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Speed Control Of Brushless Dc Motor Using Neuro Fuzzy Based Pid Controller

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***Abstract*—The main purpose of this proposed research paper is to control of brushless DC motor using Neuro fuzzy based PID controller . This research discribes modeling of four switch inverter fed BLDC motor explained with transfer function model. The control with sensor , the controller is used Neuro fuzzy based PID controller & in sensorless control the method is terminal sensing . Simulation of BLDC with NFPID controller .Speed control method of BLDC motor with NFPID controller.Comparative analysis of sensor & sensorless control of four switch inverter fed to BLDC motor.**

***Index Terms*— Brushless DC Motor (BLDC) , Neuro Fuzzy based PID Controller , Four Switch Inverter, speed control method, sensor & sensorless control..**

I. INTRODUCTION

Permanent Magnet (PM) brushless DC machines has various advantage such as high efficiency , high power factor,high torque , simple control,low cost,simple circuitary & less maintenance. Thera are two types of DC motor used (1) conventional DC motor in which flux is produced bu the stationary field pole coil current (2) Brushless DC having perment magnet produce the flux in wire wound field pole. The commutator is used in conventional DC motor , in brushless the commutator is replaced by electronically commutation.In this paper NFPID controller is applied in speed control of PMBLDC motor, For improvement of the NFPID controller Kp,Ki & Kd can be utilised by proper proportional. The PMBLDC widely used in aerospace,military purpose,electric automative,refrigeration,computer,house hold appliances. The functions of commutator and brushes are implemented by solid state switches , maintenance free motors called the Brushless DC motor are developed. Latest developments in power electronics, microelectronics and modern control technologies have greatly affected the wide spread use of permanent magnet DC motors. The roughly Classification of Permanent Magnet motors are permanent magnet synchronous motor (PMSM) and Permanent Magnet Brushless DC motors (PMBLDCM). The PMSM has sinusoidal back-emf waveform the BLDC motor has trapezoidal back-emf waveform. PMBLDC motors have superior over brushed DC motors and induction motors, like better speed-torque characteristics, high dynamic response, high efficiency, high power factor, noiseless operation , simple circuitary and wide flexibility in speed ranges. The specific torque is higher enabling it to be used in applications where space and weight are diverse factors. An advanced microcontrollers and electronics has overcome the challenge of implementing required control functions, making the BLDC motor more familar for a wide applications.
Due to the advance of the BLDC motor come at the expense of increased complexity in the electronic controller circuitary and the accurate shaft position sensing. Permanent magnet (PM) excitation is more famous in smaller motors upto below 20 kW. In above 20 KW motors, the cost and weight of the magnets become increased and it would required additional circuitary for excitation by electromagnetic or induction . However, the development of high-field PM materials, PM motors with ratings encourages to built of a few Megawatts motors

A. MACHINE CONSTRUCTION

BLDC motors are predominantly flat surface-magnet machines with flat magnet pole-arcs and concentrated stator stamping windings. The design is based on a square waveform distribution of the air-gap flux density waveform as well as the winding density of the stator phases in order to match the operational characteristics of the self-controlled inverter BLDC motors obtain permanent field excitation from permanent magnets mounted on the rotor surface. The development in permanent magnet manufacturing and technology are the responsible for reducing the cost and increasing in the applications of BLDC motors. Ferrite or ceramic magnets are the most popular in low-cost motors. These magnets are available in a permanence of 0.38 T and an almost straight demagnetization characteristic throughout the second quadrant. For specialisation, high-energy magnetic materials such as neodymium-iron-boron (Nd-Fe-B) are used. The high permanence and coactivity reduced in motor frame size for the same output as compared to using ferrite magnets motors. However, the reduction in size is additional increased in cost of the magnets.
The basic considerations while choosing the magnetic material for a motor are the torque per unit volume of the motor, operating temperature range, and severity of operational duty of the magnet. For maximumization of power density, the product of the electric and magnetic loadings of the motor should be as high as possible. A high electric loading required a long magnet length in the direction of magnetism and a high coactivity. A high power density also requires the largest permant magnet volume. Exposure to high temperatures leads to deteriorate the flux density and coercive force of permanent magnets. Hence, the highest operating temperature should be considered while choosing the magnets. Parmanant Magnets can also be

demagnetized by faulty reverse currents such as short-circuit currents occured by inverter faults. Hence, protection measures are primerily designed in the inverter and control electronics to limit the magnitude of the armature currents to a safe value.

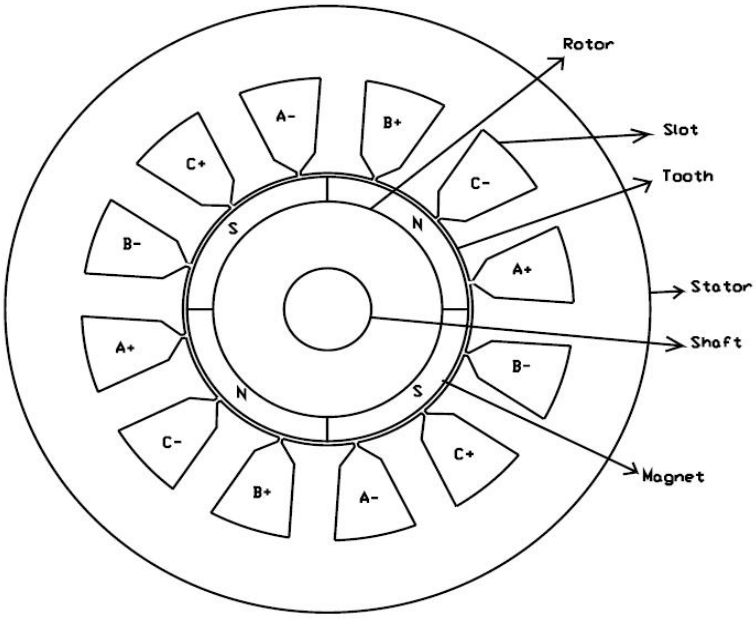

Figure 1: Three-phase BLDC motor with four poles on the rotor and 12 stator slots

B. STATOR WINDINGS

BLDC motors are often assumed in three phases, but this is not necessary in every case. In small motors light-duty cooling fans have minimal performance requirements, and it is cost effective to build them just one or two phases. On the other hand, it is preferable to use a high phase number for Megawatt ratings drives. This reduces the power-handling capacity of a single phase, and also incorporates some degree of fault tolerance. Machines of 15 phases have been built for ship propulsion. Although these are special-purpose designs, motors with four and five phases are quite common. The choice of number of stator slots will depend on the rotor poles, phase number and the winding configuration. In general, a fractional slots/pole design is famous to minimize cogging torque. The motor of fig.2.2 has six slots, which is not a multiple of the number of poles, and is hence a fractional slots/pole design. The windings could be lap-wound or concentric-wound, and the coil span could be full-pitch or short-pitch, depending on the crest width of the back-emf desired

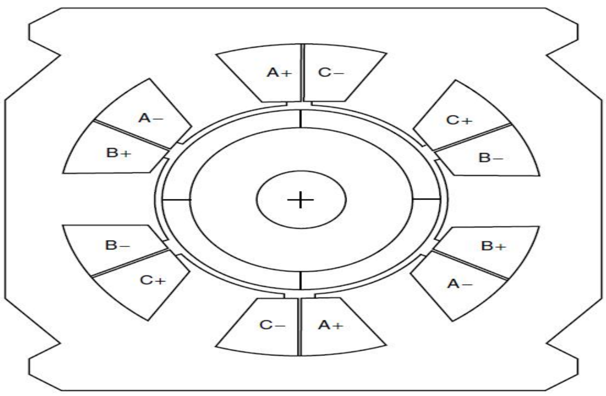

Figure 2 : Three-phase BLDC motor with six slots and four poles

C. MOTOR CHARACTERISTICS

The air-gap flux-density waveform is a pure square wave, but fringing causes the corners to be some what rounded(sinusoidal). As the rotor rotates, the waveform of the voltage induced in each phase with respect to time is an exact replica of the air-gap flux-density waveform with respect to rotor position i.e square wave. Because of fringing, the back-emf waveform takes on a trapezoidal shape. The shape of the back-emf waveform distinguishes the BLDC motor from the permanent magnet synchronous motor (PMSM), which has a sinusoidal back-emf waveform. This has given rise to the terminology “trapezoidal motor” and “sinusoidal motor” for describing these two permanent magnet AC (PMAC) machines. The back-emf voltages induced in each phase are similar in shape and are displaced by 120° electrical with respect to each other in a three-phase machine. By injecting square wave current in each phase that coincides with the crest of the back-emf waveform in that phase, it is possible to obtain an almost constant torque from the BLDC motor. The crest of each back-emf half-cycle waveform should be as broad as possible (≥120°electrical) to obtain smooth output torque. This condition is satisfied by the 12-slot motor of Fig. 2.1 because it has full-pitched coils, but not by the six-slot motor of Fig. 2.2 because the coil spans are shorter than the pole arcs. The two back-emf waveforms calculated using the finite-element method are plotted in Fig.2.3 and it can be seen that the six-slot motor has a smaller crest width, and is hence not suitable for 120 ° bipolar excitation. However, it can be used with other excitation waveforms as discussed in the section on unipolar excitation.

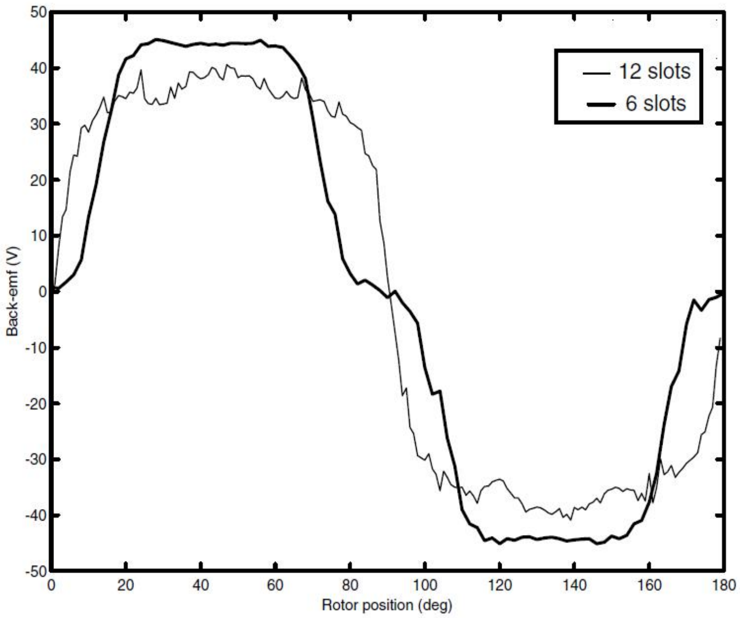

Figure 3: Back-emf waveforms of the 12-slot and the 6-slot motors

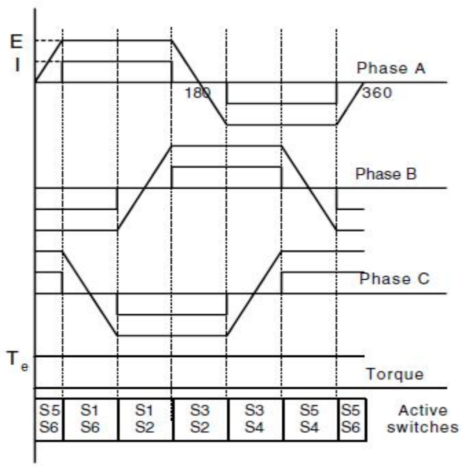

Figure 4: Back-emf and phase current waveforms for three-phase BLDC motor with 120° bipolar currents

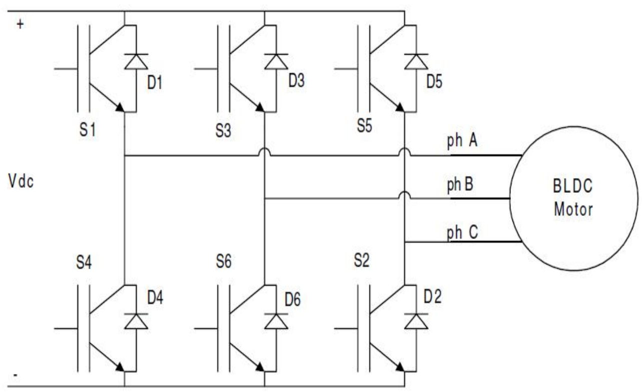

Figure 5: Schematic of IGBT-based inverter for three-phase BLDC motor

The ideal back-emf voltage and 120° phase current waveforms for a three-phase BLDC motor. The inverter switches that are active during each 60° interval are also shown corresponding to the inverter circuit. The simplicity of this scheme arises from the fact that during any conduction interval, there is only one current flowing through two phases of the machine, which can be sensed using a single current sensor in the DC link. Because there are only two inverter switches active at any time, this is also called the two-switch conduction scheme, as opposed to the three-switch conduction scheme used in PMSM motor drives. The amplitude of the phase back-emf is proportional to the rotor speed, and is given by-

$E = k\Phi\omega_m$ ………………………………...……….(2.1)

Where k is a constant that depends on the number of turns in each phase,Φ is the permanent magnet flux, and ωm is the mechanical speed. During any 120° interval, the instantaneous power being converted from electrical to mechanical is the sum of the contributions from two phases in series, and is given by-

$Po = \omega_m Te = 2EI$…………..………….…………(2.2)

Where Te is the output torque and I is the amplitude of the phase current. The expression for output torque can be written as-

$Te = 2k\Phi I = ktI$……………………………………. (2.3)

Wherekt is constant.

The similarity between the BLDC motor and the commutator DC motor can be seen from equations 2.1 and 2.3. It is because of this similarity in control characteristics that the trapezoidal PMAC motor is widely known as the BLDC motor, although this term is a misnomer as it is actually a synchronous AC motor. But it is also not a rotating field machine in the AC sense, because the armature MMF rotates in discrete steps of 60° electrical as opposed to a smooth rotation in other AC machines.

D. MATHEMATICAL MODEL

The BDCM has three stator windings and permanent magnet on the rotor. Since both the magnet and the stainless-steel retaining sleeves have high resistivity, rotor induced currents can be neglected and no damper windings are modeled.

The currants ia, ib and ic needed to produce a steady torque without torque pulsation Are shown in fig. with ac machine that have sinusoidal back EMF ,a transformation can be made from the phase variable to d, q coordinates that vary either in the stationary ,rotor synchronously rotating reference frames. Inductances that vary sinusoidal in the a, b, c frame become constants in the d, q reference frame. The back EMF being non-sinusoidal in the BDCM means the mutual inductance between the stator and rotor is non-sinusoidal; hence transformation to a d, q reference frame cannot be easily accomplished. A possibility is to find a Fourier series of the back-EMF, in which case the back EMF in the d, q reference frame would also consist of many term. This is considered too cumbersome, hence the a, b, c phase variable modeled already developed will be used without further transformation.

BLDC motor can be realized mathematically in two ways: a, b, c phase variable model and d-q axis model. In a BLDC motor, the trapezoidal back EMF implies that the mutual inductance between stator and rotor is non-sinusoidal, thus transforming to d-q axis does not provide any particularadvantage, and so abc phase variable model is preferred

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + p \begin{bmatrix} L_a & L_{ba} & L_{ca} \\ L_{ba} & L_B & L_{cb} \\ L_{ca} & Lcb & L_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \text{………….. (2.4)}$$

Where it has been assumed that the stator resistances of all the windings are equal. The back EMF's ea, eb, and ec, have trapezoidal shapes.Assuming further that there is no change in the rotor reluctances with angle then,

$L_a = L_b = L_c$

$L_{ab} = L_{ca} = L_{bc}$

Hence,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + p \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \text{………(2.5)}$$

But,

$i_a + i_b + i_c = 0$ ……..…(2.6)

$M\, i_b + M\, i_c = M i_a$ …………(2.7)

Hence,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + p \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \text{……….. (2.8)}$$

In state-space form the equations are arranged as follows:

$$P \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} 1/L-M & 0 & 0 \\ 0 & 1/L-M & 0 \\ 0 & 0 & 1/L-M \end{bmatrix} \left[\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} - \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} - \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \right] \text{............... (2.9)}$$

And the Electromagnetic torque is

Te =(eaia +ebib ecic)/wr …............(2.10)

The equation of motion is

Pwr = (Te – TL – Bwr)/J .... (2.11

Where k = a, b, c

ik is the phase current of kth phase

ek back-EMF of kth phase

Te is the electromagnetic torque
ωm is the mechanical speed of the motor
J is the rotor inertia
B is damping constant
Rs is the resistance of each phase of the motor
Lt is the inductance of each phase of the motor
Kt is torque constant
Ke is back-EMF constant
P is the number of poles
Fk(ϴr) represents the back-EMF as a function of rotor position

The currents ia, ib and ic needed to produce a steady torque without torque pulsations are shown in Fig.2.4 With AC machines that have sinusoidal back EMF's, a transformation can be made from the phase variables to d, q coordinates either in the stationary, rotor, or synchronously rotating reference frames. Inductances that vary sinusoidally in the a,b, cframe become constants in the d,q reference frame. The back EMF being non-sinusoidal in the BDCM means that the mutual inductance between the stator and rotor is non sinusoidal, hence transformation to a d, q reference frame cannot be easily accomplished. A possibility is to find a Fourier series of the back EMF, in which case the back EMF in the d, q reference frame would also consist of many terms.

Application of BLDC motor

1. BLDC motor is one of the motor types rapidly gaining popularity. BLDC are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation.

2. BLDC motor has many advantages over brushed DC motor and Induction Motor in terms of efficiency, operating life, speed range, speed versus torque characteristics. Compared with AC Induction motors, BLDC motor has such advantages as high dynamic response, Noiseless operation, High speed range.

3. The ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors.

4. The BLDC motor drive plays a vitally important role in motion control applications.

5. BLDC motors can potentially be deployed in any field-application currently fulfilled by brushed DC motors. Cost and control complexity prevents BLDC motors from replacing brushed motors in most common areas of use.

6. BLDC motors have come to dominate many applications: Consumer devices such as computer hard drives, CD/DVD players, and PC cooling fans use BLDC motors almost exclusively. Low speed, low power brushless DC motors are used in direct-drive turntables. High power BLDC motors are found in electric vehicles and some industrial machinery. These motors are essentially AC synchronous motors with permanent magnet rotors.

E. NEURO FUZZY LOGIC CONTROLLER

Parameters	Values
No. of Poles	4
Power	2Hp
Input Voltage	415
Stator Resistance per phase	1.5 ohm
Stator Inductance per phase	8.5 mH
Torque Constant	1.4 Nm/Apeak
Voltage Constant	146.077 VpeakL-L/krmp
Moment of Inertia	0.008 kgm^2
Friction Coefficient	0.01 Nms

Table 1. Parameters of Motor

Fuzzy logic controller is used for simulation of BLDC Motor with sensor. Three hall effect sensors are connected the other end of the motor and they are separated by 120 degree mechanically. A Fuzzy Logic Controller (FLC)[11-12] uses fuzzy logic as a design methodology, which can be utilized for developing linear and non-linear systems for embedded control. FLC techniques need less development time, have better performance and are good replacements for conventional control techniques, which require highly complicated mathematical models. A fuzzy logic controller does not require an exact mathematical model. It however requires knowledge-based set of heuristic rules. These rules variables. The steps involved in the design of fuzzy controller are fuzzification, rule definition and defuzzification.

For the fuzzy controller necessary data required for the simulation is given in Table 1. The two inputs given are error and change in error. The output is the reference current for the Hysteresis controller. All three membership functions are Triangular. The input and output membership functions areshown in Figures 10 to 12. The fuzzification rule is entered using the rule editor of the fuzzy toolbox as shown in Figure 13. The simulation diagram is shown in Figure 14.The overall simulation diagram with controller, four-switch inverter and BLDC motor model.

CONCLUSION

The realization of low cost and high performance three-phase BLDC motor drive system by four-switch converter topology is studied . From the observation, one should note that the development of the proper PWM control strategy should be accompanied with the reduced parts converter. As a solution, we introduced here the direct current controlled PWM and examine the performance. With the developed control scheme, it is expected that the proposed system can be widely used in commercial applications with a reduced system cost.

REFERENCES

[1] M.Vigneshkumar1 ‘‘Simulation Modeling of Inverter Controlled BLDC Drive Using Four Switch”, International Journal of Scientific & Engineering Research 351-356 Volume 4, Issue 5 May 2013.

[2] M. B. de Rossiter Correa, C. B. Jacobina, E. R. C. da Silva, and A. M. N. Lim, “A general PWM strategy for four-switch three-phase inverters,” IEEE Trans. Power Electron., vol. 21,no. 6, pp.1618–1627, Nov. 2006. [3] R. K. Aggarwal and A. T. Johns, “Digital differential relaying scheme for teed circuits based on voltageand current signal comparison,”Proc. Inst. Elect. Eng., Gen., Transm. Distrib., vol. 137, no. 6, pp. 414–423, Nov. 1990.

[4] A. HalvaeiNiasar, H.Moghbelli, and A. Vahedi, ‘‘Sensorless control of a four-switch, three-phase brushless DC motor drive,’’ presented at the Iranian Conf. Electr. Eng. (ICEE 2007), May, Iran Telecommun. Res. Center (ITRC), Tehran, Iran.

[5] A. HalvaeiNiasar, “Sensorless control of four switch, three phase brushless DC motor drives for low-cost applications,” Ph.D. dissertation, Dept. Electr. Eng., Iran Univ. Sci. Technol., Tehran, Iran, Dec. 2007.

[6] Bhim Singh, Fellow, IEEE and VashistBist, **“A Single Sensor Based PFC Zeta Converter Fed BLDC Motor Drive for Fan Applications”** 978-1-4673-0766-6/12/$31.00 ©2012 IEEE

[7] S. Ogaswara and H Akagi, “An approach to position sensorless drive for brushless dc motor”, IEEE IA, vol. 27, September / October 1991,pp. 929-933.

[8] Paul P. Acarnley and Jhon F. Watson , “Review of Position-SenorlessOperation of Brushless Permanent Magnet Machine”, IEEE Transactionon industrial electronics , vol. 53, no. 2, April 2006.

[9] P.Q. Dzung, L.M. Phuong, P.Q. Vinh, N.M. Hoang,T.C. Binh, “New Space Vector Control Approach for Four SwitchThree Phase Inverter (FSTPI), International Conference on Power Electronics and Drive Systems- PEDS 2007, Bangkok,Thailand, 2007 .

[10] T.J.E.Miller, “Brushless Permanent Magnet and Reluctance Motor Drives.” Oxford Science Publication, UK, 1989

[11] R.Krishnan, “Electric Motor Drives: Modeling, Analysis, and Control, Prentice-Hall”l, Upper Saddle River, NJ, 2001.

[12] M. B. de Rossiter Correa, C. B. Jacobina, E. R. C. da Silva, and A. M. N. Lim, “A general PWM strategy for four-switch three-phase inverters”,IEEE Trans. Power Electron, vol. 21, no. 6, pp. 1618–1627, Nov. 2006

[13] A. T. Johns, R. K. Aggarwal, and Z. Q. Bo, “Non-unit protection technique for EHV transmission systems based on fault generated noise part 1: Signal measurement,”Proc. Inst. Elect. Eng., Gen., Transm. Distrib., vol. 141, no. 2, pp. 133–140, Mar. 1994.

[14] R. K. Aggarwal, A. T. Johns, and Z. Q. Bo, “Non-unit protection technique for EHV transmission systems based on fault generated noise part 2: Signal processing,”Proc. Inst. Elect. Eng., Gen., Transm. Distrib., vol. 141, no. 2, pp. 141–147, Mar. 1994.

[15] Z. Q. Bo, “A new non-communication protection technique for transmission lines,”IEEE Trans. Power Del., vol. 13, no. 4, pp. 1073–1078, Oct. 1998.

[16] D. Xingli, G. Yaozhong, and D. Xinzhou, “A wavelet and traveling waves based non-communication high speed transmission line protection,”Autom. Elect. Power Syst., vol. 10, 2001.

[17] C. S. Burrus and R. A. Gopinath,IntroductiontoWaveletsandWavelet Transform: A Primer. Upper Saddle River, NJ: Prentice-Hall, 1998.

[18] S. Haykin, Neural Networks-A Comprehensive Foundation, 2nd ed. Upper Saddle River, NJ: Prentice-Hall, 1999.