and oscillator of phase A

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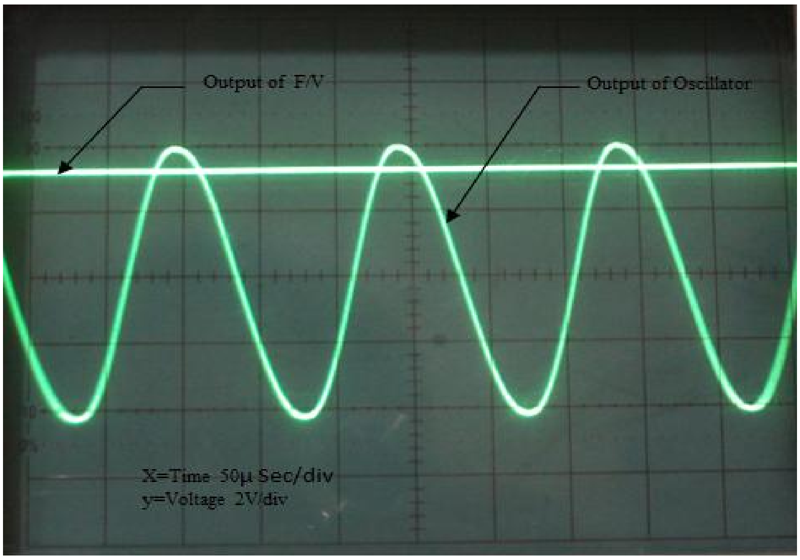

Figure (12) output waveform of F/V and oscillator of phase B

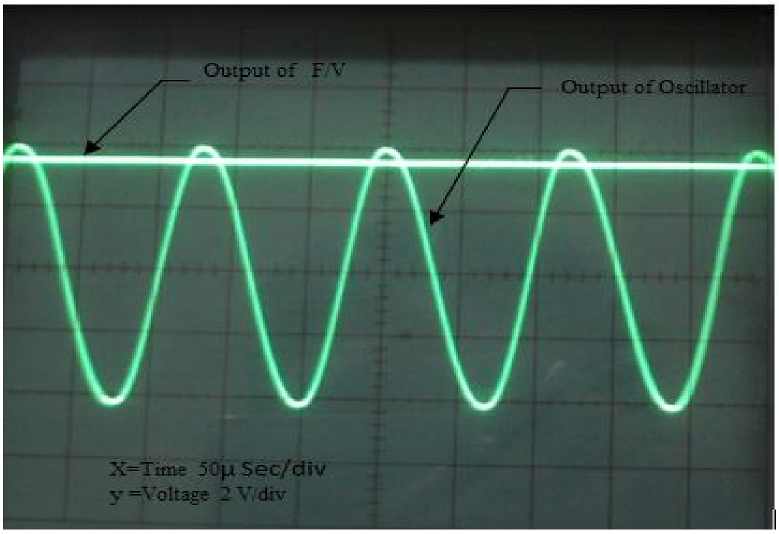

Figure (13) output waveform of f/v and oscillator of phase C

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