ISSN: 2251-9246
EISSN: 2345-6221
pp.165:171

Smart Starting of Induction Motor by Changing Core Magnetic Flux Value

Ebrahim Kazemzadeh [1], Mojtaba Zare Banadkooki [2]

[1,2] Department of Electrical Engineering,Faculty of Engineering, University of Tafresh,Tafresh ,Iran,
*Email:*Abrahim.Kazemzadeh.1993@gmail.com, mojtabazare24@gmail.com

Abstract

Single-phase squirrel cage and three-phase induction electromotors are the most popular electromotors used in industry from long ago. When an induction motor starts with direct connection method, it takes a lot of current from the power supply (several times the nominal current); so, several methods have been devised to start such electromotors. These methods either reduce the voltage of the stator or increase the value of rotor resistance. In this paper a new method is presented that reduces the value of the magnetic flux in stator core resulting in reduction of induction voltage in the rotor bars culminating in reduction of rotor and stator currents. This system reduces the electromotor loss and smartly protects itself against damages due to overload. Process functions are analyzed, the uses of the system are discussed and the operation of the electromotor is simulated in Matlab version 7.11.0.584 (R2010b) and Maxwell 16.0.

Keywords: Core magnetic flux , Impedance, induction motor ,Starting current, Winding

1. Introduction

Induction motors are most used in the Industry and its operation is based on induce the voltage in the bars or windings of the rotor and then make a magnetic field in rotor and consequently, make a mechanical torque in motor. Induction motors consist of the rotor and stator. Stator have a three-phase windings in the core. Rotor of the motor have a two types, first one is many bars that Short circuited with two rings and second type is many windings that that short circuited all of them in the end of the windings [1].

Induction motors have an inrush current in starting so they are designed with many circuits for reducing value of this inrush current .the general method is based on two way: first, stator voltage is reduced with impedance division, autotransformers or power electronic devices. In second method circuits increase a value of the rotor's impedance that reduce a rotor current and stator's [2].

If the starting circuits don't work because of the much ohmic wastes, it is possible to melt all of the insulation materials in the windings of the stator and so the motor does not work. In choosing, all of installation equipment must support the inrush current, as a result, installation equipment would be more expensive.

Those circuits have problems such as abound electrical losses, low power factor in initiation, need of expert human resources to work with circuits, etc. Low power factor in initiation causes the most of power in the motor be reactive power and do not producing useful torque.

In this new presented method, electrical losses decreased and motor starts with higher power factor that prevents from loss of energy.

In this new method motor can changes its amount of winding conductors in the stator poles according to the conditions and motor's current. It's a basic step in order to make electrical motors Intelligent. In addition in this new method motor in

Overloads is able to protect insulation materials of windings from burning.

This method is very simple and cheaper than previous methods and has ability to implement this method on motor manufacturers and also starting circuits would be removed from all industrial centers and anyone can use the induction motors and there is no need for special experts and briefly this method reduces the cost of working with motors.

In other words in this new method there are designed circuits for starting motors and a new way for protecting them.

In addition to the benefits that noted ,this proposed scheme has disadvantages such as more voluminous stator , increase in the cost of finished motor, the need for insulation of moving parts, requiring cooling systems for microcontroller section, etc.

2. Description of system operation

In this new method that is presented for the first time, magnetic flux directly reduced. In the stator Core in each phase in addition to main windings of stator poles we added number of winding that these new windings are in the same direction of main windings of the stator poles (for example both in clockwise direction).These added windings in the starting a motor are serried with the windings of stator poles so magnetic flux reduced in the stator core (checked in next section). Now Induced voltage will reduced in the rotor (secondary part of the rotary transformer) so rotor current get reduced. Since the induction motor is like a rotary transformer, stator current reduced. In other words when the resultant number of turns Increases, seen Impedance from stator increases and then causes reduction in inrush current.

After starting the motor and in normal operation, added windings are removed from windings of the stator poles and just main windings of the stator poles are in the circuit so it reduces Resultant number of turns and Increases value of the magnetic flux in the core and then motor works in normal mode (just main windings of the stator poles are in clockwise direction in the circuit). In other words in the starting mode all of the added windings are serried in the circuit and when the motor starts all of this added windings will gradually removed from circuit.

All of this acts happen by an intelligent system namely proportional with the current of the windings of the stator poles and a program that has been written in the microcontroller, motor automatically series added windings in circuit or removed it from circuit.

Strategy of the adding or removing added windings is similar to strategy of the adding or removing windings in the autotransformers. The general form of the system presented in Figure 1.

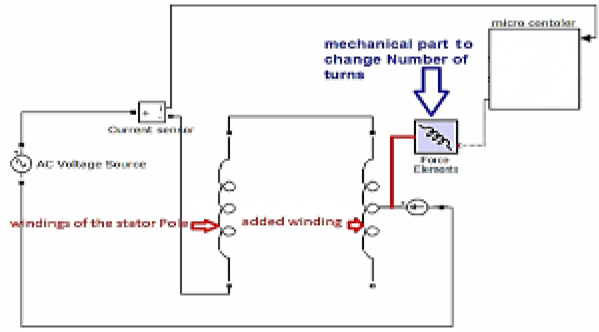

Fig. 1. The general structure of the system for each phase.

3. Formulas and Equations

As previously mentioned, in this new method we reduced value of the magnetic flux in the core and by this method we decrease initiation current. This work does with the following equations.

The equivalent circuit of Induction motors is according to figure 2 [3].

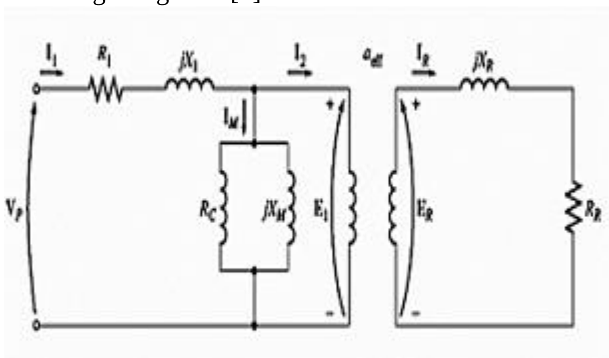

Fig. 2. Transformer model for induction motors for one phase

In section 2 we mentioned that stator has two type winding, the first type is windings of the stator poles and second is added windings are both in same direction that in the starting all of the added windings are in the circuit and when the motor start, all of this added windings gradually removed from circuit. Now the number of windings turns in the circuit obtained from equation 1[4].

$$Neq=Ncs+Nccs \qquad (1)$$

That in this equation Neq represents the number of resultant stator windings in the circuit, Ncs represents the number of windings of the stator poles, Nccs represents the number of added windings that are in the circuit. Now the magnetic flux in the core obtained from equation 2[5].

$$\phi = Neq * I\ R \qquad (2)$$

This equation represents the current in the stator windings; R represents reluctance of flux path. Value of R depend on motor physical size and is constant but value of the Neq and I change in this system.

If the voltage has a zero degree then value of the current will be obtained from equation 3[6].

$$I = v.Z_{in} \tag{3}$$

Seen Impedance from stator obtained from equation 4[7].

$$Z = \left(\frac{Neq}{Nr}\right)^2 * Zr \tag{4}$$

In this equation Z represents the seen impedance from stator, Zr represents the impedance of the rotor, Nr represents number of turns of winding rotor. Usually Z is given in specifications of motors so seen Impedance from stator after Neq is changed based on Z, is obtained according to Equation 5.

$$\frac{Znew}{Zold} = \frac{\left(\frac{Neq\ new}{Nr}\right)^2 * Zr}{\left(\frac{Neq\ old}{Nr}\right)^2 * Zr} = \left(\frac{Neq\ new}{Neq\ old}\right)^2 \tag{5}$$

In this equation Zold represents seen Impedance from stator with Neq old value of resultant stator windings in the circuit and Znew represents the seen Impedance from stator with Neq new value of resultant stator windings in the circuit. Another way to write the equation of 6 is this. Magnetizing inductance obtained from equation 7[8].

$$Znew = \left(\frac{Neq\ new}{Neq\ old}\right)^2 * Zold \tag{6}$$

$$Xm = \frac{Neq^2}{R} * \omega \tag{7}$$

In this equation Xm represents the magnetizing inductance, Rm reluctance of core, NS represents the number of stator windings turns and ω is a 2*π*f that f is a source frequency.

According to Equation 7, new magnetizing inductance when Neq is changed is:

$$\frac{Xm\ new}{Xm\ old} = \left(\frac{Neq\ new}{Neq\ old}\right)^2 \tag{8}$$

In this equation Xm new represents magnetizing inductance with Neq new value of resultant stator windings in the circuit and Xm old represents magnetizing inductance with Neq old value of resultant stator windings in the circuit.

Because added some turns to windings of stator, stator Impedance Proportional to Ratio increased is increased. Value of increased Impedance in the stator obtained from Equation 8.

$$Zs\ new = \left(\frac{Neq\ new}{Neq\ old}\right) * Zs\ old \tag{9}$$

In Figure 2, seen Impedance from Source is The resulting series of stator Impedance Sum with The resulting parallel of a Magnetizing inductance and rotor Impedance. According to Equation 5,7,8 in the seen Impedance from Source There are a Factor of ((Neq new)/(Neq old)). seen Impedance from Source obtained from Equation 9.

$$Zin = \left(\frac{Neq\ new}{Neq\ old}\right) * [(Rs + jXs) + \left(\frac{Neq\ new}{Neq\ old}\right) * \left(\frac{jXm * (Rr + jXr)}{Rr + j(Xr + Xm)}\right)] \tag{10}$$

In this equation Rs represents stator resistance, Xs represents stator reactance, Rr represents rotor resistance, Xr represents rotor reactance and Zin represents seen impedance from source.

According to equation 2, 3 and 10 magnetic flux in the core obtained from equation 11 and 12.

$$\varphi = \frac{Ns * V}{R * [(Rs + jXs) + \left(\frac{Neq\ new}{Neq\ old}\right) * (\frac{JXm * (Rr + jXr)}{Rr + j(Xr + Xm)})} \tag{11}$$

$$\varphi = \frac{Ns * V}{R * [(Rs + jXs) + (\frac{JXm * (Rr + jXr)}{Rr + j(Xr + Xm)})} \tag{12}$$

By comparing the equation 11 and 12 realize that with increasing number of turns in windings of the stator poles (Increasing Neq), magnetic flux in the core decreases.

Induction voltage in the rotor windings obtained from equation 13[9].

$$Er = 4.44 * Kwr * Nwr * fr * \varphi max \tag{13}$$

In this equation Kwr represents winding factor of the rotor (0<Kwr<1), Nwr represents the number of turns in windings of the rotor, fr represents rotor voltage frequency and φmax represents maximum magnetic flux in the core.

Now Induction voltage in the rotor make an electrical current and obtained from equation 14[10].

$$Ir = \frac{Er}{(Rr/s) + j * Xr} \tag{14}$$

In this equation S represents slip from sync speed and obtained from equation 14[11].

$$s = \frac{Ws - Wr}{Ws} \tag{15}$$

In this equation Ws represents the sync speed and Wr represents motor speed.

Briefly in the starting mode according to equation 11 with adding a some turns in the circuit, Neq increases then value of the magnetic flux in the core and maximum magnetic flux in the core are decreased and according to equation 13 induction voltage in the rotor decreased and then according to equation 14 electrical current decreases in the rotor and because of the induction motors are like rotary transformer so electrical current in the stator decreases.

Nominal current in the windings of the stator poles obtained from equation 16[12]. That in initiation with direct method it will use from 6 to 11 times more current.

$$\text{IL} = \frac{P}{\sqrt{3} * VL * cosQ} \tag{15}$$

4. System protection

In previous starting methods a protective system is needed in addition to the starting one. In other words, a series of circuits are installed in the control panel for starting and other ones for protecting the insulators of induction electromotor. In the new suggested system a current sensor (Fig. 1) measures the current continuously and when the current exceeds the nominal limit, a series of extra windings (winded in the same direction as the main ones) are entered into the system and decrease the current. In other words, Neq windings are increased and the flux of the electromotor is decreased according to equation 9 and then the induction voltage in rotor is decreased according to equation 11 and the rotor current is decreased accordingly according to equation 12 and since the induction electromotor is like a rotating transformer, starter current is decreased proportionally and the insulators of the windings of the starter are protected against high current.

5. An example of the operation of electromotor

In order to show the operation of the system, we assume an electromotor with the following specifications and analyze the operation of the system.

Assume a three-phase 75 kw bipolar induction electromotor with Y connection and 0.9 power factor and 380 volts with the following specifications: starter's resistance: 0.17 ohms, starter's reactance: 0.125 ohms, resistance transferred to rotor's starter: 0.17 ohms, reactance transferred to the rotor's starter: 0.125, core reactance: 10 ohms.

Nominal current of the above electromotor, by virtue of equation 6, is 126.61 amperes, but at the time of starting several times higher current is consumed that damage windings of starter and rotor's bars.

$$IL = \frac{75000}{\sqrt{3} * 380 * 0.9} = 126.61\ (A) \tag{16}$$

Windings of the main pole of the starter is 66 and we have added 48 extra windings in the same direction as the main ones. The extra 48 windings are serially attached to the main windings at the time of starting, thus:

$$N_{eq} = 66 + 48 = 114 \tag{17}$$

Neq has increased in comparison with the time when the 48 windings are absent (Neq=66). Thus, in equation 9 the maximum flux is decreased and according to equation 12 the voltage inducted in rotor is decreased and according to equation 13 the starting current (s=1) is decreased and since the induction electromotor is like a rotating transformer, starter's current is decreased. In other words, if this system is used, the starting current will be several times less than the direct connection method and the windings of the electromotor will not be damaged.

After starting, the current will be less than the nominal value and the extra 48 windings will exit the system gradually and Neq decreases gradually and the current is increased until the extra windings exit completely and Neq=66 and the current reaches the nominal current of 126.61 amperes.

6. Comparison

Starting with former methods decreases the power factor of the electromotor due to addition of impedance in starter or rotor (0.3-0.2 after phase), but in this method, the power factor remains fixed approximately.

According to Fig. 2, when the new windings are added in the same direction of starter's windings, the impedance of the starter increases. In other words, both the resistance and reactance of the starter increase. On the other hand, with the decrease of windings, aeff will decrease.

Therefore, in the electromotor suggested in 2.4, the impedance in 70 windings and in starting conditions will be:

$$Zin = (0.17 + 0.125j) + \left(\frac{10j * (0.17 + 0.125j)}{0.17 + 10.125j}\right) = 0.419\angle 36.8°\ (\Omega) \tag{18}$$

Then, according to equation 3, In other words, power factor will be 0.8(cos(-36.8)=0. 8).

$$I = \frac{220\angle 0°}{0.419\angle 36.8°} = 525.06\angle -36.8°\ (A) \tag{19}$$

Now, for calculating power factor in starting mode when extra 48 windings are inserted, we have to calculate impedance values as follows:

According to equation 8, starter's impedance with extra 48 windings will be:

$$Zs = \left(1 + \frac{48}{66}\right) * (0.17 + 0.125j) = (0.2936 + 0.2159j)\ (\Omega) \tag{20}$$

According to equation 6, impedance of starter in Neq=114 will be:

$$Znew = \left(\frac{114}{66}\right)^2 * (0.125j + 0.17) = (0.507 + 0.3729j) \tag{21}$$

According to equation 6, Xm new in Neq=114 will be:

$$Xm\ new = \left(\frac{114}{66}\right)^2 * (10) = 29.8347 \tag{21}$$

Thus, impedance in the new system will be:

$$Zin = (0.2936 + j0.2159) + \left(\frac{29.8347j * (0.507 + 0.3729j)}{0.507 + j(29.8347 + 0.3729)} = 0.9859\angle 36.938\ (\Omega) \tag{22}$$

Based on equation 3 then:

$$I = \frac{220\angle 0°}{0.9859\angle 36.938°} = 223.14\angle -36.938° \ (A) \quad (23)$$

In other words, power factor in this mode will be 0.799 .Thus, according to the above equations, power factor in the new system is higher than the direct connection method and starting current is decreased noticeably (from 525.05amperes in direct connection method to 223.14 amperes in the new system) that is acceptable with regard to the nominal current.

7. Accuracy of results with practical experiment

In experiments because all of coils are not quite on each other, the whole flux do not pass from all the number of rounds of coils poles. in other words some of flux close their pass from fewer number of windings in coil (for example flux start its pass from first turn and close it in middle of the coil so flux only passes from certain number of turns).so less magnetic flux produce compared with ideal condition and it can be said that effective number of turns are reduced [13].

In other words due to reduction in effective number of turns toward number of turns calculated in formula, the motor flux In a practical condition is slightly increased compared with amount of simulated flux(with formula 10) so starting current is slightly increased compared with simulated amount.

This error can be eliminated by slightly increasing in number of turns, in the other words according to motor manufacturing technology and how winding stator it's possible to increase the number of turns so as to reach the effective amount in section 5.

8. Technical and economic analysis

The proposed scheme must be analysis in two perspectives: Operational & economical.

1) In terms of finished cost:

The finished cost of proposed scheme is more than simple schemes and common schemes. the reason for this rise in prices is Issues such as Increase in number of windings, the need for a microcontroller and moving system, requiring current sensor and more needed insulation and more volume of stator toward previous schemes, etc.

2) In terms of performance and working lifetime and protective equipment:

Because of existence of smart system inside the stator, the motor starts automatically and without needing to starting circuit. In addition to starting, the scheme protects motor from over loads and does this work without disabling motor (in certain ranges of over load) toward previous schemes that disabled motor. In other words with this scheme there is no need to pay for starting system and motor protection that as a result reduce the costs. However, this scheme due to protect the motor in instantaneously against any over current, increases the useful life of the device. Manpower or users who want to use the motor do not requires special technical knowledge and reduce the costs of expert labor work.

According to the above proportional, the method of manufacturing and economic conditions using this scheme can reduce the costs of using induction motors in long time and technically make it comfortable working with this type of motors despite of more difficult engine manufacturing.

9. Results and discussion

The system has been simulated in Maxwell 16.0 and Matlab version 7.11.0.584 (R2010b). The Induction electromotor has been simulated using Matlab version 7.11.0.584 (R2010b) and the results have been as follows (values have been calculated in part 6).

Comparing Fig. 3 and Fig. 4, it is evident that starting current has decreased noticeably when the suggested system is used. Also, the figures show that this is a suitable system for starting induction electromotor as the starting current in this system is about 76% higher than the nominal current and the duration of current passage is short; thus, the windings are not damaged.

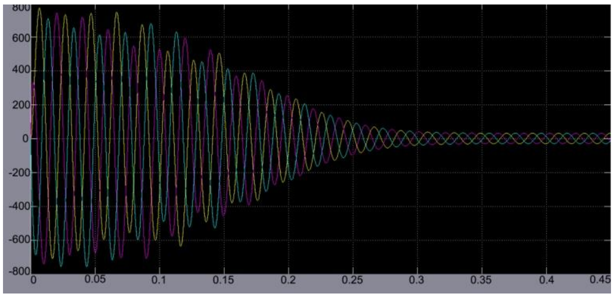

Fig. 3. Starting with direct method without the suggested system

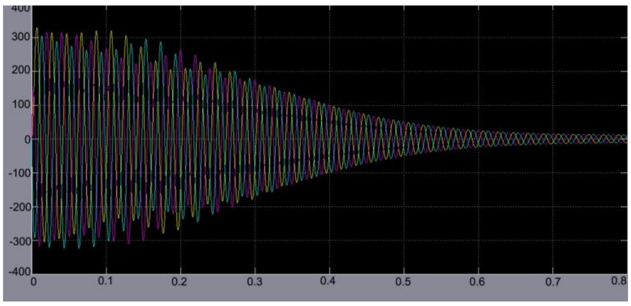

Fig. 4. Starting with direct method with the suggested system

Changes in core flux have been simulated with Maxwell 16.0 with the results of Fig. 3 and Fig. 4. Comparing figures 5 and 6 it can be concluded that maximum core flux has decreased (from 3.55 Teslas to 3.2 Teslas) and this is the cause of decrease of starting current from the value of Fig. 3 to the value of Fig. 4 (from 525.06 amperes to 223.14 amperes).

10. Conclusion

This plan is a revolutionary step forward in smart electrometers. In other words, the electromotor adjusts it's windings in proportion with the current passing the windings to prevent damage to them. This system works at the time of starting and in normal function as well to protect the system.

This system, as mentioned in 5, protects the system by decreasing flux. This is a new system as in previous plans the current is decreased using impedance division or through decrease of voltage of starter's windings with the use of an autotransformers or through increasing rotor's resistance.

As shown in 6 changes of windings can change flux effectively and can control the current.

This system can be used in all induction electromotors (which are highly used in industry). This plan decreases the costs of using induction electromotors in industry. Other systems entail problems such as high loss at the time of starting (because they insert impedance both in rotor or starter at the time of starting), low starting power factor to normal function power factor, skilled operators, etc. as well as costs for protecting system by means of bimetals, etc. All these problems are solved in this system and there will be no need for several protection systems all facilitating use of such electrometers. The user only turns on the electromotor and there will be no control circuit or protection system and former necessary requirements such as change of impedance or voltage are removed and no costly and sensitive device such as control panel, autotransformer, etc. are required anymore.

All in all, using this method, induction electromotors can be operated easily and all the shortcomings of previous methods are removed and costs of starting and maintaining induction electrometers are decreased.

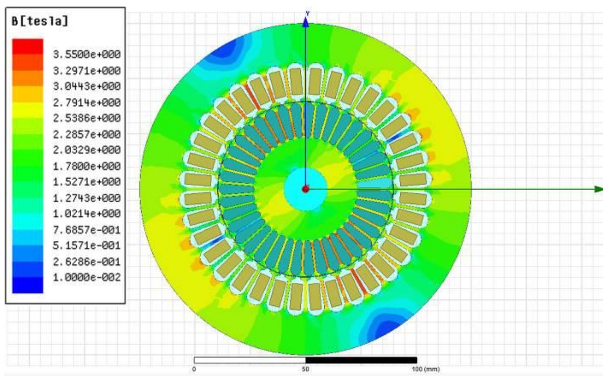

Fig. 5. Starting flux in direct method without the suggested system at phase A peak

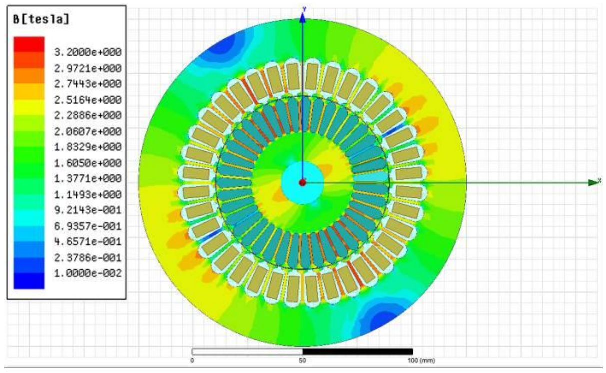

Fig. 6. Starting flux in direct method using the suggested system at phase A peak

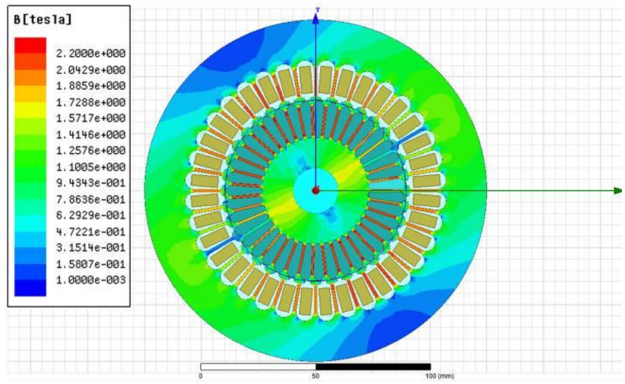

Fig. 7. Flux in normal function without extra windings at phase A peak

References

[1] Stephen J. Chapman ,"Electrical Machinery fundamentals", New York, Elizabeth A. Jones, McGraw-Hill Higher Education, pp. 380-384, 2005.

[2] Stephen J. Chapman ,"Electrical Machinery fundamentals", New York, Elizabeth A. Jones, McGraw-Hill Higher Education, pp. 430-434, 2005.

[3] Stephen J. Chapman ,"Electrical Machinery fundamentals", New York, Elizabeth A. Jones, McGraw-Hill Higher Education, pp. 389, 2005.

[4] Stephen J. Chapman ,"Electrical Machinery fundamentals", New York, Elizabeth A. Jones, McGraw-Hill Higher Education, pp. 8-11, 2005.

[5] Stephen J. Chapman ,"Electrical Machinery fundamentals", New York, Elizabeth A. Jones, McGraw-Hill Higher Education, pp. 11-15, 2005.

[6] Stephen J. Chapman ,"Electrical Machinery fundamentals", New York, Elizabeth A. Jones, McGraw-Hill Higher Education, pp. 51, 2005.

[7] Stephen J. Chapman ,"Electrical Machinery fundamentals", New York, SIXTH EDITION ,McGraw-Hill Higher Education,*pp. 68-72*, 2003.

[8] Stephen J. Chapman ,"Electrical Machinery fundamentals", New York, SIXTH EDITION ,McGraw-Hill Higher Education,*pp. 11-13*, 2003.

[9] A. E. Fitzgerald, Charles Kingsley, Jr., Stephen D. Umans, “Electric Machinery”, New York, SIXTH EDITION ,McGraw-Hill Higher Education,*pp .208-213,* 2003.

[10] Stephen J. Chapman ,”Electrical Machinery fundamentals”, New York, Elizabeth A. Jones, McGraw-Hill Higher Education, pp. 390-391, 2005.

[11] Stephen J. Chapman ,”Electrical Machinery fundamentals”, New York, Elizabeth A. Jones, McGraw-Hill Higher Education, pp. 386, 2005.

[12] A. E. Fitzgerald, Charles Kingsley, Jr., Stephen D. Umans, “Electric Machinery”, New York, SIXTH EDITION ,McGraw-Hill Higher Education,*pp. 641,* 2003.

[13] Paul C.Krause, Oleg Wasynczuk, Scott D.Sudhoff, “Analysis of Electric Machinery And Drive Systems”, New York, SECOND EDITION ,WILEY INTERSCIENCE,pp. 1-16, 2003.