VOL. 11, NO. 2, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

SURVEY ON SPEED CONTROLLERS FOR A PERMANENT MAGNET BRUSHLESS DC MOTOR

B. Gunapriya[1], M. Sabrigiriraj[2], M. Karthik[1] and R. Nithya Devi[1]
[1]Department of EEE, Coimbatore Institute of Engineering and Technology, Coimbatore, Tamil Nadu, India
[2]Department of ECE, SVS College of Engineering, Coimbatore, Tamil Nadu, India

ABSTRACT

The permanent magnet brushless DC motors are utilized more in automotive, industrial and household product due to its high torque density, compactness, high efficiency, low maintenance and simple control. BLDC motor is meant to utilize the trapezoidal back emf voltages with square wave currents to come up with constant torque. BLDC motor is electronically controlled and needs rotor position data for correct commutation of the currents even at fixed-speed application. On the other hand it's very important to lower the producing value of the BLDC motor drive for several applications. This survey presents analysis of many algorithms planned by many authors to deal with the speed control of BLDC motor effectively. The several algorithms are analyzed completely to spot their benefits and limitations. The performance analysis of the algorithms is applied to see the simplest approach. Finally the fuzzy and neural techniques are found to have superior quality for speed control of drives.

Keywords: BLDC motor, PI controller, neural network, Fuzzy logic.

INTRODUCTION

The utilization of magnet in electrical machines have and benefits than magnetic force excitation machines which ends up in high efficiency, easy construction, low cost, less maintenance and high torque or high output power per unit volume. In early nineteenth century, magnet excitation system was used for first time in electrical machines. The performance of this machine wasn't satisfactory; owing to poor quality of exhausting magnetic material create this less usable. Once the invention of alloy rested the employment of magnet excitation system will increase. Lanthanoid permanent magnets improve the ability density and dynamic performance of the machine. Induction motors are preferred machine within the twentieth century due to its easy construction, less price, dependability and low maintenance. Because of little air gap, lower efficiency and low power issue than synchronous machine it create synchronous machine to be a part in industrial applications. The schematic arrangement of permanent magnet synchronous machine is shown in Figure-1.

Due to high power to weight quantitative relation, high torque, smart dynamic control for variable speed applications, absence of brushes and electric switch create Brushless dc (BLDC) motor [1], most suitable option for prime performance applications. Also absence of brushes and electric switch, there's no drawback of mechanical wear of the moving elements [2-3]. As well, higher temperature reduction property and skill to control at high speeds [4-5] build them superior to the conventional dc machine. However, the BLDC motor constitutes a tougher drawback than its brushed counterpart in terms of modeling and system structure to its multi-input nature and paired nonlinear dynamics. Permanent-magnet brushless dc motors are additionally accepted which are utilized in superior applications. In several of those applications, the assembly of ripple-free force is of primary concern.

There are three main sources of torque production in BLDCMs [6-7]: cogging torque, reluctance torque, and mutual torque. Cogging torque is created by the stator slots interacting with the rotor magnetic field and is independent of stator current excitation. Reluctance torque is caused by the variation in phase inductance with respect to position. Mutual torque is created by the mutual coupling between the stator winding current and rotor magnetic field. In general, surface-mounted magnets are utilized in several high performances BLDCM's. As a result of the permeableness of the magnet material is almost capable that of air, the effective air gap is enlarged by the magnet. This reality ensures minimum coil impact on the rotor field from the stator coil currents.

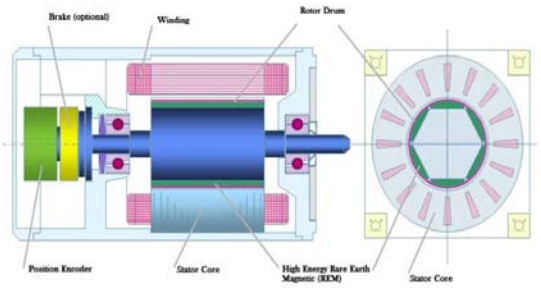

Figure-1. Schematic arrangement of magnet synchronous machine.

If a BLDCM is intended with low strikingness either the stator coil slots or rotor magnets are in skew by one slot pitch; the consequences of the primary to torque elements may be greatly reduced. Therefore, if the waveforms of the back emf voltage and current are absolutely matched, the ripple is decreased and therefore the mutual torque element is maximized.

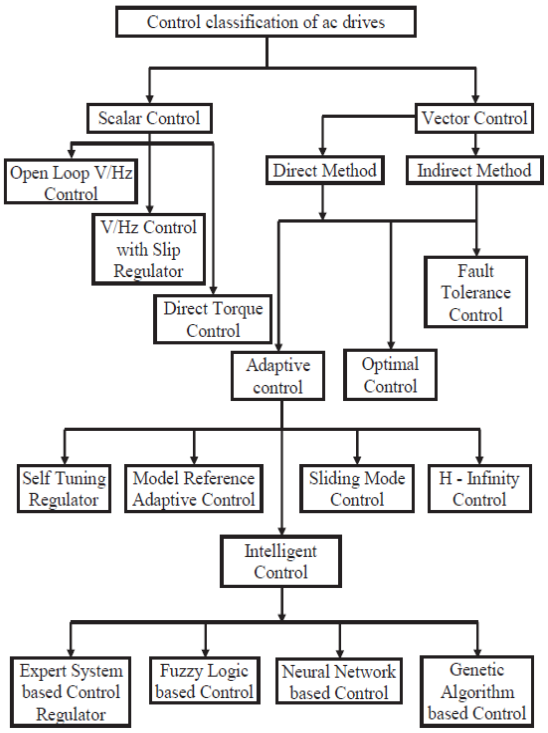

Figure-2. Classification of AC drives.

The PI and PID controllers are the more commonly used for industrial applications. The various control classifications of AC drives is shown in Figure-2. Even though they are simple to design and easy to implement, tuning the controller parameters to get optimum gain values is not an easy task. They are very sensitive to parameter variations, change in load, change in command speed and other uncertainties. Moreover, the performance of these controllers varies with the operating conditions. They are usually designed in the linear region without considering the saturation region. For high performance applications of different motors, the saturation region was also to be considered. To overcome the drawbacks of these conventional controllers, many adaptive control techniques started emerging.

Recently, global optimization techniques like genetic formula [8], Particle Swarm improvement (PSO) technique [9] and ant colony search algorithmic rule are applied for best calibration of PI controller of the BLDC drive system. These evolutionary algorithms are heuristic population-based search procedures that incorporate random variation and selection operators. Although, they appear to be smart approaches for the answer of PI gains improvement problem, however, once the system contains an extremely epistatic objective perform (i.e. wherever parameters being optimized are extremely correlated), then the range of parameters to be optimized is massive, then they need degraded efficiency to get international optimum resolution. So as to beat these drawbacks, the signal/noise ratio (SNR) algorithmic rule is employed to adapt PI controller parameters assuring deadbeat response for the current and speed of BLDC drives at certain loading conditions. This algorithmic rule doesn't need a large resolution area, and also the iterations were liable to connected with control parameters. On the other hand, it's an economical appliance and obtains higher result for uncertainties conditions at different operating points.

SURVEY

G. Murugananth [10] projected and evaluated a chopper controlled drive. The chopper control drive has an inner current control loop and an outer speed control loop. The outer control loop employs a conventional PI controller for the speed control of the PMDC motor. The anti-windup PI controller based system is projected so as to reinforce the performance of the system. The system is simulated using Matlab / Simulink and also the performances of various anti-windup schemes are analyzed.

J. Karthikeyan [11] mentioned brushless dc motors that are widely utilized in several applications that need wide selection of speed and torque control owing to its low inertia, quick response, high responsiblility and maintenance free. This current controlled technique is predicated on the generation of quasi- square wave currents using only one controller for three phases. This control strategy uses a triangular carrier for the ability transistors that is easier and effective than the other choices. the benefits of this method are: a) The stator coil currents are fully characterized by their amplitude, b) The 3 phases are controlled with constant dc element, and the part of currents are constant precisely at the same magnitude Imax, c) The dc link current measure isn't needed .d) phase currents are kept balanced and phase over currents are eliminated.

Juan W. Dixon [12] represented the technique that need to control the machine that is usually needed to count with a sensing element as a result of the electrical converter phases, engaging at any time, should be commuted on the rotor position. Encoders and resolvers are used for sensing rotor position with relevancy stator coil. These sensors, however, build the motor system a lot of difficult and automatically unreliable. A simple solution is represented to see the commutation sequence of a BLDC motor with a flux distribution. The strategy is predicated on a current sensing and also the determination of the back emf. The wave of trapezoidal back emf phenomenon is shown in figure 3. For trapezoidal flux distributions the result could also be enforced with some minor changes. The most characteristic of this kind of motor, fed with quasi-square-wave currents, that it only needs a six position sensor, and only one current controller for its full torque control. In contrast, the sinusoidal current type, the angular position needs to be known at any moment in order to control each of the three phase currents.

The solution projected makes use of knowledge restricted within the back emf. This methodology is

merely applicable whereas currents may be detected; therefore it must be complemented with a beginning methodology. The system was enforced employing a quick digital signal processor (TMS320F241) that is programmed with a closed loop PI current control for the motor to provide a constant torque. A fiber optic link is employed between the controller and also the electrical converter.

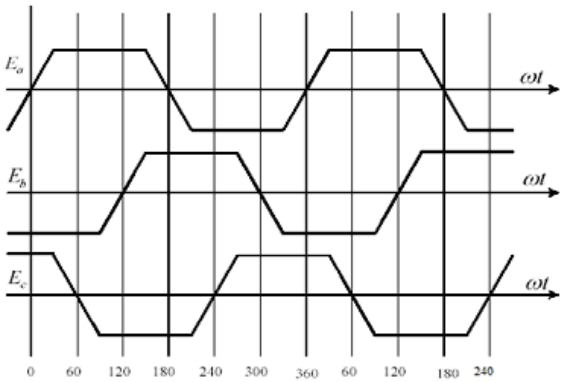

Figure- 3. Wave of trapezoidal back emf phenomenon.

Tan Chee Siong [13] mentioned a couple of logic controller. A logic controller is developed and so MATLAB Fuzzy-Logic is inserted into the Simulink model. The dynamic characteristics of the brushless DC motor like speed, torque, current and voltage of the electrical converter elements are discovered and analyzed the developed MATLAB model. Therefore to verify the effectiveness of the controller, the simulation results are compared with TMS320F2808 DSP experimental results.

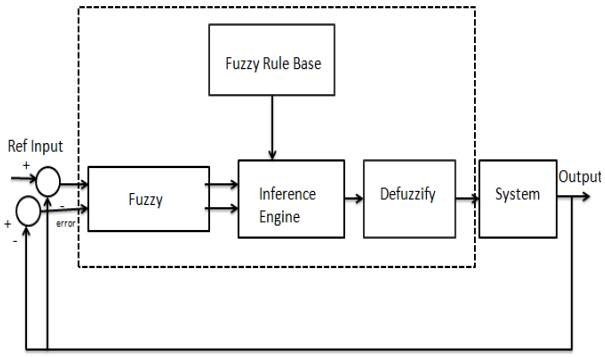

Figure-4. Fuzzification arrangement.

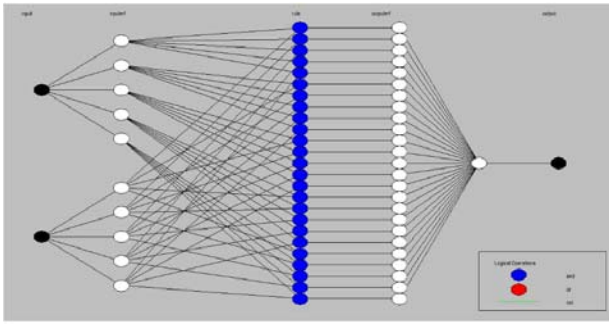

Figure-5. Structure of ANFIS speed controller.

R. Kandiban [14] discovered improved adjustive Fuzzy PI controller to manage speed of BLDCM; this paper provides a summary of performance standard PI controller, Fuzzy PI controller and adjustive Fuzzy PI controller. The Fuzzification arrangement and Structure of ANFIS speed controller is shown in Figure-4 and 5. It's tough to tune the parameters and find fulfilled control characteristics by standard conventional PI controller. The experimental results verify that an adjustive Fuzzy PI controller has higher control performance than the each fuzzy PI controller and standard PI controller. The modeling, control and simulation of the BLDC motor are done with the computer code package MATLAB/SIMULINK.

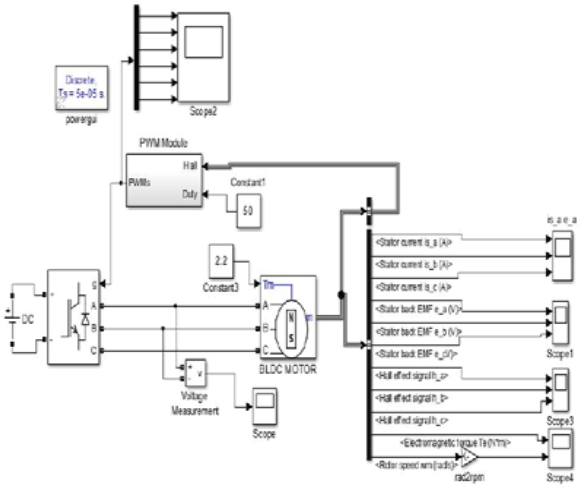

Figure-6. SIMULINK diagram of BLDC motor.

Mohammed Naseeruddin [15] says BLDC motors that are gaining attention from varied Industrial and appliance makers, as a result of its high efficiency, high power density and low maintenance value. Based on several analysis and developments within the fields of magnetic materials and power physics, their applications to electrical drives have redoubled to a major extent. During this paper, the modeling of Brushless DC motor drive system together with system for speed and current has been conferred with exploitation of MATLAB/

SIMULINK. The SIMULINK diagram of BLDC motor is shown in Figure-6. So as to determine the model, varied cases of simulation studies are found. An obtained result shows that, the model performance is satisfactory.

Ashish A [16] mentioned standard strategies of control that didn't yield desired performance of BLDC motor owing to non-dimensionality arising as a result of variation within the system parameters and ranging load. Fuzzy logic controller is used to improve BLDC performance. Another challenge is to reduce the price of the drive system. Sensorless control has benefits like value reduction, responsibility, elimination of issue in maintaining the device etc. sensorless control is extremely advantageous when the motor is operated in soiled or oily setting. For cleanup and maintenance, a hall sensor is needed for correct sensing of rotor position. During this paper the hardware style and implementation of fuzzy logic controller for sensorless control of PMBLDC motors with PIC16F877 microcontroller is conferred.

Vinod KR Singh Patel [17] explains brushless dc (BLDC) motor drives that are regularly gaining quality in motion control applications. Therefore, it is necessary to possess a low price; however BLDC motor speed/torque regulator is effective. They're employed in residential and industrial appliances like refrigerators and other systems with typical motor drive technology. A Brushless DC (BLDC) drives are noted for higher efficiency and lower maintenance. This paper presents a "Modeling and performance analysis of controlled BLDC motor and totally different schemes of PWM controlled BLDC motor". This paper presents PI model of brushless dc (BLDC) motor with the utilization of MATLAB/ SIMULINK. The PI model arrangement is shown in Figure-7. The operational parameters of specific BLDC motor involve with the calibration strategies that are want to develop in future simulations.

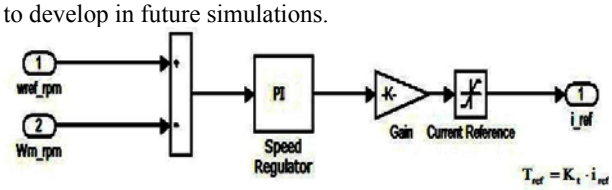

Figure-7. PI model arrangement.

A. Purna Chandra Rao [18] mentioned regarding the usage of inexperienced and ecofriendly natural philosophy that are greatly developed to save lots of the energy consumption of assorted devices. This cause the event in Brushless DC motor (BLDCM). The usage of BLDCM enhances numerous performance factors starting from higher efficiency, higher force in low-speed vary, high power density, low maintenance and fewer noise than different motors. The BLDCM will act as an alternate for ancient motors like induction and switched reluctance motors. During this paper a mathematical model of BLDC motor gives the values of assorted technical parameters with MATLAB/SIMULINK that are mentioned and also the simulation is made for a hundred and twenty degree mode of operation.

H. Shayeghi [19] confers novel calibration technique for the present and speed controllers of the Brushless DC (BLDC) motor drive system. The parameters of PI controller within the inner current control loop and outer speed control loop that vary with the operation conditions like variation of temperature and saturation phenomena or load force dynamic of the drive are adjusted so as to take care of debtor response for speed and current of motor. A Signal-to- Noise quantitative relation (SNR) improvement technique is utilized during this study to get best parameters of PI controllers. Results of the projected technique are compared with the response of Particle Swarm improvement (PSO) technique. Simulation results show that the optimized PI controllers improve considerably the dynamic performances of the motor drive system like subsiding time and overshoot against constant quantity uncertainties. Also, it's superior to the designed controller with PSO technique.

Juli Singh [20] explain about the conventional techniques for the mechanical device section current in a brushless DC drive that are much effective in low speed and can't reduce the commutation force that ripple in high speed. This paper presents the PI controller for speed control of BLDC motor. The output of the PI controllers is summed and is given because of the input to the present controller. The mathematical modeling of BLDC motor is additionally given. The BLDC motor is fed from the electrical converter wherever the rotor position and current controller act as the input. The entire mathematical model of the projected drive system is developed and simulated with MATLAB/Simulink package. The operation principle of controller part is analyzed and also the simulation results are given to verify the theoretical analysis.

Tashakori [21] confer brushed DC motor, Induction motor (IM), switched reluctance motor (SRM) and brushless DC motor (BLDC) that are simulated and compared. BLDC motor is suggested for top performance electrical vehicles. PWM change technique is enforced for speed control of BLDC motor. Behavior of various modes of PWM speed controller of BLDC motor is simulated in MATLAB/SIMULINK. BLDC motor characteristics are compared and mentioned for numerous PWM change modes underneath conventional and electrical converter fault conditions. Comparisons and discussions are verified through simulation results.

Jun-Uk Chu [22] found out the control design that consists of two layers of feedback control, particularly the chair posture control and the wheel speed control. Within the higher level of control design, the posture controller works as a reference speed generator for two wheels. Authors notice the joystick interface and therefore the posture controller in associate 8-bits microcontroller. It's on the lower layer that the controller performs four quadrant operations. For the driving system, a DSP-based BLDC motor controller with 3-phase electrical converter module is much designed with three Hall-effect detectors and one current sensor. The functions of this motor

controller embrace wheel speed control and torque control. The performance of the system through an experiment is verified.

Rajan [23] says that motors are compatible with any digital systems that the drive is often controlled by a digital controller for optimum performance. BLDC motors have the disadvantage of upper torque ripple and therefore the drive circuit produces unwanted harmonics that reduces the facility, quality and causes unwanted magnetic attraction interference. The target of the projected work is to develop a reconfigurable controller for the BLDC motor drive with symbolic logic technique to reduce the harmonics by variable shift frequency and duty magnitude relation while not moving the voltage to the drive. This method is enforced in reconfigurable VERTEX II pro development board that there's tangible improvement of performance in terms of reduction in harmonics. This controller consumes lesser power compared to the conventional electronic controllers.

Cheng-Tsung carver [24] shows the importance of variable sampling for the motor drives with low resolution position sensors. The fuzzy PI (proportional and integral) controller for brushless dc (BLDC) motors considering variable sampling impact during this paper, and this controller uses three fuzzy logics and three PI controllers to realize variable sampling control. Therefore, the simple structure of the fuzzy PI controller for BLDC motors considering variable sampling effect is not only put into practice and understand easily, but also tough in variable speed control system.

Rajan [25] mentioned the conventional motor drive technology that's replaced with Brushless DC motor (BLDC) drive which is based on the result of its higher efficiency, lower maintenance, high dependability and high torque to weight magnitude relation. This paper focuses on reconfigurable controller with symbolic logic technique for a BLDC motor for variable frequency and variable duty magnitude relation operation. In digital controller of brushless DC motor, the control accuracy is of a high level, and it have a low response time; moreover, this method is enforced with reconfigurable Vertex II pro development board. This projected energy economical controller consumes seventy MW that is a smaller amount compared to different typical controllers.

Chung-Wen adorned [26] reveal the speed measure of BLDC motors that's supported Hall sensors, that is integrate for commutation purpose. This variable sampling system response of low resolution position sensors structure is completely different from mounted sampling system. A fuzzy gain planning control is employed to handle the variable sampling system; symbolic logic is employed to mix the simplest PI controllers of various speeds to urge an appropriate gain. And, to hurry up the response beneath dynamic torque loading, a simplified torque load estimation and compensator is projected, gain planning is additionally used to regulate its output for variable sampling system. The simulation results show the controller work well beneath completely different speed commands and torque loads.

Meihua Xu, Fangjie Zhao [27] concerning speed control rule of the vehicle cooling fan driven by four section bifilar winding brushless DC motor (BLDCM). The connected algorithms as well as rotor position detection of the four-phase BLDCM, speed update and field weakening control are analyzed well. Within the style sensor less BEMF zero-crossing detection rule is employed to comprehend the right commutation with the speed of the motor that are often controlled. At low or intermediate speed, the connected parameters gained from recurrent experiments are combined and the commutation rule is made. At high speed, the motor takes advantage of physical phenomenon angle extending rule to extend the speed with the assistance of field weakening effects. All the algorithms mentioned during this paper are verified within the vehicle cooling fan controller system that supports the four section bifilar winding BLDCM.

Burg [28] confers the adaptive partial state feedback controller that is meant for rigid-link electrically-driven (RLED) robot manipulators motivated by multi-phase motors. The controller relies on structural information of the mechanical device dynamics of the RLED golem and measurements of link position and electrical winding current in every link actuators. The projected controller is meant to adapt for constant uncertainty within the mechanical device dynamics whereas utilizing a dynamic filter to come up with link speed pursuit error data. Based on the controller adaptation laws, the pseudo-velocity filter are designed with a simple approach, with the advantage that is the tip of the controller are often mathematically shown to supply semi international straight line link position.

Qi, Peng [29] connect improved particle swarm optimization (PSO) methodology for speed control of the brushless DC (BLDC) motor. With introducing a shrinkage issue into PSO rule, the speed control ability of the BLDC motor are often improved. The brushless DC motor is sculptured in Simulink and therefore the PSO rule is implemented in MATLAB. Comparison with fuzzy control technique, the projected technique is a lot of economical in the step response characteristics, such as, reducing the steady-states error; rising time, subsiding time and most overshoot in speed control of a linear brushless DC motor. New approaches, in which intelligence is not given to the system from outside but is acquired by the system through learning, have proven much more successful. Because of their self learning, self‐organizing and self‐adapting capability, neural networks have become a powerful tool for many complex applications, such as EHS systems [30].

ISSUES AND DIRECTIONS

There has been tremendous analysis for providing appropriate speed controller for PMBLDC motor. Several control methods are projected nowadays. The most disadvantages of mounted gain controllers are that their performance deteriorates as a result of changes in system

operational conditions. This has resulted within the raised demand of recent nonlinear control structures [31]. Only a few accommodative controllers are much utilized within the control of electrical drives owing to their quality and inferior performance. BLDC's main disadvantage is higher price that arises from two problems. First, BLDC motors need complicated electronic speed controllers to run. Brushed DC-motors is regulated by a relatively trivial resistor (potentiometer or rheostat), that is inefficient however conjointly satisfactory for cost-sensitive applications [31].

In variable speed operations of BLDC motor, the PI control continues to be the foremost used control. This is often due to its simplicity. However, its disadvantage is performance depends to proportional and integral gains. Therefore, once the operational condition changes like disturbances, load amendment and motor parameters variations, the re-tuning method of control gains is critical. Controllers with artificial intelligent tools like mathematical logic and neural network is applied to beat preceding issues. Totally different intelligent controllers like mathematical logic controllers (FLC), accommodative fuzzy controllers, Neuro controllers, Neuro-Fuzzy controllers are explored in literature. They might control the speed directly or as indirectly regulate the gains of PI controller [32].

- Not possible interpretation of the functionality;
- Problem in detection of variety of layers and neurons.

Every intelligent technique has special properties (e.g. ability to find out, clarification of decisions) that build them to explicit applications. The disadvantage of PI controller is poor capability of handling system uncertainty, i.e., parameter variations and external disturbance. Lustiness has gained a lot and lot of attention. In recent years, there has been intensive interest in self-standardization of these 3 controller gains. For examples, the PI self- standardization strategies support the relay feedback techniques which are conferred for various categories of systems.

INFERENCE FROM THE EXISTING WORK

Several researchers were conferred an investigation to traumatize these problems with control the speed and also the drawback of signal to noise magnitude relation through a swarm intelligence approach that may find the higher technique to unravel the issuses and it's going to be useful in numerous fields. Optimization has been a most well-liked analysis topic for several years. However, this powerful optimization has their inherent shortcomings and limitations. Fusion of the process intelligence approaches can usually provide superior performances over exploitation with one by one. Therefore, a swarm intelligence optimization based rule is projected to address complicated issues within the speed control of BLDC motor. Intensive analysis is finished on the design and implementation of fuzzy logic controller (FLC), neural network controller (NNC) and hybrid controller for prime performance applications of motor drives.

CONCLUSIONS

Reducing the price of the motor drive is fascinating for low cost applications. An easy and cost-efficient detector less position control for radial-flux static magnet brushless DC (BLDC) motor drives with single current sensor is projected during this paper. It supports the generation of quasi-square current waveforms, with only 1 current controller for the 3 phases. Not like the conventional strategies, the projected technique presents benefits like terribly easy control theme, with no need of triangular carrier modulation so as to boost the speed transient response of the BLDC motor and enhance the energy saving effect of the system it is ought to be top quality dynamic response characteristics. Therefore, to comprehend these functions, swarm optimization (SO) has been projected to manage the proportional – integral - derivative (PID) parameters of the motor speed controller.

Effectiveness of a swarm intelligence technique is very much influenced by the proximity technique. Finally, review of assorted techniques are going to be useful for higher study and inventing new ideas for even higher optimization techniques.

The FLC is that the simplest of all the intelligent controllers for motor speed control applications. However, FLCs have difficulties in deciding appropriate control laws and calculating the parameters of the membership function with the changes within the system. NNCs on the other hand, have the efficiency to adapt itself to changes within the control setting environment of the system input and output. It doesn't need sophisticated control theories and precise model of the system. However, NNC synthesis needs design of the control structure which incorporates selecting. The neural network structure, weight coefficients and activation function. The selection of neural structure as the initial step is done by trial and error method, since there is no proper procedure for this. The complexity of the selected neural network structure is a compromise between the high quality of control robustness and the possibility of control algorithm calculation in real time. Hybrid controllers like neuro fuzzy controller exploits the high of level learning and low computation power of neural network to enhance the performance of fuzzy control system. However, a well defined procedure for finding the optimum network topology for motor drives still remains as a challenge.

From this analysis it is conferred that fuzzy & neural controller plays an attractive & effective role in speed control of machines.

REFERENCES

[1] R. Civilian and D. Stupak. 1995. Disk drive employing multi mode spindle drive system. US patent 5471353, Oct 3.

[2] G.H. Jang and M.G. Kim. 2005. A Bipolar-Starting and Unipolar-Running Method to Drive an HDD Spindle Motor at High Speed with Large Starting

Torque. IEEE Transactions on Magnetics. 41(2): 750-755, Feb.

[3] E. Grochowski and R.F. Hyot. 1996. Future trends in hard disk drives. IEEE Tran. On Magnetics. 32(3): 1850-1854, May.

[4] J.D. Ede, Z.Q. Zhu and D. Howe. 2001. Optimal split ratio control for high speed permanent magnet brushless DC motors. In: Proceeding of 5th Sytems. 2: 909-912.

[5] S.X. Chen, M.A. Jabbar, O.D. Zhang and Z.J. Lie. 1996. New Challenge: Electromagnetic design of BLDC motors for high speed fluid film bearing spindles used in hard disk drives. IEEE Trans. Magnetics. l32(5): 3854-3856, Sep.

[6] T. Kenzo and S. Nagamori. 1984. Permanent Magnets and Brushless DC Motors. Tokyo, Japan, Sogo Electronics.

[7] J.R. Hendershot and Miller. 1994. Design of Brushless Permanent Magnet Motors. Oxford Univ. Press.

[8] Lin CL, Jan HY, Shieh NC. 2003. "GA-based multiobjective PID control for a linear brushless DC motor," IEEE/ASME Transactions on Mechatronics, 8: 56-65.

[9] Nasri M, Nezamabadi-pour H, Maghfoori M. 2007. "A PSO-based optimum design of PID controller for a linear brushless DC motor," Proc. of World Academy of Science, Engineering and Technology, 20: 1307-6884.

[10] G. Murugananth, S. Vijayan, S. Muthukrishnan, "Analysis of Various Anti-Windup Schemes used to Control PMDC Motors employed in Orthopedic Surgical Simulators" Life Sci J 2013;10(1):226-230] (ISSN:1097-8135).

[11] J. Karthikeyan, R. Dhanasekaran, "Simulation and Implementation of Current Control of BLDC Motor Based On a Common DC Signal", International Journal of Engineering Science and Technology Vol. 2(6), 2010, 1632-1639.

[12] Juan W. Dixon, Matías Rodríguez and Rodrigo Huerta "Simplified Sensorless Control for BLDC Motor, Using DSP Technology", web.ing.puc.cl/~power/paperspdf/dixon/53a.pdf.

[13] Tan Chee Siong, Baharuddin Ismail, Siti Fatimah Siraj, Mohd Fayzul Mohammed, "Fuzzy Logic Controller for BLDC Permanent Magnet Motor Drives", International Journal of Electrical & Computer Sciences IJECS-IJENS Vol: 11 No: 02.

[14] R. Kandiban, R. Arulmozhiyal, "Design of Adaptive Fuzzy PID Controller for Speed control of BLDC Motor", International Journal of Soft Computing and Engineering (IJSCE) ISSN: 2231-2307, Volume-2, Issue-1, March 2012.

[15] Mohammed Naseeruddin1, A. Mallikarjuna Prasad, "Analysis of the Speed Control of BLDC Motor on MATLAB/SIMULINK", National Conference On Electrical Sciences -2012 (NCES-12) ISBN: 978-93-81583-72-2.

[16] Ashish A. Zanjade and J.W. Bakal, "Hardware Implementation of Fuzzy Logic Controller for Sensorless Permanent Magnet BLDC Motor Drives", International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 4, April – 2013, ISSN: 2278-0181.

[17] Vinod KR Singh Patel, A.K. Pandey, "Modeling and Performance Analysis of PID Controlled BLDC Motor and Different Schemes of PWM Controlled BLDC Motor", International Journal of Scientific and Research Publications, Volume 3, Issue 4, April 2013, ISSN 2250-3153.

[18] A. Purna Chandra Rao, Y. P. Obulesh and Ch. Sai Babu "Mathematical Modeling of BLDC Motor with Closed loop Speed Control using PID Controller under Various Loading Conditions", ARPN Journal of Engineering and Applied Sciences, Vol. 7, NO. 10, October 2012 ISSN 1819-6608.

[19] H. Shayeghi, A. Akbarimajd, A. Mohammadian,G. Shokri, "Speed and Current Controllers Design of BLDC Motor Using SNR Optimization Technique" International Research Journal of Applied and Basic Sciences ISSN 2251-838X / Vol, 4 (1): 99-106.

[20] Juli Singh, "Analysis the Speed Control of BLDC Motor Drive using Sensors" International Journal of Engineering Research and Applications (IJERA), Vol. 2, Issue 3, May-Jun 2012, pp.2868-2884.

[21] A. Tashakori, M. Ektesabi "Comparison of Different PWM Switching Modes of BLDC Motor as Drive Train of Electric Vehicles" World Academy of Science, Engineering and Technology 67 2012.

[22] Jun-Uk Chu, In-Hyuk Moon, Gi-Won Choi, Jei-Cheong Ryu, Mu-seong Mun, "Design of BLDC motor controller for electric power wheelchair", Mechatronics, ICM '04. Proceedings of the IEEE International Conference on 2004, Page(s):92 - 7e.

[23] Rajan, A.A, Vasantharathna, S. "Fuzzy logic based reconfigurable optimal switching controller for BLDC motor for reduced harmonics", IPEC, 2010 Conference Proceedings, Page(s): 578 – 583.

[24] Cheng-Tsung Lin, Chung-Wen Hung, Chih-Wen Liu, "Fuzzy PI Controller for BLDC motors Considering Variable Sampling Effect", Industrial Electronics Society, 2007. IECON 2007, 33rd Annual Conference of the IEEE, Page(s): 1180 – 1185.

[25] Rajan, A.A, Raj, R.D, Vasantharathna, S, "Fuzzy based reconfigurable controller for BLDC motor", Computing Communication and Networking Technologies (ICCCNT), International Conference on 2010, Page(s):1 – 7.

[26] Chung-Wen Hung, Jhih-Han Chen, Chang, H.T, "A Minimal Fuzzy Gain Scheduling Speed Controller and Torque Compensation for the Variable Sampling System of BLDC Motors", Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), Fifth International Conference on 2011, Page(s):434 – 437.

[27] Meihua Xu, Fangjie Zhao, Guoqin Wang, Wenrong Yang, "Study of speed control algorithm in four phase BLDC vehicle cooling fan controller", Fuzzy Systems and Knowledge Discovery (FSKD), Eighth International Conference on 2011 (Volume:4), Page(s): 2408 – 2411.

[28] Burg, T, Dawson, D, Hu, J, Lim, S, "An adaptive partial state feedback controller for RLED robot manipulators actuated by BLDC motors", Robotics and Automation, 1995. Proceedings, IEEE International Conference on 1995 (Volume: 1), Page(s):300 - 305 vol.1.

[29] Qi, Peng, "An improved PSO-based optimum design of speed controller for BLDC motor", IEEE, 2012.

[30] M. Karimi, F. Najafi, H. Sadati and M. Saadat,"Application of a flexible structure artificial neural network on a servo□hydraulic rotary actuator," in Springer, Int. J. Adv. Manuf. Technol., vol. 39, no. 506, 2008, pp. 559-569.

[31] Bhim Singh, A.H.N.Reddy, S.S.Murthy, "Hybrid Fuzzy Logic Proportional Plus Conventional Integral-Derivative Controller for Permanent Magnet Brushless DCMotor",

[32] Rao, "Energy efficient Ceiling fans using BLDC motors- A practical implementation", Proc. of the Intl. Conf. on Advances in Computer, Electronics and Electrical Engineering, doi: 10.3850/978-981-07-1847-3 P0369.

[33] Muhammad Salman Khan, Master's thesis, Development of Detailed Drive Model in Matlab/Simulink with Automatic Optimization of Control Loops.