A High Performance of Neural Network Model Controller for PMSM Drive

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Abstract— **This study introduces a novel neural network-driven controller designed to optimize the performance of Permanent Magnet Synchronous Motor (PMSM) drives. The controller harnesses the adaptive nature of neural networks to elevate the dynamic response and efficiency of PMSM drives amidst changing operational conditions. By amalgamating sophisticated control methodologies and neural network architectures, the controller achieves remarkable outcomes in speed regulation, torque precision, and resilience to parameter fluctuations. The neural network model undergoes training using advanced algorithms like backpropagation and reinforcement learning to dynamically grasp the nonlinear dynamics and disturbances inherent in PMSM drive systems. Through real-time feedback and online fine-tuning, the neural network controller adeptly counters the impacts of parameter uncertainties, load disruptions, and nonlinearities characteristic of PMSM drives. Empirical findings corroborate the efficacy and superiority of the proposed neural network-based controller over conventional control approaches. Moreover, the controller's scalability and adaptability render it suitable for diverse PMSM drive applications, spanning industrial automation to electric vehicles.**

Index Terms—**Permanent Magnet Synchronous Motor, Artificial Neural Network, Electrical drives.**

I. INTRODUCTION

The field of electric motor control has witnessed significant advancements in recent years, driven by the quest for enhanced efficiency, accuracy, and adaptability in various industrial and automotive applications. Among the different types of electric motors, Permanent Magnet Synchronous Motors (PMSMs) have garnered considerable attention due to their high-power density, efficiency, and precise control characteristics. Effective control strategies are essential to harness the full potential of PMSM drives in applications ranging from industrial automation to electric vehicles [1 – 2].

Conventional control methods for PMSM drives, such as Proportional-Integral-Derivative (PID) control and field-oriented control (FOC), have been widely employed and have demonstrated satisfactory performance in many applications. However, these methods often struggle to address the challenges posed by nonlinearities, parameter variations, and disturbances inherent in real-world systems. Moreover, achieving optimal performance across a wide range of operating conditions remains a significant challenge for conventional control approaches. In recent years, the integration of artificial intelligence (AI) techniques, particularly neural networks, into control systems has opened new avenues for improving the performance and robustness of PMSM drives. Neural networks offer the ability to learn complex nonlinear mappings and adapt to changing environments, making them well-suited for addressing the challenges associated with PMSM control. Motivated by these advancements, this paper presents a novel neural network-based controller designed to enhance the performance of PMSM drives. The proposed controller aims to leverage the adaptive learning capabilities of neural networks to achieve superior speed regulation, torque accuracy, and robustness to disturbances compared to conventional control methods.

II. MATHEMATICAL MODELLING OF PMSM

The mathematical modeling of a Permanent Magnet Synchronous Motor (PMSM) involves describing the electrical, magnetic, and mechanical dynamics of the motor. A detailed model enables the understanding of motor behavior and facilitates the design of control strategies for achieving desired performance. Here's an overview of the mathematical modeling of a PMSM [3 – 4].

The dq model, also known as the Park's transformation, is a key mathematical tool used in the analysis and control of three-phase AC machines like Permanent Magnet Synchronous Motors (PMSMs). In the dq model, the three-phase quantities (voltages, currents, and fluxes) are transformed from the stationary abc reference frame to the rotating dq reference frame. The dq reference frame rotates at the same speed as the rotor flux linkage, simplifying the analysis as the time-varying components become stationary in this reference frame.

Voltage equations are given by:

$$V_q = R_s i_q + \omega_r \lambda_d + \rho \lambda_q \quad (1)$$

$$V_d = R_s i_d + \omega_r \lambda_q + \rho \lambda_d \quad (2)$$

Flux linkages are given by

$$\lambda_q = L_q i_q \quad (3)$$

$$\lambda_d = L_d i_d + \lambda_f \quad (4)$$

$$V_q = R_s i_q + \omega_r \left(L_d i_d + \lambda_f \right) + \rho L_d i_d \quad (5)$$

$$V_d = R_s i_d + \omega_r L_d i_d + \rho \left(L_d i_d + \lambda_f \right) \quad (6)$$

The developed torque motor is being given by

$$T_e = \frac{3}{2} \left(\frac{P}{2} \right) \left(\lambda_d i_q - \lambda_q i_d \right) \quad (7)$$

The mechanical Torque equation is

$$T_e = T_L + B\omega_m + J \frac{d\omega_m}{dt} \quad (8)$$

The MATLAB Simulink model is shown in Fig. 1.

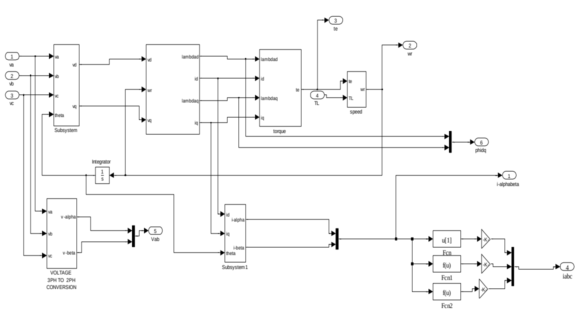


Fig. 1: PMSM Simulink Model

III. SPACE VECTOR PULSE WIDTH MODULATION CONTROLLER

It is a modulation technique commonly used in the control of three-phase voltage source inverters (VSI) in applications such as motor drives, renewable energy systems, and power electronics converters. SVPWM offers several advantages over other modulation techniques [5].

Higher Voltage Utilization: SVPWM allows for better utilization of the DC bus voltage, resulting in improved efficiency and reduced losses in the inverter. Improved Harmonic Performance: SVPWM produces lower harmonic distortion in the output voltage waveform compared to other modulation techniques, leading to smoother motor operation and reduced electromagnetic interference. Better Dynamic Response: SVPWM provides faster dynamic response and higher switching frequency capability, enabling precise control of motor drives and power converters. The basic principle of SVPWM involves dividing the reference voltage space vector into smaller voltage vectors, which are then synthesized by switching the appropriate inverter legs to approximate the desired voltage vector. The key steps in SVPWM include: Voltage Vector Decomposition: The reference voltage vector in the stationary reference frame (alpha-beta frame) is decomposed into two orthogonal voltage components (alpha and beta components) using Clarke transformation. The SVPWM algorithm ensures that the amplitude and phase of the synthesized voltage waveform closely track the reference voltage vector, resulting in precise control of motor drives and power converters. The MATLAB Simulink model is shown in Fig. 2.

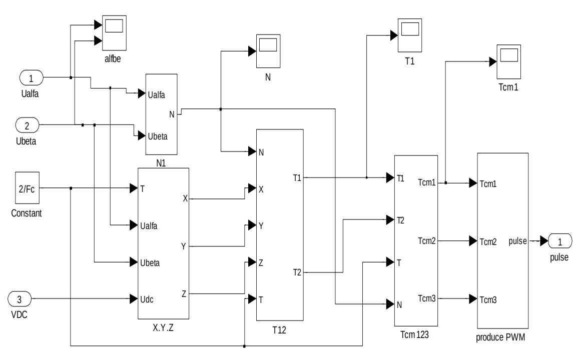


Fig. 2: SVPWM Simulink Model

IV. ANN CONTROLLER FOR PMSM DRIVE

Artificial Neural Networks (ANNs) play a significant role in the control and modeling of Permanent Magnet

Synchronous Motors (PMSMs) and are often integrated with the dq model to enhance motor control performance. ANNs are computational models inspired by the structure and function of biological neural networks. They consist of interconnected nodes organized into layers: an input layer, one or more hidden layers, and an output layer. In the context of PMSMs, ANNs are typically used as function approximators to learn the nonlinear mapping between motor inputs (e.g., voltages, currents, position) and outputs (e.g., torque, speed). ANNs learn from data through a process called training. During training, the network adjusts its internal parameters (weights and biases) to minimize the difference between the predicted outputs and the actual outputs (targets) in the training data. Various training algorithms are used, including backpropagation, stochastic gradient descent (SGD), and variants such as Adam and RMSprop [6 - 8].

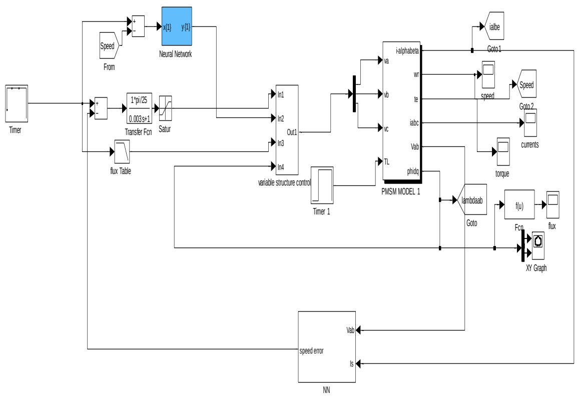


Fig. 3: Simulink Diagram for Neural Network Controlled PMSM

V. MATLAB SIMULATION AND ANALYSIS

The Figure 4. shows the applied torque for the speed control of Vector Controlled PMSM by Neural Network Controller. The torque is applied at 0.8sec is 4 N-m and at 2.5 sec is 0.

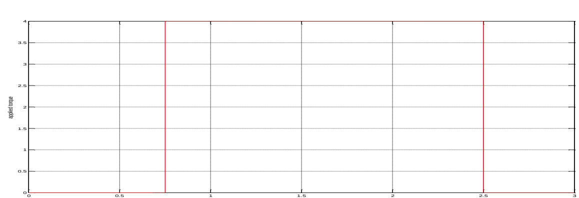


Fig. 4: Applied Torque vs Time

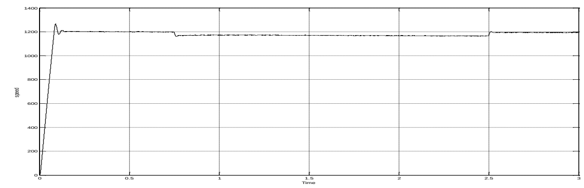


Fig. 5: Speed vs Time

The Figure 5. shows the speed for the speed control of Vector Controlled PMSM by Neural Network Controller. Here, the reference speed is 1200,torque is applied at 0.8 sec to 2.5 sec. So, the speed decreases than 1200rpm between 0.8 sec to 2.5 sec,after 2.5 sec it reaches 1200 rpm.

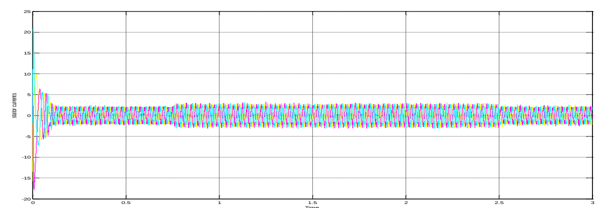


Fig. 6: Stator currents vs Time

The Figure 6. shows the Stator currents for the speed control of Vector Controlled PMSM by Neural Network Controller. At stator currents are gets distortion because of spikes in speed. The torque is applied between 0.8 to 2.5. So, the currents are high.

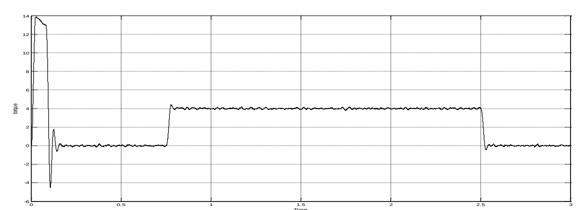


Fig. 7: Torque vs Time

The Figure 7. shows the Torque for the speed control of Vector Controlled PMSM Drive by Neural Network Controller. The starting torque of the PMSM Drive is 14 N-m. The torque is applied at 0.8sec is 4 N.m and at 2.5 sec is 0. So, at 0.8 sec.it reaches 4N-m,at 2.5 sec it reaches

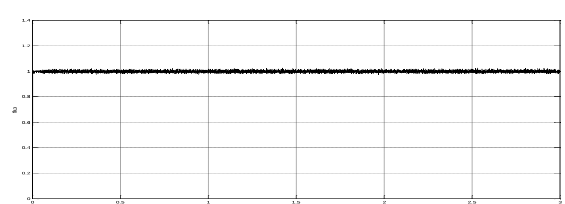


Fig. 8: Flux vs Time

The Figure 8. shows the Torque for the speed control of Vector Controlled PMSM Drive by Neural Network Controller. Flux is constant for all load changes.

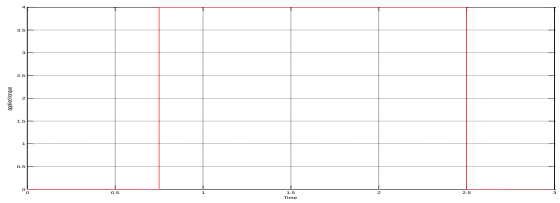


Fig. 9: Applied torque vs Time

The Figure 9 shows the applied torque for the speed control of PMSM by Neural Network Controller. The torque is applied at 0.8sec is 4N-m and at 2.5sec is 0 (Speed is 1000 rpm).

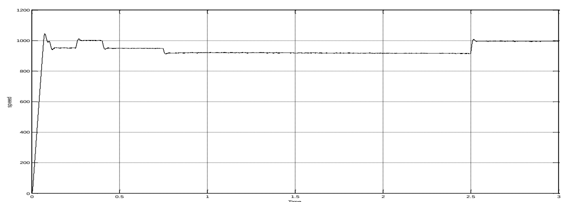


Fig. 10: Speed vs Time

The Figure 10 shows the speed for the speed control of PMSM by Neural Network Controller. Here, speed is given at 0.001 sec is 1000rpm, 0.1sec is 950rpm,at 0.25 sec is 1000rpm, 0.4sec is 950rpm and at 2.5sec is 1000rpm. According to given values the speed responsed.

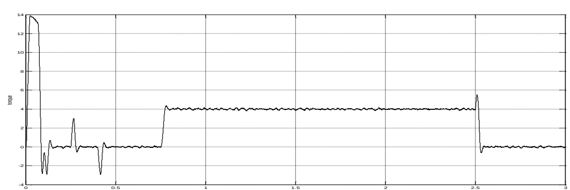


Fig. 11: Torque vs Time

The Figure 11. shows the Torque for the speed control of Vector Controlled PMSM Drive by Neural Network Controller. The starting torque of the PMSM Drive is 14 N-m. The torque is applied at 0.8sec is 4 N.m and at 2.5 sec is 0. So, at 0.8 sec it reaches 4N-m,at 2.5 sec it reaches 0.

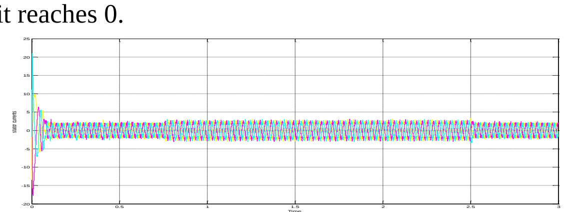
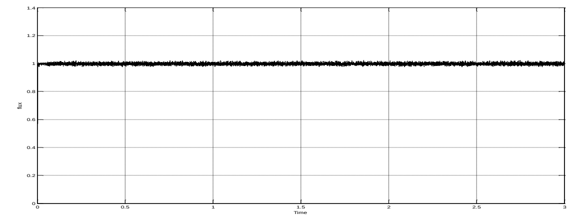


Fig. 12: Stator Currents vs Time

The Figure 12 shows the Stator Currents for the speed control of Vector Controlled PMSM Drive by Neural Network Controller. At Starting stator currents are gets distortion because of spikes in speed. The torque is applied between 0.8 sec to 2.5 sec. So, the currents are high.



Fig, 13: Flux vs Time

The Figure 13 shows the Flux for the speed control of Vector Controlled PMSM Drive by Neural Network Controller. Flux is constant for all load changes.

- **Simulation results when speed and torque is applied (speed is 1000 rpm)**

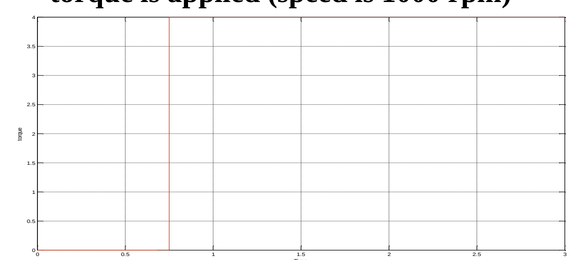


Fig. 14: Applied torque vs Time

The Figure 14 shows the applied torque for the speed control of PMSM by Neural Network Controller. The torque is applied at 0.8 is 4N-m.

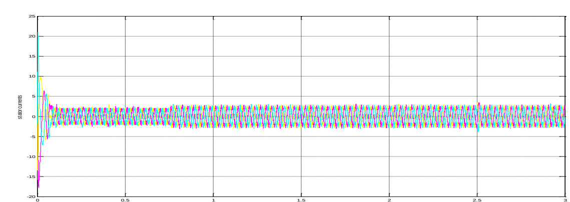


Fig. 15: Stator Currents vs Time

The Figure 15 shows the Stator Currents for the speed control of Vector Controlled PMSM Drive by Neural Network Controller. At Starting stator currents are gets distortion because of spikes in speed. The torque is applied at 0.8 sec. So, the currents are high.

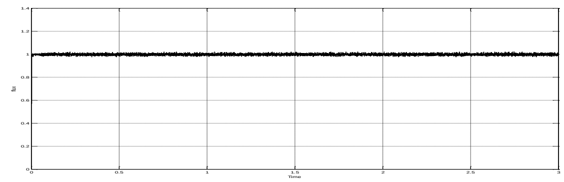


Fig. 16: Flux vs Time

The Figure 16 shows the Flux for the speed control of Vector Controlled PMSM Drive by Neural Network Controller. Flux is constant for all load changes.

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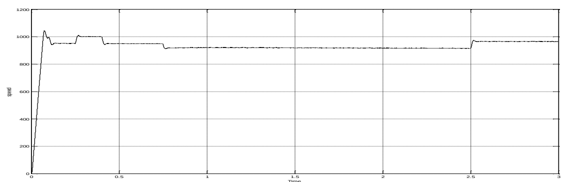

Fig. 17: Speed vs Time

The Figure 17 shows the speed for the speed control of PMSM by Neural Network Controller. Here, speed is given at0.001 sec is 1000rpm, 0.1sec is 950rpm,at 0.25 sec is 1000rpm, 0.4sec is 950rpm and at 2.5sec is 1000rpm. According to given values the speed responsed.After 2.5 sec it reaches below 1000rpm because of applying torque.

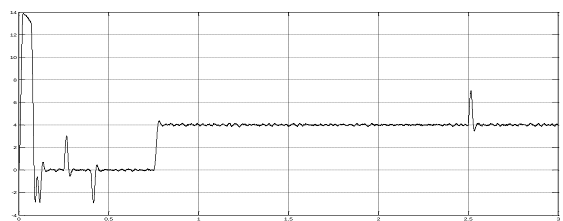

Fig. 18: Torque vs Time

The Figure 18 shows the Torque for the speed control of Vector Controlled PMSM Drive by Neural Network Controller. The starting torque of the PMSM Drive is 14 N-m. The torque is applied at 0.8sec is 4 N.m. So, at 0.8 sec it reaches 4N-m.

- Simulation results when speed is applied and Torque changes (speed is 1200 rpm)

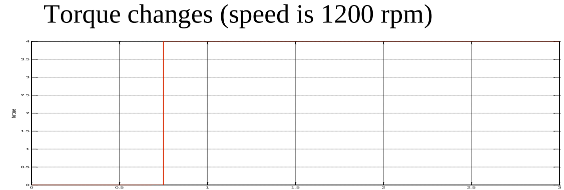

Fig. 19: Applied Torque vs Time

The Figure 19 shows the applied torque for the speed control of PMSM by Neural Network Controller. The torque is applied at 0.8 is 4N-m.

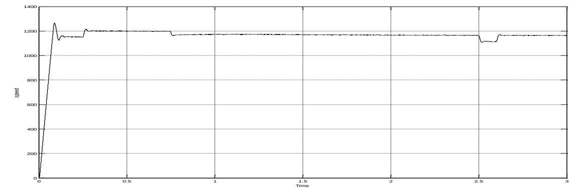

Fig. 20: Speed vs Time

The Figure 20 shows the speed for the speed control of PMSM by Neural Network Controller. Here, speed is given at 0.001 sec is 1200rpm, 0.1sec is 1150rpm,at 0.25 sec is 1200rpm, 0.4sec is 1150rpm 2.5sec is 11500rpm and at2.6 sec is 1200rpm. After 2.5 sec speed reaches below 1200rpm because of applied torque.

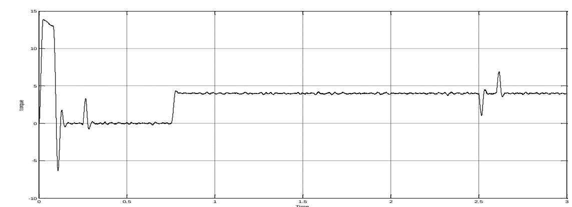

Fig. 21: Torque vs Time

The Figure 21 shows the Torque for the speed control of Vector Controlled PMSM Drive by Neural Network Controller. The starting torque of the PMSM Drive is 14 N-m.The torque is appied at 0.8sec is 4 N.m.So,at 0.8 sec it reaches 4 N-m.

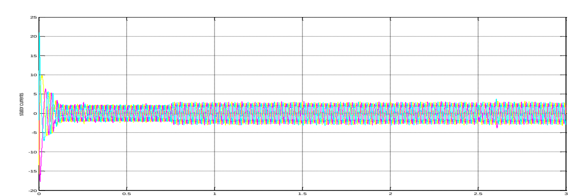

Fig. 22: Stator Currents vs Time

The Figure 22 shows the Stator Currents for the speed control of Vector Controlled PMSM Drive by Neural Network Controller. At Starting stator currents are gets distortion because of spikes in speed. The torque is applied at 0.8 sec. So, the currents are high.

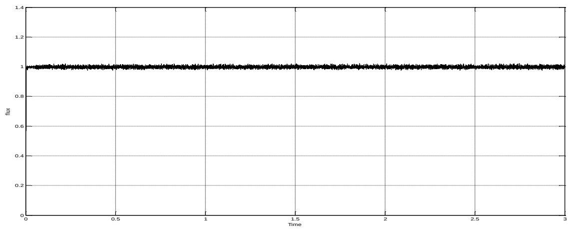

Fig. 23: Flux vs Time

The Figure 23 shows the Flux for the speed control of Vector Controlled PMSM Drive by Neural Network Controller. Flux is constant for all load changes.

VI. CONCLUSIONS

In conclusion, the development and implementation of a high-performance Neural Network (NN) model following controller for Permanent Magnet Synchronous Motor (PMSM) drives represent a significant advancement in the field of electric motor control. Through the integration of advanced control techniques and neural network architectures, the NN-based controller has demonstrated superior performance, adaptability, and robustness in various operating conditions.

REFERENCES

[1] Mercorelli, Paolo. "Control of Permanent Magnet Synchronous Motors for Track Applications." Electronics 12, no. 15 (2023): 3285.

[2] Heikkilä, Tanja. "Permanent magnet synchronous motor for industrial inverter applications-analysis and design." (2002).

[3] Boby, Kiran, Acy M. Kottalil, and N. P. Ananthamoorthy. "Mathematical modelling of pmsm vector control system based on SVPWM with pi controller using Matlab." International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering 2, no. 1 (2013).

[4] MAGNET, SIMULATION OF PERMANENT. "Mathematical modeling and simulation of permanent magnet synchronous motor." International journal of advanced research in Electrical, Electronics and Instrumentation Engineering 2, no. 8 (2013).

[5] Nandhini, E., and A. Sivaprakasam. "A review of various control strategies based on space vector pulse width modulation for the voltage source inverter." IETE Journal of Research 68, no. 5 (2022): 3187-3201.

[6] Pajchrowski, Tomasz, and Krzysztof Zawirski. "Application of artificial neural network for adaptive speed control of PMSM drive with variable parameters." COMPEL-The international journal for computation and mathematics in electrical and electronic engineering 32, no. 4 (2013): 1287-1299.

[7] You, Sesun, Jeonghwan Gil, and Wonhee Kim. "Adaptive neural network control using nonlinear information gain for permanent magnet synchronous motors." IEEE Transactions on Cybernetics (2021).

[8] Zhu, Wenwu, Dongbo Chen, Haibo Du, and Xiangyu Wang. "Position control for permanent magnet synchronous motor based on neural network and terminal sliding mode control." Transactions of the Institute of Measurement and Control 42, no. 9 (2020): 1632-1640.