© 2014 IJIRT | Volume 1 Issue 11 | ISSN: 2349-6002

A Review of Speed Control Techniques Using PMSM

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Abstract- **The aim of this paper is to present the study of various speed control techniques using permanent magnet synchronous motor (PMSM). The PMSM is increasingly used in high-performance applications in industry. Such applications require speed controllers with high accuracy, high performance and flexibility and efficiency in the design process and implementation. The several speed control techniques are available and these control techniques vary from the type of controller used for PMSM to the type of software/hardware implementation. A review of various control techniques is highlighted in this paper with respect to speed control & implementation of a speed controller.**

Index Terms- **PMSM, Speed control, Sensorless control, Neuro-fuzzy.**

I. INTRODUCTION

Synchronous motors are most widely used in industrial applications as both high efficiency and accurate performances are demanded in industrial applications. The permanent magnet synchronous motor is increasingly playing an important role in advanced motor drives. A "permanent magnet synchronous motor" (PMSM) or "permanent-magnet motor" (PMM) is a synchronous motor that uses permanent magnets rather than windings in the rotor that create constant magnetic field. The PMSM can be thought of as a cross between an AC induction motor and a brushless DC motor (BLDC). They have rotor structures similar to BLDC motors which contain permanent magnets. However, their stator structure resembles that of its ACIM cousin, where the windings are constructed in such a way as to produce a sinusoidal flux density in the airgap of the machine. As a result, they perform best when driven by sinusoidal waveforms. There are two types of PMSM depending on the mounting of permanent magnets. One is surface mounted PMSM and another is interior permanent magnet. Interior permanent magnet (IPM) is the most widely used type in PMSM. PMSM are typically used for high-performance and high-efficiency motor drives. Because of their high performance/cost ratio, the attention toward PMSM in variable speed application is greater.

Permanent magnet synchronous motor (PMSM) has gained a wide acceptance in motion control applications due to its high performance, compact structure, high air-gap flux density, high power density, high torque to inertia ratio, and high efficiency. Permanent Magnet Synchronous Motor technology maximizes performance in variable speed applications. Recent research has reported that the PMSM is being increasingly used in high-performance applications, such as robots and industrial machines, which require speed controllers that provide not only accuracy and high performance, but also flexibility and efficiency in the design process and implementation. But in industrial applications, there are many uncertainties, such as system parameter uncertainty, external load disturbance, friction force, unmodeled uncertainty, always diminish the performance quality of the pre-design of the motor driving system. To cope with this problem, in recent years, many intelligent control techniques and other control methods have been developed and applied. The various control strategies and methodologies are available for speed control of PMSM.

II. OVERVIEW OF CONTROL STRATEGIES AND METHODOLOGIES

Permanent magnet motor control is mainly consisting of the type of controller used and the implemented algorithm. There are many approaches regarding both the controller type (ranging from fuzzy logic and neural networks to classical PID (proportional-integral-derivative) based control algorithms) and the implementation (ranging from pure hardware implementations to combined hardware-software or pure software solutions). Another key factor, which contributed to the successful adoption of techniques or strategies, is the availability of a wide range of design tools. To enhance the control performance, in recent years, many nonlinear control methods have been developed for the PMSM system, such as: Linearization control, Adaptive control, Robust control, Sliding mode control, Disturbance observer-based control, Finite time control, Fractional order control, Fuzzy control, Neural network control. These approaches improve the control performance of the motor from different aspects. Control of torque, rotation speed, position for quadrants and low speed operation, with high-performance dynamic behavior, are often required in industrial applications but they are sensitive from the standpoint of the control strategies reliability.

To achieve high performance & high efficiency control, various control techniques are used to control speed, torque, position of rotor. This study has highlighted a broad classification of speed control techniques. The vector control technique is one of the techniques used for speed control of PM synchronous motors. The vector control technique is also referred as field-oriented control (FOC). In particular, the method implies the measurement of motor currents and successively their transformation into a coordinate system rotating with the rotor of the machine. Sensorless Control is also one of the methods for speed control. In sensorless control, the rotor position information is needed to efficiently perform the control of the PMSM, but a rotor position sensor on the shaft decreases the robustness and reliability of the overall system in some applications. Therefore, the aim is not to use this mechanical sensor to measure the position directly but instead to employ some indirect techniques to estimate the rotor position. Field/Flux Weakening Control is also one of the methods used. To overcome the base speed limitation, a field-weakening algorithm can be implemented. Also Model predictive control (MPC) is one of the most practical advanced control techniques in industrial applications. Also techniques evolved from artificial intelligence such as Fuzzy logic control, neural networks, Neuro-Fuzzy hybrid systems, are used for speed control of PMSM. Other methods such as MRAS or hybrid methods such as combination of fuzzy logic and sensorless or fuzzy-neuro also can be used.

Also hardware implementation of such systems such as using FPGA, DSP, and microcontrollers also plays important role in co design. When software and hardware partitioning is involved, a co design methodology is required to obtain an adequate tradeoff that fulfill the awaited specifications of the system. Many co design techniques are reported. FPGAs represent a useful companion to DSPs in industrial context if not an alternative. FPGA embedded processors reveal sufficiently for the software part of most control algorithms. The use of microcontroller or DSP circuits is related to the availability of A/D and D/A converters. A companion interface board is then necessary, and the question of A/D and D/A converters is a little bit eluded compared to the efficiency offered by mixed hardware/software implementation of control algorithm. Hence hardware implementation of such systems such as using FPGA, DSP or microcontrollers also plays important role in speed control methodologies.

III. PMSM SPEED CONTROL TECHNIQUES

Depending on the control strategies used & methodologies for hardware implementation used, the speed control techniques can be broadly classified into intelligent control techniques (such as fuzzy logic control, neural networks), sensorless control techniques, hybrid techniques and the other techniques/ methods. A review on such various control strategies is highlighted in this study with respect to speed control & implementation of a speed controller.

A. Fuzzy Logic Control

Intelligent control techniques such as fuzzy control, adaptive fuzzy control, have been developed and applied to motor drives to yield high operating performance. It is widely used in speed control of PMSM. Y. S. Kung, C. S. Chen, K. Wong, M. H. Tsai, presented the study of “Development of a FPGA-based Control IC for PMSM Drive with Adaptive Fuzzy Control”. In this study, Mathematical model of the PMSM is presented and the vector control scheme is used in the current loop of the drive. Then, to increase the performance of the PMSM drive, an adaptive fuzzy controller (AFC) constructed by a fuzzy basis function and a parameter adjustable mechanism is derived and applied to the PMSM drive to cope with the dynamic uncertainty and external load effect. After that, a FPGA-based control IC is designed to realize the controllers which have two IPs (Intellectual Properties); a Nios embedded processor IP and an application IP. The Nios processor is used to perform the function of an adaptive fuzzy position controller for PMSM drive. The application IP is used to perform the current vector control of the PMSM drive, which includes SVPWM generation, coordinate transformation, PI controller and the pulse detection of the quadrature encoder. A FPGA embedded with a Nios processor is successfully developed in the servo control IC of PMSM drives. This FPGA-based servo control IC allows a fully digital function and high performance control for the PMSM drive [1]. Y.-S. Kung, M. H. Tsai, C. S. Chen, in further study have presented “FPGA-based Servo Control IC for PMLSM Drives with Adaptive Fuzzy Control”. A FPGA embedded with a Nios processor is successfully developed in the servo control IC of PMLSM drives. A new generation of Field Programmable Gate Array (FPGA) technologies enables to integrate an embedded processor IP and an application IP into a SoPC (System-on-a-Programmable-Chip) environment. The development of high performance speed control of a permanent magnet linear synchronous motor (PMLSM) drive based on this SoPC environment is presented in this study [2].

In further study, speed control of PMSM is done using simulation of fuzzy controller based on genetic algorithm. Nihat Ozturk, Emre Çelik have presented the simulation of speed control of a permanent magnet synchronous motor (PMSM) with genetic based fuzzy controller. An application of Genetic algorithm to learn the knowledge base of a fuzzy controller has been presented in this study. The whole knowledge base is parameterized and optimized to obtain an optimal fuzzy controller without expert knowledge. The results of genetic based fuzzy controller have been compared to the conventional fuzzy controller for PMSM speed control [3]. Takagi–Sugeno fuzzy speed controller design for a permanent magnet synchronous motor has been presented by Han Ho Choi, Jin-Woo Jung. Based on Takagi–Sugeno (T–S) fuzzy approach, fuzzy speed control system for a permanent magnet synchronous motor (PMSM) has been designed. Linear matrix inequalities (LMI) existence conditions were derived for designing a fuzzy speed regulator and acceleration observer & the gain matrices were parameterized using these conditions. The proposed T–S fuzzy speed control system has been implemented by using a TMS320F28335 floating point DSP [4]. In [5], “Simulation of PMSM Vector Control System with Fuzzy Self-Adjusting PID Controller Using MATLAB”, has been presented. The entire PMSM control system is divided into several independent functional modules such as PMSM body module, inverter module and coordinate transformation module and SVPWM production module and the simulation model of the PMSM control system can be obtained by combining these modules using the powerful simulation modeling capabilities of Matlab/Simulink. The fuzzy control system has the prominent advantage in complex, time lag, time varying and non-linear system control. The fuzzy-PID controller has the advantages of both PID control and fuzzy control, so it can get better control performance. The controller is used as the speed controller which can adjust the controller parameters on-line according to the speed error and the derivative of speed error change. The simulation results show that, the system can run smoothly and the fuzzy self-adapting PID controller have less regulating time, stronger, robust compared to the traditional PI controller.

In [6], the study of “Fuzzy Adaptive Controllers for Speed Control of PMSM Drive” is presented. Fuzzy Adaptive Controller is applied to PMSM drive. The objective of the Fuzzy Adaptive Control (FAC) is to tune the scaling factors of the direct fuzzy logic controller (FLC) through adaptation mechanism. The adaptation mechanism produces a compensation signal, which is added to the output signal of the direct fuzzy controller to force the system to behave like the model. High performances, the efficiency and robustness have been achieved by using the FAC. R. Venkatesh kumar, Dr. T. Govindaraj have proposed the “Adaptive Fuzzy Logic Based Speed Control of Permanent Magnet Synchronous Motor”. In the proposed system fuzzy logic control is used to implement the direct current, quadrature current and as well as the adaption mechanism. The Controller is designed for robust speed control of a PMSM under model parameter and load torque variations. The simulation for speed control of PMSM by using fuzzy logic controller is developed using Simulink [7].

In further study by same authors, “AFLC Based Speed Control of PMSM Drive” is presented. An adaptive fuzzy logic control (FLC) for the speed control of the PMSM has been proposed. The study demonstrates a robust Kalman filter for the estimation of motor quantities. The Least mean square algorithm incorporated along with fuzzy inference, optimizes the weights used for combining the rules, which in turn makes the controller more efficient. The simulation results show that the proposed control strategy operates robustly under modeling uncertainty, with a good dynamic performance [8].

B. Neural Networks

Neural Networks are also one the intelligent control techniques and these can be directly used for PMSM speed control. A. Dinu, M. N. Cirstea, and S. E. Cirstea have presented, “Direct Neural-Network Hardware-Implementation Algorithm”. An algorithm for compact neural-network hardware implementation is presented, which exploits the special properties of the Boolean functions describing the operation of artificial neurons with step activation function. The algorithm contains three steps: artificial-neural-network (ANN) mathematical model digitization, conversion of the digitized model into a logic-gate structure, and hardware optimization by elimination of redundant logic gates. This strategy bridges the gap between ANN design software and hardware design packages [9].

M. Lia, D. Liua, presented “A Novel Adaptive Self-turned PID controller based on Recurrent-Wavelet-Neural-Network for PMSM Speed Servo Drive System”. PMSM speed control system is a complex system that has the characteristics of nonlinearity, strong coupling and multi-variable. The conventional PID controller is difficult to adjust in such kind of system especially in conditions having rigid requirements. So it is difficult to get a flexible, fast and accurate response. In this study, a new PMSM adaptive PID controller based on recurrent wavelet neural network (RWNN) is proposed. This algorithm uses WNN to turn the PID parameters adaptively. The recurrent nodes increase the network response speed and ensure stable outputs. The network training algorithm is working online for obtaining optimal parameters to realize an adaptive system with strong learning ability and good robustness. The proposed algorithm has overcome the problems that conventional PID encounters, and improves the performance in PMSM speed regulation. [10]. In [11], “Speed Control of PMSM Drives by Using Neural Network Controller” has been presented. In this study, a feed forward neural network is applied in place of PI controllers of the vector control scheme of the PMSM. The design of a Neural Network based approach is used to enhance efficiency in a vector control of PMSM, to ensure robustness against load and parameters variations and to achieve the required performances.

C. Sensorless Control Techniques

Sensorless control techniques can also be used for speed control of PMSM. Y. S. Kung, N. V. Quynh, N. T. Hieu, J. M. Lin, have presented “FPGA Realization of Sensorless PMSM Speed Controller Based on Extended Kalman Filter”. Based on extended Kalman filter (EKF), the design and FPGA implementation of a sensorless control intellectual property (IP) for PMSM drive is presented in the study. The mathematical model for PMSM is derived and the vector control is built up. Then rotor flux angle (FA) and rotor speed estimated by using EKF are feedbacked to the current loop for vector control and to the speed loop for speed control. The VHDL is adopted to describe the behavior of the sensorless speed control IP which includes the circuits of space vector pulse width modulation (SVPWM), coordinate transformation, EKF, and PI controller. Finally, its performance demonstrated through cosimulation by using Simulink/ModelSim and implementation by using FPGA. The use of EKF in sensorless PMSM drive can accurately estimate the rotor FA and rotor speed, and it can give a good step response performance in case of low speed control, inverse speed control, and high speed control as well [12]. In [13], the study presents, “Low-speed sensorless control of pmsm motor drive using a nonlinear approach backstepping control: FPGA-based implementation”. This study presents a speed control technique for a PMSM drive based on newly nonlinear backstepping technique. A not adaptive speed regulator is designed for PMSM and the control scheme is based on an adaptive pole placement control strategy integrated to a Backstepping control scheme. The overall stability of the system is shown using Lyapunov technique. Also a new contribution of FPGAs for control of electrical machines has been presented. The simulation results show, good performance obtained with the proposed control as compared with the nonlinear control by state feedback. This shows the robustness and reliability of the control algorithm used.

In [14], “Back-EMF Sensorless Control Algorithm for High Dynamics Performances PMSM” has been presented. In this study, the sensorless control system is based on the back electromotive force space vector estimation. This control algorithm is based on the estimation of rotor speed and angular position starting from the back electromotive force space vector determination without voltage sensors by using the reference voltages given by the current controllers instead of the actual ones. The use of the back EMF space vector is advantageous respect to any other system using flux estimation because of the integrator elimination avoiding the problem of use of devices or sub systems for its compensation. The system presented in the study show the validity of the proposed low cost sensorless control algorithm and the high dynamic performances of the sensorless control system also with reduced equipment. H. Kim, J. Son, J. Lee, have presented “A High-Speed Sliding-Mode Observer for the Sensorless Speed Control of a PMSM”. This study proposes a sensorless speed control strategy for a permanent-magnet synchronous motor (PMSM) based on a new sliding-mode observer (SMO). In this a sigmoid function is used for the switching function instead of the signum function with a variable boundary layer to overcome the time delay. In order to apply a sensorless PMSM control, a high-speed SMO is proposed, which estimates the rotor position and the angular velocity from the back EMF. The stability of the new SMO has been proved with the use of a Lyapunov stability analysis. The validity of the proposed high-speed PMSM sensorless velocity control & superiority of the algorithm has been confirmed through simulations and experiments [15].

D. Hybrid Control Techniques

Hybrid control techniques are also used for speed control. These are the combination of two techniques such as neural networks and fuzzy logic called as Neuro-Fuzzy systems, fuzzy logic is also integrated with sensorless control technique.

H. H. Chou, Y. S. Kung, N. V. Quynh, S. Cheng, presented the study of “Optimized FPGA design, verification and implementation of a neuro-fuzzy controller for PMSM drives”. The study presents a neural fuzzy controller (NFC) for speed loop of PMSM drives based on the technology of FPGA. To increase the performance of the PMSM drive system, a fuzzy controller (FC) whose parameters are adjusted by a radial basis function neural network (RBF NN) is applied to the speed controller for coping with the effect of the system dynamic uncertainty. VHDL is adopted to describe the behavior of the speed controller of PMSM drives which includes the circuits of space vector pulse width modulation (SVPWM), coordinate transformation, NFC, etc. This study has presented a FPGA-based NFC controller for PMSM drives and successfully demonstrated its performance through co-simulation by using Simulink and ModelSim [16].

C. Elmas, O. Ustun , H. H. Sayan, has presented “A neuro-fuzzy controller for speed control of a permanent magnet synchronous motor drive”. A four layer neural network (NN) is used to adjust input and output parameters of membership functions in a fuzzy logic controller (FLC). The back propagation learning algorithm is used for training this network. The performance of the proposed controller is verified by simulations and the hardware implementation of the controllers is made using a TMS320F240 DSP. [17]. In [18], “Intelligent Speed Control of Permanent Magnet Synchronous Motor Drive Based-on Neuro-Fuzzy Approach” is presented. A neural network-based architecture is described for fuzzy logic control. The specified rules and their membership functions of fuzzy systems are represented as the processing nodes in the neural network structure. Then, the fuzzy rules and the membership functions are tuned by the supervised gradient decent learning algorithm. It achieves high dynamic performance and accurate speed tracking control with good steady-state characteristics. The developed controller is robust, inherently adaptive in nature, and capable of learning and hence recommended for high-performance industrial drive applications.

In the study of “Robustness of Adaptive Fuzzy for PMSM Sensorless Speed Controller” by N. V. Quynh, Y. S. Kung and L. T. Hien, an integration of adaptive fuzzy controller for PMSM & sensorless control technique with SMO has been presented. A rotor speed estimation is based on sliding mode observer (SMO). Space-vector pulse width modulation was used for slipping frequency vector control system. The study of simulation results shown that the motor’s speed has good performance speed under different external load condition; integrated controller in an IC saves space and avoids the influence of external factors such as noise or temperature [19]. In [20], “Adaptive Fuzzy Logic Based Speed Control of Permanent Magnet Synchronous Motor Using FPGA” has been proposed. In the proposed system, the FPGA scheme integrates Fuzzy logic control technique and space vector pulse width modulation principle to control the rotor position angle and motor speed. The Back-EMF based Sensor-less algorithm combined with vector control strategy implemented to estimate rotor position and speed. To achieve a high performance, to guarantee the robustness and to avoid the system nonlinearity or the uncertainty the Fuzzy Logic Control implemented. The simulation results shows that FPGA based speed control performance in terms of response time and accuracy is better than other hardware based speed control techniques, also the proposed system is more flexible in control scheme implementation.

E. Other Techniques

Other techniques or methods are also used for PMSM speed control. In [21], "Control of Permanent Magnet Synchronous Motor using MRAS" is proposed. In this study, model reference adaptive system based adaptive strategy has been used for speed estimation. In this method MRAS is completely independent of stator resistance (Rs) and is less parameter sensitive, as the estimation algorithm is only dependent on q -axis stator inductance (Lq). In this proposed method the Popov's criterion is used for adaptive speed estimation. The whole drive system is simulated by the use of Matlab/Simulink. The validity of the proposed adaptive strategy has been verified by simulation and experiments and it has a good performance. In compare to previously developed methods in the literature such as: EKF, neural networks and sliding mode control this method consumes less computational time and it is easy to implement.

J. Bastos, A. Monti, E. Santi presented "Design and Implementation of a Nonlinear Speed Control for a PM Synchronous Motor using the Synergetic Approach to Control Theory (SACT)". This study presents a nonlinear control scheme based on the SACT, which allows the designer to generate the required control laws by following a direct method. This scheme is also well suited for digital control implementation. The simple and systematic nature of the SACT design procedure allows the designer to generate the required control laws by following a direct automatable method. The proposed SACT controller is implemented on a PMSM using a DSP-based platform and its performance is verified through the comparison of the experimental and simulation results [22]. M. Novak has presented "FPGA Based Controller for High-Speed Permanent Magnet Synchronous Motor". This study presents the development of a controller for a high-speed permanent magnet synchronous motor based on Field Programmable Gate Arrays. The controller design shows much promise to handle field-oriented control for higher speeds than previously available with digital signal processors. Also the FPGA implementation of the PMSM controller removes the limitations imposed by the DSP implementation and that in will allow us to reach higher speed with future motors. The FPGA is so fast that even a sensor less control could be implemented as it allows calculating a real time model of the motor [23]. C. Dufour, J. Bélanger, S. Abourida, V. Lapointe have presented "FPGA-Based Real-Time Simulation of Finite-Element Analysis Permanent Magnet Synchronous Machine Drives". In this study, a real-time simulator of a PMSM drive modeled from FEA-analysis software presented and executed on a FPGA card for HIL testing of motor drive controllers. The PMSM model is implemented then feed by the PMSM back-EMF and winding inductances values which are pre-computed from the JMAG-RT FEA software. The models are implemented on an FPGA chip, with no VHDL coding, using the RT-LAB real-time simulation platform from Opal-RT and a Simulink blockset called Xilinx System Generator (XSG). The overall model compilation and simulation is entirely automated by RT-LAB [24]. In [25], "Real-Time Simulation of a Complete PMSM Drive at 10 µs Time Step" is presented. This study presented a description and results of the fastest PC-based real-time (RT) simulator of an AC drive. The RT simulator is used to simulate a complete PMSM drive circuit in a Hardware-In-The-Loop (HIL) application. This consists of a PMSM fed by a 3-phase IGBT inverter, a DC link capacitor and a 3-phase diode bridge. This drive model runs on RT-LAB electric drive simulator and connected to an external controller by analog and digital inputs and outputs for closed loop operation.

In [26], "Speed Control for a PMSM Servo System Using Model Reference Adaptive Control and an Extended State Observer" is proposed. In this study, the design of a speed controller based on the MRAC for the PMSM has been investigated. A model reference adaptive controller (MRAC) based on the Lyapunov stability theory is designed. In order to improve the disturbance rejection ability of the controller, a composite controller which combines the MRAC method with an ESO has been proposed. An extended state observer (ESO) is introduced to estimate the lumped disturbances. Simulation and experimental results validate that the composite method can obtain a satisfying performance with a faster transient response and a better disturbance rejection capability. In [27], "Simulation Based Analysis of Two Different Control Strategies for PMSM" is presented. In the study, a sensorless scheme based on MRAS for control of PMSM drive system is proposed. The results are obtained from comparison of two algorithms of vector control of PMSM: traditional FOC using position sensor and model reference adaptive system (MRAS) approach based on sensorless vector control. Based on results obtained, advantages and disadvantages of the proposed control structures are discussed. Results obtained show that sensorless control strategy based on MRAS approach can be applied successfully in PMSM drives with low cost. The proposed method is simple, needs a low computation capacity and has a high speed adaptation even at very low speeds. In [28], "Implementation of Hybrid Control for Motor Drives" is presented. Hybrid control is a general approach for control of a switching-based hybrid system (HS). This class of HS includes a continuous process controlled by a discrete controller with a finite number of states. The hybrid control algorithm requires both computing velocity for real-time implementation and code flexibility for management of low-performance functions and analog–digital interfaces. Codesign appears as a promising methodology for partitioning hybrid-control algorithm between software (flexible) and hardware (velocity) while taking care of overall time constrains. In this paper, the implementation of hybrid-control algorithm for a PMSM drive is performed through a codesign approach on an Excalibur board, embedding a CPU-core (Nios-2 by Altera) inside field-programmable gate array. Experimental results show the effectiveness of the implementation.

S. Carbone, V. Delli Colli, R. Di Stefano, G. Figalli and F. Marignetti, have proposed "Design and Implementation of High performance FPGA Control for Permanent Magnet Synchronous Motor". The study reports the design of an FPGA implementation of a high performance control for PMSM with sinusoidal flux distribution. The objective of this work is to test a single chip FPGA solution in order to simplify the HW, to allow an easy reconfiguration of the control architecture, and mainly to make a step towards a System on Programmable Chip (SOPC) sensor-less PMSM drive exploiting the high computational throughput of the adopted device. Experimental verification has been carried out, with an Altera Stratix II device [29]. H. Liu and S. Li, have presented "Speed Control for PMSM Servo System Using Predictive Functional Control and Extended State Observer". In order to optimize the control performance of the PMSM servo system, the predictive functional control (PFC) method is introduced in the control design of speed loop. The PFC-based speed control design consists of two steps. A simplified model is employed to predict the future q-axis current of PMSM. Then, an optimal control law is obtained by minimizing a quadratic performance index. To achieve a satisfying effect, an improved PFC method, called the PFC+ESO method, is developed. It introduces extended state observer (ESO) to estimate the lumped disturbances and adds a feedforward compensation item based on the estimated disturbances to the PFC speed controller. The simulation and experimental results have validated that the servo system can obtain a satisfying performance with fast transient response, good disturbances rejection ability.

IV. CONCLUSION

The aim of this paper is to present the study of various control techniques used for speed control of permanent magnet synchronous motor (PMSM). As PMSM is increasingly used in high-performance applications in industry, such applications require speed controllers with high accuracy, high performance and flexibility and efficiency in the design process and implementation. The study reviews that various approaches are available regarding both the controller type (ranging from fuzzy logic, neural networks to classical PID control algorithms) and the implementation (ranging from pure hardware implementations to combined hardware-software or pure software solutions). However, the majority of the reviewed papers lack a holistic modeling of the control system. There is a gap between the design and simulation of the controller and on other side, the design of the hardware implementation. This affect on the accuracy, performance and efficiency of the control system of PMSM. Thus the future scope is to try to fill in the gap in the existing literature by developing a novel system which will overcome drawbacks of the existing methods.

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