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An Alpha-Cut Based Intelligent Controller-Sensor-Less Speed Control of Induction Motors

Ugwu K. I., Alor M. O., Eke J.

Abstract: - This paper presents modeling of induction machine to achieve sensor-less speed control of induction motor by applying alpha-cut fuzzy logic field oriented controlling (FOC) system. Development of non-linear model of induction machine was the major contribution to this work which takes into consideration the error in flux estimation and use of PI controllers for flux regulation. For speed regulation the model was simplified and with the use of (high gain) P.I controllers it is possible to regulate the q-axis current. With simulations, it is shown that the control methodology highly depends on flux frequency and load, and this has an easier constructional advantage over the conventional drive that requires shaft mounted speed sensor, or other control methods that exhibit much heat dissipation.

I. INTRODUCTION

Induction motor for many years has been regarded as the workhorse in industrial applications. In the last few decades induction motor has evolved from being a constant speed motor to a variable speed,
variable torque machine. For high power and torque applications, induction motor remains more efficient to use. The shift from DC machine to AC machine is for known reasons, such as robust design, size, cost and efficiency (Peter Vas, 1990).The DC machines requires periodic maintenance due to mechanical commutator which also limits speed loading capacity. Conventional speed control methods of induction machine includes;

-Speed control by change of applied voltage
-Rotor resistance control
-Cascade control
-Pole changing scheme
-Stator frequency control

But the conventional control methods have the following difficulties.

-It depends on the accuracy of the mathematical model of the systems.
-The expected performance is not met due to the load disturbance, motor saturation and thermal variation.
-Classical linear control shows good performance only at one operating speed.
-The coefficient must be chosen properly for acceptable result whereas choosing the proper coefficient with varying parameters like set point is very difficult.

In this work artificial intelligence techniques was used to add intelligent control which applies alpha-cut control by use of Park and Clarke transformations.

Making A.C. machines sensor less, is a part of making structure of AC drives close to DC drive and increases the robustness of the whole system. As there are many restrictions generated by using mechanical sensors, more over the extra expense and allocation problems that made using such sensors difficult in some cases.

The proposed sensor less speed control method of induction motors valid for both low speed and very low speed range is to be considered using fuzzy logic field oriented control, that is stator terminal voltages and current estimate, to estimate the rotor angular speed, slip angular speed and rotor flux.

II. THEORY

Sensor less speed control method

Comparing various methods of speed control of induction motor with their drawbacks, a sensor less speed control of induction motor is considered in work using fuzzy logic field oriented control method (FOC) with interest in

-Injecting a low frequency signal to change the mechanical dynamics of the motors to control the machine at a very low speed, (Veli-Matti Leppanen, 2003). Similar technique is used by
(Blaschke, et al, 1996).If the orientation error is zero, them audible noise and torque ripple of the machine are not affected by the injection. Thus is the advantage of this system.

-Another methods to control induction at very low speed is to develop new flux observer (Ah-
Choy Liew, 1998). The advantages of this technique is that it is stable in low dynamic environment for wide spread range of sensorless speed control of induction motor (Rehman, 2002). The observer is capable of

operating at very low speed (Lascu, 2005). These observers are very sensitive to the parameter (Barut, 2003) of the machine and the stability at very low speed of control system depends on the accuracy of these parameters.
The alternative to these techniques is to inject a high frequency signal either current or voltage and then detect saliency in the machines. The same technique is used (Caruana, 2003) where flux angle information is taken from zero sequence current. These methods are not practicable, as they require an extra sensor on the neutral to measure the zero sequence current or voltage.
Low frequency injection methods are more suitable for feasible applications (Consoli A., 2007). Here a low frequency signal is injected and flux angle information is extracted from the zero sequence voltage. For this setup a star-connected stator winding is required.

III. METHODOLOGY

In D.C machines, the air-gap current are regulated independently, hence torque is proportional to air-gap flux once the air-gap flux is fixed. In the case of induction machine, torque is a cross product of air-gap flux and stator currents, both of which have two axis components expressed in d-q plane. All these four components affect torque production.
In line with the above fundamentals of torque control, this work employs the application of Clarke transform to convert 3-phase current to two axis plot to create variables i_α and i_β, and Park transform to align quadrant currents i_d and i_q with the rotating plot to remain constant during steady state condition, since they are reference variables that generate error signals for sensor less speed control action.

The fuzzy logic of sensor less field oriented control of induction machine is achieved by;
a) Developing motor models
b) System formulation
c) Simulation of results.

Field oriented control

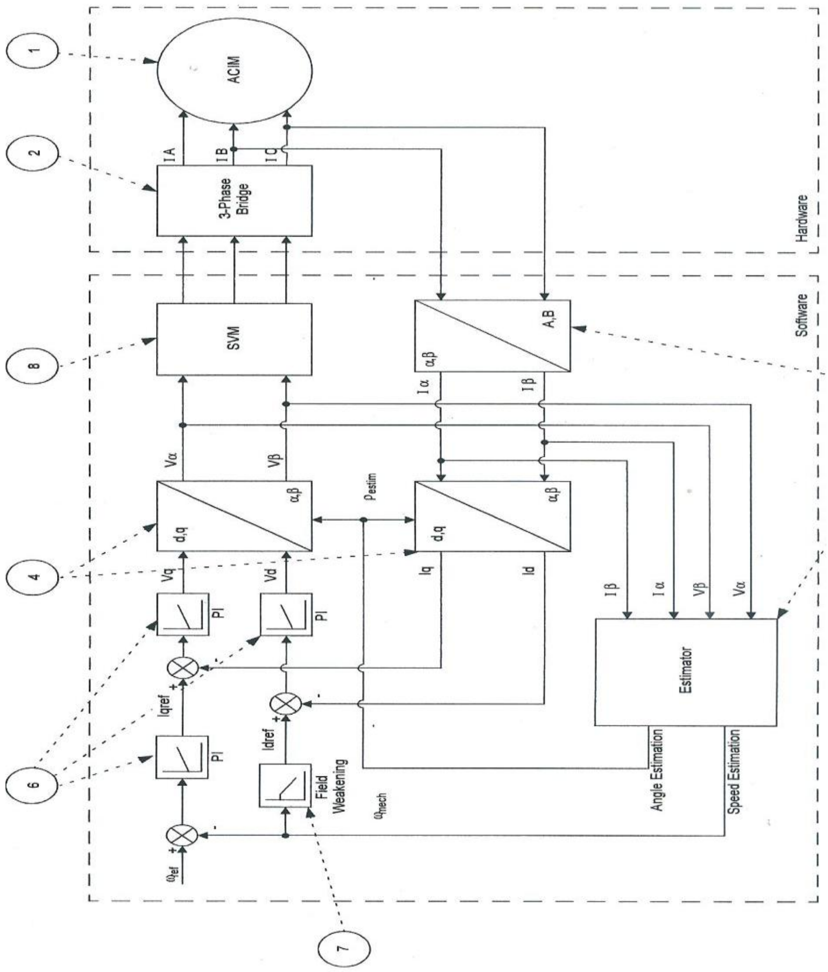

Fig.1: Field Oriented Speed Control Drive of Induction Motor

1 AC induction motor.
2 3-Phase Bridge-rectifier, inverter, acquisition and protection circuitry software blocks.
3 Clarke forward transform block.
4 Park forward transform block.
5 Angle and speed estimator block.
6 Proportional integral (PI) controller block.
7 Field weakening block.
8 Space vector modulation block.

Sensor less Field Oriented Control

The field oriented control principles applied to an ACIM are based on the decoupling between;
-the current components used for magnetizing flux generation and;
-the torque generation
The speed controller is based on PI regulator. The output of this regulator has set points for the torque and the flux applied to the field control block.

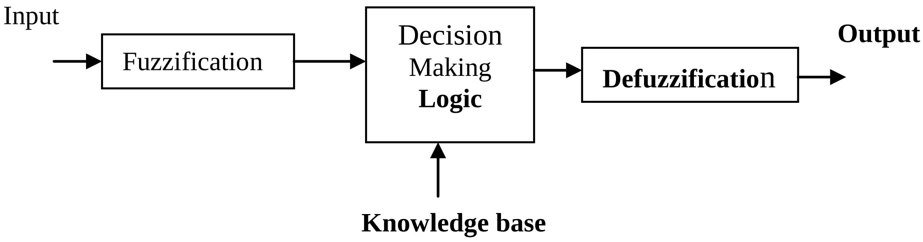

Fig.2: Fuzzy Steps for Generating Torque

Step 1: Calculate X,Y,Z., X, Z and α

$$x = i_{ds},\ y = i_{qs} \quad (1)$$

$$X = R^2_s + \omega^2_e L^2_s \quad (2)$$

$$Y = 2\omega_e \frac{L^2_m}{L_r} R_s \quad (3)$$

$$Z = R^2_s + \omega_e^3 cr^2 L^2_s \quad (4)$$

$$X' = \frac{X+Z+\sqrt{(X-Z)^2 + Y^2}}{2} \quad (5)$$

$$Z' = \frac{X+Z+\sqrt{(X-Z)^2 + Y^2}}{2} \quad (6)$$

$$I^*_{qs} = I^*_{qs} = \frac{1_{max}}{\sqrt{2}} \quad (7)$$

$$\begin{bmatrix} I^*_{ds} \\ I^*_{qs} \end{bmatrix} = \begin{bmatrix} \text{Cos } \alpha - \sin \alpha \\ \sin\alpha \quad \cos \alpha \end{bmatrix} \begin{bmatrix} x' \\ y' \end{bmatrix} \quad (8)$$

Where

$$x' = \left[\frac{V^2_{max} - Z' I^2_{max}}{X' - Z'} \right]^{1/2} \quad (9)$$

Step 2: Calculate the reference current I^*_{ds} and I^*_{qs} in order to generate the maximum torque.

$$I^*_{ds} = \left[\frac{\sqrt{Z}}{\sqrt{X}\,(Y + \sqrt{4XZ})} \right]^{1/2} V_{max} \tag{10}$$

(11)

$$\left| \sqrt{Z}(Y + \sqrt{4XZ}) \right| v_{max}$$

$$T_e = (3/2)(P/2) \frac{L_m^2}{L_r} I^*_{qs} I^*_{ds} \tag{12}$$

Step 3: Calculate the reference torque from and speed relation of an induction motor.

$$T_{ref} = \frac{2J}{P} \frac{\omega_{ref} - \omega_r}{T} + B\omega_r \tag{13}$$

Where
'J' motor
'B' biscous coefficient
'P' pole number
'T' sampling period

Step 4: When $T_{ref} \geq T_{maxs}$ maximum torque operation is required. When $T_{ref} < T_{max}$, maximum torque operation is not required. In order to obtain good dynamic response, I^*_{ds} should be determined according to the operating point and I^*_{qs} is given as follows:

$$I^*_{qs} = \frac{T_{re}}{\frac{3P}{4} \frac{L_m^2}{L_r} I^*_{ds}} \tag{14}$$

Step 5: Then for the final stage, Input voltages V^*_{ds} and V^*_{ds} can be obtained from the motor model.

Control Scheme of Sensor less Field Oriented of Induction Motor
This consists of ;

- Control algorithm block
- 3-Phase inverter and Signal conditioning block

3-phase inverter and signal conditioning block generates 3-phase sinusoidal voltage to the motor for conditioning signals connected to DSC.

- This signal applied to the stator (time varying) generates rotating reference frame (d-q) rotor position is estimated by measuring two phase current (Ia and Ib) and third determined by assuming the sum of the three currents is equal to zero.
- Parks Transform, transforms rotor flux angle from fixed reference frame Iα and Iβ to rotating reference frame (Id and Iq) responsible magnetizing flux generation.

- Iα and Iβ, Vα and Vβ is used to estimate rotor position and motor speed
- Speed error between reference speed and estimated speed is fed to PI controller, the output Iq generates torque
- Vd and Vq are transformed back to fixed frame using Inverse Park transformation block
- Vd and Vq is fed to Space Vector Modulation to trans form the fixed stator reference frame voltage to signals that drive the power inverter

- **Control Algorithm Block**

- Direct Clarke Transform block, transforms 3-phase currents or voltages into orthogonal vectors in fixed reference frame
- Clarke Transform block converts 3-phase currents to fixed stator reference frame
- At the estimator block, the estimator inputs are α and β currents and voltages, and their outputs are the estimated rotor angle and mechanical speed of the motor
- The PI controller is the control loop feedback mechanism that corrects the error between the measured process variable and its reference value.
- The last block SVM generates PWM signals to the 3-phases of the motor .

IV. DATA COLLECTION

Hardware description

The sensor less field oriented vector control for induction machine is designed in steps and each step is simulated. The description of the reference machine parameters used is stated below. The machine chosen for this work is ABB premium efficiency induction motor (M4BP 160 MLB) with its technical data and parameter description given in Table 1 and 2

Table 1: M4BP 160 MLB Technical Data (Test Motor)

Property	Data	Property	Data
Machine type	Induction motor	Nominal Power Factor	0.84
Number of pole pairs	4	Nominal Speed	17848.3 [rpm]
Slip	0.287	Max. Torque Slip	0.178
Nominal Voltage	415 [V]	Nominal Frequency	50 [Hz]
Rated Torque	81.49 [Nm]	Nominal Power	15 [K Watts]
Stator Current	49.08 [A]		

Table 2: M4BP 160 MLB Parameter Descriptions (Test Motor) At Room Temperature

Parameter	Value	Parameter	Value
Stator resistance, r_s	0.106 [Ω]	Rotor resistance, r_r	0.0764 [Ω]
Leakage inductance, l_σ	5.31 [mH]	Magnetizing inductance, l	56.02 [mH]
Stator leakage inductance, x	5,834 Ω	Rotor inertia, j	2.8Kg.m^2

The load machine used is an ABBs induction motor. The speed controller ACSM-1 (Load drive) are, proportional gain kp=10, integration time T_i=0.75 secs.

V. SIMULATION RESULT

The simulation result occurred over 3 seconds. The speed response of the system is the outcome that is utmost significant to us. When an input speed command is fed into the system, we will observe the speed developed by the rotor of the induction motor over time. The three criteria to be fulfilled as far as speed responses are concerned are:

1. That our system develops a speed response that closely resembles the input speed command
2. That our system is stable because stability is the most important design specification for any control system.
3. That we are trying on achieving a quick transient response (i.e. quick acceleration) and a response that is ‘smooth’.

Table 3: Rotor Speed

Time,(sec.)	Speed,(rpm)
0	-100
0.1	0
0.2	100
0.25	200
0.3	300
0.4	400
0.65	500
1.0	500
1.2	400
1.25	300
1.35	200
1.4	100
1.5	0
0	-100

Table 4: Electromagnetic Torque

Time,(sec)	0	0.5	1.0	1.5	2	2.5	3
Speed,(rpm)	500	450	560	-800	-1200	-1200	-1200

Table 5: Bus Voltage

Time,(sec)	0	0.5	1.0	1.5	2.0	2.5	3
Voltage,(volt)	628	632	632	632	632	632	632

VI. DATA ANALYSIS

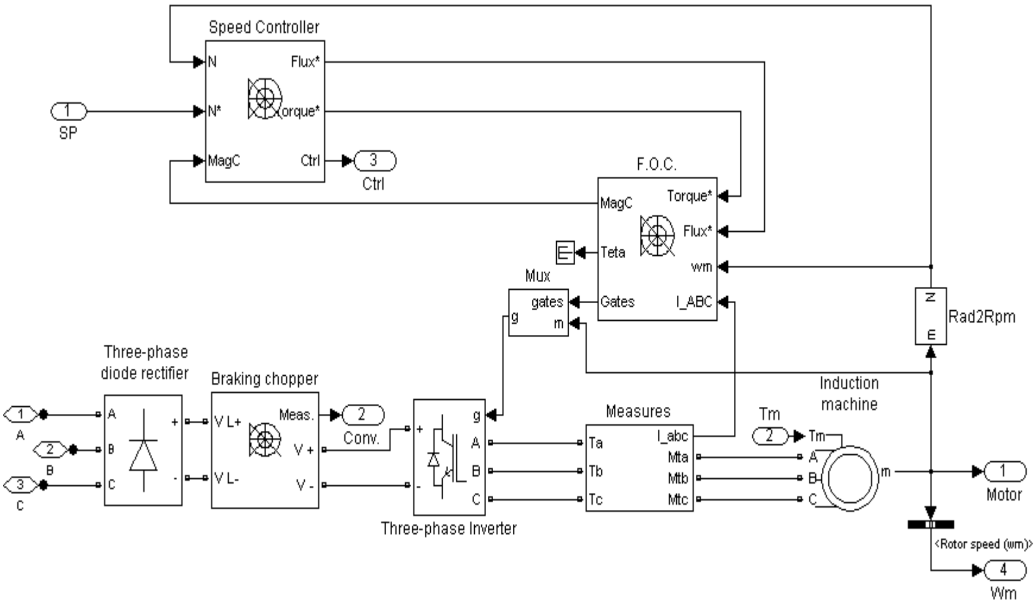

Fig 3:Simulation Block Diagram for Field Oriented Control

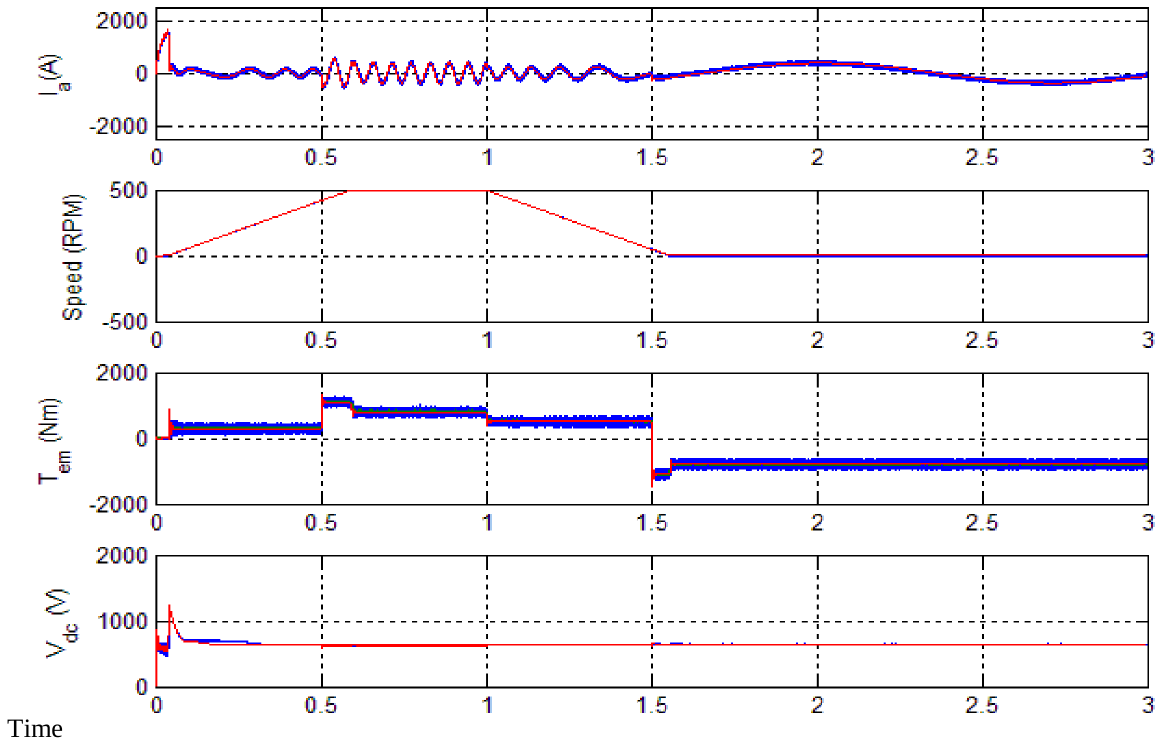

Fig: 4 Full simulation outputs of field oriented fuzzy speed control of induction motor.

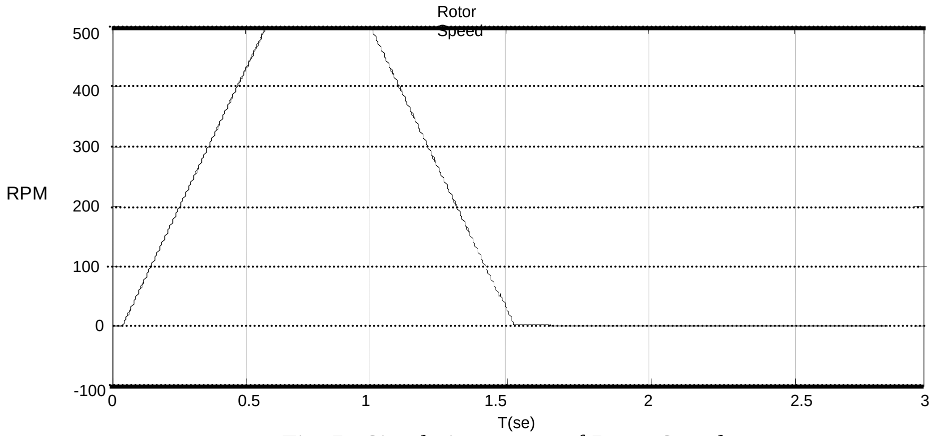

Fig:.5 Simulation output of Rotor Speed

Fig. 5 shows the speed response of sensor less field oriented system of induction motor speed control. At t = 0 sec., with speed set point of 500 rpm. On no-load, the motor speed followed precisely a linear acceleration ramp up to a speed set point of 500 rpm at 0.6 sec. The load torque was applied at 0.5sec while the motor was still ramping, but the motor still maintained constant speed with stability up to a period of 1sec. when it was switched off. The loading of the motor showed no effect on the rotor speed. At t = 1sec when the motor was switched off, the motor coasted down with a linear deceleration to zero speed due to inertia.

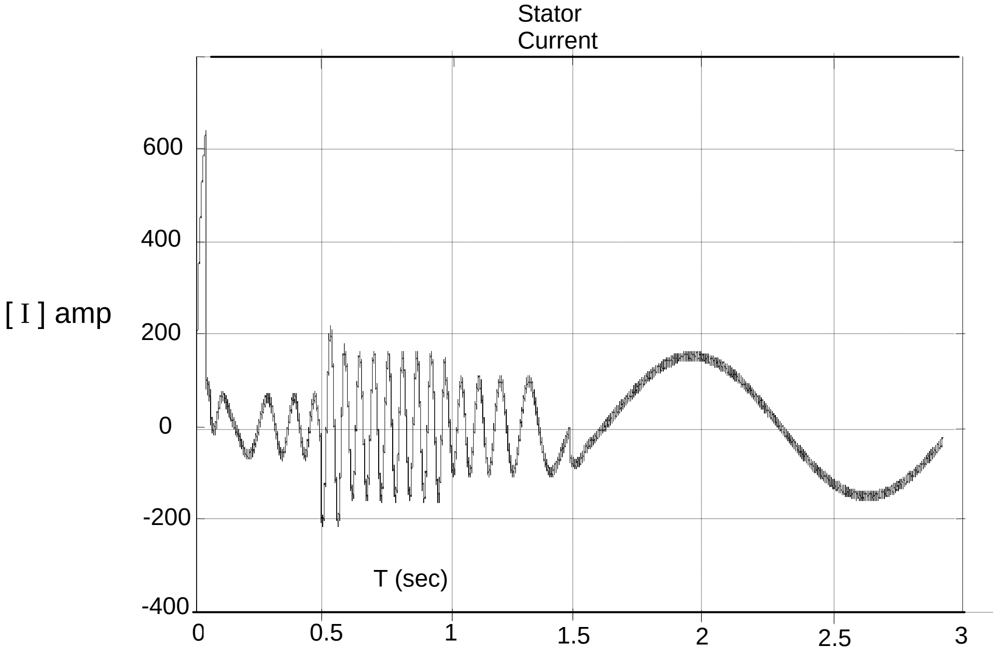

Fig.6 Simulation Output of Stator Current

Fig.6 above shows the simulation result of induction motor load current using fuzzy logic field oriented speed control system. It shows that in the initial state, the current signal presents a high value because it is necessary for a high torque to increment the rotor speed. At t=0, with the speed set point of 500rpm, the graph showed a sharp rise of stator current at start due to high starting torque , which stabilized fast within a short period of about 0.1 sec. When full load torque was applied to the motor shaft 0.5 sec, the variation of stator current was almost constant but still has to compensate for friction up to a period of 1sec when the load was removed. This shows the suitability of the control system for effective regulation of load current.

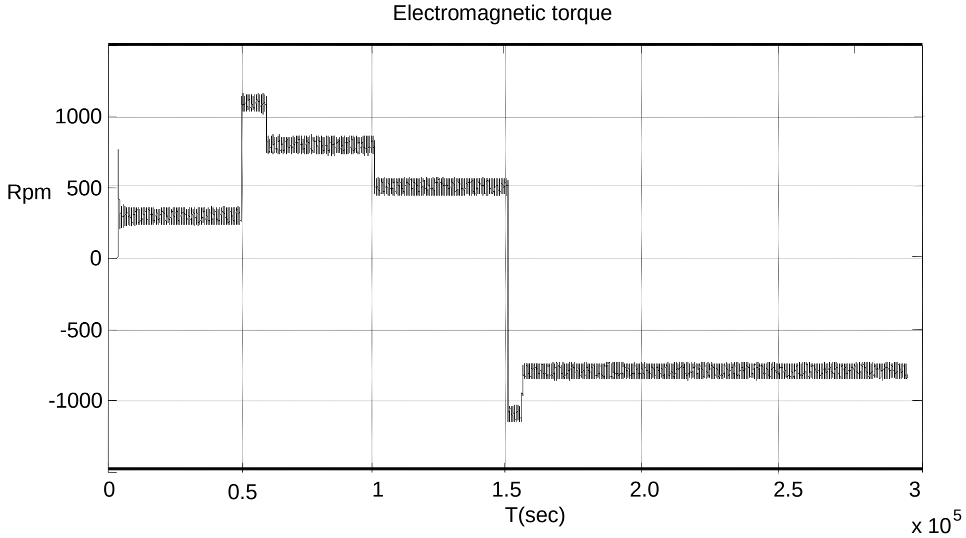

Fig 7: Output Simulation of Electromagnetic Torque

Fig. 7 shows the effect of electromagnetic torque on field oriented method of induction motor speed control. Between the time t = 0 – 0.5 sec., the nominal torque is zero. At t = 0.5 sec. when the load was applied , the motor experienced high torque rise which stabilized fast within 0.1 sec. and remained constant throughout the load period of up till 1.0 sec. when the load was removed. The high frequency changes in the torque will be filtered by the mechanical inertia. This showed that field oriented control of sensor less speed control of induction motor has a good electromagnetic torque response.

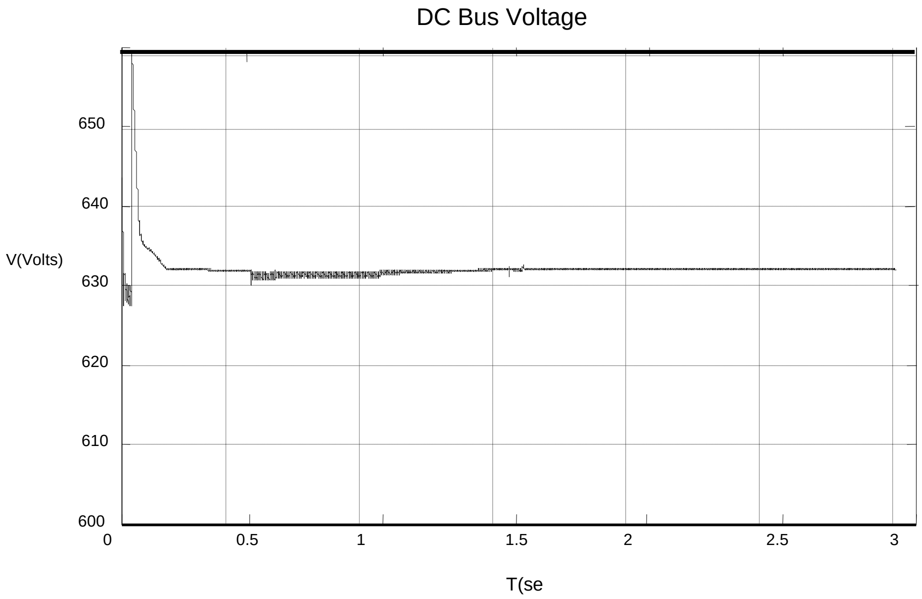

Fig 8: Simulation Output of Direct Current Bus Voltage

Fig 8: shows the voltage of the control unit, which rose sharply at the start of the machine but stabilized and remained constant during the run period irrespective of load applied

VII. CONCLUSION

The major design criteria set out to fulfill are:

i. That the system develops a speed response that closely resembles the input speed command.
ii. That the system is stable.
iii. That the system achieves a quick transient response (i.e. quick acceleration and a response that is ‘smooth’.

Conclusively, the following were resolved and ascertained;

(1) Fuzzy Indirect Field Orientation Control of an induction motor was successfully implemented and tested using MATLAB / SIMULINK.
(2) Field Orientation control is an effective technique for driving an induction motor. A speed profile with a good speed response was generated. Furthermore, the system was stable.
(3) Weakening of the rotor and flux can extend the speed range of operation.
(4) Simulation result of the system without speed feedback made the speed response to become unstable.
(5) Increasing the proportional gain of the torque controller made the system to approach unstable regions of operation which were later resolved.

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