Nonlinear Adaptive Sliding Mode Based Direct Torque Control of Three Phase Induction Motor Speed Control System

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Abstract-Enlistment motor is a steady speed machine when worked from the mains. Anyway it is important to fluctuate the speed of the motor in a few applications. The speed of a motor essentially relies upon the supply frequency and number of shafts. The Field Programmable Gate Array (FPGA) innovation gives Programmable System-on-Chip (PSoC) situations for outlining modern computerized ASIC controllers for particular applications. This work introduces an FPGA based speed control Integrated Chip (IC) for three-phase induction motor drives. Direct torque control (DTC) is one technique utilized in factor frequency drives to control the torque of three-phase AC electric motors. This includes figuring a measurement of the motor's attractive flux and torque in view of the deliberate voltage and current of the motor. In this work was significantly reduce the torque flux and ripples based on Nonlinear Adaptive Sliding Mode controller with DTC scheme. The tuning of PID controller parameters to be used as a piece of a three-phase induction motor, NASMC system is utilized to tune each parameter of PID to improve the response of three phase induction motor drive structure. The Simulated results shows that the effectiveness of proposed NASMC controller and the simulation developed using Matlab Simulink software. A hardware model additionally created to approve the proposed simulation, in hardware FPGA based NASMC controller fed three phase Induction Motor is proposed utilizing single chip IC to work variable voltage and variable frequency, and in general 97% effectiveness was accomplished in full load condition.

Keywords: Direct Torque Control (DTC), Field Oriented Control (FOC), Flux, NASMC

1. Introduction

The development from dc drives to different types of AC drives has been propelled by the proceeding with a requirement for simplicity and reliability. Although it is conceivable to accomplish the AC motor's abnormal state of speed control by the use of the trans-vector theory, the subsequent controller turns out to be excessively perplexing, making it impossible to execute for an extensive variety of applications. An option to the trans-vector control is the direct torque control (DTC), which spoke to a stage in blend change. The presence of rapid computerized flag processor (DSP) and application particular coordinated circuit (ASIC), DTC innovation has turned out to be famous in air conditioning motor drives.

Nowadays FPGA innovation got much consideration by modern analysts for designing and implementing superior ASIC digital controller with the committed design for induction motor control. The FPGAs give programmable framework on-chip planning situations by fusing the programmability of programmable rationale gadgets and the design of gate arrays which makes it an acknowledge answer for drive applications. Not at all like conventional arrangements in view of microprocessors and digital signal processing (DSP) gadgets, have the FPGAs introduced hardware parallelism by breaking the paradigm of sequential execution.

In this work introduces a strategy for enhancing the speed control of 3-phase induction motors (IM) utilizing half breed direct torque controller (DTC) utilizing Nonlinear versatile sliding mode strategies. An entire reproduction of the traditional DTC and shut circle for speed control of a 3-phase IM was tried utilizing Simulink. The speed control of the IM is finished by utilizing the customary proportional integral (PI) controller and NASMC. The proposed NASMC has a nature of PI controller to decide the torque reference for the motor. The impact of a variety of the speed reference directions on the dynamic reaction has been unmistakably tried for

both traditional and NASMC speed controllers. The primary the target of this paper is to think about a nonlinear versatile sliding mode controller with the PI controller. The work is structured as follows: Section 2 introduces a literature survey on previous DTC techniques on Induction motor. In Section 3, the proposed materials and methods are. Section 4 presents the experimental results. Finally, Section 5 concludes the work.

2.   Literature Survey

Present day control strategies for induction motor drives have been growing extremely solid in most recent couple of decades. In any case, a control structure of an induction motor (IM) is more confused in examination with a DC drive control structure, in light of the fact that the stator field pivots and different issues emerge because of the way that the rotor currents and rotor flux of a squirrel-confine induction motor can't be directly estimated [1-2]. Different reasons of said many-sided quality are entangled input flag handling, parameter varieties and complex non-direct elements of induction machines [3-5]. By and large, most utilized control strategies for induction motor drives are the accompanying: Direct torque control (DTC), Vector Control (VC) and Scalar Control (SC). At present, in current methodologies it is creating sensor less AC drives and applications utilizing artificial intelligence

For superior utilizations of AC drives there are essentially two techniques for electromagnetic torque control: vector control and direct torque control. These two control calculations have similar properties. Direct torque controlled drives were presented over 10 years after the fact than vector controlled drives. The most known DTC techniques directly control the torque and stator flux by methods for wanted voltage space vectors acquired from look-into tables [6-9]. The modeling of an IM drive utilizing DTC with use of fuzzy is performed in [10-11], it is smarter to comprehend the DTC and its troubles. The reference voltage vector is then acknowledged utilizing a voltage vector modulator. A few varieties of DTC-SVM have been proposed and examined in the literature [12-15].

The different strategies for speed control of Induction motor through semiconductor gadgets are given in [16-19] as under: Scalar control, Vector control, DTC and DTC with SVM and Fuzzy based control. The above discussed all methods have some drawbacks ,so in this work implementation of NASMC method is presented in the entire of the control scheme to replace the conventional controllers for flux, torque decoupled control, and the outer speed regulation loop.

3.   Materials and Method

The block diagram of the proposed Direct Torque Control of Induction motor is shown in figure 1. As indicated by the block diagram, the proposed Nonlinear Adaptive Sliding Mode Controller has been incorporates into two types of hysteresis current controllers. The proposed sliding mode control methodology is one of successful nonlinear control strategies
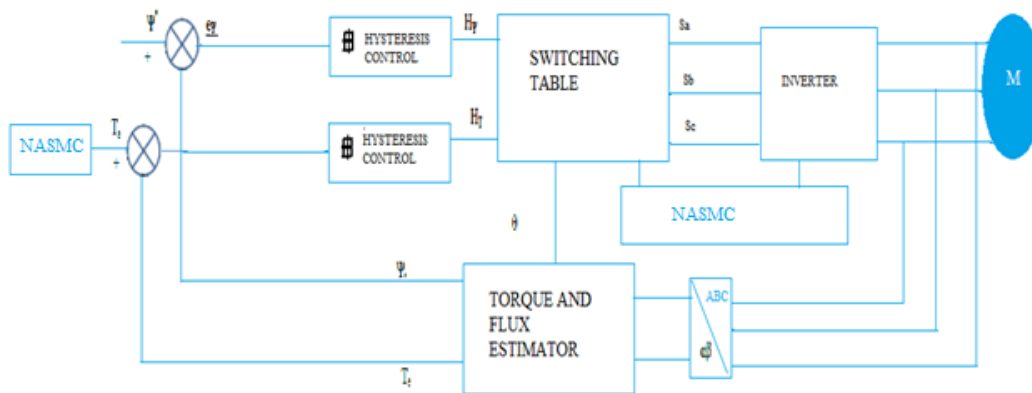

Figure 1. Block diagram of the proposed system

The above Figure 1 demonstrates the Block diagram of proposed framework. By driving the phase direction towards a foreordained sliding surface in limited time, the state can be kept on the sliding mode utilizing broken control law. Keeping in mind the end goal to plan a sliding mode controller, two fundamental advances ought to be deliberately investigated, in particular, the choice of sliding mode surface and the outline of control law.

3.1.   Direct torque control of IM - NASMC

The DTC-based speed closed loop control arrangement of IMs is appeared in Figure 2. The speed, flux and current controllers are planned utilizing Nonlinear Adaptive Sliding Mode Control system.
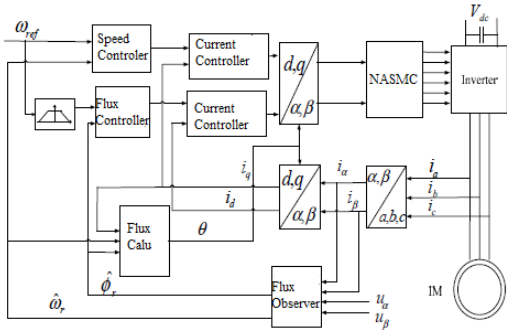
Figure 2. Induction Motor DTC – NASMC

3.1.1.   NASMC Current Controller

Moreover NASMC to track the speed reference powerfully necessitates that the torque thus current be endlessly changing or exchanging between two states which would be severely blocked by the inductive properties of the motor. Likewise, the reachability condition could forever discontent. Along these lines the proposed current control topology in which the three-phase streams are set to track three adjusted sinusoidal signals, this is accomplished by setup appears in Figure 3.
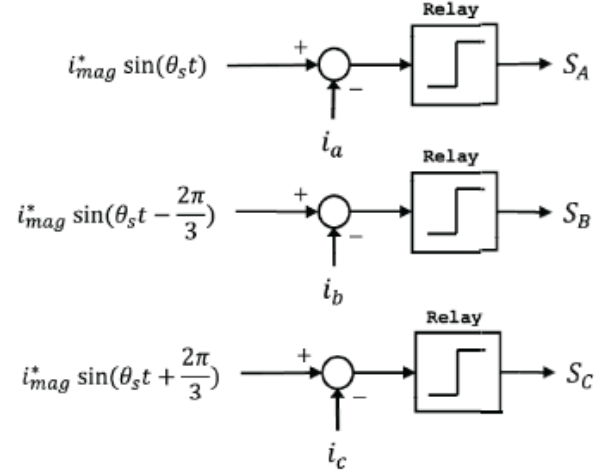
Figure 3. NASMC -Current Controller

In figure 3 each relay represents a NASMC and all three operate in parallel. The NASMC variable can be defined as

$$\sigma_1 = i^*_{mag} \sin(\theta_s) - i_a \qquad (1)$$

$$\sigma_2 = i^*_{mag} \sin\left(\theta_s - \frac{2\pi}{3}\right) - i_b \qquad (2)$$

$$\sigma_3 = i^*_{mag} \sin\left(\theta_s + \frac{2\pi}{3}\right) - i_c \qquad (3)$$

Where

$$\theta_s = \int w_s \, dt$$

i^*_{mag} = Current magnitude reference

3.1.2.   NASMC – Speed Control

For any induction motor energized by a sinusoidal voltage input, the torque-speed qualities can be concentrated to decide the resultant enduring state T_{ssm} and to make of the torque condition.

$$T_{ssm} = \left(\frac{3P}{2}\right)(i_s)^2 \left(\frac{R_r L_m^2}{R_r^2 w_{slip}^2 L_m^2}\right) w_{slip} \qquad (4)$$

$$w_{slip} = w_s - \left(\frac{P}{s}\right) w_m \qquad (5)$$

Knowing the articulation for T_{ssm}, can set both i_s and w_s with the end goal that at some random reference speed w_m, the enduring state torque produced by the induction motor is equivalent to the heap torque T_{Load}. With respect to stator recurrence w_s can be set to machine rating while size of the stator current can be utilized as control variable for

this issue, the size required at unfaltering state i_{mag} can be ascertained as

$$i_{mag} = \sqrt{2}\, i_s = \sqrt{T_{load}\left(\frac{4}{3P}\right)\left(\frac{R_r^2 + w_{slip}^2 + L_m^2}{w_{slip}R_r L_m^2}\right)} \qquad (6)$$

In view of steady-state esteem the uncertain model to determine the issue of any motor parameter confuses, an amendment term i_{adj} is presented. The term is acquired through passing the speed mistake 'e' through a traditional PI-controller with the end goal that

$$e = w_m^* - w_m \qquad (7)$$

$$i_{adj} = K_p e + K_1 \int e\, dt \qquad (8)$$

$$i_{mag}^* = i_{mag} + i_{adj} \qquad (9)$$

3.1.3. NASMC algorithm steps

Step1: The 3-phase stator streams i_a, i_b , i_c and the rotor speed w_r are estimated.

Step2: The 3-phase currents are changed over to a 2-axis framework as appeared in Figure 2. This change gives the factors i_α and i_β from the deliberate $i_a, i_b , and\ i_c$ values. i_α and i_β time changing quadrature current qualities as saw from the point of view of the stator.

Step3: The over 2-axis organize framework is then rotated to line up with the rotor flux utilizing a change point data ascertained at the last emphasis of the control circle (Figure.2) This transformation gives the i_d and i_q variables from i_α and i_β.

Step 4: Error signals are framed utilizing i_d , i_q and their reference esteems for each. The i_d reference is utilized to control rotor charging flux. The i_q reference is utilized to control the rotor yield of the engine. The mistake signals are the contributions to the PD controller. The yield of the controller give v_d and v_q, which is a voltage vector that will be sent to the engine.

Step5: Another organize change point is figured. The engine speed, the rotor electrical time consistent, i_d and i_q are the contributions of this change.

Step6: The v_d and v_q yield esteems from the PI controller are pivoted back to the stationary reference outline utilizing the new edge. This computation

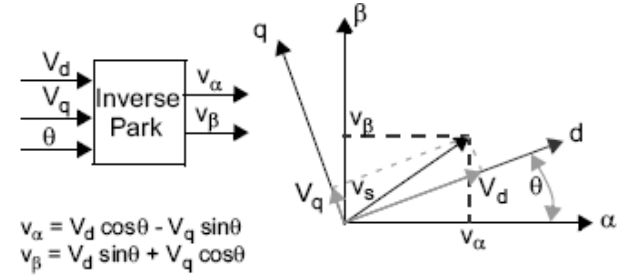gives quadrature voltage esteems v_α and v_β (appears in figure 4)

$v_\alpha = V_d \cos\theta - V_q \sin\theta$
$v_\beta = V_d \sin\theta + V_q \cos\theta$

Figure 4. Inverse Park Transformation

Step7: The v_α and v_β esteems are changed back to 3-phase voltage esteems which are then used to compute new PWM duty cycle esteems that create the coveted voltage vector (appears in figure 4)
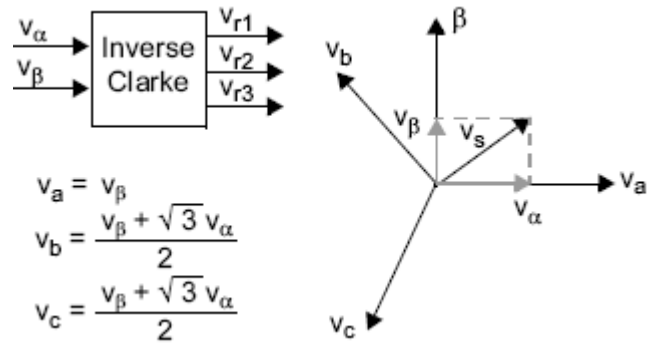

$v_a = v_\beta$

$v_b = \dfrac{v_\beta + \sqrt{3}\, v_\alpha}{2}$

$v_c = \dfrac{v_\beta + \sqrt{3}\, v_\alpha}{2}$
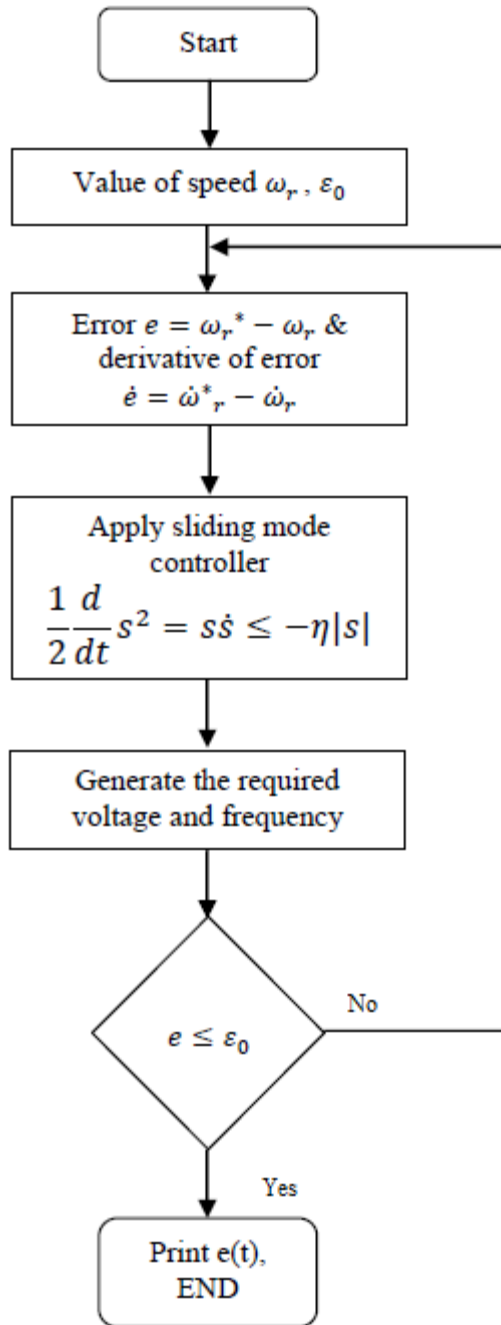
Figure 5. Inverse Clarke Transformation

Figure 6. Flow Chart of proposed NASMC

The above figure 6 shows the functional flow diagram of proposed nonlinear adaptive sliding mode controller with direct torque control of Induction motor. By using NASMC technique the reference speed and running speed was same so it achieve low steady state error. On the off chance that the error is not as much as this esteem, the error of esteem is printed, and the control procedure stops. Generally, the system is rehashed to active error esteem.

4. Results and discussion

In this section to discuss the simulation results and performance analysis of proposed induction motor speed control system using Nonlinear Adaptive Sliding Mode Controller. The performance of the proposed NASMC validated through simulation, the simulation was developed by using Matlab2017a software. The function diagram of the Simulink demonstrate is appeared in Figure 7.
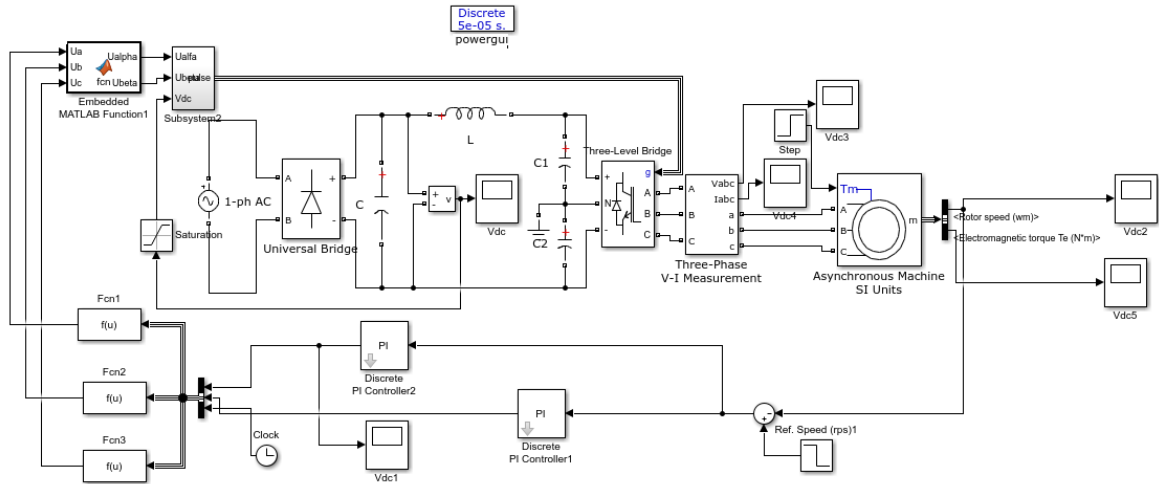
Figure 7. Simulink model screen

The above figure 7 illustrates the Simulink model screen in DTC of TIM utilizing Nonlinear Adaptive Sliding Mode Control (NASMC). The following figures 8 to 11 shows the simulation results of voltage, current, torque and speed response of proposed system.
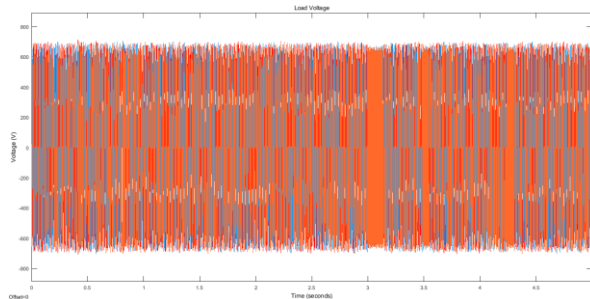

Figure 8. Load Voltage

The output voltage of proposed system is shown in figure 8, by using suggested Nonlinear Adaptive Sliding Mode controller the output flux, noise and harmonics are controlled perfectly. The maximum rms range of the response is 250V.
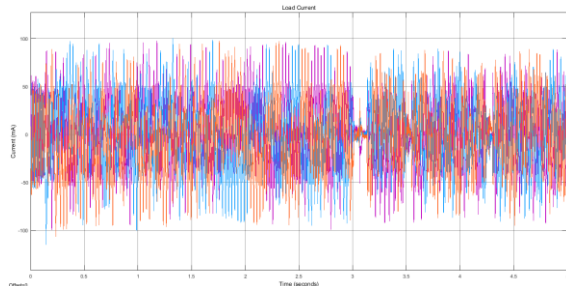

Figure 9. current response

The above figure 9 shows the current response of proposed three phase induction motor speed control system. In the consistency response, the result of output current have 0.5mA Root Mean Square (RMS) at 5 Hz.
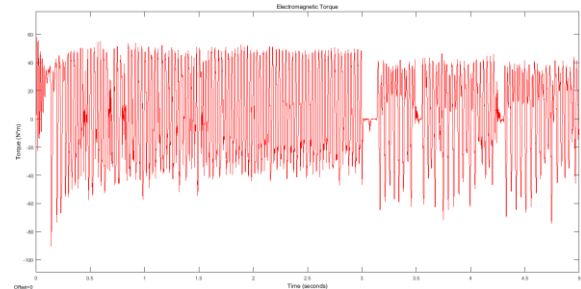

Figure 10. Electromagnetic Torque

The above figure 10 demonstrates the electromagnetic torque response for anticipated nonlinear adaptive sliding mode control (NASMC).This strategy contributes enhanced rotor speed reaction and maintain the constant response of Electromagnetic Torque in TIM is in the field of 20 (N*m).
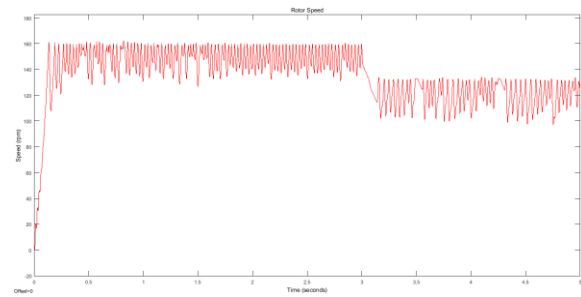

Figure 11. Rotor speed

The rotor speed response was shown in above figure 11. In this work the rotor speed was perfectly controlled by using NASMC method. In this no-load circumstance, the rotor speed would in the long run quicken to synchronous speed of 168.8 rpm. In view of NASMC regulation technique there is 5.9% distinction with the calculated of synchronous speed.

Table 1. Design parameters

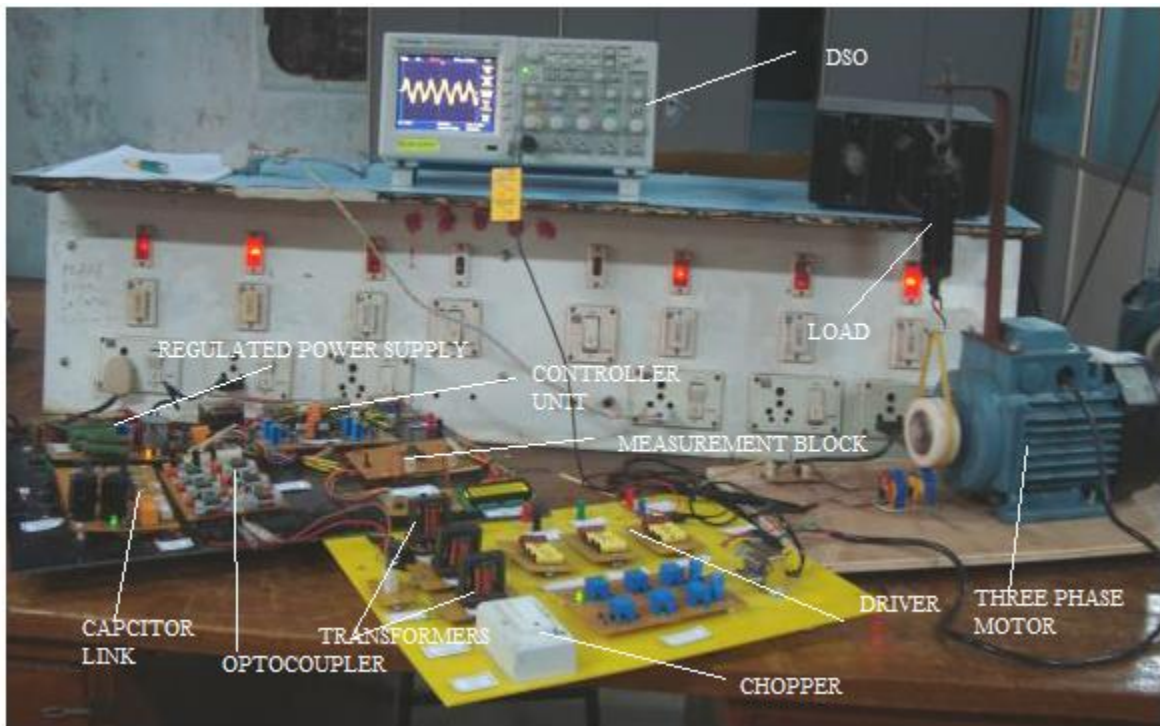| PARAMETERS	SYMBOL	VALUE
Input voltage range	Vin	230V
Output voltage	Vo	430v AC
Output power	Po	1.29KW
Magnetizing inductance	Lm	310µH
Leakage inductance	Lik	15.8 µH
Quality factor	Q	0.61
Resonant frequency	Fr	38.4KHz
Switching frequency	Fs	38.4KHz
Resonant capacitor	Cr	1.09 µF
Snubber capacitor	CT1, CB1	6.8nF

Figure 12. Hardware Implementation of three phase induction motor system

The hardware implementation of FPGA based direct torque induction drive is appeared in above figure 12. In hardware usage the speed control is accomplished by controlling the switching pulses for the inverter and harmonics are diminished specifically. IRF840 MOSFET switches are utilized for inverter outline, TLP250used in optocoupler circuit, the FPGA has inbuilt DAC to create triangular waveform. The outcomes acquired from the hardware execution is as demonstrated as follows,
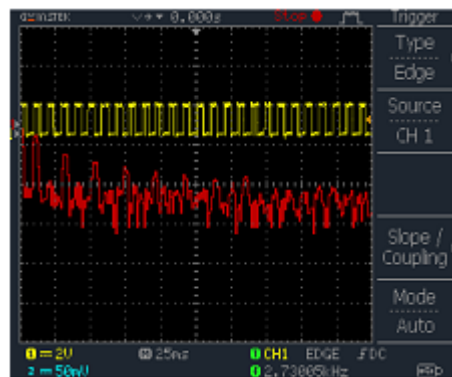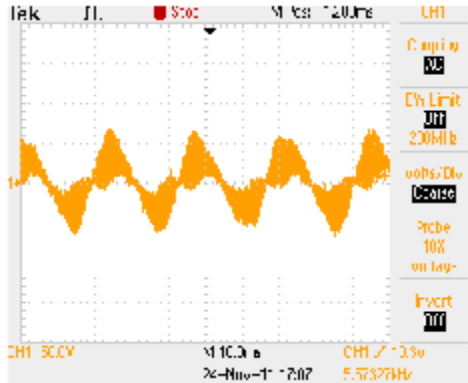
(b)

**Figure 13. Hardware Result a) Gate Pulse
b) Inverter Response**

The above figure 13 shows the hardware implementation results of proposed system. The FPGA Real time controller is utilized to produce PWM pulses at various frequencies by various transporter frequencies. The modulation index is fluctuated by changing the amplitude of the reference or sine wave. These switching pulses are given to four switches of the inverter. The rms yield of the inverter is fluctuated by shifting modulation index. The consonant profile of yield voltage of the inverter is fluctuated by changing the transporter recurrence. Simulation is done utilizing MATLAB Simulink.

Table.2.Control system parameters for varying load condition

Methods	Peak time(sec)	Reference value(rpm)	Peak Overshoot (%)	Recovery time(sec)	Steady state error value (rpm)	Steady state error (%)
FUZZY	0.6010	1500	1.4151	0.60	9.25	0.82
ANFIS	0.6002	1500	0.9814	0.56	8.1	0.66
Proposed NASMC	0.8948	1500	0.7414	0.43	6.2	0.46

From the simulation result the performance comparison was analyzed in Table 2. From this comparison table clearly says that as compared with other traditional method the proposed NASM controller deliver perfect result. In this research work the following parameters are used validated the performance for proposed work for example rise time, peak time, peak overshoot and settling time.
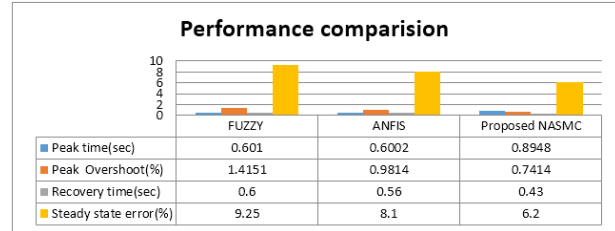

Performance comparision			
	FUZZY	ANFIS	Proposed NASMC
■ Peak time(sec)	0.601	0.6002	0.8948
■ Peak Overshoot(%)	1.4151	0.9814	0.7414
■ Recovery time(sec)	0.6	0.56	0.43
■ Steady state error(%)	9.25	8.1	6.2

Figure 14. Performance comparison

The above-mentioned figure 4.10 shows the performance comparison of different controller with various parameters. As compared with other controllers the proposed NASMC controllers has given significant outcomes. In the proposed NASMC controller has indicated unrivalled execution under every working condition of TIM control.

5.   Conclusion

This work discussed the detailed study of NASMC based direct torque control of induction motor. A full digital controller for nonlinear adaptive sliding mode controller adjusted direct torque control for acceptance engine has been proposed. The primary preferred standpoint of this strategy is that the all the logic is executed persistently and all the while and new fast calculations can be utilized in this way. The Simulated results show that this framework offers variable AC voltage which is prepared for driving in a speed-torque plane by using MATLAB Simulink condition. The experimental setup was produced by utilizing FPGA SPARTAN 3. Actualizing the control algorithm in a hardware description language (HDL) permits high adaptability and innovation independence. A similar algorithm can be straightforwardly integrated into some other FPGA or even in an ASIC. The experimental outcomes confirm that all methodologies have great execution in the entire speed extend with or without load. Every one of these techniques create currents of equivalent quality under load conditions. In hardware FPGA based NASMC controller fed three phase Induction Motor is proposed utilizing single chip IC to work variable voltage and variable frequency, and

in general 97% effectiveness was accomplished in full load condition.

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