

# Enhanced PMDC Motor Modeling Using a Neural Network Multi-Model Approach

**Moussa Aberkane**

National Polytechnic School of Oran  
Algeria

**Abdelouaheb Ghrieb**

National Polytechnic School of Oran  
Algeria

**Ramzi Salim**

National Polytechnic School of Oran  
Algeria

**Abdellatif Seghiour**

Higher School of Electrical Engineering and  
Energetics of Oran  
Algeria

**Abdelkader Mekri**

Higher School of Electrical Engineering and  
Energetics of Oran  
Algeria

*This paper presents a novel modeling methodology for Permanent Magnet DC (PMDC) motors using a multi-model framework based on Neural Network (NN) Multi-Layer Perceptron (MLP) architecture. Departing from conventional single-model paradigms, the proposed approach employs an ensemble of specialized MLP networks, whose optimal configuration is guided by adaptive performance evaluation. Comprehensive experimental and simulation results reveal that this multi-model framework achieves substantial enhancements in modeling precision, increased resilience to operational disturbances, and superior overall performance when contrasted with single-network implementations. Laboratory bench tests verify the method's efficacy across varied operational scenarios, including transient states. Owing to its adaptable and scalable nature, this methodology emerges as a valuable asset for sophisticated control strategies and real-time diagnostic applications in PMDC motor systems.*

**Keywords:** Modeling, Neural Network, MLP, Permanent Magnet DC motors, Multi Model.

## 1. INTRODUCTION

Modern industry faces growing systemic complexity, posing significant challenges in modeling and control for automation engineers [1]. The effective operation of these systems requires not only advanced control strategies but also mathematical models capable of faithfully representing their dynamic behavior [2].

Permanent Magnet DC (PMDC) motors are key components of these systems, distinguished by their energy efficiency, high torque density, and rapid response [3]. Their simple construction and maintenance-free operation make them suitable for various applications [4]. The 220 W motor modeled in this study is representative of the precision actuators used in demanding fields such as collaborative robotics, industrial automation, and medical devices, where model accuracy is crucial for performance and reliability.

However, accurate modeling of these motors remains a major technical challenge due to complex influencing factors such as load fluctuations, friction, magnetic saturation, and environmental disturbances [5, 6]. These factors can lead to performance degradation if not properly accounted for. Therefore, developing a reliable model is essential for performance optimization, control strategy refinement, and the implementation of effective diagnostic systems [7].

To address this challenge, Artificial Neural Networks (ANNs) offer a promising approach for modeling PMDC motors [8, 9]. Recognized as a revolutionary advancement in information processing [10, 11], ANNs

can learn autonomously and make decisions, serving as powerful tools in fields like modeling and diagnosis [12, 13]. They are distinguished by their learning capacity and their ability to process data in a parallel and distributed manner [14, 15].

The literature presents various neural network approaches for tackling such complexities. The work in [16] introduces a method for nonlinear dynamic system identification using a Recurrent Multilayer Perceptron (RMLP) and a dynamic gradient descent algorithm, reporting an order-of-magnitude improvement in convergence speed. Similarly, [17] employs a Multilayer Perceptron (MLP) as a universal approximator for nonlinear problems in atmospheric sciences, bypassing the need for prior assumptions about data distribution.

Multi-model strategies have also been extensively explored. The study in [18] proposes a neural multi-model method that decomposes a system's operating space into local zones, each represented by a distinct MLP, with outputs combined via Gaussian weighting functions. Expanding on this, [19] presents a multimodel approach using a Recurrent Trainable Neural Network (RTNN) with stability constraints, integrated within a fuzzy-neural structure. Reference [20] offers a systematic three-step method to determine the base models for a multimodel representation, using Kohonen networks for clustering and recursive least squares for estimation. This concept is applied in [21] for fault diagnosis in induction motors using a multi-model neuro-fuzzy approach and the LOLIMOT algorithm. Further, [22] investigates heterogeneous multiple models and concludes that a combined learning algorithm is most effective for systems with strongly overlapped validity functions.

However, recent single-network approaches still suffer from limited accuracy across the full operating range, especially during transient states. They often fail

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Correspondence to: Mousa Aberkane, National Polytechnic School of Oran, Maurice Audin (ENPOMA), P.O. Box 1523, El M'naouer, Oran, Algeria  
E-mail: mdrakibulislam.bgd@gmail.com

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to capture local nonlinearities such as friction variations or magnetic saturation. This gap motivates our multi-model strategy, where several specialized neural networks collectively cover different dynamic regimes.

Recent research continues to leverage these concepts. The work in [23] defines a novel multimodal adaptive control strategy for Permanent Magnet Synchronous Motors (PMSMs) using embedded neural networks for real-time adaptability. In reference [24], a multi-neural network architecture for modeling asynchronous machines is proposed, where the number of networks is adaptively determined based on learning error, demonstrating improved accuracy over a single-network model.

This research focuses on using neural networks as a modeling approach to develop a multi-model for a PMDC motor, aiming to achieve a more accurate and robust representation. The objective of the proposed approach is to establish an intelligent model capable of adapting to the system's different operational ranges.

This article is structured as follows: Section 2 presents the mathematical model of PMDC motors; Section 3 details neural network modeling and the construction of the neural multi-model; Section 4 evaluates the performance of the proposed system via simulation; Section 5 presents the experimental validation conducted at the laboratory of the Higher School of Electrical and Energy Engineering of Oran (ESGEE); finally, Section 6 synthesizes the main conclusions of the study.

## 2. MATHEMATICAL MODELLING OF THE DC MOTORS

Mathematical model of the permanent magnet DC motor can be found very often in the literature. Here, it will be referred to briefly [25].

The supply voltage  $u(t)$  is equal to the sum of the counter-electromotive force (back EMF) and the voltage drops across the armature resistance and inductance [26]:

$$u(t) = Ri(t) + L \frac{di(t)}{dt} + e(t) \quad (1)$$

where:  $i(t)$  is the armature current,  $R$  is the armature resistance,  $L$  is the armature inductance, and  $e(t)$  is the back EMF given by :

$$e(t) = K_e \omega(t) \quad (2)$$

with the angular velocity of the rotor and the back EMF constant.

The equation of motion is :

$$J \frac{d\omega(t)}{dt} = T_m(t) - T_f(t) - T_l(t) \quad (3)$$

where:  $J$  is the total moment of inertia (rotor and load),  $T_m(t)$  is the motor torque,  $T_f(t)$  is the friction torque, and  $T_l(t)$  is the load torque.

The motor torque is given by :

$$T_m(t) = K_t i(t) \quad (4)$$

where  $K_t$  is the torque constant.

The friction torque can be modeled as the sum of several components:

$$T_f(t) = T_c \text{sign}(\omega(t)) + B\omega(t) + T_s \delta(\omega(t)) \quad (5)$$

where:  $T_c$  is the Coulomb friction torque (constant, opposed to motion),  $B$  is the viscous friction coefficient,  $T_s$  is the static friction torque (which occurs when the velocity is zero), and  $\delta(\omega(t))$  is a function that equals 1 if and 0 otherwise.

However, a more common and simpler modeling approach is to use viscous friction and Coulomb friction:

$$T_f(t) = B\omega(t) + T_c \text{sign}(\omega(t)) \quad (6)$$

Magnetic saturation can be accounted for by varying the constants  $K_e$  and  $K_t$  as a function of the current. A simple approach is to model the saturation as a non-linear function of the current.

The load torque can vary with time and position. It can be modeled as a given function or as a disturbance. Thus, the complete model becomes:

$$L \frac{di(t)}{dt} = u(t) - Ri(t) - K_e(i)\omega(t) \quad (7)$$

$$J \frac{d\omega(t)}{dt} = K_t(i)i(t) - B\omega(t) - T_c \text{sign}(\omega(t)) - T_l(t) \quad (8)$$

Magnetic saturation makes the system nonlinear because and depend on the current.

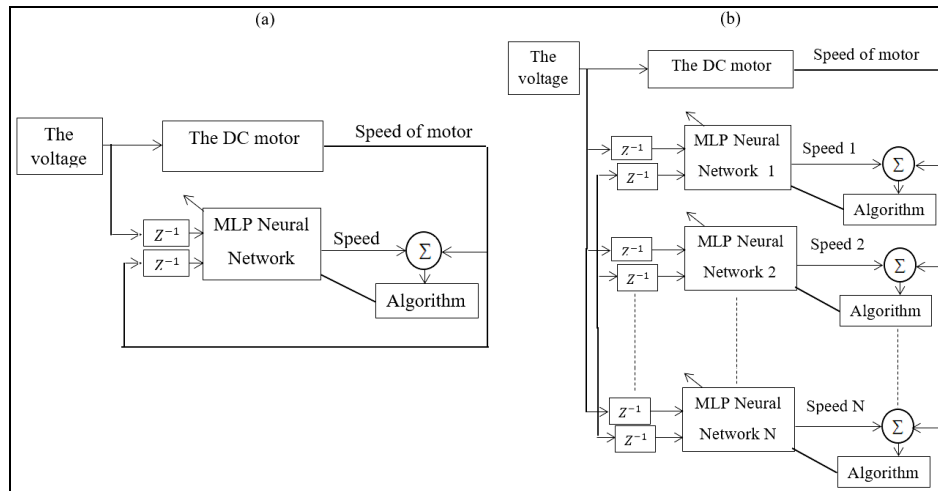


Figure 1. (a) The architecture series-parallel for the identification, (b) The architecture for the identification of multi model

### 3. NEURAL NETWORK MODELING

Neural networks are widely employed across numerous industrial fields. Indeed, there are various types of neural networks, each characterized by its unique learning capability and capacity to explain decisions [27, 28].

Consequently, modeling accuracy is fundamentally determined by the chosen neural architecture [29, 30].

Figure 1 (a) presents the series-parallel modeling approach, where the neural network is fed with historical machine data, encompassing both input and output variables.

The proposed approach involves using several interconnected neural network models, linked in parallel, to create a global model. The number of neural models was determined based on an analysis of the learning results from a single neural network after initial modeling. This single model reproduces the PMDC output but exhibits learning errors, which are localized at specific ranges of the network's output. Accordingly, the machine data was partitioned into intervals based on the analysis of these error values. These intervals were then used to construct a neural multi-model, as illustrated in figure 1 (b).

### 4. SIMULATION AND RESULT

Figures 2 and 3 show the voltage used and the machine speed, respectively.

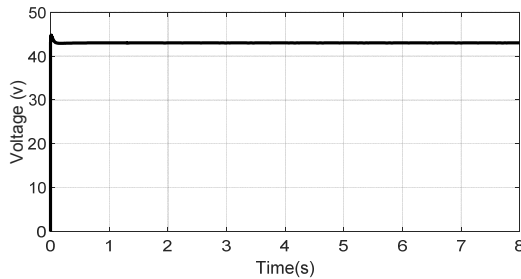


Figure 2. The supply voltage of dc motors.

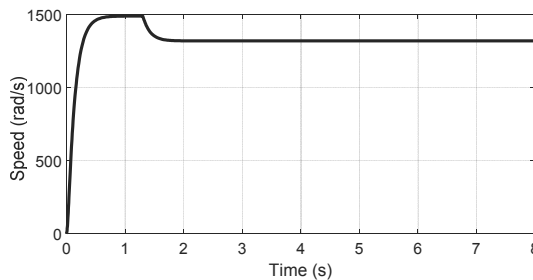


Figure 3. The speed of dc motors.

Figure 4 shows the neural network used, which comprises a hidden layer of 6 neurons, each neuron in this layer use a hyperbolic tangent activation function (equation 9), an input layer of 2 neurons and an output layer of a single neuron, this layer uses a linear activation function as:

$$\text{Tansig}(n) = \frac{2}{(1 + e^{-2n}) - 1} \quad (9)$$

$$\text{Purelin}(n) = 1 \quad (10)$$

The neural network is trained using the Levenberg – Marquardt algorithm as the core optimization method. The model's performance is assessed by computing the mean squared error (MSE), defined as follows:

$$\text{MSE} = \frac{\sum_{j=1}^N (z_j - \sigma_j)^2}{N} \quad (11)$$

The same type of neural network was used to generate the neural model and multi model.

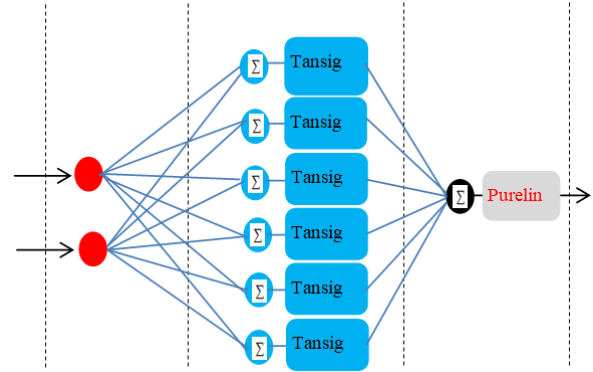


Figure 4. The MLP machine speed model

When comparing the machine output and the neural network model output, the training error is detected, as shown in figure 5.

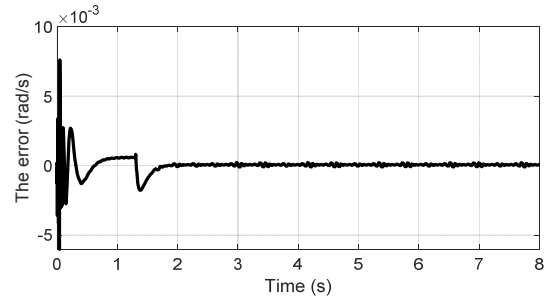


Figure 5. The training error of speed

The error curve displays a uniform spread of error values, visible on this curve, over the time intervals [0s 0,22s] and [0,22s 8s].

To solve this precision problem, we propose the multi-model neural network technique, based on decomposing the machine data (voltages and speed) according to the spread of error values. In this study, the data was split into two distinct segments:

The first segment covered the time interval [0s 0,22s], and the second segment included the interval [0,22s 8s]. Two neural network models were generated, each corresponding to one of these time intervals. The error of this multi-model is shown in figure 6.

The data was then divided into three segments corresponding to the time intervals [0s 0,22s], [0,22s 2s], and [2s 8s]. Three separate neural models were developed to handle these segments. The corresponding errors of the multi-model are shown in figure 7.

The neural model error (fig. 5) has a minimum value almost equal to  $-6.02 \cdot 10^{-3} \text{ rad/s}$  and a maximum value almost equal to  $7.6 \cdot 10^{-3} \text{ rad/s}$ .

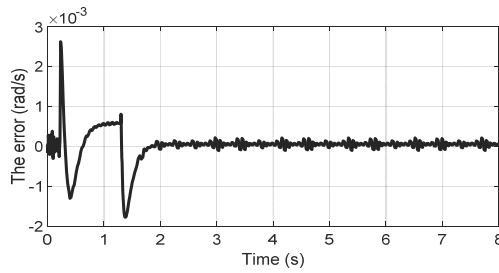


Figure 6. The training error of the multi model (2 models)

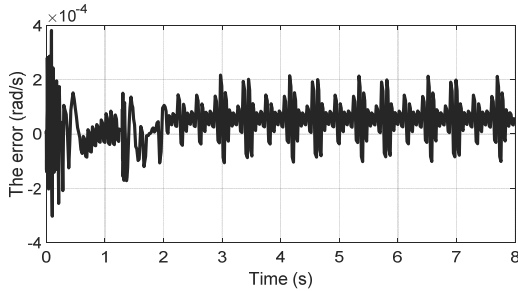


Figure 7. The training error of the multi model (3 models).

On the other hand, (fig. 6). the neural multi model error has a minimum value almost equal to  $-1.76 \cdot 10^{-3} \text{ rad/s}$  and a maximum value almost equal to  $2.62 \cdot 10^{-3} \text{ rad/s}$ .

It can be observed that the error values of the neural multi-model are consistently lower than those of the single neural model.

This indicates that the model composed of two neural networks achieves higher accuracy than the model based on a single network.

Furthermore, the model incorporating three neural networks demonstrates improved performance compared to the two-network version.

Specifically, both the minimum and maximum error values are reduced in the three neural networks model (fig. 7) (minimum  $\approx -3.03 \cdot 10^{-4} \text{ rad/s}$ , maximum  $\approx 3.81 \cdot 10^{-4} \text{ rad/s}$ ).

These results suggest that increasing the number of specialized networks within the multi-model framework enhances the overall modeling accuracy.

The mean square error (MSE) of the neural model is  $6.7918 \cdot 10^{-5}$ , while that of the neural multi model with two model is  $3.9505 \cdot 10^{-7}$ . This significant suggests that the neural multi model has significantly higher accuracy than the neural model. The MSE of the neural multi model with three models is  $1.9758 \cdot 10^{-7}$ .

This significantly suggests that the neural multi model with three model has significantly higher accuracy.

Figure 8 shows the electromagnetic torque of dc motors.

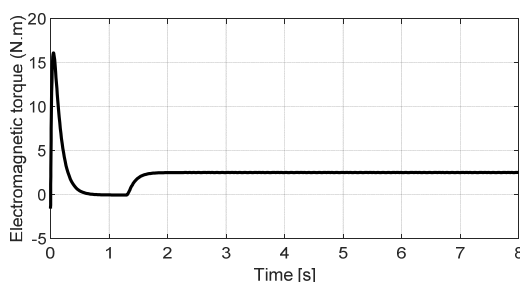


Figure 8. The electromagnetic torque of dc motors.

Figure 9 shows the neural network used for the electromagnetic torque, and the error of this model is shown in figure 10.

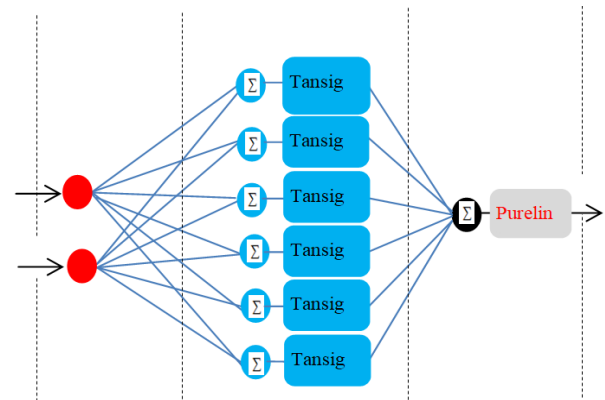


Figure 9. The MLP machine electromagnetic torque model

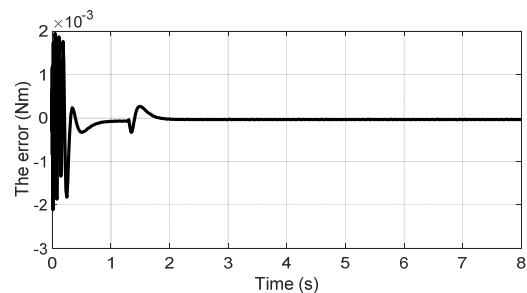


Figure 10. The training error of electromagnetic torque

The error curve displays a uniform distribution of error values, visible over the time intervals  $[0s \ 0,33s]$  and  $[0,33s \ 8s]$ .

To address this precision issue, we propose a multi-model neural network approach, which involves decomposing the machine data (voltages and electromagnetic torque) based on the spread of error values.

In this study, the data was divided into two distinct segments:

- The first segment covered the interval  $[0s \ 0,33s]$ ,
- The second segment included  $[0,33s \ 8s]$ .

Two neural network models were trained, each corresponding to one of these intervals. The error of this multi-model approach is illustrated in figure 11.

Next, the data was split into three segments corresponding to the intervals  $[0s \ 0,33s]$ ,  $[0,33s \ 1,8s]$ , and  $[1,8s \ 8s]$ . Three separate neural network models were developed for these segments. The corresponding errors of the multi-model system are shown in figure 12.

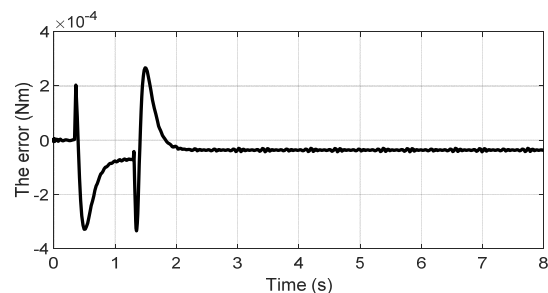
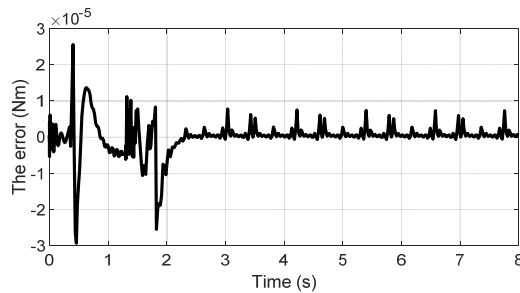


Figure 11. The training error of the neural multi model (2 models)

Figures 11 and 12 demonstrate that the two-model neural multi-model achieves lower minimum and maxi-

num error values than the single neural model. Moreover, the three-model neural multi-model further reduces these error values compared to the two-model version.



**Figure 12.** The training error of the neural multi model (3 models)

**Table 1.** Shows the values of the models.

| Model type      | The value of training model        | Model of Single MLP   | Multi model of two MLP | Multi model of three MLP |
|-----------------|------------------------------------|-----------------------|------------------------|--------------------------|
| The Speed model | The minimum value of error (rad/s) | $-6,02 \cdot 10^{-3}$ | $-1,76 \cdot 10^{-3}$  | $-3,03 \cdot 10^{-4}$    |
|                 | The maximum value of error (rad/s) | $7,6 \cdot 10^{-3}$   | $2,62 \cdot 10^{-3}$   | $3,81 \cdot 10^{-4}$     |
|                 | The MSE                            | $6,79 \cdot 10^{-5}$  | $3,95 \cdot 10^{-7}$   | $1,97 \cdot 10^{-7}$     |
| The             | The minimum value of error (Nm)    | $-2,11 \cdot 10^{-3}$ | $-3,34 \cdot 10^{-4}$  | $-2,93 \cdot 10^{-5}$    |

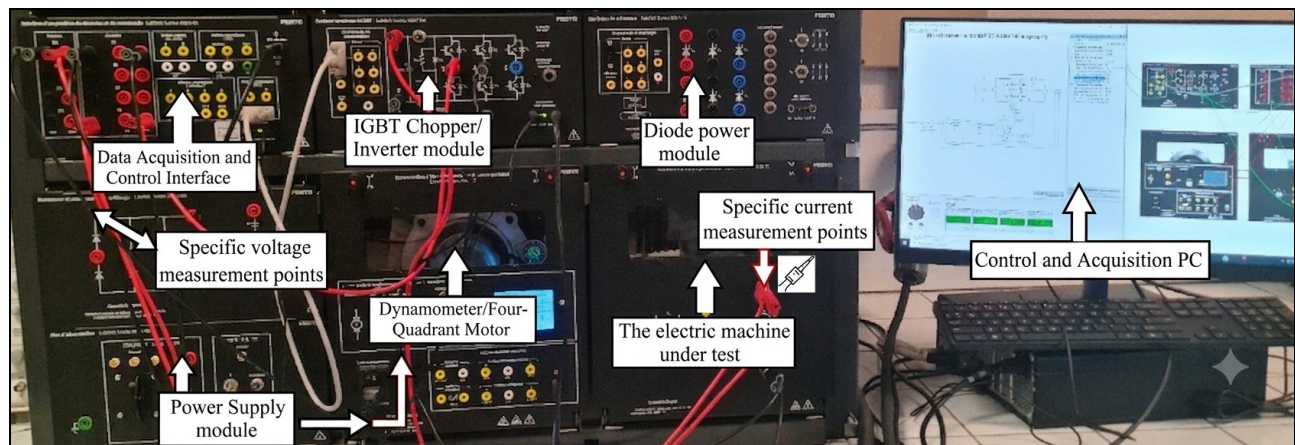
|              |                                 |                      |                       |                       |
|--------------|---------------------------------|----------------------|-----------------------|-----------------------|
| torque model | The maximum value of error (Nm) | $1,94 \cdot 10^{-3}$ | $2,67 \cdot 10^{-4}$  | $2,55 \cdot 10^{-6}$  |
|              | The MSE                         | $1,58 \cdot 10^{-7}$ | $1,034 \cdot 10^{-9}$ | $8,76 \cdot 10^{-10}$ |

Quantitatively, the single neural model has an MSE of  $1,58 \cdot 10^{-8}$ , whereas the two-model multi-model yields an MSE of  $1.034 \cdot 10^{-9}$ . Notably, the three-model multi-model achieves an even lower MSE of  $8.76 \cdot 10^{-9}$ . This substantial improvement confirms that the three-model approach delivers significantly higher accuracy.

## 5. EXPERIMENTAL RESULTS

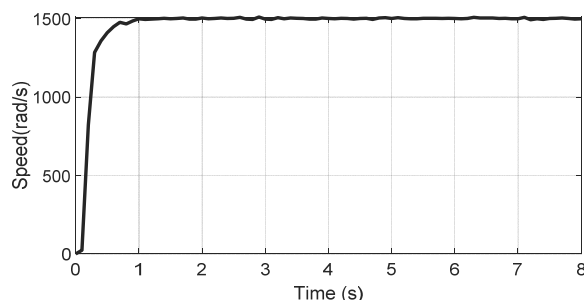
Experimental tests were conducted using a LabVolt test bench equipped with a data acquisition interface (Model 9063-01), an IGBT chopper/inverter (Model 8837-B6), a four-quadrant power supply (Model 8960-36), and a permanent magnet DC motor (Model 8213-11, 220 W, 3600 rpm, 48 V, 5.5 A). The system, controlled by the IGBT inverter, was instrumented to measure electrical quantities (voltage, current, speed, torque) in real time via analog and digital I/O. Acquired data was processed and visualized on a computer, confirming strong agreement between simulated and experimental results.

The experimental tests were conducted in the laboratory of the Higher School of Electrical Engineering and Energetics of Oran (ESGEE), as shown in the photograph of figure 13.

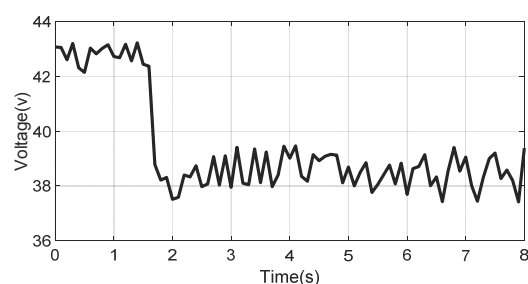


**Figure 13.** The experimental test-rig

Figure 14 and 15 show the voltage used and the machine speed, respectively.



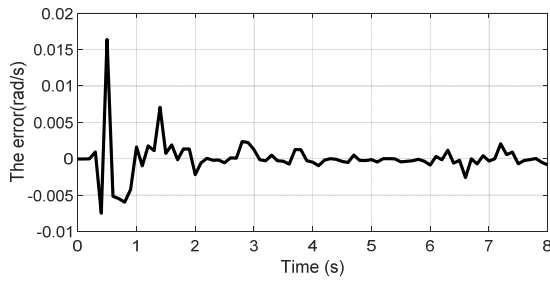
**Figure 14.** The speed of dc motors.



**Figure 15.** The supply voltage of dc motors.

Figure 16 highlights a learning discrepancy between the actual and predicted outputs, characterized by a uniform distribution of residuals across two distinct

phases: the transient period [0s 3s] and the steady-state regime [3s 8s].



**Figure 16. The training error of speed**

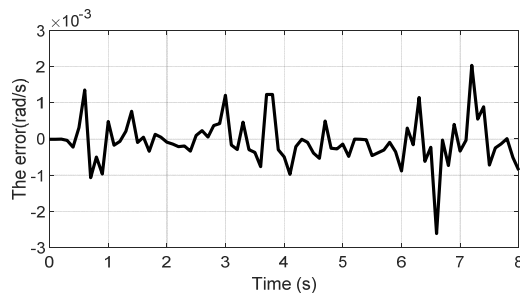
Learning error analysis revealed a uniform distribution of residuals between actual and predicted outputs, divided into two distinct phases: transient [0s 3s] and steady-state [3s 8s]. To improve accuracy, a neural network-based multi-model approach was implemented. Data was segmented into time intervals reflecting error distribution (fig. 19).

The two-network model was structured around two distinct intervals: Interval 1 [0s 3s] corresponding to the transient regime and Interval 2 [3s 8s] covering the steady-state operation. This approach significantly reduced the minimum and maximum errors to  $-7.5 \cdot 10^{-3}$  rad/s and 0.016 rad/s respectively, achieving a mean square error (MSE) of  $3.9505 \cdot 10^{-7}$ , demonstrating notable improvement compared to the single-network model which had an MSE of  $6.7918 \cdot 10^{-5}$  (fig. 17).

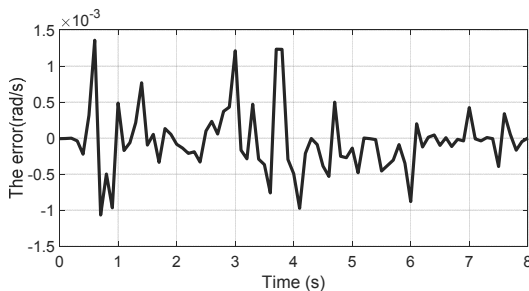
To further optimize performance, a three-network model was implemented with finer temporal segmentation: [0s 3s] for the initial transient phase, [3s 6s] for the transition to established operation, and [6s 8s] for advanced steady-state behavior.

Further error reduction was achieved (min:  $-1.06 \cdot 10^{-3}$  rad/s, max:  $1.35 \cdot 10^{-3}$  rad/s) with an MSE of  $1.9758 \cdot 10^{-7}$ , validating the efficacy of adding networks (fig. 18).

This increased granularity provided additional precision in modeling the system's different operational phases.

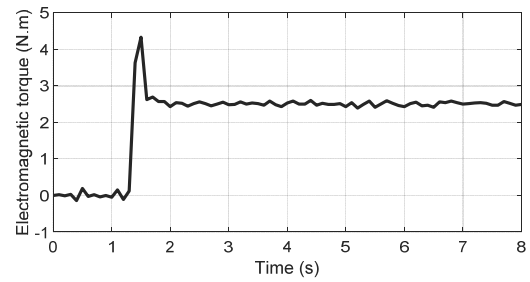


**Figure 17. The training error of the multi model (2 models)**



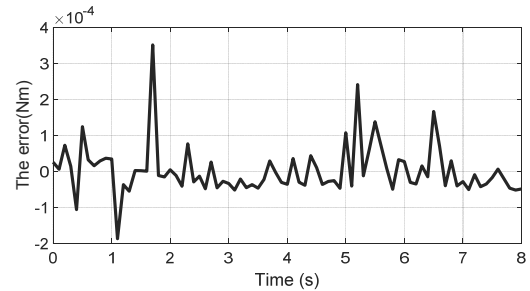
**Figure 18. The training error of the multi model (3 models).**

Figure 19 shows the electromagnetic torque of DC motors.



**Figure 19. The electromagnetic torque of dc motors.**

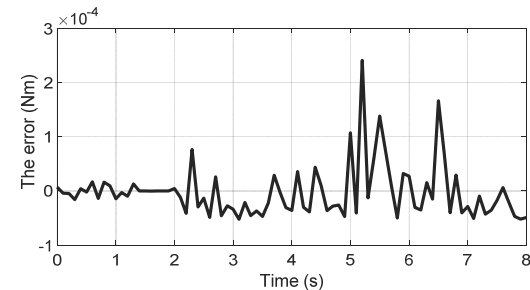
The error of this model is shown in figure 20.



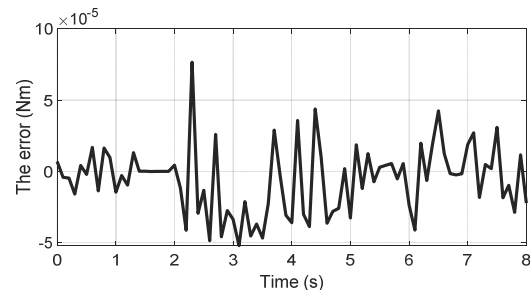
**Figure 20. The training error of electromagnetic torque**

A similar analysis was applied to electromagnetic torque, with adjusted segments ([0s 2s], [2s 5s] and [5s 8s]).

The three-network model achieved an MSE of  $6.1695 \cdot 10^{-10}$  (fig. 22), compared to  $2.4065 \cdot 10^{-9}$  for two networks (fig. 21) and  $4.8899 \cdot 10^{-9}$  for a single network, confirming the robustness of the multi-model approach.



**Figure 21. The training error of the neural multi model (2 models)**



**Figure 22. The training error of the neural multi model (3 models)**

Table 2 summarizes the comparative performance of the models, highlighting:

- Progressive reduction in errors (min/max) and MSE as the number of networks increases.
- System adaptability to dynamic variations, critical for real-time industrial applications.

This methodology, experimentally validated, provides a precise and flexible alternative to traditional models, with potential for optimization in more complex systems.

**Table 2. Shows the values of the models.**

| Model type       | The value of training model        | Model of Single MLP   | Multi model of two MLP | Multi model of three MLP |
|------------------|------------------------------------|-----------------------|------------------------|--------------------------|
| The Speed model  | The minimum value of error (rad/s) | $-7,50 \cdot 10^{-3}$ | $-2,61 \cdot 10^{-3}$  | $-1,06 \cdot 10^{-3}$    |
|                  | The maximum value of error (rad/s) | 0,016                 | $2,03 \cdot 10^{-3}$   | $1,35 \cdot 10^{-3}$     |
|                  | The MSE                            | $6,79 \cdot 10^{-5}$  | $3,95 \cdot 10^{-7}$   | $1,97 \cdot 10^{-7}$     |
| The torque model | The minimum value of error (Nm)    | $-1,86 \cdot 10^{-4}$ | $-5,2 \cdot 10^{-5}$   | $-5,20 \cdot 10^{-5}$    |
|                  | The maximum value of error (Nm)    | $3,51 \cdot 10^{-4}$  | $2,40 \cdot 10^{-4}$   | $7,64 \cdot 10^{-5}$     |
|                  | The MSE                            | $4,88 \cdot 10^{-9}$  | $2,40 \cdot 10^{-9}$   | $6,16 \cdot 10^{-10}$    |

## 6. CONCLUSION

This paper introduces an innovative modeling approach for Permanent Magnet DC (PMDC) motors using a multi-model neural network architecture.

The results demonstrate that this method significantly outperforms single-network models in terms of accuracy and robustness, both in simulation and experimental validation. The key advantages of this multi-model approach include substantial error reduction (minimum, maximum, and MSE) through specialized networks for different operational ranges, enhanced adaptability to dynamic variations (critical for real-time industrial applications), and increased flexibility for seamless integration into advanced diagnostic and control systems.

Experimental validation conducted on a LabVolt test bench confirmed strong agreement between simulation results and practical measurements, reinforcing the method's reliability. Future research directions may include extending this approach to other electrical machine types or optimizing neural network architectures for further performance improvements. In conclusion, this research advances intelligent modeling techniques for electric actuators, providing a precise, adaptable solution for demanding industrial applications.

The multi-model neural network approach establishes a new paradigm for accurate motor modeling, with potential applications, including embedded fault diagnosis, predictive maintenance in servo drives, high-precision positioning in collaborative robots, and torque control in medical robotic systems. Its modular design allows easy adaptation to other actuator types.

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## REFERENCES

- [1] Vidyalakshmi, G., Gopikrishnan, S., Boulila, Wadii, et al.: Digital Twins and Cyber- Physical Systems, A New Frontier in Computer Modeling. Computer Modeling in Engineering & Sciences, Vol. 143, No. 1, pp. 51, 2025.
- [2] Suman, S.K. and Kumar, A.: Investigation and implementation of model order reduction technique for large scale dynamical systems. Archives of Computational Methods in Engineering, Vol. 29, No 5, pp. 3087-3108, 2022.
- [3] Alkamachi, A.: Permanent magnet DC motor (PMDC) model identification and controller design, Journal of Electrical Engineering, pp. 303-309, 2019.
- [4] Pandya, V., Mehta, S., and Pramod, P.: Modeling, Characterization, and Identification of Permanent Magnet DC Motors, IEEE International Electric Machines & Drives Conference (IEMDC). San Francisco, CA, USA, pp. 1-7, 2023.
- [5] Joshi, M. C and Samanta, S.: Modeling and control of bidirectional DC-DC converter fed PMDC motor for electric vehicles. Annual IEEE India Conference (INDICON). IEEE, p. 1-6, 2013.
- [6] Xia, C., L.: Permanent magnet brushless DC motor drives and controls. John Wiley & Sons, 2012.
- [7] Maheriya, S., et Parikh, P.: Modelling of Brushed DC motor and Various type of control methods. Journal for Research, Vol. 1, 2016.
- [8] Siddiqi, F. R, Ahmad, S., Akram, T, et al.: Artificial Neural Network- Based Data-Driven Parameter Estimation Approach: Applications in PMDC Motors. Mathematics. Vol. 12, No 21, pp. 3407, 2024.
- [9] Gupta, R. A., Kumar, Rajesh, et Bansal, Ajay Kumar.: Artificial intelligence applications in Permanent Magnet Brushless DC motor drives. Artificial Intelligence Review, Vol. 33, No 3, pp. 175-186, 2010.
- [10] Kommula, B. N, and Kota, V. R.: An effective sustainable control of brushless DC motor using firefly algorithm- artificial neural network based FOPID controller. Sustainable Energy Technologies and Assessments, Vol. 52, pp. 102097, 2022.
- [11] Wang J., Chen X., Zhang F et al.: Building load forecasting using deep neural network with efficient feature fusion. Journal of Modern Power Systems and Clean Energy, Vol. 9, pp. 160-169, 2021.
- [12] Tathawadekar N., Doan NAK., Silva CF et al.: Modeling of the nonlinear flame response of a bunsen-type flame via multilayer perceptron. Proceedings of the Combustion Institute. Vol. 38, pp. 6261- 6269, 2021.

- [13] Rashidi M., Alhuyi Nazari M., Mahariq I., et al.: Modeling and sensitivity analysis of thermal conductivity of ethylene glycol-water based nanofluids with alumina nanoparticles. *Experimental Techniques*, Vol. 16, pp. 1–8, 2022.
- [14] Fukuda, T and Shibata, T.: Theory and applications of neural networks for industrial control systems. *IEEE Transactions on industrial electronics*, Vol. 39, No 6, pp. 472-489, 2002.
- [15] Kerdpi boon, S., Kerr, W, L., and Devahastin, S.: Neural network prediction of physical property changes of dried carrot as a function of fractal dimension and moisture content. *Food research international*, Vol. 39, No 10, pp. 1110-1118, 2006.
- [16] Parlos, A. G., Chong, K, T., and Atiya, A. F.: Application of the recurrent multilayer perceptron in modeling complex process dynamics. *IEEE Transactions on Neural Networks*, Vol. 5, No 2, pp. 255-266, 1994
- [17] Gardner, M, W., and Dorling, S. R.: Artificial neural networks (the multilayer perceptron), a review of applications in the atmospheric sciences. *Atmospheric environment*, Vol. 32, No 14, p. 2627-2636, 1998.
- [18] Slimani, A, Errachdi, A., and Benrejeb, M.: The neural multi-model approach for nonlinear systems identification, *International Conference on Control, Automation and Diagnosis (ICCAD)*. IEEE, pp. 1-5, 2019.
- [19] Baruch, I. S., Flores, J. M., Thomas, F, and al.: A multimodel recurrent neural network for systems identification and control. *IJCNN'01, International Joint Conference on Neural Networks. Proceedings (Cat. No. 01CH37222)*. IEEE, pp. 1291-1296, 2001.
- [20] Talmoudi, S., Abderrahim, K., Abdennour, R., Ben, et al.: Multimodel approach using neural networks for complex systems modeling and identification. *Nonlinear Dynamics and Systems Theory*, Vol. 8, No 3, pp. 299-316, 2008.
- [21] A. Wolfram and R., Isermann.: Fault detection of inverter-fed induction motors using a multi-model approach based on neuro-fuzzy models. *European Control Conference (ECC)*, Porto, Portugal, pp. 1367-1372, 2001.
- [22] El Ferik, S, and Adeniran, A. A.: Modeling and identification of nonlinear systems, A review of the multimodel approach—Part 2. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, Vol. 47, No 7, pp. 1160-1168, 2016.
- [23] Zhaona, Lu., Chuanxing, W, Junlong, W, and al.: Adaptive Control of Multimodal Permanent Magnet Synchronous Motor Based on Embedded Neural Network. *International Journal of High Speed Electronics and Systems*, pp. 2540122, 2024.
- [24] Ghrieb A., Salim R., Aberkane M.: Modeling an asynchronous machine based on artificial intelligence multi-models. *Journal of Vibration and Control*, 2025.
- [25] Ristanović, M and Lazic, D.: Experimental validation of improved performances of an electromechanical aerofin control system with a PWM controlled DC motor. *FME Transactions*. Vol. 34, pp. 15-20, 2006.
- [26] Perišić, N and Jovanović, R.: Control of direct current motor by using artificial neural networks in Internal model control scheme. *FME Transactions*. Vol. 51, N 1. pp 109-116, 2023.
- [27] Zhang, B., & Govindaraju, R., S.: Geomorphology-based artificial neural networks (GANN) for estimation of direct runoff over watershed. *Journal of Hydrology*. 273: pp 18–34, 2003.
- [28] Lin J-W., Huang C-W, Shih C-H, Chen C-Y.: Retracted: Fuzzy Lyapunov Stability Analysis and NN Modeling for Tension Leg Platform Systems. *Journal of Vibration and Control*. Vol. 17, pp 151–158, 2011.
- [29] Cameron, D., Kneale, P. & See, L.: An evaluation of a traditional and a neural net modelling approach to flood forecasting for an upland catchment. *Hydrol Processes*. Vol. 16. pp 1033–1046, 2002.
- [30] Bandibas, J. C. & Kohyama, K. An efficient artificial neural network training method through induced learning retardation: inhibited brain learning. *Asian Journal of Geoinformatics*. 1(4): 45–55, 2001.

## NOMENCLATURE

|             |                                                  |
|-------------|--------------------------------------------------|
| $u(t)$      | Supply voltage (V)                               |
| $i(t)$      | Armature current (A)                             |
| $R$         | Armature resistance ( $\Omega$ )                 |
| $L$         | Armature inductance (H)                          |
| $e(t)$      | Back electromotive force (V)                     |
| $\omega(t)$ | Angular velocity (rad/s)                         |
| $K_e$       | Back-EMF constant (V/(rad/s))                    |
| $J$         | Moment of inertia ( $\text{kg}\cdot\text{m}^2$ ) |
| $T_m$       | Motor torque (Nm)                                |
| $T_f$       | Friction torque (Nm)                             |
| $T_l$       | Load torque (Nm)                                 |
| $K_t$       | Torque constant (Nm/A)                           |
| $B$         | Viscous friction coefficient (Nm/(rad/s))        |
| $T_c$       | Coulomb friction torque (Nm)                     |

## ACRONYMS AND ABBREVIATIONS

|      |                                   |
|------|-----------------------------------|
| ANN  | Artificial Neural Network         |
| EMF  | Electromotive Force               |
| IGBT | Insulated-Gate Bipolar Transistor |
| MLP  | Multi-Layer Perceptron            |
| MSE  | Mean Squared Error                |
| NN   | Neural Network                    |

*PMDC* Permanent Magnet Direct Current  
*RMLP* Recurrent Multi-Layer Perceptron  
*RTNN* Recurrent Trainable Neural Network

## APPENDIX

| Motor Parameters             | Symbol | Value  | Unit             |
|------------------------------|--------|--------|------------------|
| Armature resistance          | $R_a$  | 1,4    | $\Omega$         |
| Armature inductance          | $L_a$  | 2,8    | $mH$             |
| Rotor inertia                | $J$    | 0,0012 | $kg \cdot m^2$   |
| Back-EMF constant            | $K_e$  | 0,015  | $V / (rad / s)$  |
| Viscous friction coefficient | $B$    | 0,001  | $Nm / (rad / s)$ |
| Torque constant              | $K_t$  | 0,015  | $Nm / A$         |

## УНАПРЕЂЕНО МОДЕЛИРАЊЕ PMDC МОТОРА КОРИШЋЕЊЕМ ВИШЕМОДЕЛСКОГ ПРИСТУПА НЕУРОНСКЕ МРЕЖЕ

М. Аберкане, А. Гриб, Р. Селим, А. Сегноур,  
 А. Мекри

Овај рад представља нову методологију моделирања за DC моторе са перманентним магнетима (PMDC) коришћењем вишемоделског оквира заснованог на архитектури вишеслојног перцептрона (MLP) неуронске мреже (NN). Одступајући од конвенционалних парадигми једног модела, предложени приступ користи ансамбл специјализованих MLP мрежа, чија је оптимална конфигурација вођена адаптивном евалуацијом перформанси.

Свеобухватни експериментални и симулацијски резултати показују да овај вишемоделски оквир постиже значајна побољшања у прецизности моделирања, повећаној отпорности на оперативне поремећаје и супериорним укупним перформансама у поређењу са имплементацијама једне мреже. Лабораторијски тестови потврђују ефикасност методе у различитим оперативним сценаријима, укључујући прелазне стања. Захваљујући својој прилагодљивој и скалабилној природи, ова методологија се појављује као вредна предност за софистициране стратегије управљања и дијагностичке примене у реалном времену у PMDC моторним системима.