Starting of BLDC Motor Without Position Sensors

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Abstract.

This paper discusses about finding of initial rotor position when motor is not yet started or motor is stand still. The main or key point of finding initial rotor position is by simple detection and voltage comparison of each phase & responses of current which is related with the stator inductance variation. In the proposed method 3 voltages-pulse are injected and we achieved a resolution of 30°.The method effectives is verified by using simulation. In extension of this we derived an equation for initial rotor position. Which depends on the currents of each phase.

Keywords; Brushless dc (BLDC), voltage-pulse injection, initial rotor position.

1 Introduction

BRUSHLESS DC motors are mostly used in many applications which are related to industries due to their good starting torque, power density and its silent operation and their good efficiency the applications are hard disc, electric cars and traction applications for railway engines. So, by using a power electronic drive is a very good solution in recent times. A

BLDC motor driven by 3 phase inverter, as displayed in Fig. 1, having the information about rotor position will make motor to run properly and it will result in stable operation is obtained by phase excitation and synchronizing to the position of rotor. The information of rotor is generally obtained by sensors which detect position like encoders or hall sensors, because of this sensors usage the drive circuit is not accepted when cost and reliability is considered. So, in order to have solution to this some techniques which are known as sensorless control techniques are developed for control of BLDC motor in less cost and for the reliable operation in recent times.

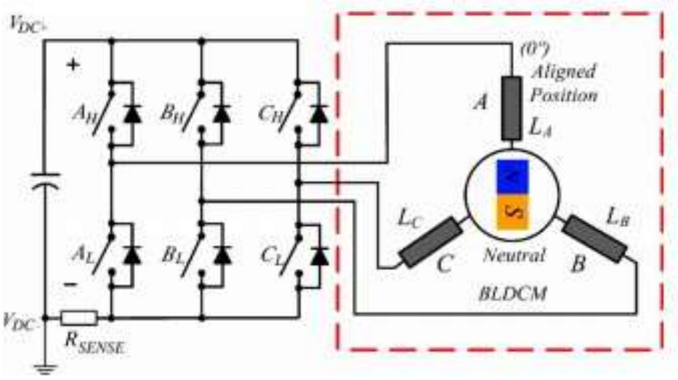


Fig. 1. BLDC motor driven by 3 phase inverter

The initial starting of motor is one of the major concerns for the BLDC motor when going without sensors. As back-EMF is detection is widely used control for the sensorless BLDC motor and back Emf is not be available when the motor is at stand still position. the main point in the BLDC motor sensorless operation is the finding the position of rotor with good accuracy at standstill and making the motor to start successfully. The start-up done in open-loop and its draw-back is explained in [1] and in [2] due to no information about characteristics of load there is a chance of reverse rotation which happens temporarily will lead to loss of information about position of rotor. By energizing two phases, the rotor is pre-aligned to a known position is explained in [3] which leads to the motor locking. Due to static friction which is very large so alignment of rotor to a known position may fail is explained in [4]. So, it is necessary to find a solution to all the problems which are related to starting and to find the rotor position at standstill position of to obtain the good and reliable operation of sensorless BLDC motors. By comparison and finding of current response of DC link and response of voltages of each phase we can find the position of rotor, which are obtained by giving voltage pulse to windings that are selected [5] is considered as this is the good practice and can be adopted for application like EV's and tractions also where position of rotor is major component because of high load.

Some important techniques of finding of position of rotor in BLDC motors are explained in [7]-[9]. Motor is started easily and back EMF is used for control while motor is running at some speed all these happens only if we are able to find the position of rotor at stand still position. In this paper back EMF of the motor and its point of zero-crossing point is obtained by finding the difference of voltage among the DC link mid-point and the open phase.

The method depends on principle when stator windings is supplied with a dc voltage, the position of rotor decides the flux resulting that obtains from the dc excitation the and magnet of rotor. This results to the variation within induced the EMF voltage between the windings of stator related consistently with the position of rotor. However, majority of methods that are mentioned need either some complex techniques for sensing or the methods are consuming a lot of time for the implementation of algorithms to find the position of rotor at stand still position, so these methods are not practical to implement with a microcontroller of less cost. In this paper, position estimation of rotor depends on a simple identification and differentiation technique voltages of each phase and responses of current, obtained by providing the 3 voltage pulses in a specified sequence. Section II explains the method for estimation of position of rotor at standstill position and Section III explains equation for the position of rotor at stand still and then Section IV talks about conclusion.

2 Initial Rotor Position Estimation Method

The stator core and its saturation effect is the main principle to find the position of rotor, obtained by magnet of rotor. A Sequence of voltage pulse are given to BLDC motor (having switches A_H, B_L, and C_L; shown in Fig. 1) at different true rotor positions. The main principle of the method that is proposed used when motor is stand still and to find rotor position and then to compare each phase stator inductance.

The proposed method consists of two parts:1. Comparison of Inductance 2. Process of Polarity Identification

A. Comparison of Inductance

The BLDC motor is given a sequence of two voltage pulses in the above operation. The pulse-injecting interval and the freewheeling interval are also present in each pulse. These cycles are depicted on Fig 2 below

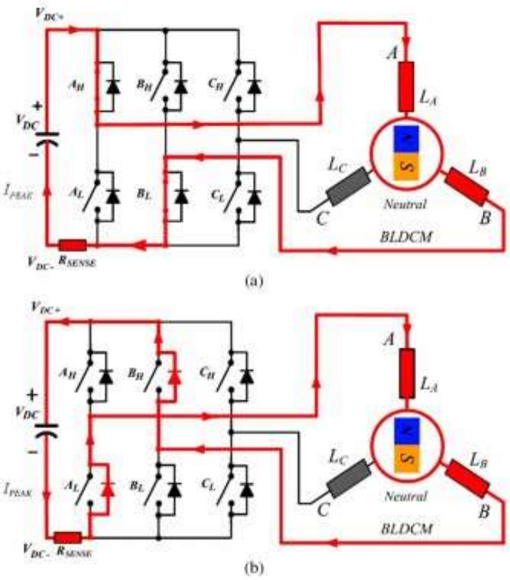


Fig. 2. During the first voltage-pulse injection, the switching states for the BLDC drive in Fig. 1 are shown. (a) Time of pulse injections. (b) Time of freewheeling

I. First Voltage-Pulse Injection

By turning "on" switches AH and BL, the first voltage pulse is pumped into the phase-A and phase-B windings, as shown in Fig2 (a). The phase-A winding is connected to the positive dc bus, Vdc+, and the phase-B winding is connected to the negative dc bus, Vdc, during this pulse injecting interval, while the phase-C winding is floating with no current flowing through it. As a result, the voltage across the phase-B winding can be detected through the negative dc bus and the phase-C terminal. The equivalent circuit is shown in Fig. Because the winding resistances and the current sensing resistor, RSENSE, are so small, the dc bus voltage, Vdc, during the pulse-injecting interval can be approximated as

$$V_{dc} \approx [L_A(\theta_0) + L_B(\theta_0)]\frac{di_1(on)}{dt}$$

$$\approx L_A(\theta_0)\frac{\Delta i_1(on)}{T_{S1}(on)} + L_B(\theta_0)\frac{\Delta i_1(on)}{T_{S1}(on)}$$

$$= V_{AN1(on)} + V_{BN1(on)} \quad \rightarrow (1)$$

Where ,

$$L_a(\theta_0) = L_{aa}(\theta_0) + L_{ab}(\theta_0)$$

$$L_b(\theta_0) = L_{bb}(\theta_0) + L_{ab}(\theta_0) \quad \rightarrow (2)$$

are the phase-A and phase-B efficient inductances, respectively. The reciprocal inductances of phase A and phase B due to currents in the phase B and phase A windings, respectively, are Laa and Lbb. Ts1(on) is the pulse-injecting interval time, and V_{AN1}(on) and V_{NB1}(on) are, respectively, the initial rotor position and the current shift during these pulse-injecting intervals, at the first pulse-injecting interval, the voltages around the phase-A and phase-B windings It is important to note that since $L_{ab}(\theta_0) = L_{ba}(\theta_0)$ the magnitudes of induced voltages due to mutual inductances in phases A and B are the same. As a result, phase-A and phase-B self-inductances account for the majority of the induced voltage difference in phases A and B due to pulse-voltage injection. The winding voltages V_{AN1}(on) and V_{NB1}(on) can be rewritten in terms of Vdc using (1) as a starting point.

$$V_{AN1}(on) = \frac{L_A}{L_A + L_B} Vdc$$

$$V_{NB1}(on) = \frac{L_B}{L_A + L_B} Vdc \qquad \rightarrow (3)$$

The switches AH and BL are switched off after the first pulse-injecting interval. As a result, as shown in Fig. 2(b), the corresponding freewheeling interval occurs, and the analogous circuit is shown in Fig. 3. (b). During this freewheeling time, the dc bus voltage can be approximated by

$$V_{dc} \approx -L_A(\theta_0)\frac{\Delta i_{1(off)}}{T_{s1(off)}} - L_B(\theta_0)\frac{\Delta i_{1(off)}}{T_{s1(off)}}$$

$$= V_{NA1}(off) + V_{BN1}(off)$$

where i1(off) is the freewheeling interval current, Ts1(off) is the freewheeling interval time, and V_{NA1}(off) and V_{BN1}(off) are the voltages around the phase-A and phase-B windings during the freewheeling interval, respectively. The overall voltage drops over both phase-A and phase-B windings during the freewheeling interval is the polar opposite of the pulse-injecting interval; hence, the immediate shift in the bus voltage reflects to phase-A and phase-B windings in the same way. As a result of (1) and (4), it is clear that

$$L_A(\theta_0)\frac{\Delta i_1(on)}{T_{s1}(on)} = -L_A(\theta 0)\frac{\Delta i_1(off)}{T_{s1}(off)}$$

(or)

$$V_{AN1}(on) = V_{NA1}(off)$$

$$L_B(\theta_0)\frac{\Delta i_1(on)}{T_{s1}(on)} = -L_B(\theta 0)\frac{\Delta i_1(off)}{T_{s1}(off)}$$

(or)

$$V_{BN1}(on) = V_{NB1}(off) \quad \rightarrow (5)$$

Furthermore, during the freewheeling interval [Fig3b], the voltages around the phase-A and phase-B windings are

$$V_{BN1}(off) = \frac{L_B}{L_A + L_B} \cdot Vdc$$

$$V_{NA1}(off) = \frac{L_A}{L_A + L_B} \cdot Vdc \quad \rightarrow (6)$$

Finally, it can be re expressed, from (3) and (6), that

$$V_{NA1}(off) - V_{BN1}(on) = \frac{L_A - L_B}{L_A + L_B} \cdot Vdc \rightarrow (7)$$

From (7), Since both V_{NA1}(off) and V_{NB1}(on) are referenced to Vdc, it is obvious that the values of L_A and L_B can be compared to each other by voltage comparison between V_{NA1}(off) and V_{NB1}(on).

II. Second Voltage-Pulse Injection:

A second voltage pulse of the same interval is pumped into the phase-A and phase-C windings using the same theory. By turning “on” switches A_H and C_L, the phase-A winding is connected to Vdc+ and the phase-C winding is connected to Vdc, while the phase-B winding is left floating. The switches A_H and C_L are then switched off, and the resulting freewheeling interval occurs as a result. The equivalent circuit during the second pulse injecting interval and the corresponding freewheeling interval are shown in Fig. 4(c) and 4(d), respectively, similar to the first pulse injecting interval described in the previous section (d). As a result, the detected voltages across the phase-A and phase-C windings (and, thus, L_A and L_C) can be compared using the equation below:

$$V_{NA2}(off) - V_{NC2}(on) = \frac{L_A - L_C}{L_A + L_C} \cdot Vdc \rightarrow (8)$$

The voltage across the phase-C winding during the second pulse-injecting interval is VNC2(on), and the voltage across the phase-A winding during the second freewheeling interval is VNA2(off). With a reference to Vdc, these voltages can be easily determined via the phase-B

terminal. Furthermore, the detected phase voltages $V_{NB1(on)}$ and VNC2(on) can be used to calculate the relative values of L_B versus L_C as

$$V_{NB1}(on) - V_{NC2}(on) = (L_B - L_C)\frac{L_A}{(L_A + L_B)(L_A + L_C)} \cdot Vdc \quad \rightarrow (9)$$

Finally, the winding inductance values L_A, L_B, and L_C can be compared to each other using the formula (7)– (9). Table II shows how to evaluate the relationship between inductance comparisons and potential initial rotor positions (the north pole). However, as seen in the condition $L_B > L_C > L_A$, a single inductance comparison can map into two opposite sectors. For example, the condition $L_B > L_C > L_A$ can define the probable initial location as being in either the 0–30 or 180–210 sectors. As a result, an additional process is needed to decide which of the two opposite sectors the rotor magnet pole actually locates. This extra step is known as "polarity determination," and it is explained next.

B. Process of Polarity Identification

The application of the third pulse-voltage injection is needed for rotor magnet polarity detection. At the end of each of the three pulse injecting cycles, the peak dc-link currents (I1, I2, and I3) are sampled and then registered. The injection order is indicated by the subscripts (1, 2, and 3). The following paragraph will clarify how to determine the polarity of a magnet The north and south poles of the rotor magnet can be calculated using the concept that as a function of the magnet polarity,

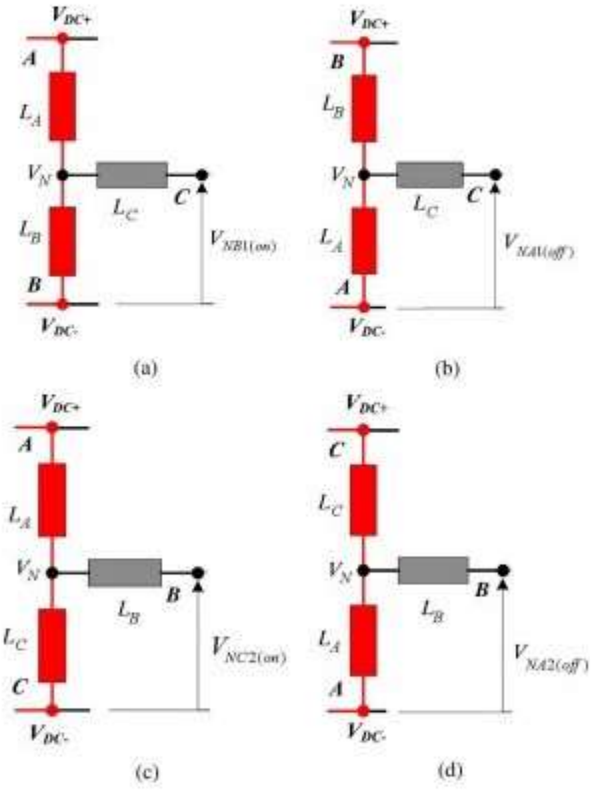


Fig. 4. Detection of terminal voltage. (a) The first voltage-pulse injection's pulse-injection interval. (b) The first voltage-pulse injection's freewheeling interval. (c) The second voltage-pulse injection's pulse-injection interval (d) The second voltage-pulse injection's freewheeling interval.

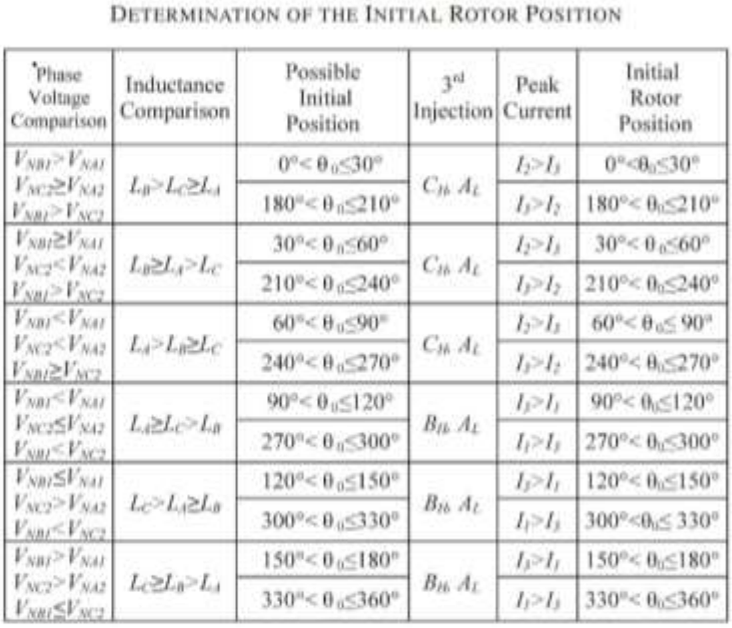
the third voltage pulse will be applied, which appears to cause the stator to increase or decrease the saturation level further. As a result of this constraint, the third pulse-voltage injection is selected based on the following criteria.

1) If 0◦ < $\theta_0 \leq$ 90◦ or 180◦ < $\theta_0 \leq$ 270◦, the switches on C_H and A_L for the 3rd injection and compare I_2 with I_3.

2) Else, if 90◦ < $\theta_0 \leq$ 180◦ or 270◦ < $\theta_0 \leq$ 360◦, the switches on B_H and A_L for the 3rd injection and compare I_1 with I_3.

By using the above method, we can get initial rotor position by a resolution of 30^o. moreover we don't have any direct relationship between initial rotor position and voltages or Inductance.

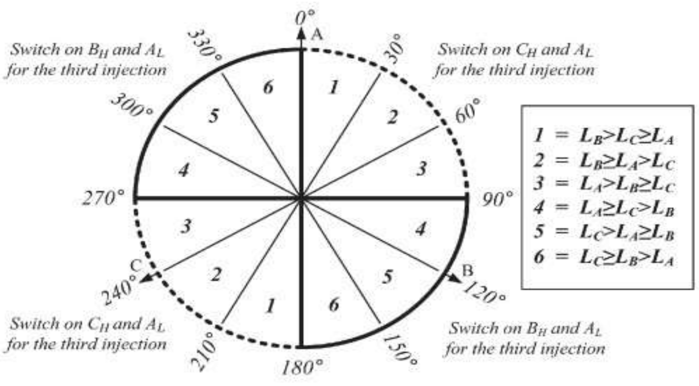
So, by using regression method an equation is derived which gives the relation between initial rotor position and the voltages



DETERMINATION OF THE INITIAL ROTOR POSITION

*Phase Voltage Comparison	Inductance Comparison	Possible Initial Position	3rd Injection	Peak Current	Initial Rotor Position
$V_{NB1}>V_{NA1}$ $V_{NC2}\geq V_{NA2}$ $V_{NB1}>V_{NC2}$	$L_B>L_C\geq L_A$	$0°<\theta_0\leq 30°$	C_H, A_L	$I_2>I_3$	$0°<\theta_0\leq 30°$
		$180°<\theta_0\leq 210°$		$I_3>I_2$	$180°<\theta_0\leq 210°$
$V_{NB1}\geq V_{NA1}$ $V_{NC2}<V_{NA2}$ $V_{NB1}>V_{NC2}$	$L_B\geq L_A>L_C$	$30°<\theta_0\leq 60°$	C_H, A_L	$I_2>I_3$	$30°<\theta_0\leq 60°$
		$210°<\theta_0\leq 240°$		$I_3>I_2$	$210°<\theta_0\leq 240°$
$V_{NB1}<V_{NA1}$ $V_{NC2}<V_{NA2}$ $V_{NB1}\geq V_{NC2}$	$L_A>L_B\geq L_C$	$60°<\theta_0\leq 90°$	C_H, A_L	$I_2>I_3$	$60°<\theta_0\leq 90°$
		$240°<\theta_0\leq 270°$		$I_3>I_2$	$240°<\theta_0\leq 270°$
$V_{NB1}<V_{NA1}$ $V_{NC2}\leq V_{NA2}$ $V_{NB1}<V_{NC2}$	$L_A\geq L_C>L_B$	$90°<\theta_0\leq 120°$	B_H, A_L	$I_3>I_1$	$90°<\theta_0\leq 120°$
		$270°<\theta_0\leq 300°$		$I_1>I_3$	$270°<\theta_0\leq 300°$
$V_{NB1}\leq V_{NA1}$ $V_{NC2}>V_{NA2}$ $V_{NB1}<V_{NC2}$	$L_C>L_A\geq L_B$	$120°<\theta_0\leq 150°$	B_H, A_L	$I_3>I_1$	$120°<\theta_0\leq 150°$
		$300°<\theta_0\leq 330°$		$I_1>I_3$	$300°<\theta_0\leq 330°$
$V_{NB1}>V_{NA1}$ $V_{NC2}>V_{NA2}$ $V_{NB1}\leq V_{NC2}$	$L_C\geq L_B>L_A$	$150°<\theta_0\leq 180°$	B_H, A_L	$I_3>I_1$	$150°<\theta_0\leq 180°$
		$330°<\theta_0\leq 360°$		$I_1>I_3$	$330°<\theta_0\leq 360°$

TABLE – I- Determination of the initial rotor position



3 Equation for the Initial Rotor Position

Here, initial rotor position is considered as independent variable and voltages of two rheostats are taken as two dependent variables. As we are having 2 dependent variables, we can't solve or derive equation by using the simple regression method. Definitely multiple regression method must be used. The term "multiple regression" refers to the process of examining the relationship between multiple independent and dependent variables. The following equation is used to measure multiple regression where there are two independent variables and one dependent variable.

$$Y = a + b_1X_1 + b_2X_2$$

Where, Y is a Dependent variable= For a given value of X1 and X2 the Estimated value of Y, X1 & X2 = Independent variables

b1 = The amount of change in Y caused by a unit change in X1. b2 = The amount of change in Y caused by a unit change in X2.

a, b1 and b2 = Amount of change in generated Y

The number of equations is determined by how many independent variables there are. When there are two independent variables, there are three equations to solve. The equations used to calculate a and b values are as follows:

$$\sum Yi = na + b1 \sum X_{1i} + b2 \sum X_{2i}$$

$$\sum X1i\, Yi = a \sum X1i + b1 \sum X_{21i} + b2 \sum X_{1i}\, X_{2i}$$

$$\sum X2i\, Yi = a \sum X2i + b1 \sum X_{1i}\, X_{2i} + b2 \sum X_{22i}$$

By using the above equations, we need to find a, b1, b2 to get the equation of initial rotor position. We noted down the readings of the voltages for each and every 5 degrees interval for example at 5 degrees we noted down voltages and at 10 degrees we noted down the next readings so in this manner we noted down the readings from 0 to 360 degrees

Fig: 5 Experimentation

Above is the picture of the experimentation. The components used are signal generator, Optocoupler, Two Rheostats, one BLDC motor and two DSO's. Signal generator is to give pulse to the motor which is of less voltage because motor should be in stand still position. With the signal generator we are not getting good number of voltages in outputs. So, we used Opto-coupler to increase the voltage. Then we changed the position of rotor in such a manner that with the interval of 5 degrees. Then we recorded voltages across the 2 rheostats and taken total 72 readings

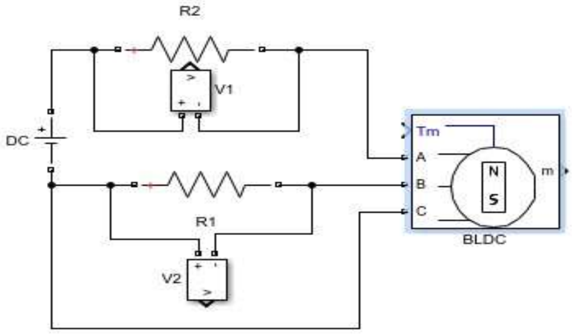


Fig: 6 circuit used for the experimentation

The BLDC motor of having internal rotor having the following specifications Poles = 8, Voltage = 48v, Wattage = 800w, Ns = 750rpm. As shown in fig 6 three of two phases are connected with 2 resistors and by using a pulse generator, a pulse of 5v to 10v is given to the motor and we noted down voltage across the resistors for each particular angle. Here we taken readings at every 5-degree interval. The experiment is conducted and below are some sample data which are taken as just for verification

Rotor angle	**V1**	**V2**
15	13.14	15.6
70	14.5	16.535
155	14.7	15.8
230	15.6	16
305	16.2	15.8

TABLE – II- Evaluate the relationship between inductance comparisons and potential initial rotor positions

The equations of multiple regression method are given below

$$72*a + 399.18*b_1 + 362*b_2 = 13140$$

$$399.18*a + 2185.988 * b_1 + 1980.64 * b_2 = 72438.55$$

$$362*a + 1980.64 * b_1 + 1801.22 * b_2 = 65071.5$$

By solving above equations, the values of a, b1, b2 obtained as a = 67.03, b1 = 100.56, b2 = -87.92

The equation for initial rotor position is

$$\theta = 67.03 + 100.56 * V1 - 87.92 * V2$$

Rotor angle	**V_1**	**V_2**	**Angle obtained**	**Error**
15	13.14	15.6	16.8364	1.8364
70	14.5	16.535	71.392	1.392
155	14.7	15.8	156.126	1.126
230	15.6	16	229.046	0.954
305	16.2	15.8	306.966	1.966

TABLE – III- Error in the initial rotor position

By using this equation if we find voltage across two resistors, we can get the initial rotor position. In such a manner from the data of 72 readings we cross checked the equation whether it is giving correct rotor angle or not. Below are the few samples taken from data to show the accuracy of the equation

From the table-III we can see error in the initial rotor position from the equation derived is about ± 2 degrees.

4 Conclusion

In this paper we tried find the initial rotor position by 2 methods two methods works on the principle of Inductance variation in the stator windings. The entire process is done when motor is in standstill position. Method 1 gives a range of angle for position of rotor. This method gives with a resolution of 30 degrees. But method 2 is much accurate as compared to method 1. In method the equation derived will give almost exact initial rotor position with an error of 2 degrees

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