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THE EFFECT OF LOAD VARIATION ON THE PERFORMANCE AND STABILITY OF DUAL STATOR INDUCTION MACHINE USING PID CONTROLLER

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Abstract- *Induction machine is reliable, thus very usable in the industry especially its usability in the electric vehicle. A major limitation is the speed variation with load variation. The main objective of this work is to show the effect of load variation on the performance and stability of Dual Stator Induction Machine (DSIM) using PID controller. The analysis involved varying the load using 5N, 10N and 15N with performance metrics like step response analysis (overshoot, rise time and settling time) and Bode plot analysis. To analyse the complex vector model of the Dual Stator Induction Machine, a complete set of simulations were implemented using MATLAB/Simulink software. From the analysis, it was found out that the PID controlled DSIM: under 5N shows moderate torque stability, medium torque overshoot and high current ripple; under 10N shows poor torque stability, high torque overshoot and very high current ripple; under 15N shows unstable/oscillatory torque stability, very high torque overshoot and very high current ripple. The time domain metrics under different loads shows that the PID controlled DSIM: under 5N has an overshoot, rise time and settling time of 4.6%, 0.213s and 0.598s respectively; under 10N has an overshoot, rise time and settling time of 9.4%, 0.186s and 0.594s respectively; under 15N has an overshoot, rise time and settling time of 16-3%, 0.164s and 0.808s respectively. The frequency response shows that for 5N, 10N and 15N, the PID controlled DSIM peak gain is -6.02(at 2.83e $-^{08}$ rad/s), -9.04dB (at 0,927 rad/s) and -10dB (at 1.17 rad/s) respectively. The implications of the findings are: PID controller has a reactive and limited ability to handle sudden disturbances in the form of load variations. The step response analysis shows that increase in load leads to increased overshoot and relative increase in settling time. The frequency response from Bode plot reveals that with the PID controller (for the DSIM), an increase in load leads to more instability in the system.*

Keywords: Load Variation, Performance, Stability, Dual Stator, Induction Machine.

I. INTRODUCTION

A Dual Stator Induction Motor or Machine (DSIM) is an induction machine which has two separate three-phase stator windings, sharing the same machine core and the common squirrel cage rotor winding [1][2]. In the machine, alternating current is applied to the stator and alternating currents are induced in the rotor by transformer action [3]. The asynchronous machine also known as a three phase induction machine is an Alternating Current (AC) machine which converts mechanical energy into electrical energy in the case of generator or converts electrical energy into mechanical energy in the case of a motor. Induction machines are referred to as asynchronous machines because an induction machine always runs at a speed lower than the synchronous speed in its mechanism. Synchronous speed means the speed of the rotating magnetic field in the stator of the machine [4]. *Dual stator* Induction machine consists of a standard squirrel-cage rotor and stator with separate windings wound on dissimilar number of poles. Each stator is fed from an independent variable-frequency variable-voltage inverter [5][6].

The DSIM is a rotating machine and as such produces torque unlike the linear induction motor which is basically a rotating squirrel-cage induction motor opened and spread-out flat and produces linear force along its flat axis [7]. An induction motor has more loss and less efficiency when it works at variable speed necessitated by load variation. The rotor and stator are separated by air gap which allows free rotation of the rotor and the magnetic field generated in the stator induces an emf in the rotor bars [8].

This research seeks to address the effect of load variation on the performance and stability of DSIM using PID controller. The PID controller is a development upon the PI controller which is a type of feedback control system that adjusts the output signal to reduce the difference the process variable and the set point.

A PID (Proportional-Integral-Derivative) controller is a widely used control loop feedback mechanism in industrial control systems. It combines three control actions; proportional, integral, and derivatives to provide a robust and effective means of controlling dynamic systems. The PID controller is particularly valued for its simplicity, effectiveness, and ease of implementation.

The proportional term produces an output that is proportional to the current error value, which is the difference between the desired set point and the actual process variable. The proportional gain kp determines the reaction to the current error. A higher k_p results in a larger output for a given error, leading to a faster response. However, using only proportional control can lead to a steady-state error, as it does not account for past errors.

The integral term accumulates the past errors over time, providing a corrective action based on the history of the error. The integral ki determines how much influence the accumulated error has on the output. This term helps eliminate steady-state error by adjusting the control output based on the total accumulated error.

The derivative term predicts future error based on its rate of change, providing a damping effect that helps reduce overshoot and improve system stability. The derivative gain kd determines the influence of the rate of change of the error on the output. This term helps to react to changes in the error quickly.

The PID controller is a fundamental tool in control engineering, providing a simple yet effective means of managing dynamic systems. Its ability to combine proportional, integral, and derivative actions allows for improved stability.

As in other analysis of same form, the simulation results are been demonstrated on the platform of MATLAB/Simulink according to [9]

II. METHODOLOGY

A, Dual Stator Induction Machine Model (DSIM)

The DSIM is made up of a stator that contains two identical three phases windings displaced by an electric angle γ (γ = 30°) and a squirrel cage rotor. It is a very complex system when it comes to machine analysis taking into account its exact configuration with the distribution of its windings and its own geometry. Thus, it is necessary to adopt certain simplification hypotheses such that the machine is supposed to be "linear". This means that the saturation and the hysteresis effects of the magnetic circuits of the machine are neglected. Similarly, the phenomenon causing variations of resistances and inductance are also neglected. The magneto-motive air gap force produced by each winding is assumed to have a sinusoidal spatial distribution, which amounts to neglecting space harmonics. The machine air gap is of constant width, and it is assumed that the two three-phase stator windings are balanced and identical [10] [11] *(Holakooie et al, 2019; Levi, 2008).* The model of the dual stator induction machine is expressed by state space representation as follow [12] [13] [14] *(Meroufel et al, 2017; Moati et al, 2018; Yahia et al, 2018):*

Representing the DSIM model in state space model, the state equation of the form expressed in equation was used as follows [15] *(Moati and Kouzi, 2019):*

$$\dot{X} = AX + BU \quad (1)$$

$$X = \left[\lambda_{ds1}\ \lambda_{qs1}\ \lambda_{ds2}\ \lambda_{qs2}\ \lambda_{dr}\ \lambda_{qr}\right]^T \text{ is the state vector} \quad (2)$$

$$U = \left[V_{ds1}\ V_{qs1}\ V_{ds2}\ V_{qs2}\ 0\ 0\right]^T \text{ is the control input vector} \quad (3)$$

Then, the matrices A and B are determined by obtaining the following equations:

$$A = \begin{bmatrix} -a11 & a12 & \omega_s & 0 & a15 & 0 \\ a21 & -a22 & 0 & \omega_s & a25 & 0 \\ -\omega_s & 0 & -a33 & a34 & 0 & a36 \\ 0 & -\omega_s & a43 & -a44 & 0 & a46 \\ a51 & a52 & 0 & 0 & -a55 & -a56 \\ 0 & 0 & a63 & a64 & -a65 & -a66 \end{bmatrix} \quad (4)$$

$$B = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (5)$$

B. **Controller Design**

The PID control law is expressed as:

$$u(t) = k_p e(t) + k_d + k_i \int e(t)dt + k_d \frac{de(t)}{dt} \quad (6)$$

where $e(t) = \omega_{ref} - \omega_r$

The classical numerical PI regulator is well suited to regulating the motor torque to the desired values as it is able to reach constant reference. The transfer function takes the form [16]*(Benyoussef, 2022):*

$$G(s) = \frac{k_p(s)+k_i}{js^2+(f+k_p)s+k_i} \quad (7)$$

Where $p(s) = s^2 + \left(\frac{f+k_p}{j}\right)s + \frac{k_i}{j} = 0$

C. **System Implementation**

The implementation of the DSIM control strategy involves several steps. The goal is to investigate its performance and stability using conventional PID control method. The evaluation considers varying load conditions (5N, 10N,15N) with comprehensive performance metrics such as step response analysis (overshoot, rise time, settling time, steady state error) and bode plot analysis. To validate the complex space-vector model of the DSIM, a complete set of simulations was carried out. MATLAB® /Simulink 2021b modeling software was used for the simulation of the proposed DSIM due to its extensive libraries and tools for control, optimization and system identification. A conceptualized block diagram for the modeling and simulation setup is shown in Figure 1.

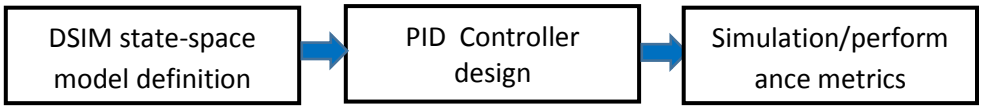

Fig.1: Block diagram of the DSIM system architecture

C. Setting Up the MATLAB Environment

The simulation was conducted by replacing the derived state-space model (A, B, C, D) with the actual DSIM and controller parameters to simulate responses for PID..The MATLAB script simulates a unit step input, which represents a disturbance load change. Finally running the simulation to generate all comparative plots for each condition and controller.

A new MATLAB script (DSIM _Control _Comparison) was created using the control system toolbox to generate PID functions. System parameters (Rs, Ld, Lq, km, J, B, P) were defined at the beginning. The state-space matrices (A, B, C, D) were constructed based on DSIM dynamics and stored as an ss (state-space) object. After constructing the state-space, the controllers were manually selected (kp, ki, kd) for each loop and then combined into a diagonal matrix for feedback looping.

The code was structured into clear sections (modeling, controllers, simulation, and plotting). The simulation was finally executed with a time vector t=0:0.01:1, speed of 1500 RPM, and step inputs depending on load conditions. System parameters are specified in Table 1. The MATLAB codes are shown in appendix A, B, C, and D.

Table 1: Dual Stator Induction Machine (DSIM) Parameters.

Parameter	Value
R_{s1}	0.435Ω
R_{s2}	0.435Ω
L_{s1}	$0.002H$
L_{s2}	$0.002H$
R_r	0.816Ω
L_m	$0.0693H$
L_r	$0.002H$
K_f	$0.001Nm.s/rad$
J	$0.089Kg.m^2$
P	4
F	50Hz

Implementation of the proposed PID based DSIM was done using MATLAB scripts and subsequently in Simulink environment showing the bonds between components. The simulation employs block from the Simulink Simscape Blocksets. The DSIM block was obtained from the synchronous machines (electromechanical) blockset, and the power block was obtained from the sink blockset. Figure 3.4 shows the Simulink models of the PID based DSIM..

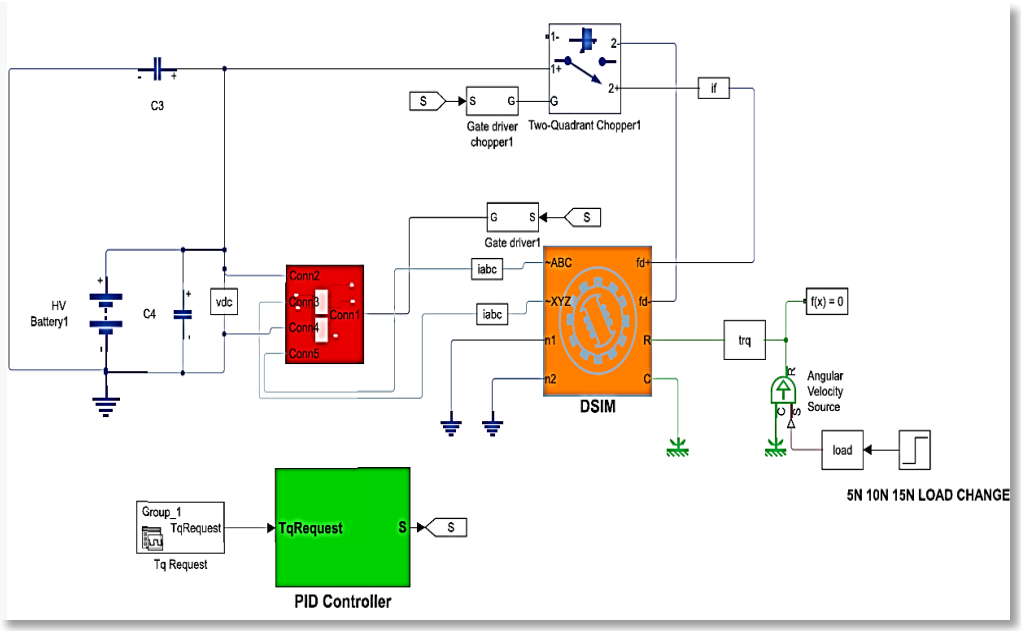

Figure 2: Simulink Model of PID Controller-based DSIM

III. RESULT AND DISCUSSION

A. Result for Current, Torque and Speed Response of PID-Based DSIM

This section present the result for current, torque and speed response of PID-Based Dual Stator Induction Machine for 5N, 10N and 15N Loads. Figures 3 depicts the PID controller based DSIM outcomes concerning torque, speed, rotor, and stator currents under 5N load change. The stator currents reflect how the machine draws power to meet load demands. With PID control, the current response is generally sharp and sometimes excessive. The electromagnetic torque generated by the machine reflects how the controller counters the applied load. In case of PID control, torque tends to lag behind the load changes. As can be seen, there is an abrupt overshoot from 0.1s to 0.5s before it stabilizes. This indicates the controller's reactive nature and limited ability to handle sudden disturbances.

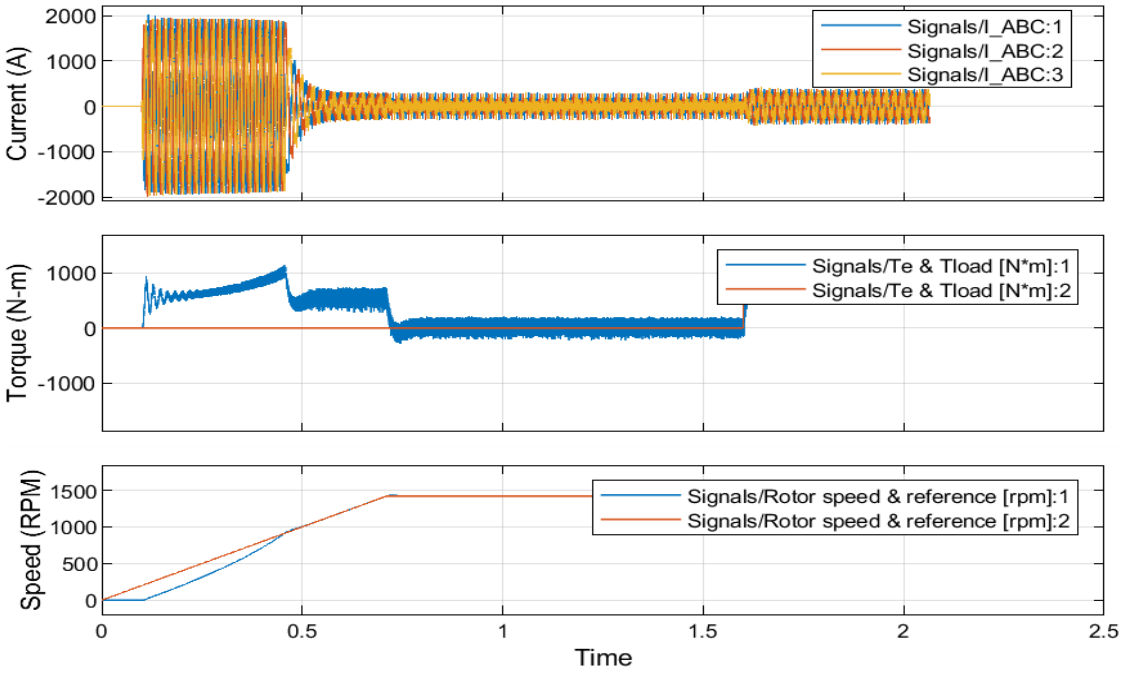

Figure 3: Current, Torque, and Speed Response of PID-based DSIM for 5N load

Under varying load conditions, the speed of the DSIM is a critical performance metric. With a PID controller, the speed deviates from the reference whenever a load is applied. These deviations involve a drop in speed from 1500 RPM to 1400 RPM followed by a slower recovery, as shown in the figure 4. At **10N**, PID overshoot increases noticeably.

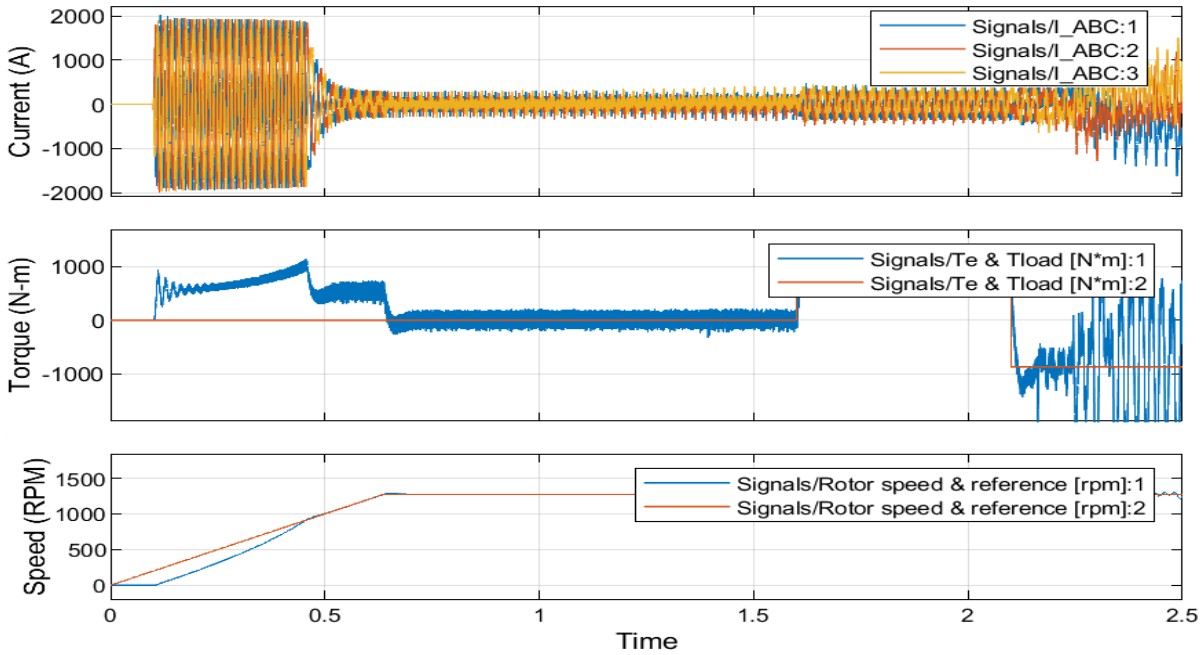

Figure 4: Current, Torque, and Speed Response of PID-based DSIM for 10N load

Figure 5 depicts the applied mechanical Load (15N), where response speed and torque are measured against time. Rotor currents, torque, and speed values are depicted on the y-axes, while x-axes indicate time. Load steps cause current spikes, delayed torque rise, and a significant drop in speed. As can be seen, each load step causes a spike in current, often accomplished by ripple or asymmetry between the two stators. PID performs poorly under high load in terms of torque smoothness and current regulation. Its control law lacks adaptability, resulting in energy inefficiency and higher thermal risk. Torque overshoot in PID indicates poor dynamic control, leading to mechanical stress and potential wear.

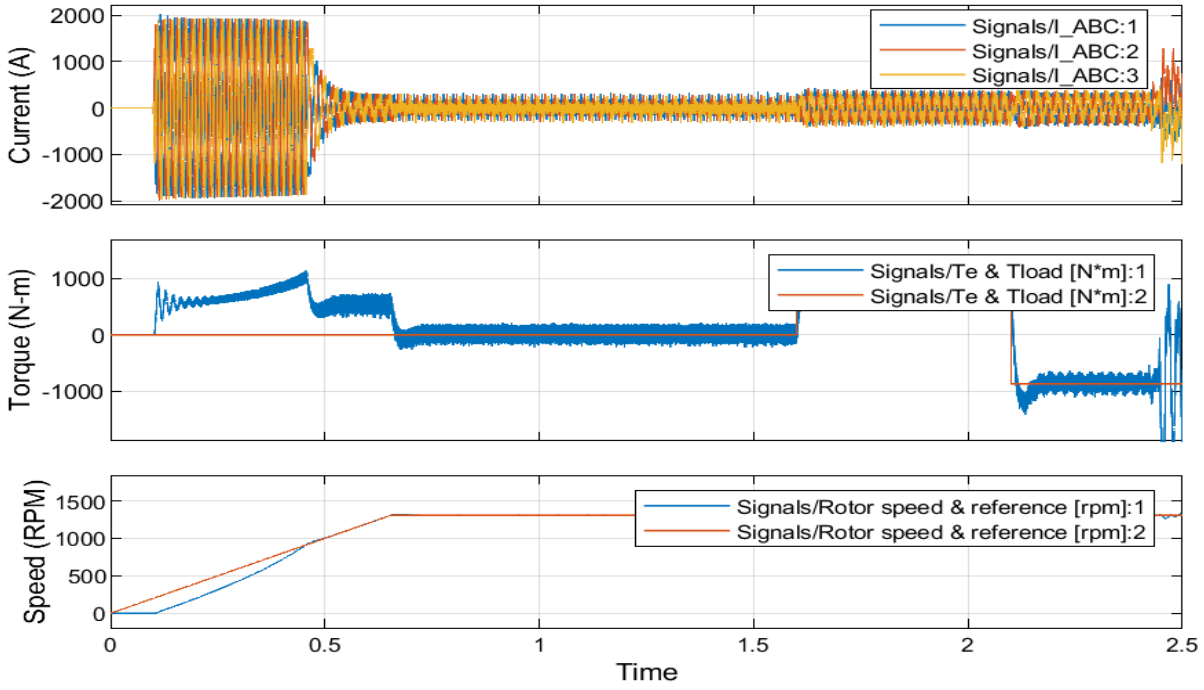

Figure 5: Current, Torque, and Speed Response of PID-based DSIM for 15N load

Table 2: Summary of Current, Torque, and Speed Responses

Load (N)	Controller	Torque Stability	Torque Overshoot	Current Ripple	Efficiency Implication
5	PID	Moderate	Medium	High	Lower due to current spikes
10	PID	Poor	High	Very High	Poor energy use, risk of heat
15	PID	Unstable/Oscillatory	Very High	Very High	Risk of overheating

B. Step Response Analysis (Time-Domain Response) Results of PID Controlled DSIM

In figure 6, the rotor speed step response of PID-based Dual Stator Induction Machines under 5N load disturbance shows an overshoot of 4.6%.

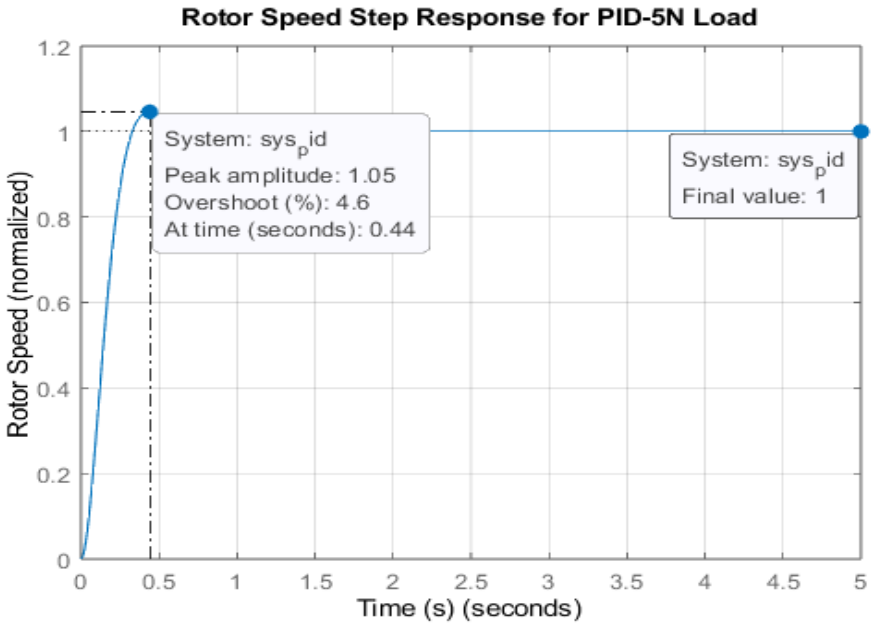

Figure 6: Step response of PID-based DSIM showing overshoot (5N Load)

In figure 7, the rotor speed step response of PID-based Dual Stator Induction Machines under 10N load disturbance shows an overshoot of 9.47% due to increased load.

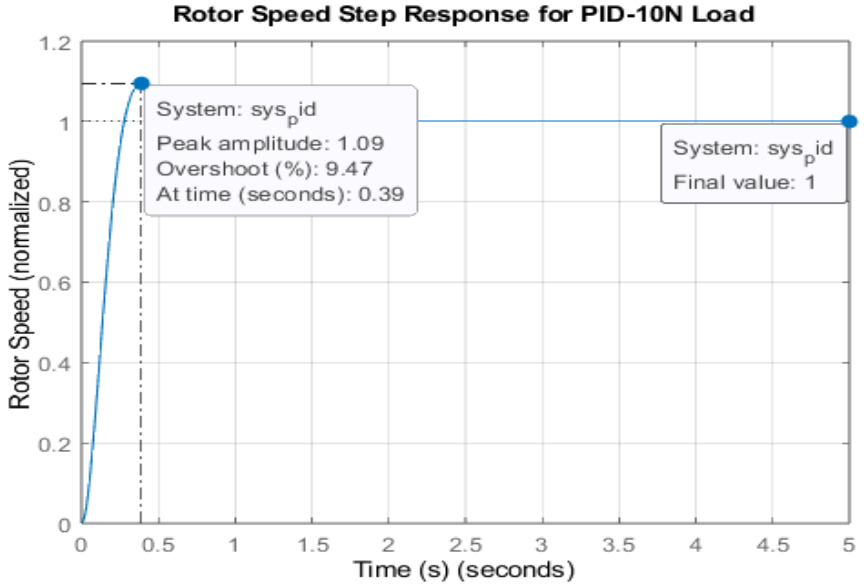

Figure 7: Step response of PID-based DSIM showing overshoot (10N)

In figure 8, the rotor speed step response of PID-based Dual Stator Induction Machines under 15N load disturbance shows an overshoot of 16.3%.

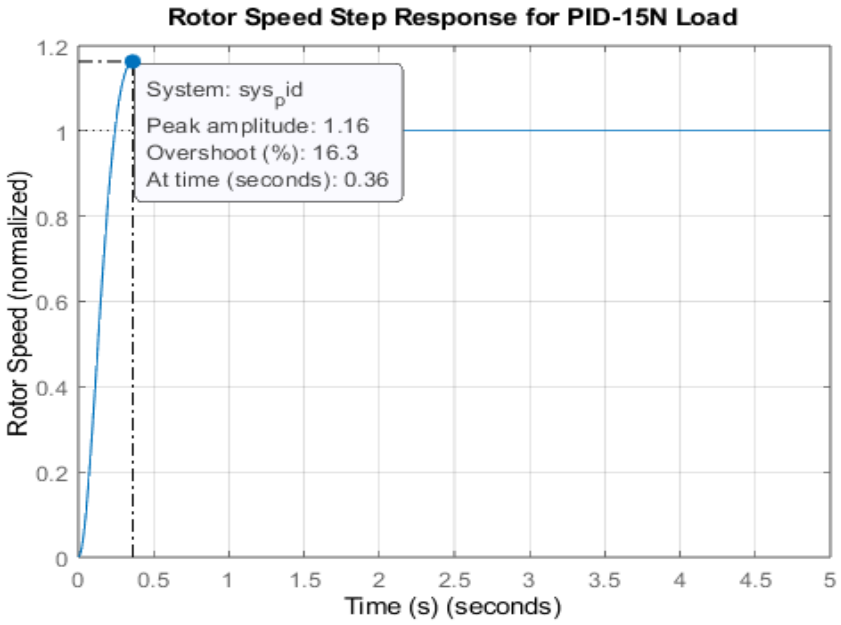

Figure 8: Step response of PID-based DSIM showing overshoot (15N)

In figure 9, the rotor speed step response of PID-based Dual Stator Induction Machines under 5N load disturbance shows a rise time of 0.213 second and settling time of 0.598 second.

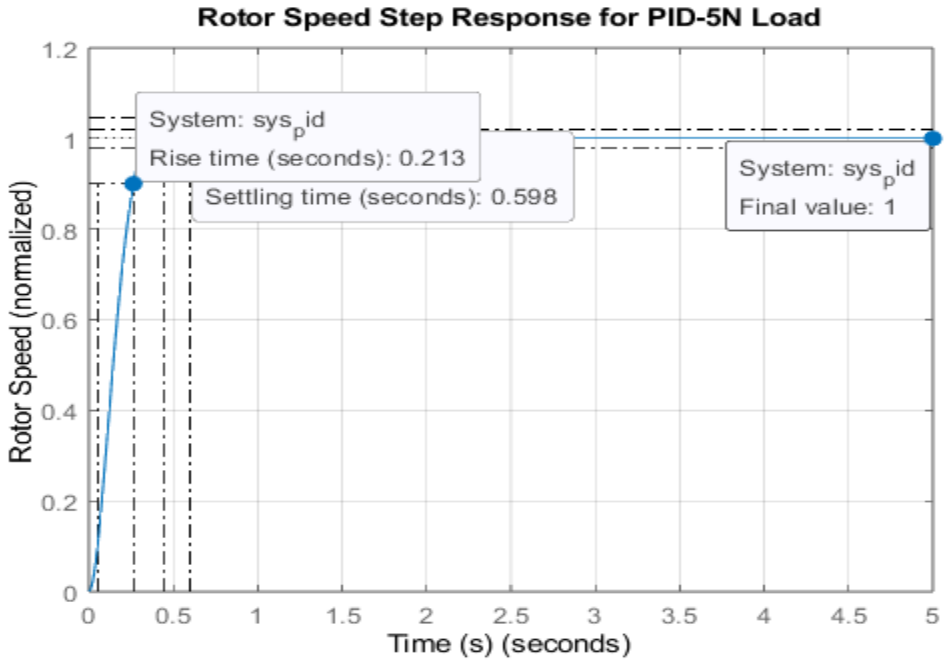

Figure 9: Step response of PID-based DSIM showing rise time and settling time (5N load)

In figure 10, the PID-based Dual Stator Induction Machines at 10N load takes a longer time of 0.594 second to settle (or stabilize) and 0.186 second to rise.

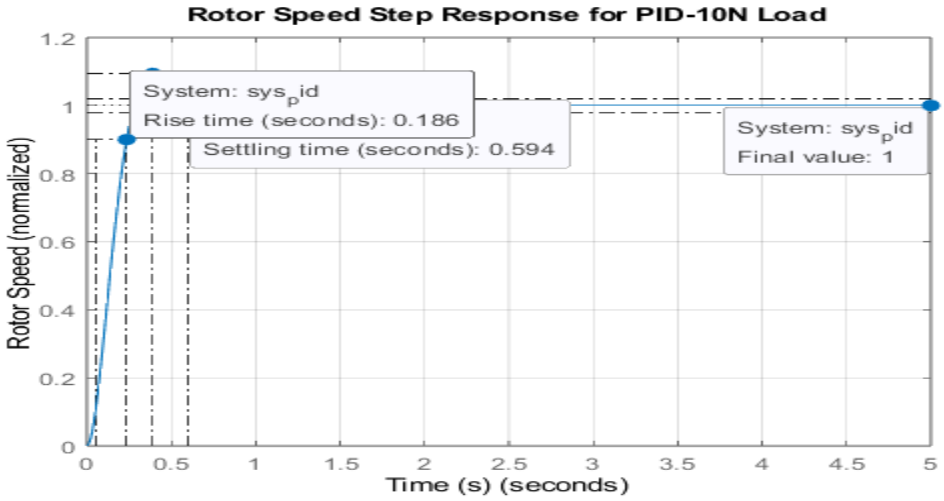

Figure 10: Step response of PID-based DSIM showing rise time and settling time (10N)

In figure 11, the rotor speed step response of PID-based Dual Stator Induction Machines under 15N load disturbance shows a rise time of 0.164 second.

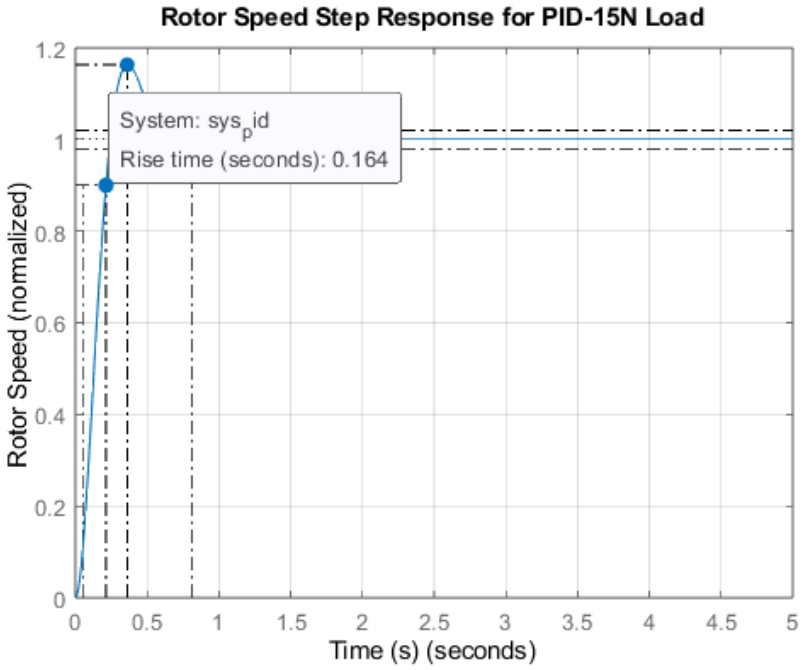

Figure 11: Step response of PID-based DSIM showing rise time (15N)

In figure 12, the rotor speed step response of PID-based Dual Stator Induction Machines under 15N load disturbance shows a settling time of 0.808 second.

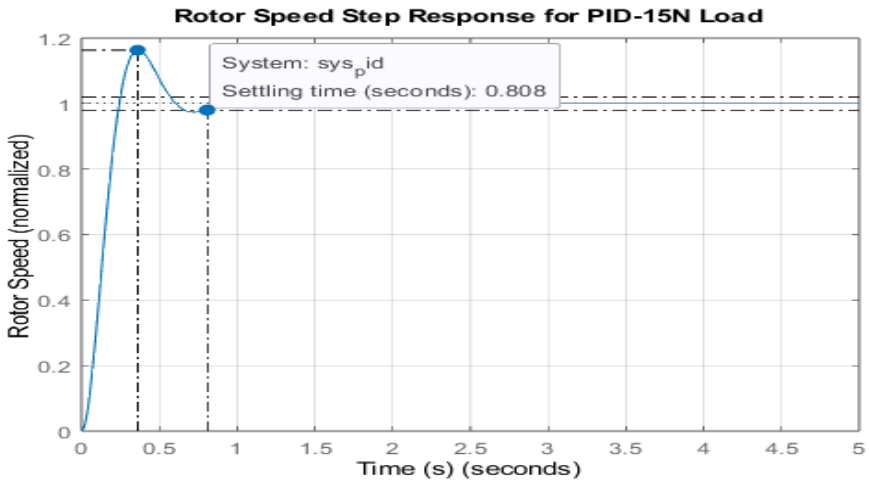

Figure 12: Step response of PID-based DSIM showing settling time (15N)

Table 6: Time-Domain Metrics under Different Load Conditions

Load (N)	Controller	Overshoot (%)	Settling Time (s)	Rise Time (s)
5	PID	4.6	0.598	0.213
10	PID	9.47	0.594	0.186
15	PID	16.3	0.808	0.164

C. Frequency Response (Bode Plot) Analysis of PID Controlled DSIM

This section presents the Frequency Response (or Bode Plot) Results of PID Controlled Dual Stator Induction Machine for 5N, 10N and 15N loads. In figure 13, the frequency response (Bode Plot) of PID-based Dual Stator Induction Machine under 5N disturbance shows a peak gain of -6.02dB at a frequency of $2.83e-^{08}$ rad/s.

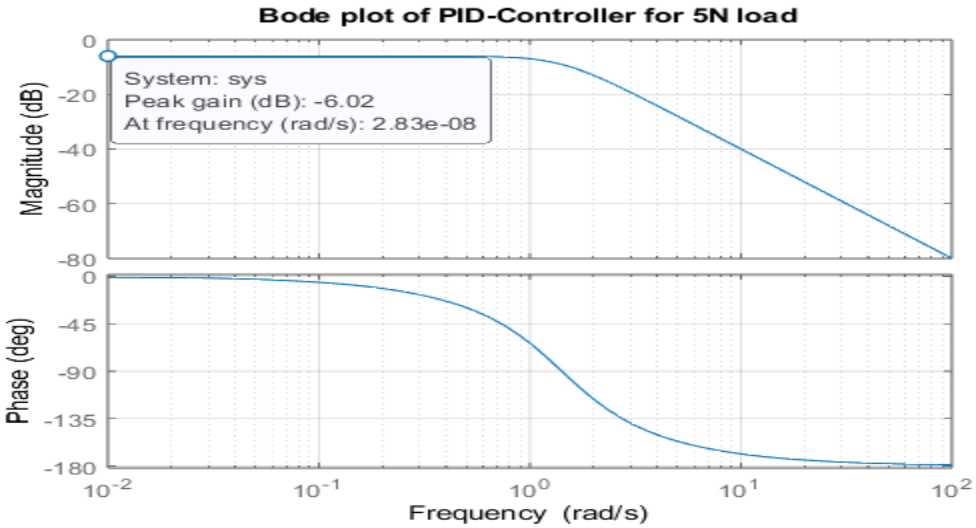

Figure 13: Bode plot of the PID-based DSIM showing peak gain (5N)

In figure 14, the frequency response (Bode Plot) of PID-based Dual Stator Induction Machine under 10N disturbance shows a peak gain of -9.042dB at a frequency of 0.926rad/s.

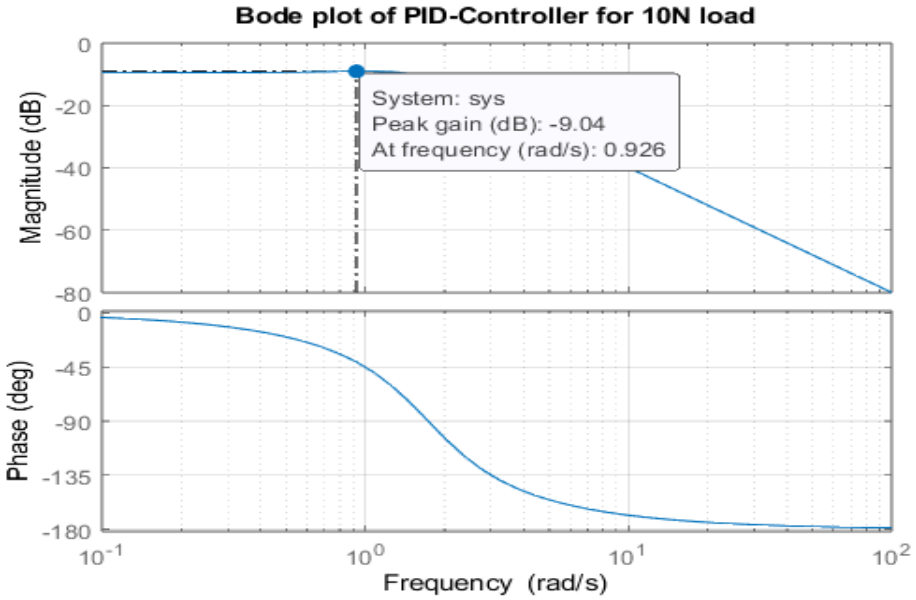

Figure 14: Bode plot of the PID-based DSIM under 10N load

In figure 15, the frequency response (Bode Plot) of PID-based Dual Stator Induction Machine under 15N disturbance shows a peak gain of -10dB at a frequency of 1.17rad/s.

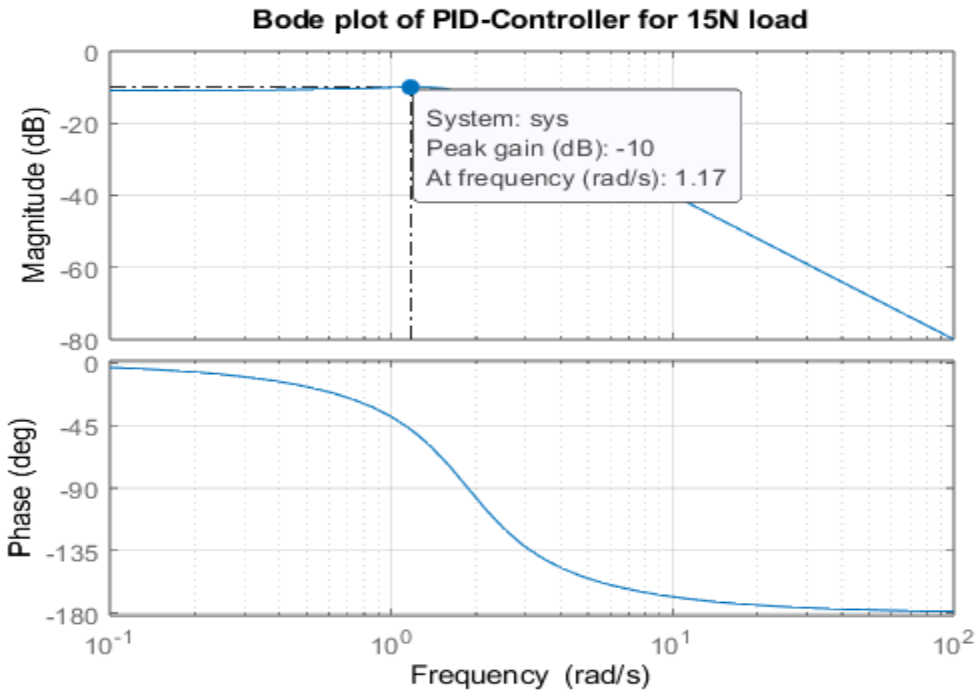

Figure 15: Bode plot of the PID-based DSIM under 15N load

IV.CONCLUSION

The performance of the Dual Stator Induction Machine was examined under load variation of 5N, 10N and 15N using PID controller**.** Performance metrics considered include **overshoot, settling time,** and **peak time**, with frequency domain analysis via **Bode plot** to assess robustness and stability margins.

The controller (PID) has a reactive nature and limited ability to handle sudden disturbances in the form of load variation. With PID controller, the current response is sharp and sometimes excessive. The torque tends to lag behind due to load variation. Speed deviates from the reference whenever a load is applied.

The step response analysis shows that increase in load leads to (i) increased overshoot, other factors remaining the same and (ii) relative increase in settling time.

The frequency responses from Bode plot reveal that with the PID controller (for the DSIM), an increase in load leads to more instability in the system.

REFERENCES

[1] I.U. Uju and B.S. Bere. ' Evaluation of the Performance and Stability of Dual Stator Induction Machine Using PID and H-Infinity Controllers'. International Research Journal of Engineering and Technology, pp 628- 646, 2025.

[2] B.S. Bere and I.U. Uju. 'Improvement of the Performance and Stability of Dual Stator Induction Machine Using LQR Controller'. International Research Journal of Engineering and Technology, pp 598- 614, 2025.

[3] M. Mataray and V. Kakkar. 'Asynchronous Machine Modeling Using Simulink Fed byPWMInverter'. International Journal of Advances in Engineering & Technology, Vol.1, Issue 2, pp. 206-214, 2011.

[4] K.Daware(2022), Working principle and types of an Induction Motor ,Available at https://www.electricaleasy.com/2014/02/working-principle-and-types-of.html.

[5] A.R. Munoz and T.A Lipo., Dual stator winding induction machine drive; IEEE Trans. Ind. Appl. 36: 1369–1379, 2000.

[6] A.R. Soman and R.M. Holmukhe. 'Double Stator Induction Machine for Variable Speed and Variable Torque Applications'. SSRG International Journal of Electrical and Electronics Engineering, 2021

[7] I.D. Nzeife, C.B. Mbachu and I, U, Uju. 'Improving the Performance Of Single-sided Linear Induxtion Motors Using Edge End Effect Reduction Technique'. International Journal Of Innovative Engineering, Technology and science, Vol. 4, No.1, 2021.

[8] I. U. Uju and U. Asiwe. 'International Journal Of Trends In Scientific Research and Development', Vol.2, Issue 3, pp 287-294, 2018.

[9] E. Otor and I.U. Uju. 'Mathematical Implementation Of Effect Of Increase In Divergence Angle Of a Diffuser On Speed and Power Generation Of HAWT Using Disk Theory' International Journal Of Innovative Engineering, Technology and science, Vol. 4, No.1, 2021.

[10] M, H. Holakooie, M. Ojaghi, and A. Taheri. 'Modified DTC of a Six-Phase Induction Motor With a Second-Order Sliding-Mode MRAS-Based Speed Estimator', IEEE Transactions on Power Electronics, 34(1), pp. 600–611, 2019.

[11] E. Levi. 'Multiphase Electric Machines for Variable-Speed Applications", IEEE Transactions on Industrial Electronics', 55(5), pp. 1893–1909, 2008.

[12] A. Meroufel, S. Massoum, ,A. Bentaallah, P. Wira, F.Z. Belaimeche, and A. Massoum, (2017). Double star induction motor direct torque control with fuzzy sliding mode speed controller, Revue Roumaine des Sciences Techniques-Serie Electrotechnique et Energetique, 62(1), pp. 31–35, 2017.

[13] Y.Moati, K. Kouzi, A. Bencherif, and S. Bensaoucha. 'New Design of Neural Direct Power Control of DSIM Fed by Indirect Matrix Converter', In: Hatti, M. (ed.) Renewable Energy for Smart and Sustainable Cities, ICAIRES 2018,Lecture Notes In Networks and Systems, Vol. 62, Springer, Cham, Switzerland, 2018, pp. 216–224, 2019.

[14] M. Yahia, K. Katia, M. Khalil, and B. Saddam, 'Direct Torque Control to Improve the Performances of the DSIM Powered by Indirect Matrix Converter'.International Conference on Communications and Electrical Engineering (ICCEE), El Oued, Algeria, pp. 1–5, 2018

[15]Y. Moati and K. Kouzi .'Investigating the Performances of Direct Torque and Flux Control for Dual Stator Induction Motor with Direct and Indirect Matrix Converter, Periodica Polytechnica Electrical Engineering and Computer Science, pp.1-9, 2019.

[16] E. Benyoussef and S. Barkat. 'Five-level Direct Torque Control with Balancing Strategy of Double Star Induction Machine'. Int J Syst Appl Eng Dev. 2020;14(Dci):116–23.

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