FPGA BASED PREDICTIVE SLIDING MODE CONTROLLER OF THREE-PHASE INVERTER

Vishakha Saurabh Shah[1], Saurabh Anil Shah[2]
[1,2]Assistant Professor at PRMCEAM, Badnera-Amravati,(M.S)India,
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Abstract

This paper proposes the Predictive sliding mode controller which is based on Adaptive Neuro-fuzzy Inference system. In this Predictive current VSS control strategy introduced to control the voltage source inverter as a system with the finite number of possible state and selecting over each sampling period and the voltage vector that minimizes the quadratic cost function. Common DSP solutions are rarely used as compared to FPGA hardware and main advantage of this method is that all the logic is executed continuously and simultaneously. This ANFIS controller introduced for considering the voltage source inverter with a finite number of possible states and selecting that possible state speed can be controlled. Brushless ac motor can provide good transient response and this proposed control method is applicable for all types of ac loads as well as ac motors. The result analyzed by design switching based current controller for a three phase load driven by a power inverter and speed controller for BLAC motor by using Xilinx Spartan 3E FPGA.

Index Terms: Brushless alternating-current (BLAC) motor, Field programmable gate array, Finite state machine (FSM), Predictive Sliding mode controller, Adaptive Neuro-Fuzzy Inference system, Supervisor.

I.INTRODUCTION

The use of Power Converter has become very popular in recent decades for a wide range of low, medium and high power application including drives, energy conversion, traction, and distributed generation. The Digital Signal Processors that are the sequential processing device in which characteristics and programming are known. The Field Programming gate arrays is the architecture and reconfigurable digital logic devices, which contain a variety of programmable logic blocks called logic elements which can be configurable using a VHDL (Very High Speed Integrated Circuit Hardware Description Language). The advantages of FPGA over sequential hardware of DSPs are flexible memory architecture, wide parallelism, and deep pipelining. FPGA show great potential for control applications, power electronics and real time hardware emulation, applications such as motor control, active power filters, multilevel inverters or dc/dc power converters.

Predictive control method is introduced for considering the voltage source inverter (VSI) as a system with a finite number of possible states and selecting over each sampling period, the voltage vector that minimizes quadratic cost functions. This dissertation work suggests the FPGA based Sliding mode controller is used and the experimental results will be presented using a BLAC motor as the inverter load.

HARDWARE IMPLEMENTATION USING VHDL:

VHDL (Very High Speed Integrated Circuit Hardware Description Language) is a hardware description language is widely used in electronic design automation to describe digital and mixed signal systems such as FPGA and Integrated circuits. VHDL software design is used because it has potential for traditional coding efforts are significantly reduced on the one hand and, on the other hand the control algorithms can be verified offline. For these purpose Xilinx Spartan 3E FPGA software is introduced. After using this software, it delivers more power full FPGA and Xilinx then adapted the technology to combine separate component in a single chip. Design controller for three phase load driven by power inverter will be simulated in Xilinx Spartan 3E

software and implemented within Field-programmable gate array (FPGA) device.

II.RELATED WORK:

[1] Aleksander Malinowski (2011)[3]This paper survey on embedded system design and its application. In this paper several embedded system are discussed and compared including digital signal processors, application- specific integrated circuits, gate arrays, FPGA, microcontrollers and microprocessors. It's compared embedded system with computer platform and found it required less power of computation and very limited memory size. Embedded system is economical in both hardware as well as software. This paper concludes that Embedded system is maturely developed and solve various very complex problem in industrial application.

[2] Concettina Buccella (2012)[4]This paper present a general overview on digital device such as microcontroller and Field programmable gate arrays , hardware and software design techniques as well as implementation issues useful for designing modern high-performance power converter. The integration of the processing system with programmable logic significantly increases the functionality and utilization of hardware resources and decreases power comparable to ASIC. This paper concludes that analog system has various drawbacks as compared to digital control system. AC drive power converter has high efficiency and high performance with modern and energy efficient techniques, like vector and sensor less control.

[3] Eric Monmasson (2007)[5]This paper focused on FPGA based intelligent controller for modern industrial application. In this paper Timely case studied are presented to illustrated the benefits of an FPGA implementation using the proposed system modeling and design methodology. This paper conclude that control algorithm when implemented in an FPGA, can have a very short execution time due to the high degree of parallelism of its architecture.

[4] José Rodríguez (2007)[6]This paper used predictive current control method and its application to voltage source inverter. The performance of the proposed predictive control method is compared with hysteresis and pulse width modulation control. This paper provides evaluation the behavior of the current error for each switching state in single- phase active filter.

[5] Patricio Cortes (2010)[7] This paper focused on Model Predictive control of Multilevel cascaded H-Bridge Inverters. This Predictive current control method used as a discrete time model of the system to predict the future value of the current for all voltage vectors and minimizes the cost of functions. We found that in this paper modified control strategy reduces the amount of calculations without affecting the system performance. This predictive control method has a very good reference tracking and reduced common voltages, with fast calculations.

[6] Anand Sathyan (2009)[16] In this paper they discussed development of advanced motor increase the efficiency of motor and reliability of the system. Brushless DC motor is used to improve the efficiency, less maintenance and higher cost. In this paper the market driven is focused on profit margin due to this reason conventional motor drives replaced by advanced motor drive. A Pulsewidth – modulation control has been implemented for a trapezoidal BLDC motor drive system. We found that the aim of this paper is to develop a low cost controller for applications where inefficient single phase motor are used.

[7] Jose Rodriguez (2012)[18] High performance control strategies for electrical drives with the basis of comparative study between FOC and PTC applied to induction machines. This paper concluded that predictive control has a very powerful alternative in the field of power electronics and drives. In this continuous development of more powerful microprocessor have made it possible to successfully apply predictive control in control of both electrical machines and power converters.

[8] Saverio Bolognani (2009) [20]This paper focused on design and implementation of Model predictive control for electrical motors drives. In this paper current controller and speed controllers are combined with including all of the state variables of the system instead of keeping the conventional cascade structure. The main contribution in this paper is that MPC controller is used for electrical drive taking all critical aspects and also gives some suggestions for future studies and development. We conclude that MPC applied to the combined control of the motor speed and current, it is suitability for directly addressing multivariable systems and capability of systematically coping with hard constraints on inputs and states.

[9] Matthias Preindl (2011)[21] In this paper Model predictive direct current control is presented which is also called as novel current

control approach. This introduced control strategy for demonstration has been implemented on a small scale PM synchronous machine drive system with two level VSI. It reduced switching frequency upto 70% compared to linear control combined with pulse width modulation and fast dynamic response. System model used predictive control to predict the future behavior and to select the control action on the basis of an optimality criterion. We conclude that MPDCC increase the efficiency and converter power density and also it has fast dynamic response which can be compared to the fast responses of DTC.

[10] Ali M. Almaktoof (2014)[23]In this predictive controller is used to control the load current of three phase inverter. Predictive controller has several advantages and easy to implement. Power converter have finite number of switching state, the model predictive current optimization problem can be simplified and reduced to the prediction of the system behavior only for those possible switching states. The powerful and robustness of the proposed control methods are evaluated through simulation results. We found that proposed control method has been done by checking the load current and error between the reference and actual current for four prediction steps. This control method provides very good current tracking behaviors and fast dynamic response.

[11]Tapan Kumar Chakraborty (2014)[24]This paper present simulation works of line commutated inverter fed three phase synchronous motor under variable frequency condition. For reliable operation of the system, the dc motor drives are not advisable due to some drawbacks, such as mechanical commutator needs regular maintenance, power/weight ratio will be reduces due to the commutator has additional weight, the commutator construction increase the cost of the DC motor drive and unsuitable to explosive and dusty environments. We found that the hardware for the system based on speed positioning is very complicated.

[12] Nazmul Islam Raju (2012)[25]studied In this paper for harmonic reduction of inverters Pulse Width Modulation technique is used and it shows how to generate Switching signal SPWM using Three phase PWM voltage source inverter of different simple Op-Amp Circuits/analog Circuit. In Industrial application variable frequency and variable voltage supply is needed for that purpose we used single phase and Three phase Induction Motor and other rotating machines. To control the VSI and for harmonic reduction several switching technique is used. But Sinusoidal PWM and the space vector PWM technique we used mostly.We analyzed that designed Op-Amp/Analog Circuits controlled the PWM inverter works accurately. If the carrier frequency is increased much enough than the filtering system will be much better and loss will be less.

[13] G.Jegadeeswari(2012)[26]studied a neural network predictive controller for three phase inverter fed induction machine speed control. The performance comparisons of neural network predictive controller are achieved with the help of Integral absolute error and Integral time weighted absolute error. NNP controller is designed to control the motor speed by varying it's reference value and regulate the motor speed. We found that NNP controller is used to control the speed of Induction Motor.

[14] Erika Twining studied Grid current regulation of Three phase voltage source inverter with an LCL input Filter. An alternator filter is LCL network which can achieve reduced levels of harmonic distortion at lower switching frequency and with less inductance and therefore has potential benefits for high power application. To verify the stability of control algorithm across a range of operating condition by Linear analysis, simulation and experimental result are used.Multi variable control strategies have been proposed to regulate the gird current VSI connected through LCL Filters, but these strategies are complex and sensitive to variations in system parameters. We have found that harmonic performance can be achieved that lower value of input inductance would be required for a simple inductive filter which offers potential for significant reduction in filter cost.

[15] Jithesh M.V.(2012) [27]studied Single phase unipolar Inverter by using fixed switching frequency sliding mode controller. In this paper model was implemented MATLAB/Simulink with the sim power system block set and this model MOSFET used as switching device. In single phase unipolar Inverter circuit AC output is obtained from DC input by appropriate sequence of switching scheme due to this pulse width modulation technique is used in control the operation of switches. This fixed switching frequency sliding mode controller work as bang bang controller. We found that SPWM with unipolar switching has better harmonic profile as

compared to Bipolar voltage switching due to this SPWM with unipolar voltage switching will use as switching scheme for the single phase Inverter. This controller gives better responses in the output voltage and load current.

[16] Liviu Mihalache (1997)[28]In this paper DSP control method of Single phase Inverters for UPS application used a digital control strategy for high performance single phase Inverter to maintain THD of less than 1% in presence of unknown loads and deadbeat control solution . Last 15 years many advanced technique is proposed to regulate the instantaneous output voltage, faster response, improved total harmonic distortion and better disturbances rejection. Deadbeat controller is simple, reliable and easy to implement fully digital control strategy that provides excellent disturbance rejection and fast dynamics response. We found that disturbances of heavy nonlinear load are rejected by deadbeat control solution.

[17] Syed Faiz Ahmed (2014)[29] In this paper Model Predictive Control technique is implemented control strategy for single Inverter. Power supply, adjustable speed AC servo drives and uninterrupted power supply are the Industrial application and for this Pulse Width Modulated Inverter is used. When MPC technique start its prediction process than it minimizes the specific objective function over prediction horizon. When prediction process is completed than next sampling interval is ready for execute and this is the continuous process with new available Information. We analyzed that state space model was developed and MPC technique has been implemented to obtain the desired response and attain robustness of good level, with respect to load disturbances. And result shows that inverter perform reasonably well.

[18] Shubhangi S. Ambekar (2012)[30]In this paper we will get high efficiency due to thyristorised power control method. It designed continuous Hopfield Neural network for harmonic minimization in single phase inverter output voltage. The Artificial Neural Network controlled method is used to drive finite state machine in MATLAB simulation and is compared with SPWM controlled VSI driving the same motor load.The problem of harmonic elimination will avoid by using pulse modulation with selective Harmonics elimination method.To control 200kw single phase Induction motor in MATLAB Simulink by using ANN controlled inverter output. We analyzed that artificial neural network is developed for reducing the low order of harmonics in single phase inverter circuit and it is observed that the result show a significant improvement in the voltage spectrum of the inverter. When increasing output voltage of the inverter, cost of the device it was reducing.

[19] Shanthi B. (2010)[31] In this paper it reducing the THD of output of the five level cascaded inverter under steady state as well as set point tracking with fast transient response are approach for control point of view. In this PI controller is used to regulate the AC output voltage because it can reduced the steady state error to zero. A fuzzy logic control scheme is also used to improve the transient response for both loading and unloading condition as well as regulate the output voltage with zero steady state error under disturbances with minimum THD. We found that FLC performs better than PI controller in view of harmonic content of the steady state output voltage with linear loads whereas better output voltage is observed with PI control under loads with less non-linearity and it is found than FLC perform better in FPGA based control.

[20] Fatih Korkmaz (2013) [32] In this paper it reduced the torque ripples of the Induction motor on the Direct Torque Control method. New approach is introduced in this paper named as Fuzzy logic based space vector modulation method (FL-SVM). Due to this method is minimize the flux and torque errors as the output of optimum space vector. We analyzed new fuzzy logic based spaced vector modulation technique proposed for DTC controlled induction motor driver and the simulation has been carried out in MATLAB/Simulink to compare the system behaviors at vary load and speed conditions by reducing the torque errors.

[21] M.V. Subramanyam[33] In this paper Fuzzy logic control of closed loop controller is used to driven the three phase induction motor by five level Multi level inverter. Fuzzy logic technique is the best technique and we can effectively apply. Fuzzy logic techniques can applied to complex problems such as closed loop control which reduce the time and cost. We found that Fuzzy logic control of closed loop controller is used to driven a three phase induction motor by five level Multi level inverter.

[22] M. Nasir Uddin (2006) [34] In this paper for speed controller it used fuzzy logic technique and the motor is fed from a four switch three phase pulse width modulation inverter. 4S3Ph

inverter has some advantages over the 6S3Ph inverter such as reduced price due to reduction in number of switches, reduced number of interface circuit to supply logic signals for the switches, simple control algorithm, , reduced Switching losses, and less real – time computational burden. We analyzed that the proposed inverter fed IPMSM has good performance, cost reduction, high efficiency, high power factor and robustness. And also we analyzed that it has other inherent advantageous features.

[23] P.Tripura (2011) [35] This paper present an intelligent speed control system based on fuzzy logic for a voltage source pulse width modulation inverter fed indirect vector controlled induction motor drive. In this low precision of the speed regulator debases the performance of the whole system. This is the disadvantage of the PI controller therefore, PI controller replace by intelligent controller based on fuzzy set. We analyzed that fuzzy logic has various advantage over a intelligent controller is that it is simple to control, low cost and the possibility to design without knowing the exact mathematical model of plant.

[24] T.D.Dongale (2012) [36] This paper present the implementation and comparative study of dynamic behaviour of three phase induction motor with different control strategies such as neural network techniques ,PID controller, and Fuzzy logic. In this fuzzy system is designed using Mamdani's reasoning method which is simpler than other method. We found that the speed controlling of AC induction motor with neural network controllers is smooth and system performance give good result in terms of overshoot and settling time.

[25] Neelima Shitole (2014) [37] Implementation of three phase induction motor control drive using PID and Fuzzy technique. In this paper Fuzzy logic controller provides an alternative to PID controller when the available system models are inexact or unavailable. To control the speed of conveyor systems, blower speeds, pump by AC motor drives. We analyzed that PID controller is very much but it has some limitations that is it has more settling time. Therefore Fuzzy controller is used because it provides minimum settling time as compared to PID Controller and also it is a real time matlab inference for such nonlinear application in linear fashion.

[26] Meenu Gupta (2002) [38] In this paper a novel fuzzy logic controller is present for high performance induction motor drive system. AI technique can be used as electrical motor controller without requiring to system mathematical model. Simulink induction machine models is easy to understand and it is easily available. The attractive fuzzy logic control approach which can accommodate motor parametric variations and difficulty in obtaining an accurate mathematical model of induction motor due to rotor parametric and load time constant variations. We analyzed that by using Artificial intelligent technique we can increase the reliability of drive efficiency, performance and also decrease the volume, weight and cost of them decreases.

[27] C. Sasikumar (2013) [39] In this paper Induction motor play vital role in Engineering field. Fuzzy flatness based control is applied in the speed controller of Induction motor. This method reduces tracking error and gives better performance and torque ripple. In this Fuzzy control is designed for Flatness control to improve the performance. We analyzed that The Flatness control is difficult problem in Induction motor but it can improve the operation performance of the Induction Motor effectively.

[28] T. D. Dongale (2012) [40] There is Performance comparison of PID and Fuzzy control technique in Three phase Induction motor control. In this paper they used AC motor because it improved the performance, reliability, feasibility of speed, higher efficiency, easy scalability and torque control by different technique. We analyzed that PID controller is good due to its ability of auto tuning. In this Fuzzy controller offered negligible settling time than PID controller and no overshot. Speed controlling of AC induction motor with Fuzzy controller is smooth and easy than PID controlling method.

[29] Prof. Suraj R. Karpe (2013) [41] In this paper it perform four switch, Three phase inverter fed induction motor drive system. In this a simulation model of the drive system is developed and analyzed in order to verify the effectiveness of the approach. We found that this control scheme produced very fast response of the Induction motor drive. It also show good performance in parameter variation, speed operation under the effect of load disturbances, and reversal of speed. In this paper MATLAB SIMULINK is used for software and the hardware implementation is carried out in using Spartan-3 processor.

[30] J.Rekha (1995) [42] This paper control the speed of Brushless DC motor on resonant pole Inverter using Fuzzy logic controller. In this paper a new soft switching inverter has been developed to overcome over voltages and over current problem existing resonant link inverter. Fuzzy logic based soft switching resonant pole inverter using transformer which generate dc link voltage notches during chopping which an minimized the drawback of soft switching. We analyzed that a major problem in the design and operation of the Three phase PWM voltage source inverter (VSI) boost rectifier is the high switching loss which limits maximum switching frequency for a given power rating. Voltage stress on all the switches is low and it is not greater than the DC supply voltage.

III.PROPOSED CONTROL DESIGN:

The Predictive switching control is introduced for considering the VSI as a system with finite number of possible states. PSC strategy which is based on the finite number of possible switching states can be generated by a Voltage Source Inverter and the model of the system can be used to predict the behaviors of the variables for each switching state. The proposed controller is that control the current and speed of the BLAC motor by controlling the finite number of possible switching states. This control will be done by ANFIS controller. It generate the rule for selecting the switching state. Due to ANFIS controller we can predict the next switching state. This is nothing but the Predictive sliding mode controller.

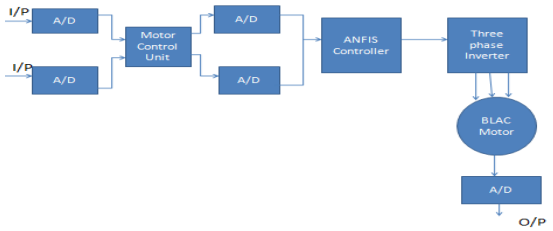

Fig.1. Block diagram of FPGA controller of BLAC motor

In this Block Diagram Input is converted into digital form by using A/D converter. This conversion is required for FPGA controller. It has two inputs one is reference current and second is Normal current. Both will be converted into analog to digital form. Digital Input will give to ANFIS algorithm. By using ANFIS algorithm it generates IF-THEN rule to control the current and speed of the motor. In this way we can control the Current and Speed of the motor. This is the continuous process until BLAC motor will not stopped.

IV.IMPLEMENTATION AND TESTING

Substituting the common DSP solution by FPGA based ones means a tradeoff between the DSP capacity for arithmetic operations and the FPGA concurrence. The ANFIS algorithm can be quite simple, but it is designed for Concurrence point of view such as the switching control proposed. Fig.1.presents the general structures of the different elementary modules. Motor controller is divided into two parts of Implementation.

The initial part is the driver's parts with analog-to-digital converter and digital-to-analog converter and RS232 module for connecting the host PC equipment to the graphical user interface. The current controller is the second part, In this part current controlled by ANFIS algorithm by applying IF-THEN rule and also a second-order PLL filter to reduce switching frequency. The complete system controlled by FPGA controller. The VHDL code was created in XILINX ISE software. The software scheme is divided into individual blocks for better transparency. The data path is composed of adders, multipliers, multiplexer, and registers. This data transfer between these operators is managed by a control unit.

V.RESULTS

In order to test the proposed Xilinx Spartan 3 FPGA based controller, experiments were carried out on an in house built FPGA Prototyping platform. The experimental results are illustrated in Fig.2. Fig.2.shows the transient of speed (ω), the three phase current, comparison between switches with one, two, or three voltage legs at the same time and voltage vectors (spectrum) $V_k\,(S_1, S_2, S_3)$ of the three phase Inverter. At the time of 9.53ns, mechanical load is connected to the motor.

The results show a predominant usage of switching that uses only one inverter's voltage leg. Calculation of the switching number was implemented inside a time interval of 10μs.

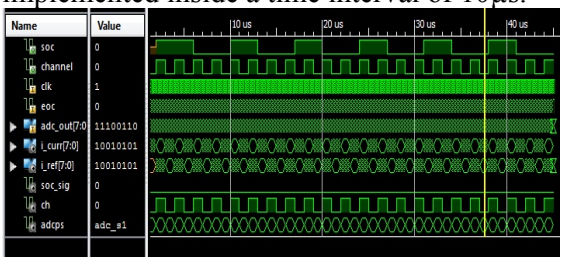

Fig.2.Simulate Behavioral Model

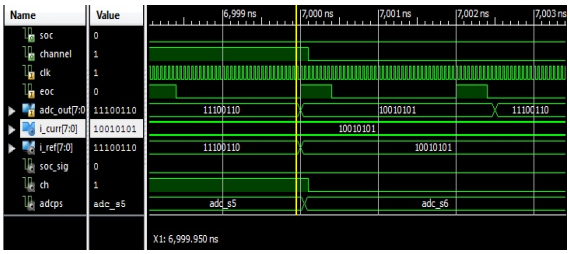

Fig.3.Output of FPGA Controller

The step responses of three-phase currents and speed are shown in fig.3. and it also show the output of FPGA controller are based on simulation from the Xilinx 9.1 ISE, using Timing Analyzer and Waveform Generator. We controlled Voltage Sector by using ANFIS Algorithm and predict the next finite number of Possible State. According to that we controlled the speed of the BLAC Motor.

VI.CONCLUSION

The Predictive sliding mode controller is introduced in this paper by using Adaptive Neuro-Fuzzy Inference System controller is simple and Powerful. The design specifications of this controller are fast dynamic response, robustness to load electrical parameter, reduced switching frequency and simple hardware implementation. The ANFIS controller is implemented on FPGA for controlling the finite number of states by considering the voltage source inverter and over each sampling period the switching state minimizes the quadratic cost functions. In this way next possible state is predict by FPGA implementation on Xilinx Spartan 3E FPGA.

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