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# Modelling and Simulation of PI Controller Based Induction Motor

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***Abstract: The induction motors are used in wide ranges of industrial applications. In particular many industrial applications or general applications the squirrel cage induction motor is used due to absence of brushes and slip rings. In this paper through MATLAB software the model of three phase induction is designed and tested. In addition to that the proportional integral controller is used to control the speed of the induction motor. The uncomplicated control structure and trouble-free implementation are the two main reasons for using proportional integral controller for the speed control of induction motor. The parameters like d-q axis stator current, d-q axis rotor current, stator current, rotor current, torque and speed are obtained graphically.***
***Keywords: Induction motor, PI controller.***

## I. INTRODUCTION

In many industrial applications the induction motor are used because of the merits like easy maintenance, low cost, robustness and better performance. The induction motor is further classified in to two types on the basics of rotor. They are squirrel cage induction motor and slip ring induction motor. The squirrel cage induction motors are cheaper in cost and also has almost all the merits of AC motor compare to the slip ring induction motor. In addition the squirrel cage induction motor requires less maintenance and rugged in construction. Actually induction motor is also known as asynchronous motors, because the induction motor always runs lower than synchronous speed. The speed of the rotating magnetic field in the stator is called as synchronous speed. In general the induction motors are classified in to two types on the basics of input supply. They are single phase induction motor and three phase induction motor. [1] Has given the detailed information about electrical machinery and drive system.

Merits of three phase induction motor:

- Self starting
- Robust in construction
- Less brush sparking
- Less armature reaction
- Economical and easier to maintain

## II. BLOCKING DIAGRAM OF PROPOSED METHOD

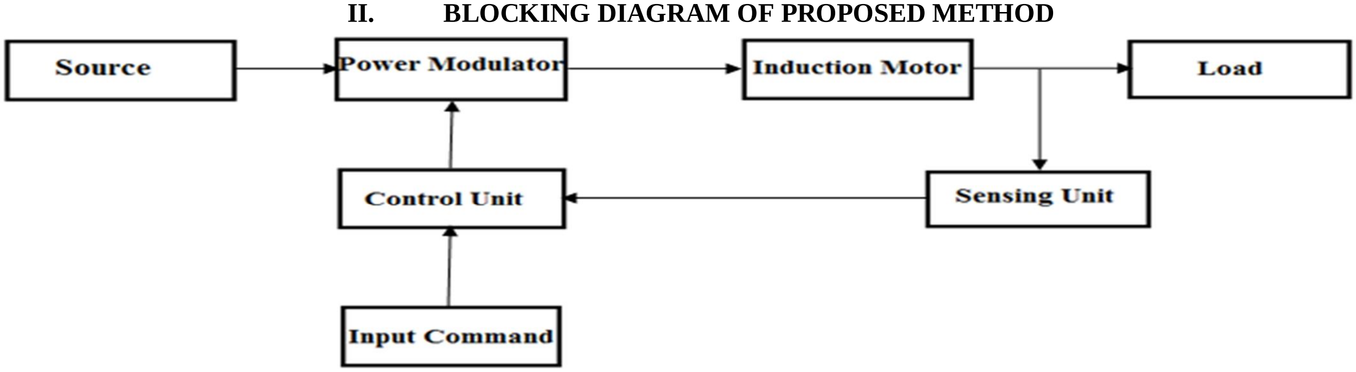


Figure 1: Block diagram of Induction motor's Speed control

The motion control is required mainly in industrial and domestic applications. Therefore the drives are the system employed for this type of purpose. If this is the case then use of induction motors with such system is called induction motor drive. Therefore in induction motor drives by using the sensors and proportional integral control algorithm speed control of induction motor is done. In

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this paper speed control of three phase induction motor with proportional integral control algorithm has been implemented and simulated in matlab simulink software.

## III. CONSTRUCTION AND WORKING PRINCIPLE OF INDUCTION MOTOR

The induction motor consists of two major parts. They are stationary part as a stator and rotating part as a rotor. The stator windings are present in the stator of the induction motor. In addition to that the stator part of induction machine is further consisting of three parts. They are stator frame, stator core and stator wing or field winding. The rotor is connected to mechanical load through shaft. The below figure 1 and figure 2 shows the construction of stator and rotor of the induction machine respectively. [2] Has given the analysis of induction motor.

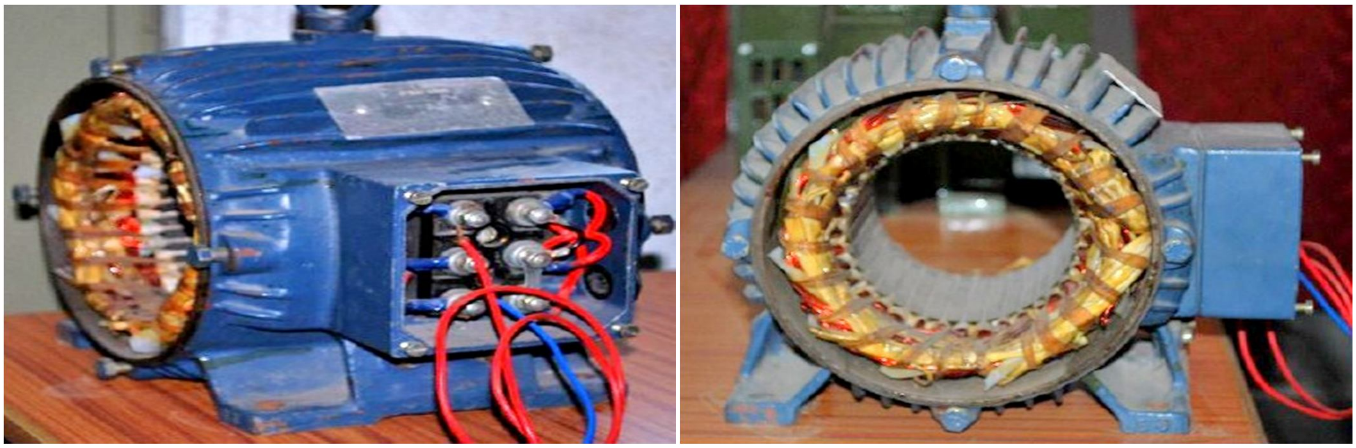

Figure 2: Wound stator of an induction motor

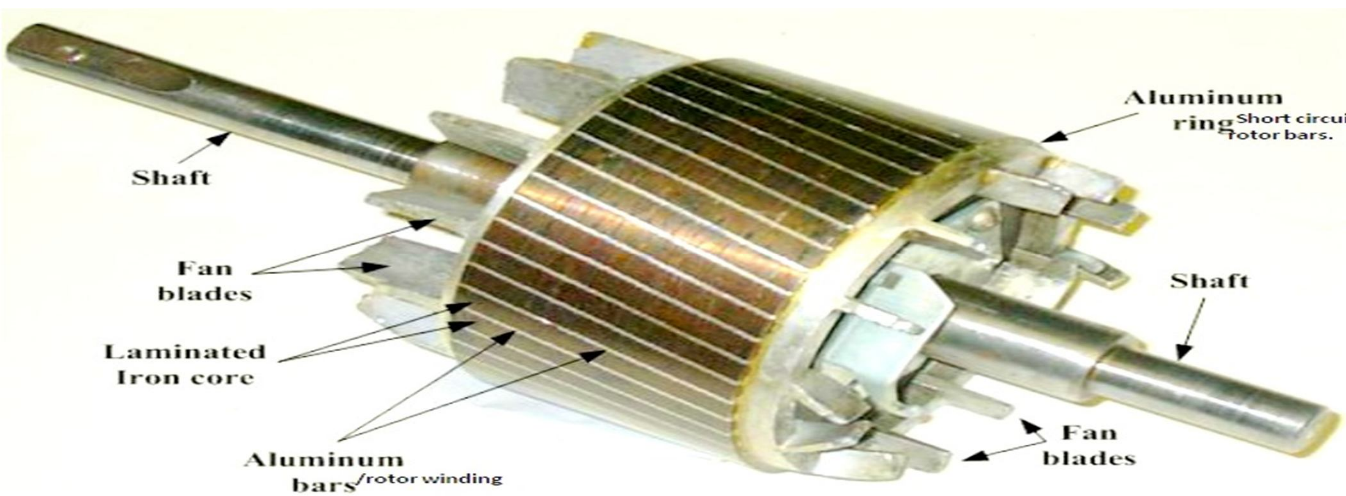


Figure 3: Squirrel cage induction motor

[3] Has implemented the dynamic simulation of cage rotor induction motor. As we all know that to produce torque in any electrical motor it requires two fluxes. Once the two fluxes start linking each other and start producing torque that makes a motor to rotate. The widely used motor in case of AC operation is induction motor. Actually this type of motor doesn't need any starting devices since it is a self starting motor. When the stator winding or primary winding is linked to the three phase supply the rotating magnetic field is produced. Hence the rotating magnetic fields speed will be synchronous speed.

According to faradays law of electromagnetic induction an induced electro motive force in any circuit is due to rate of change of magnetic flux linkage through the circuit. In case of induction motor the rotor winding is either directly shorted by end ring or closed through an external resistance and cut the stator magnetic field an electro motive force is induced in the rotor copper bar and because of this electro motive force a current flows through the rotor conductor. In this case the relative velocity between rotating flux and static rotor conductor is the only reason for the generation of current. So according to Lenz's law the rotor will rotate in the

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same direction to reduce the relative velocity.

## IV. MATHEMATICAL MODELLING OF THE INDUCTION MOTOR

Three phase balanced distributed windings with each phase separated from other two windings by 120 degree in space is present in the stator of induction motor. The three phase rotating magnetic field is produced if current flows through these windings. In an adjustable speed drive system using a power electronics converter the behavior of induction machine is accountable. This induction machine constitutes an element within a feedback loop. The dynamic performance of an induction machine is complex due to three reasons. They are coupling effect of stator and rotor winding in addition to this coupling co-efficient varies with rotor position. Therefore induction machine model is described by a set of differential equations with time varying co-efficient. [4-5] has implemented the induction machine model in simulink.
From the power converter the balanced three phase supply is given to the motor. The two axis theories are used for dynamic modelling of motor. The time varying parameters are expressed in mutually perpendicular d and q axis. By assuming stationary or rotating reference frame theory the d-q dynamic model of the machine is represented.

$d^s$ and $q^s$ axis are fixed on stator for stationary reference frame. And also rotates at an angle with respect to rotor in rotating reference frame. The machine variables appear as dc quantities in steady state condition at synchronously rotating reference frame with sinusoidal supply. [6-7] has designed the d-q model of induction machine.

### *A. Three phase to two phase transformation*

Stationary axis [$a_s$, $b_s$, $c_s$] each 120 degree apart.
Stationary two phase voltage is transformed to three phase voltages.

$$V_{as} = V_{qs}{}^{s}\cos\theta + V_{ds}{}^{s}\sin\theta \rightarrow Equation.1$$

$$V_{bs} = V_{qs}{}^{s}\cos(\theta - 120^{\circ}) + V_{ds}{}^{s}\sin(\theta - 120^{\circ}) \rightarrow Equation.2$$

$$V_{cs} = V_{qs}{}^{s}\cos(\theta + 120^{\circ}) + V_{ds}{}^{s}\sin(\theta + 120^{\circ}) \rightarrow Equation.3$$

The above three Phase voltage are represented in matrix form.

$$\begin{Bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{Bmatrix} = \begin{Bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - 120^{\circ}) & \sin(\theta - 120^{\circ}) & 1 \\ \cos(\theta + 120^{\circ}) & \sin(\theta + 120^{\circ}) & 1 \end{Bmatrix} \begin{Bmatrix} V_{qs}{}^{s} \\ V_{ds}{}^{s} \\ V_{os}{}^{s} \end{Bmatrix} \rightarrow Equation.4$$

Take inverse transformation. The voltages $V_{ds}{}^{S}$ and $V_{qs}{}^{S}$ are converted in to three phase voltages. Now phase voltages are represented in matrix form.

$$\begin{Bmatrix} V_{qs}{}^{s} \\ V_{ds}{}^{s} \\ V_{os}{}^{s} \end{Bmatrix} = \begin{Bmatrix} \cos\theta & \cos(\theta - 120^{\circ}) & \cos(\theta + 120^{\circ}) \\ \sin\theta & \sin(\theta - 120^{\circ}) & \sin(\theta + 120^{\circ}) \\ 1 & 1 & 1 \end{Bmatrix} \begin{Bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{Bmatrix} \rightarrow Equation.5$$

$V_{os}$ = zero sequence [may or may not present]

$\theta = 0$ And $V_{os}$ is neglected

$$V_{as} = V_{qs}{}^{s} \rightarrow Equation.6$$

$$V_{bs} = \frac{1}{2}V_{qs}{}^{s} - \frac{\sqrt{3}}{2}V_{ds}{}^{s} \rightarrow Equation.7$$

$$V_{cs} = -\frac{1}{2}V_{qs}{}^{s} + \frac{\sqrt{3}}{2}V_{ds}{}^{s} \rightarrow Equation.8$$

$$V_{qs}{}^{s} = V_{as} \rightarrow Equation.9$$

$$V_{ds}{}^{s} = -\frac{1}{\sqrt{3}}(V_{bs} - V_{cs}) \rightarrow Equation.10$$

*B. Two phase stationary [$d^s$-$q^s$] to two phase synchronous rotating frame [$d^e$-$q^e$] transformation.*

Stationary frame axis [$d^s$, $q^s$]

Synchronous rotating frame axis [$d^e$, $q^e$]

Rotating speed $[\omega_e]$ with respect to axis [$d^s$, $q^s$]

Angle between axis [$d^s$, $q^s$] $\theta_e = \omega_e t$

$$V_{ds} = V_{qs}{}^{s}\cos\theta_e - V_{ds}{}^{s}\sin\theta_e \rightarrow Equation.11$$

$$V_{qs} = V_{qs}{}^{s}\sin\theta_e + V_{ds}{}^{s}\cos\theta_e \rightarrow Equation.12$$

Rotating frame parameters to stationary frame parameters transformation.

$$V_{qs}{}^{s} = V_{qs}\cos\theta_e + V_{ds}\sin\theta_e \rightarrow Equation.13$$

$$V_{ds}{}^{s} = -V_{qs}\sin\theta_e + V_{ds}\cos\theta_e \rightarrow Equation.14$$

Three phase voltages are balanced [Assumed]

$$V_{as} = V_m\cos(\omega_e t + \varphi) \rightarrow Equation.15$$

$$V_{bs} = V_m\cos(\omega_e t + \varphi - \frac{2\pi}{3}) \rightarrow Equation.16$$

$$V_{cs} = V_m\cos(\omega_e t + \varphi + \frac{2\pi}{3}) \rightarrow Equation.17$$

Substitute equation 15, 16, 17 in equation 9 and 10 we get,

$$V_{qs}{}^{s} = V_m\cos(\omega_e t + \varphi) \rightarrow Equation.18$$

$$V_{ds}{}^{s} = -V_m\sin(\omega_e t + \varphi) \rightarrow Equation.19$$

$$V_{qs} = V_m\cos\varphi \rightarrow Equation.20$$

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$$V_{ds} = -V_m \sin\varphi \rightarrow Equation.21$$

### C. Motor dynamic model in stationary frame

By substitute $\omega_e = 0$ in Stanley equation the stator equation are as follows;

$$V_{qs}{}^s = R_s i_{qs}{}^s + \frac{d}{dt}\psi_{qs}{}^s \rightarrow Equation.22$$

$$V_{ds}{}^s = R_s i_{ds}{}^s + \frac{d}{dt}\psi_{ds}{}^s \rightarrow Equation.23$$

$$0 = R_r i_{qr}{}^s + \frac{d}{dt}\psi_{qr}{}^s - \omega_r \psi_{dr}{}^s \rightarrow Equation.24$$

$$0 = R_r i_{dr}{}^s + \frac{d}{dt}\psi_{dr}{}^s + \omega_r \psi_{qr}{}^s \rightarrow Equation.25$$

$\psi_{qs}{}^s, \psi_{ds}{}^s$ - Stator flux linkages of the q axis and d axis

$\psi_{qr}{}^s, \psi_{dr}{}^s$ - Rotor flux linkages of the q axis and d axis

$R_s, R_r$ -Resistance of the stator and rotor

$\omega_r$ -Speed of the rotor

$$V_{dr} = V_{qr} = 0$$

Whenever air gap flux and rotor mmf interacts the electromagnetic torque will be produced by the induction machine. The general vector form expression of electromagnetic torque equation is,

$$T_e = \frac{3}{2}\frac{P}{2}(\overline{\psi_m}) * (\overline{I_r}) \rightarrow Equation.26$$

Stationary frame torque equations for the corresponding values can be written as follows,

$$T_e = \frac{3}{2}\frac{P}{2}(\psi_{dm}{}^s i_{qr}{}^s - \psi_{dm}{}^s i_{dr}{}^s) \rightarrow Equation.27$$

$$T_e = \frac{3}{2}\frac{P}{2}(\psi_{dm}{}^s i_{qr}{}^s - \psi_{qm}{}^s i_{ds}{}^s) \rightarrow Equation.28$$

$$T_e = \frac{3}{2}\frac{P}{2}(\psi_{ds}{}^s i_{qs}{}^s - \psi_{qs}{}^s i_{ds}{}^s) \rightarrow Equation.29$$

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$$T_e = \frac{3}{2}\frac{P}{2}(\psi_{dr}{}^{s} i_{qs}{}^{s} - \psi_{qr}{}^{s} i_{ds}{}^{s}) \rightarrow Equation.30$$

$$T_e = \frac{3}{2}\frac{P}{2}(\psi_{dr}{}^{s} i_{qr}{}^{s} - \psi_{qr}{}^{s} i_{dr}{}^{s}) \rightarrow Equation.31$$

## V. PROPORTIONAL INTEGRAL CONTROLLER

Because of easy design, low cost and simple structure the proportional integral controllers are most widely used in industries. As an on-off controller the proportional integral controller eliminates forced oscillation and steady state error. The overall stability and response of the speed will have negative impact due to integral mode. Therefore the proportional integral controller will not increase the speed of the response. Because proportional controller does not have means to predict what will happen with the error in near future. So by introducing derivative mode this problem will be solved. So now the proportional controller now gets the ability to predict error in future and then decreases reaction time. In industries speed of the response is not an issue then proportional integral controller is most widely used. Actually proportional integral controller is an integral error compensation scheme.

The integral of the actuating signal is the reason for the response of the output. The output produced by this type of controller consists of two terms. In those two terms one is the proportional to the actuating signal and other is proportional to its integral. Therefore in general this type of controller is known as PI controller or proportional plus controller.

$$output(t) = K_p e(t) + K_I \int_0^t e(\tau)d\tau \rightarrow Equation.32$$

$e(t)$ =Set Reference Value – Actual Calculated Value

$$e(t) = \omega_{ref} - \omega_m(t) \rightarrow Equation.33$$

$$T_{ref}(t) = T_{ref}(t-1) + K_p[e(t) - e(t-1)] + K_1 e(t) \rightarrow Equation.34$$

$K_p$ & $K_I$ -Speed controller's gain

## VI. SIMULATION MODEL OF THE INDUCTION MOTOR

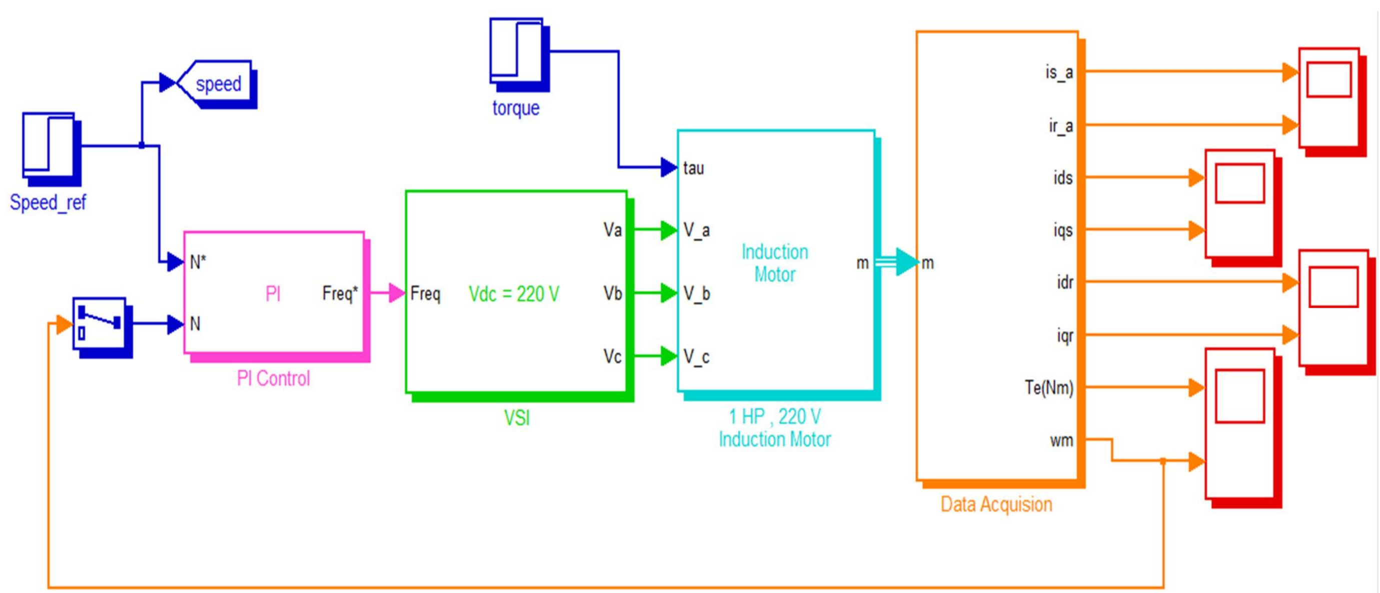


Figure 4: MATLAB Simulink model of Induction motor

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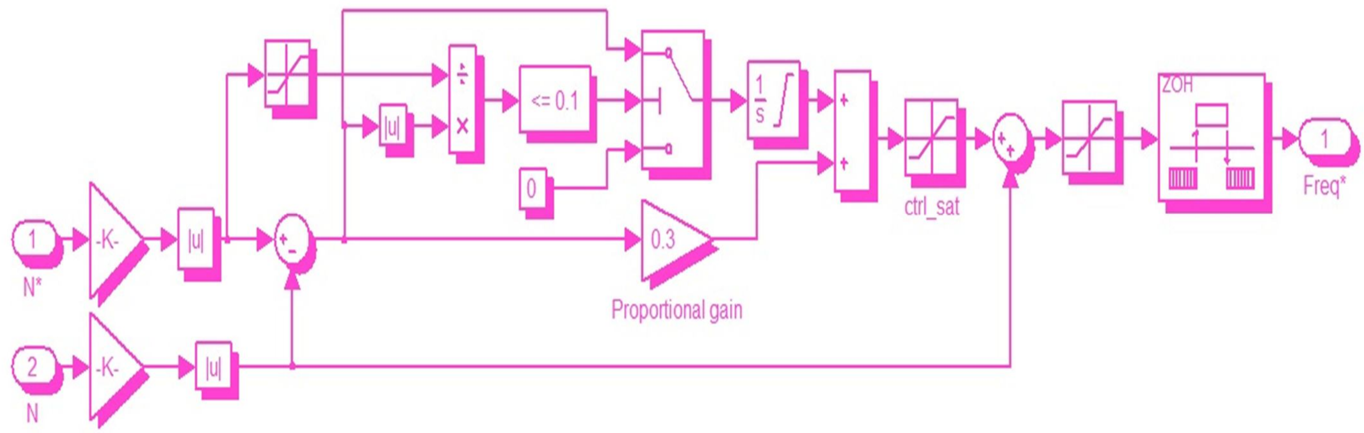


Figure 5: MATLAB Simulink Sub system model of PI controller

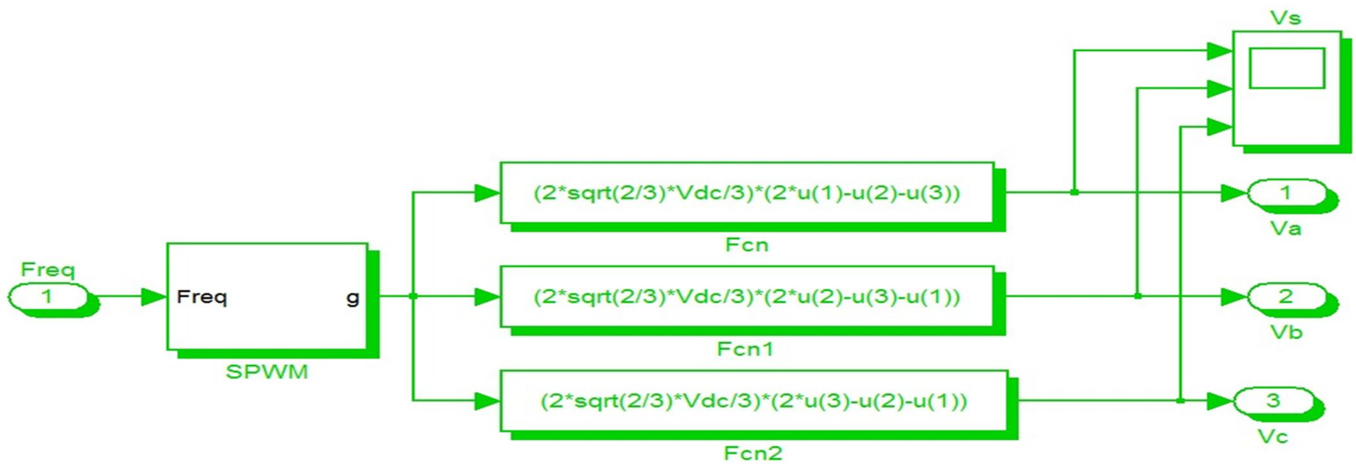


Figure 6: MATLAB Simulink Sub system model of VSI

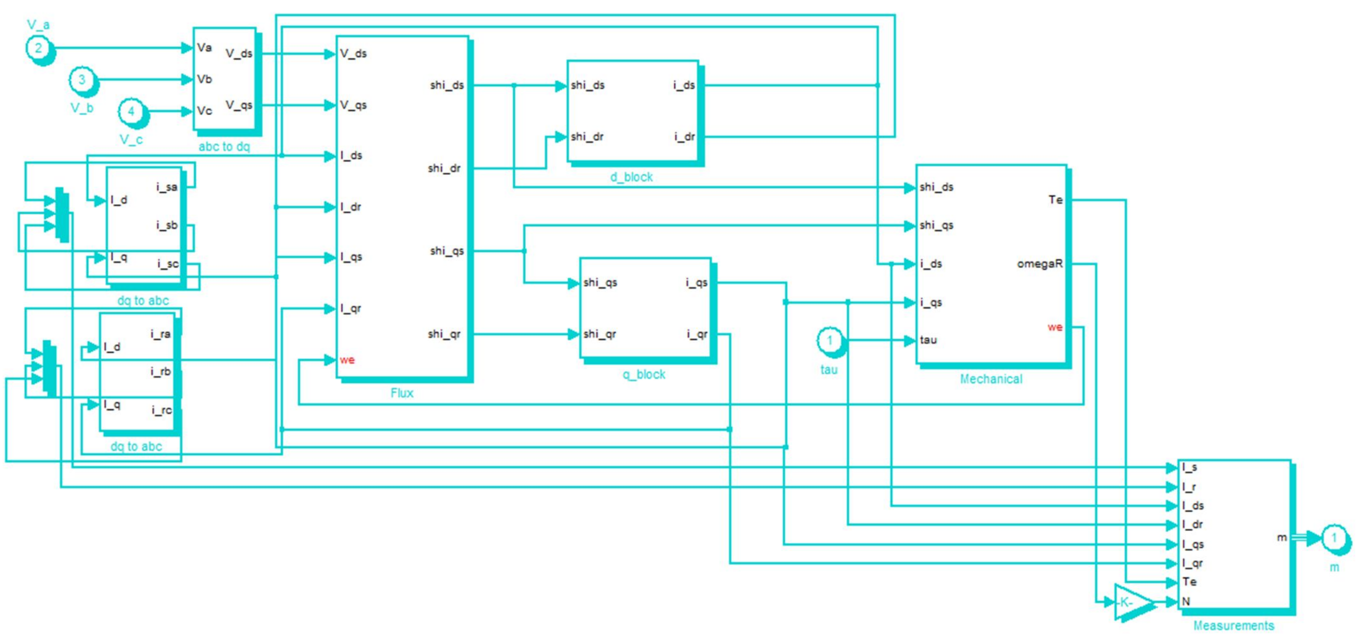


Figure 7: MATLAB Simulink Sub system model of Induction motor

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## VII. SIMULATION RESULTS

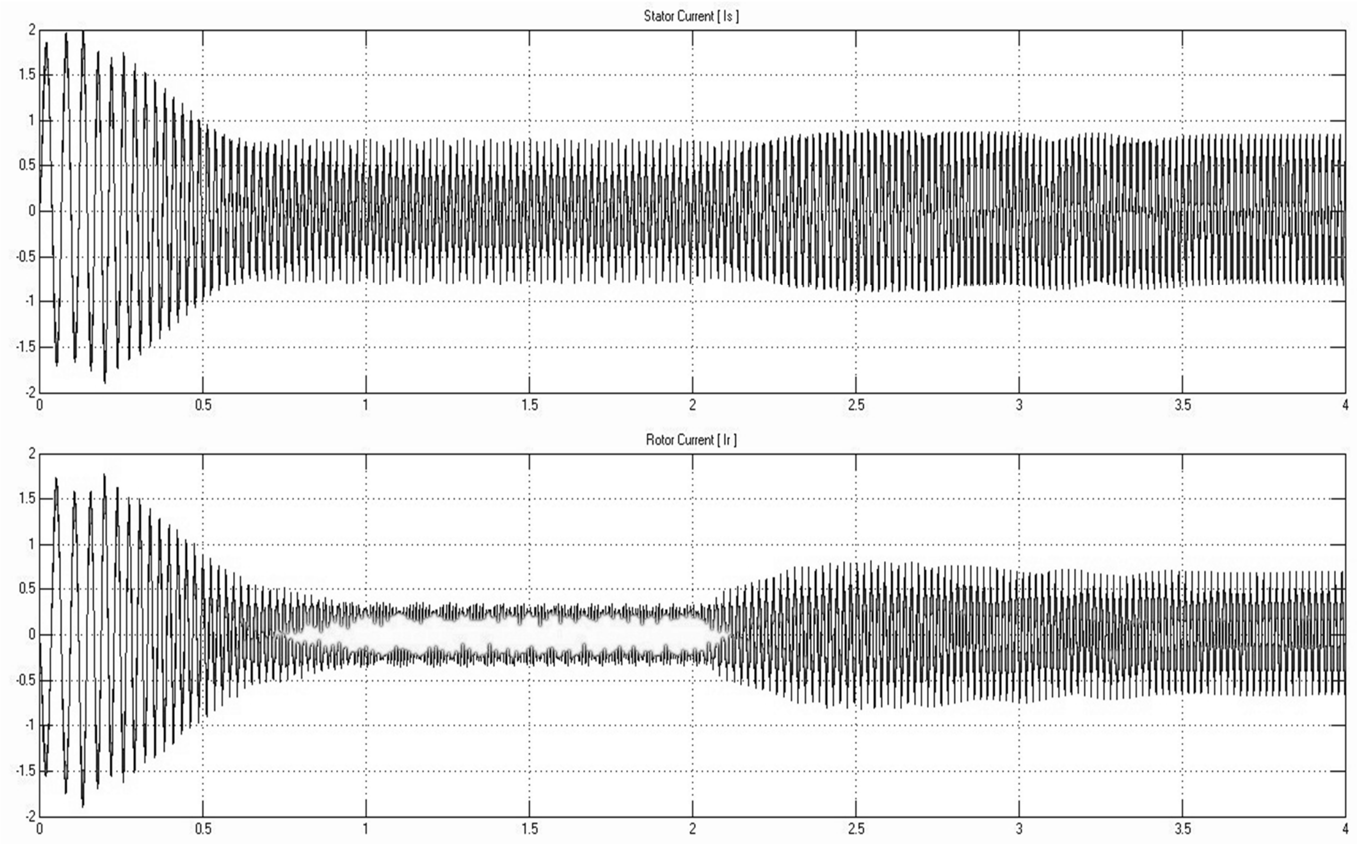


Figure 8: Stator and rotor current

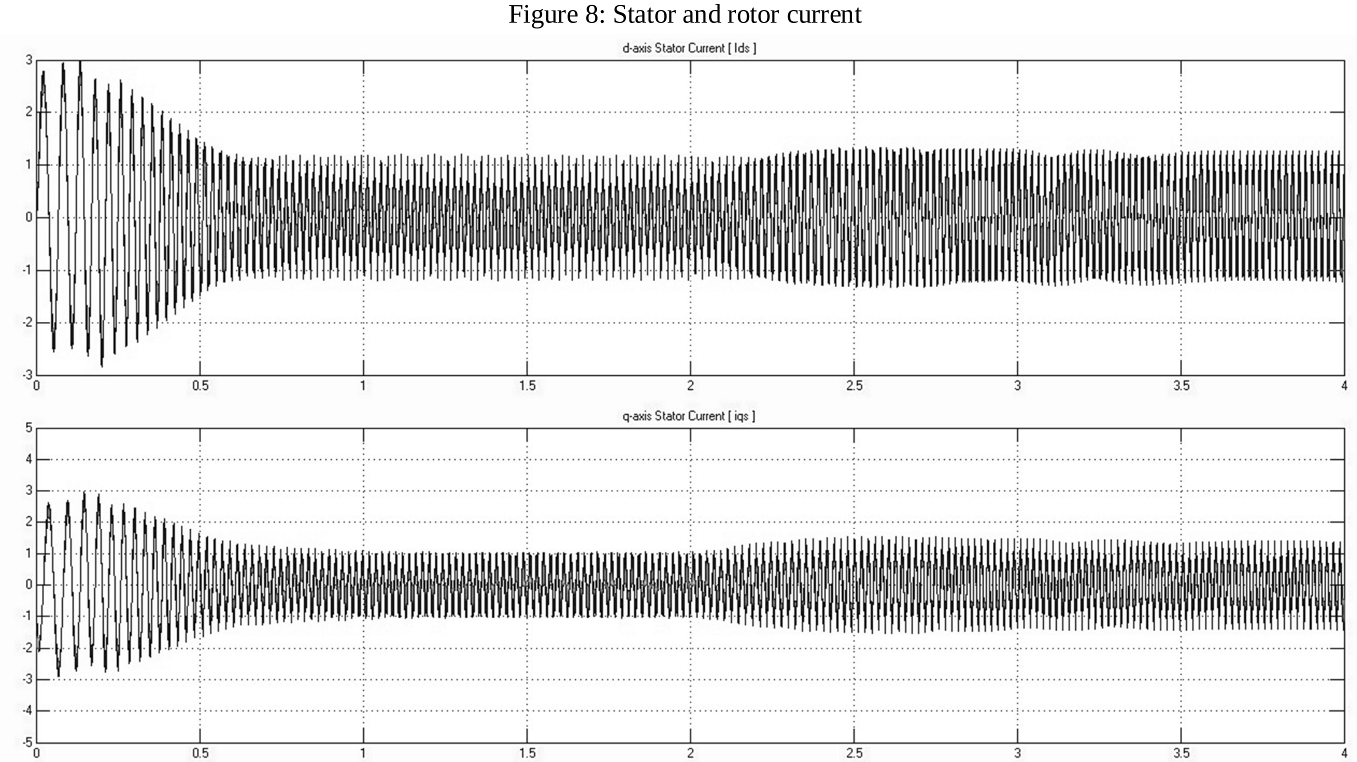


Figure 9: d and q axis stator current

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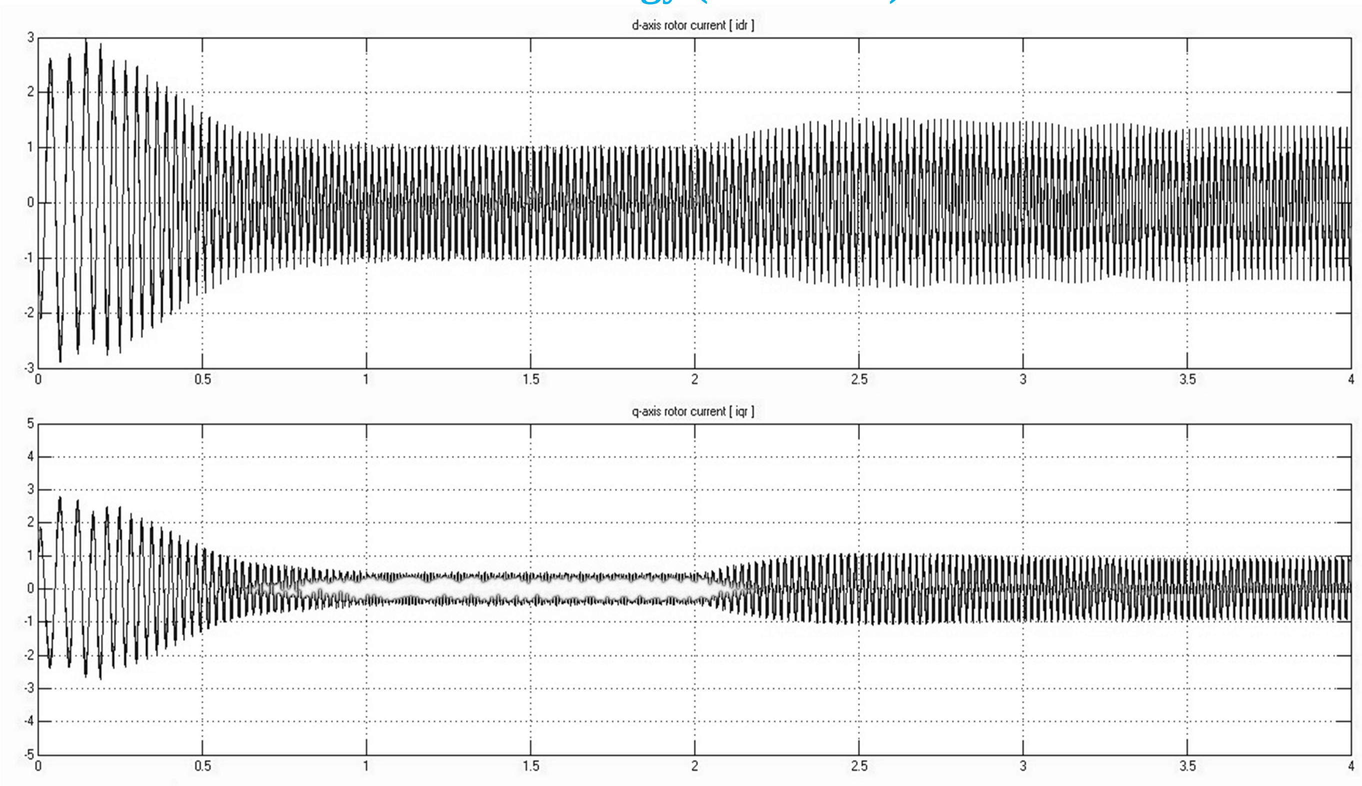


Figure 10: d and q axis stator current

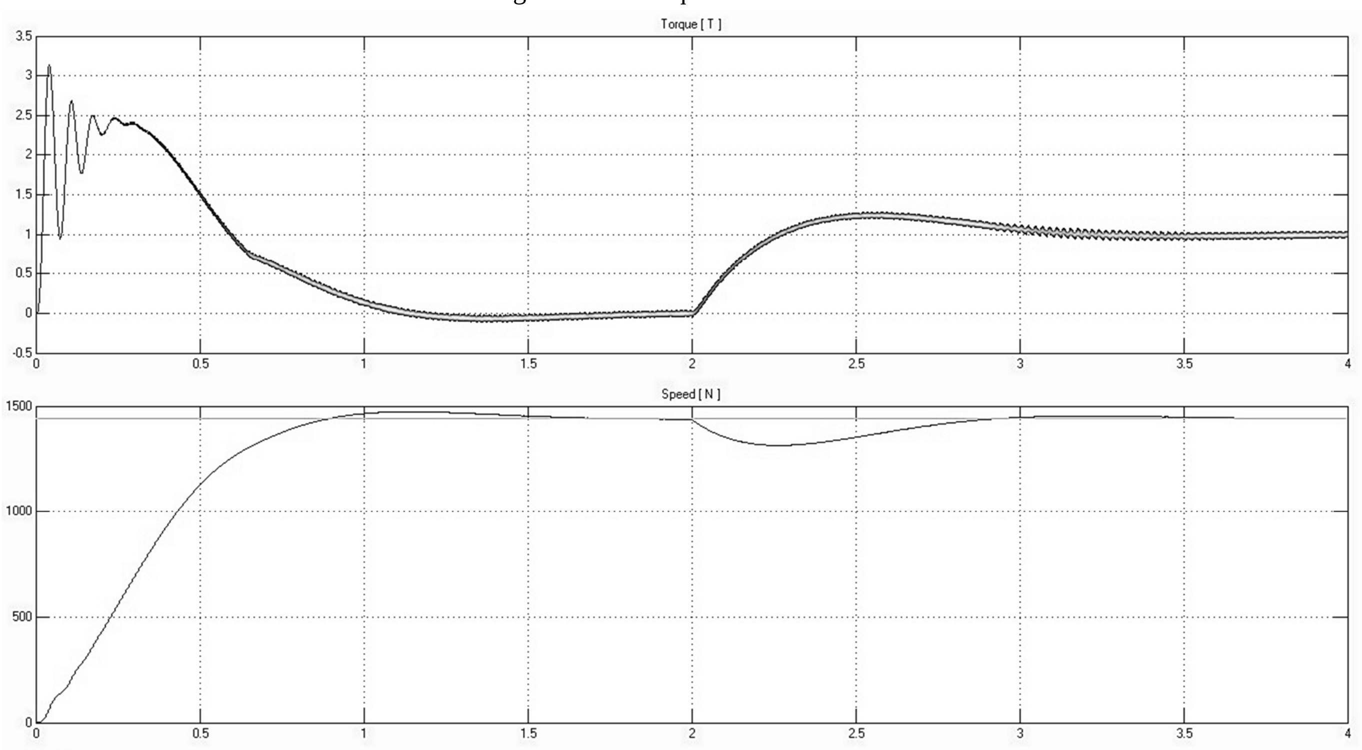


Figure 11: Torque and speed

## VIII. CONCLUSION

In this research paper the speed control of induction motor is achieved using Proportional integral controller in MATLAB software and also tested successfully by evaluating the parameters like d-q axis stator current, d-q axis rotor current, stator current, rotor current, torque and speed. In addition to that the design and implementation of a proportional integrated control structure is uncomplicated and trouble free.

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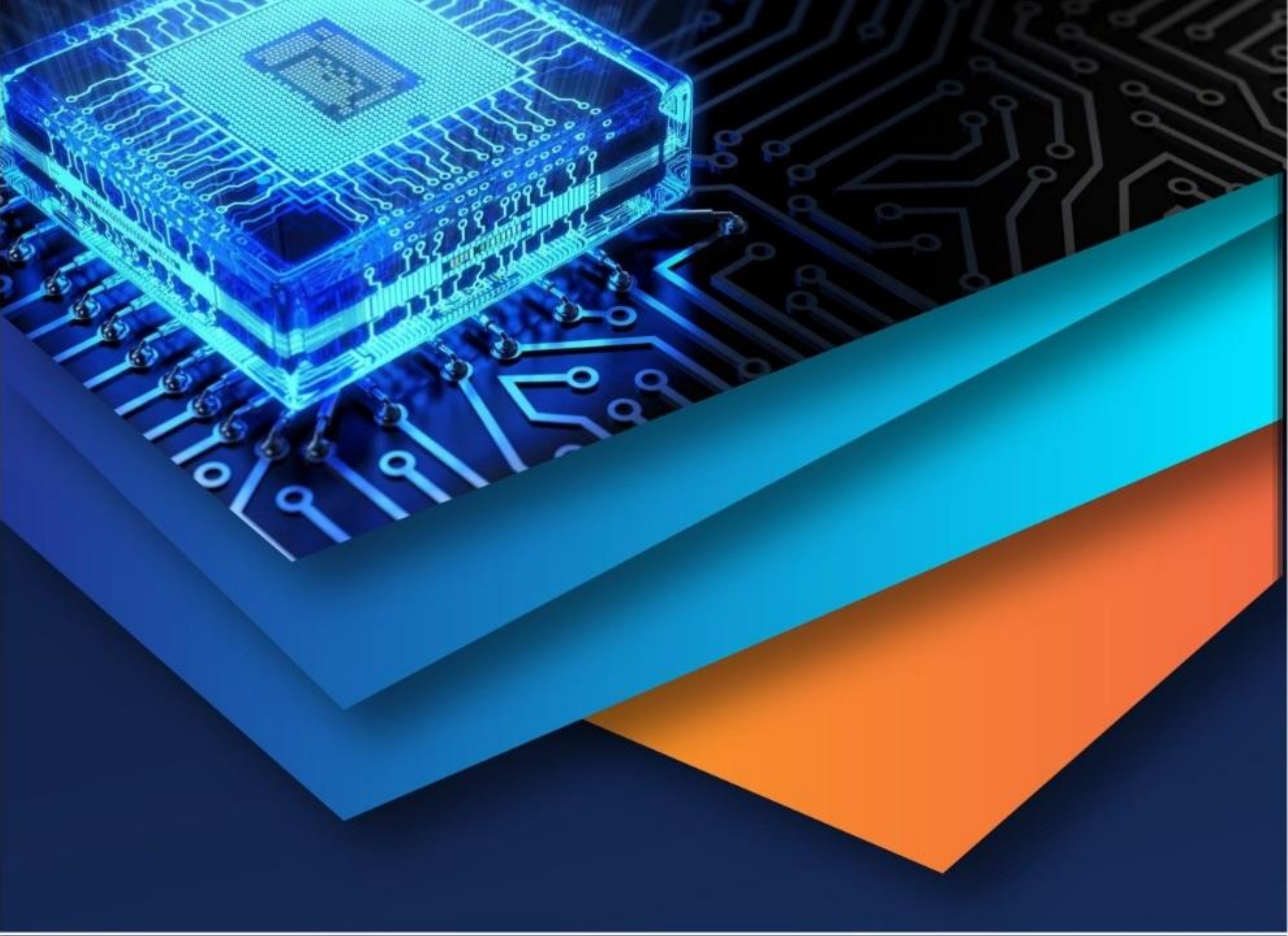
## BIOGRAPHY

Mr.J.Vikramarajan received his Master degree in Power Electronics and Drives and Bachelor degree in Electrical and Electronics Engineering from VIT University, India. He has published several international research books and journals. His research interests are electrical machines, power electronic applications, power quality, power electronic converters and power electronic controllers for renewable energy systems.

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