Journal of Applied Research and Technology

www.jart.icat.unam.mx

*Journal of Applied Research and Technology* 22 (2024) 274-283

Original

# PMSM motor drive and their control schemes

I. Qureshi* • V. Sharma

*Engineering College Bikaner, Rajasthan, India*

Received 09 18 2023; accepted 01 22 2024
Available 04 30 2024

**Abstract:** This work examined various MATLAB/Simulink control strategies for a permanent magnet synchronous motor (PMSM) Drive, including closed-loop PI control, fractional order (FO) control and open-loop control. More tuning flexibility and improved adaptability to intricate and nonlinear systems are possible with Fractional Order Controllers. Especially in systems with unknown or time-varying dynamics, this frequently results in improved control performance. When compared to integer order PI controllers, it aids in lowering steady-state error. The characteristics of the system and the controller's response were more closely matched after the fractional order exponent was changed. Furthermore, by precisely controlling the transient response and constant speed response available at the desired load, the fractional order (FO) controllers facilitate smoother transitions between various control modes or set points and aid in lowering overshoot and rise time in dynamical systems. With MATLAB simulation software, the control techniques have been modelled and simulated in under steady-state and dynamic load scenarios, the suggested scheme offer effective performance.

*Keywords:* Closed-loop, open-loop, PMSM Drive, Fractional Order Control

*Corresponding author.
*E-mail address:* irfanqureshi.ee@ecb.ac.in (I. Qureshi).
Peer Review under the responsibility of Universidad Nacional Autónoma de México.

## 1. Introduction

In this section various control strategies described by the researchers have been presented.

### *1.1. Open loop control*

Zhao et al. (2004) have developed a novel Volt/Hz scheme for extra high speed Permanent magnet synchronous motor (PMSM). Chandra et al. (2015) have presented an open-loop control technique with space vector PWM scheme PMSM Drive. Liu et al. (2017) have proposed stability operation of PMSM Drive in open loop. Tang and Akin (2017) have developed an improved least-mean-square (LMS) based algorithm to minimize dead-time glitches in PMSM V/F controller techniques. For commercial appliances such as fan, thrust, and compressor drive, a cost-effective sensor-less controller scheme of PMSM constructed on Volt/Hz control is developed by Tu et al. (2017).

Volt/Hz control scheme PMSM Drive is proficient in acquiring relief from the pricey rotor location sensor and it has vast investigative importance. This scheme for PMSM Drive is proposed by Aijun and Xinhai (2017). (Pacha & Zossak, 2019), starting of PMSM Drive in open loop has been described.

### *1.2. PMSM MTPA control*

Ahmed et al. (2017) have presented a novel MTPA technique for IPMSM motor with online search algorithm. Wide speed control concerning machines nonlinearity has been described (Ge et al., 2016). Lai et al. (2018) have proposed a novel MTPA based scheme with speed harmonics measurement. Li et al. (2019) have developed MTPA control method which is independent of drive parameter. de Castro et al. (2020) have presented an ANN based MTPA control algorithm.

Han and Liu (2021) have described the effect of vibration and noise in MTPA control PMSM Drive. Lee and Choi (2022) have proposed MTPA control with P&O algorithm for PMSM Drive. Huang et al. (2023) have investigated an offline data based MTPA control technique for IPMSM drive.

### *1.3. PMSM field weakening control*

Sun et al. (2017) have developed a novel flux weakening algorithm with hybrid dual inverter technique. DC link voltage has been more utilize by this scheme. Xu et al. (2019) have explained swarm optimization scheme for flux weakening control in PMSM Drive. Zheng and Sun (2020) have investigated cost function predictive model flux control scheme for PMSM motor. The advantage of this method is to increase the torque at greater speed. Zheng et al. (2020) also studied the predictive model technique. Wang et al. (2022) have proposed a novel modulation technique for PMSM Drive.

### *1.4. Fractional order PI controller*

Rajasekhar et al. (2011) have developed a special hybrid PSO FO-PI scheme for PMSM Drive. Li et al. (2014) have proposed FO-Pi scheme for PMSM Drive. Thakar et al. (2016) also explained the FO-PI technique for PMSM Drive.

Kumar et al. (2021) have presented the FO-PI scheme for PMSM Drive speed control. The system was developed in a lab-view, and an evaluation of FOPI and Existing PI was studied. Li et al. (2023) have proposed the FO-PI scheme to minimize for voltage faults in PMSM Drives.

The usefulness of a fractional order-proportional integral (FO-PI) controller in optimizing the dynamics of a dynamic system has been examined. The efficiency of the FO-PI controller was found to have the potential to improve the performance of dynamical systems.

The characteristics of the system better matched the response of the controller by modifying the fractional order exponent of FO-PI control. Additionally, because they enable more precise control of the transient response, the proposed controllers help to reduce overshoot and rise time in dynamical systems and enable smoother transitions between various control modes or set points.

## 2. Suggested control scheme

This paper presented the various PMSM Drive speed control schemes. The Figure 1 shows the proposed scheme.

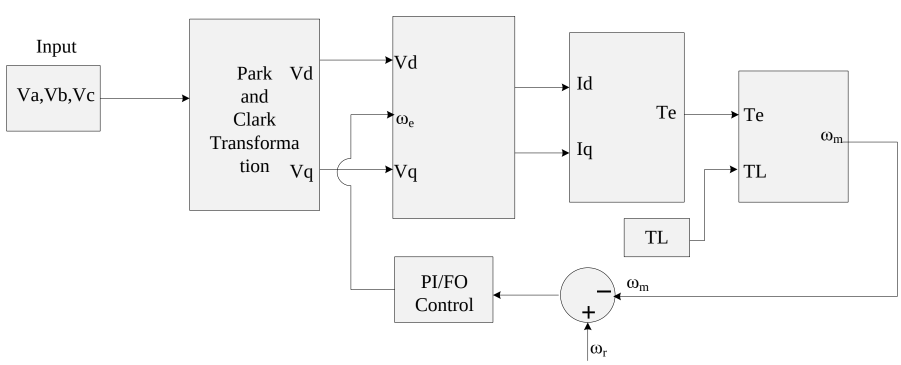


Figure 1. Proposed scheme.

The voltage and current of the drive are used to compute the momentum of the motor. So, the sensor is not used for speed sensing.

Clark and Park's conversions are used for vector control. Calculated speed is then compared with reference speed then a FOPI control is being used to minimize error. FOPI is superior to exiting PI controller. The FOPI gives smother transitions between different states.

### *2.1. Vector transforms*

Park's and Clark's transformations are key to vector control. The transformation function is used is given by following program.

$function\ [vd, vq] = ParkClarke(va, vb, vc, theta)$

$if\ isempty\ (theta)$

$theta = 0;$

$end$

$vd = (2/3) * (va * cos(theta) + vb * cos(theta - (2 * pi/3)) + vc * cos(theta + (2 * pi/3)));$

$vq = (2/3) * (-va * sin(theta) - vb * sin(theta - (2 * pi/3)) - vc * sin(theta + (2 * pi/3)));$

$end$

## 3. Control schemes for PMSM Drives

Different techniques to control the PMSM Drive have been presented in this section and simulated in MATLAB. The block diagrams have been depicted of these schemes.

In open loop, there is no feedback signal to speed; only reference speed is used as shown in Figure 2. In closed loop, there is a feedback signal of the speed; this signal is compared with the reference signal as shown in Figure 3. The PI regulator reduced the fault signal and the 2-$\phi$ quantity is being transformed to 3- $\phi$ before being applied to the PWM inverter PMSM Drive.

Two manage loops have been used. The interior loop controls the motor's stator currents. The external loop with FO-Pi controller controls the rpm of the motor as depicted in Fig.4. A $3 - \phi$ PMSM driven via a PWM inverter. The PWM inverter is designed by using the MATLAB library. Its output passes through the restricted voltage source blocks before giving to the stator windings of the PMSM Drive.

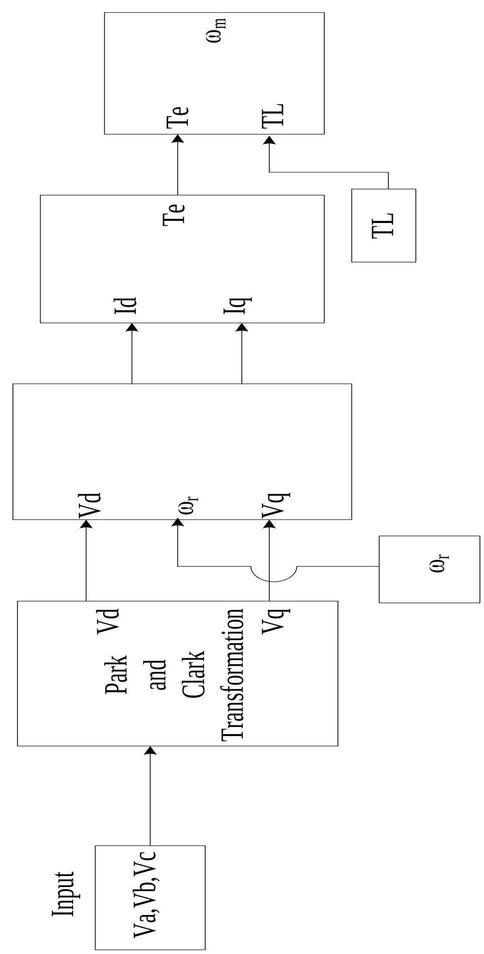


Figure 2. Open-loop PMSM Drive.

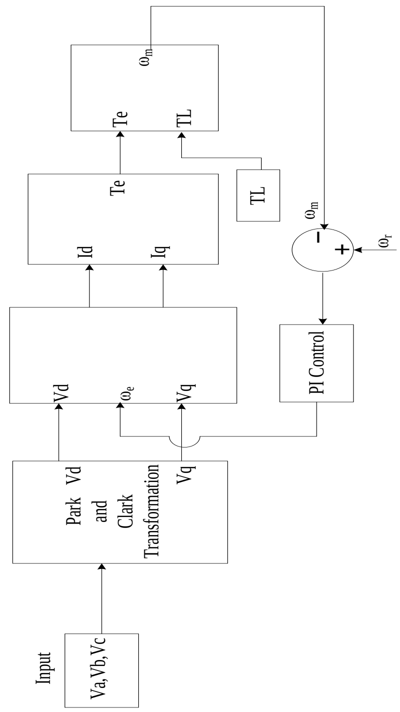


Figure 3. Closed-loop PWM-controlled PMSM Drive.

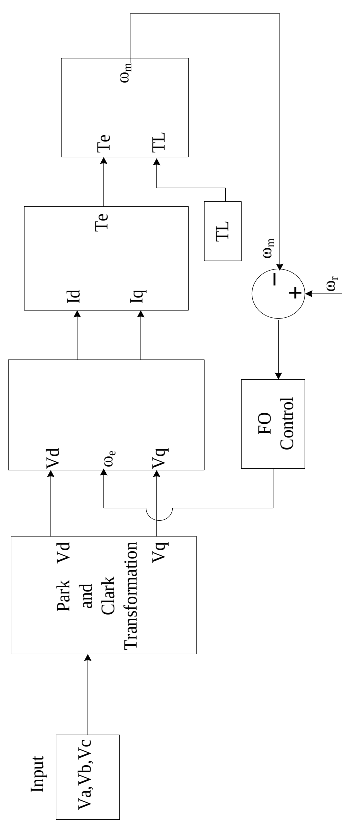


Figure 4. FOPI control PMSM Drive.

## 4. Simulation results and discussion

Figure 5 shows the open-loop control of PMSM Drive.

In open-loop system no feedback signal for the speed so the desired speed is not achieved with this, we must use some closed-loop system for this.

As shown in Figure 6 the closed-loop PI control PMSM Drive, the desired speed around 300 rps achieved and the is 3Nm; After 0.5 sec. load torque reduced and the torque is 1 Nm.

Figure 7 shows the FO control PMSM Drive. The results are better the existing PI control. Torque and speed are found very stable. A comparison of the speed and torque has been provided in the Section 4.2.

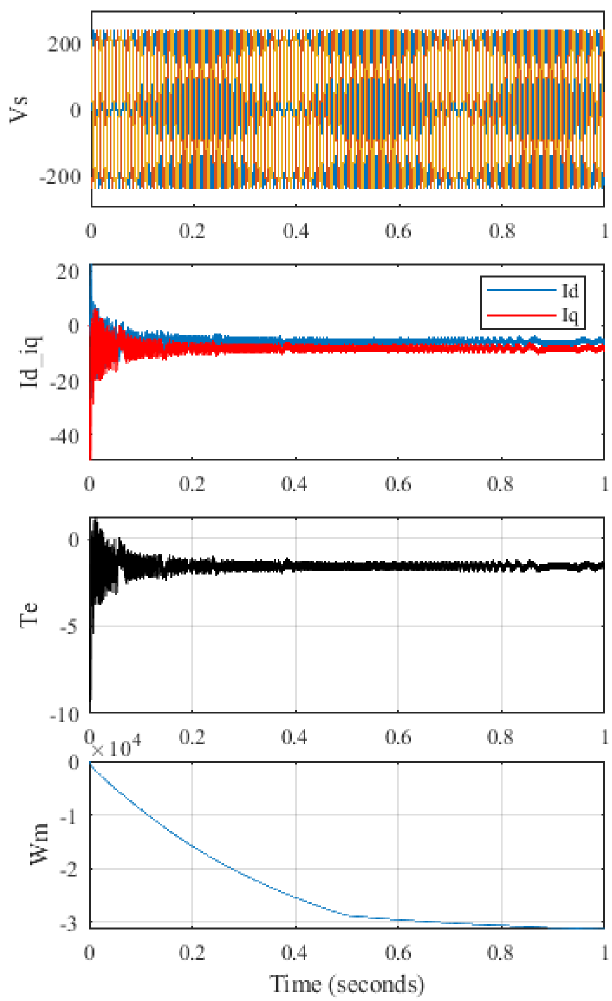


Figure 5. Open-loop PMSM Drive.

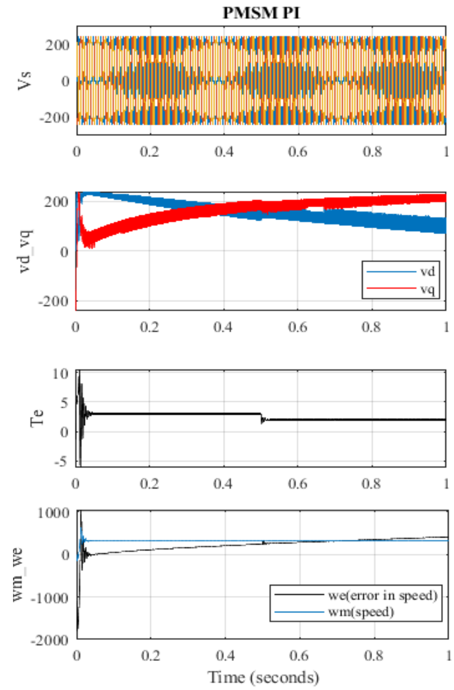


Figure 6. Closed loop with PI control PMSM Drive.

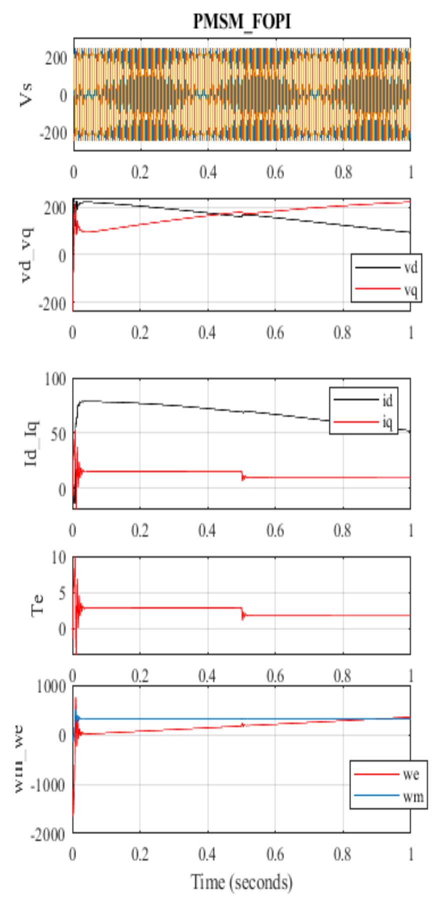


Figure 7. FOPI control sensor-less PMSM Drive.

### 4.1. Fractional order proportional integral (FOPI) controller

A FOPI (Qureshi & Sharma, 2023) employed in the speed loop of the PSMM drive is represented in Figure 8.

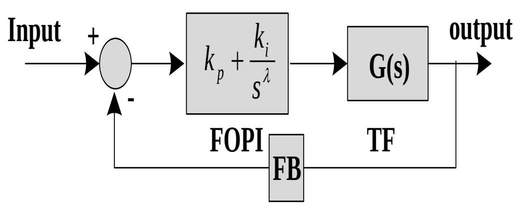


Figure 8. FOPI controller.

The transferal function of a FOPI is given by (1).

$$C(s) = k_p + k_i S^{-\lambda} \tag{1}$$

Where, $\lambda$ is a positive real parameter between 0 and 1.

In FOPI controller values can be tuned by different ways. But in our system, a simple method is being used, because of their commercial used purpose. The parameter of $k_p$ and $k_i$ changed by existing hit and trial method for pi controller and value of $\lambda$ in FOPI is set via same method to achieve the desired response.

### 4.2. Comparison of FOPI and PI control techniques

Figure 9 Shows speed comparison of controllers.

Using FOPI controller speed reaches stable condition faster the PI as depicted in Figure 9. As seen from the starting of motor. The Figure 10 shoes the torque comparison between the PI and FOPI controller, FOPI has smother response than PI controller as seen from the Figure 10 FOPI control waveform has fewer transients the PI.

The Table 1 has been presented the comparison of FOPI and PI controller.

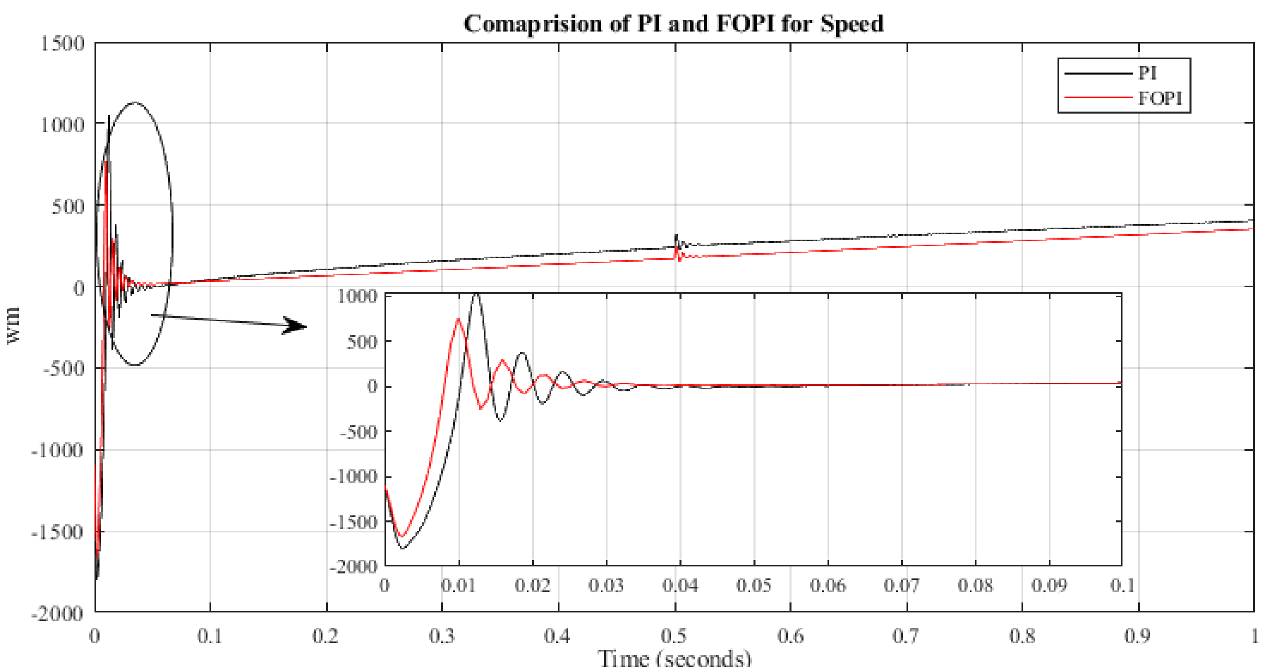


Figure 9. Comparison of PI and FOPI controller for speed.

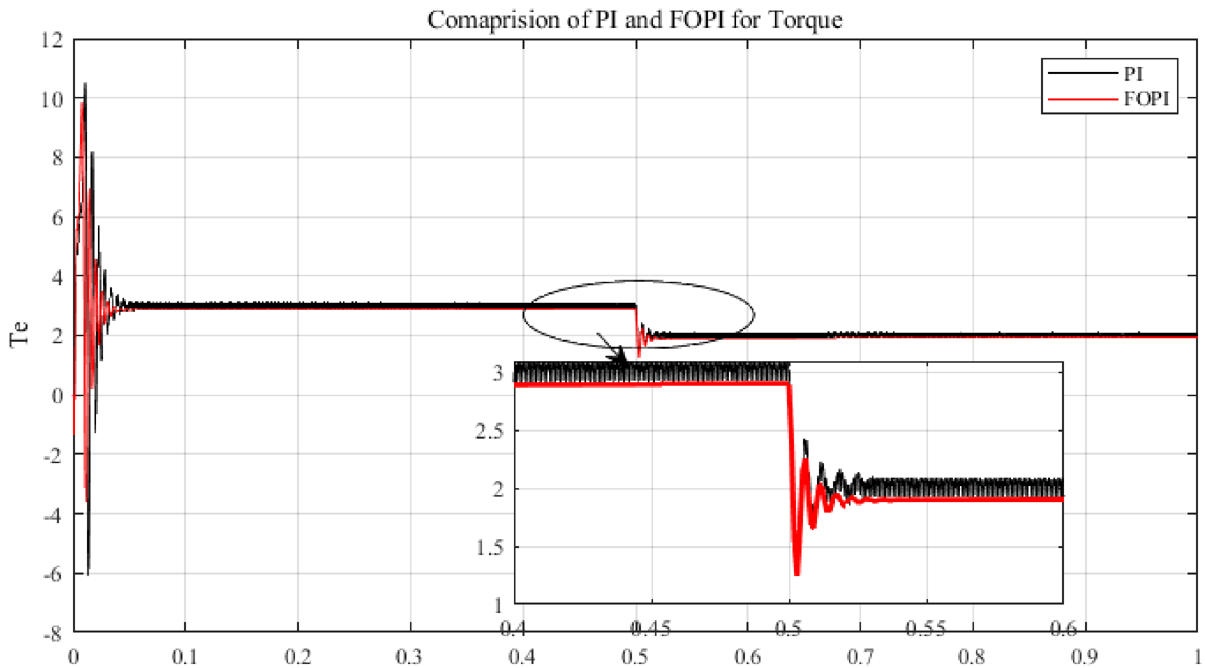


Figure 10. Comparison of PI and FOPI controller for torque.

Table 1. Comparison of FOPI and PI.

| Parameter | FO Control | PI Control |
|---|---|---|
| Response time | Very good | Good |
| Stability | Much faster to reach stable condition than PI | Better than open loop but not as FOPI |
| Dynamic system | Smother transient response than PI. | Good but not as FOPI |
| Switching | Switching in different states is smother than PI | God but not as FOPI |
| Fluctuations | Less fluctuation in motor | Fluctuations are more compared to PI |

## 5. Conclusion and Future Scope

In this the speed-toque control of PMSM Drive using PI and Fractional Order Control methods has been presented. The open-loop PMSM Drive is easy to implement for the low cost and small industrial applications. The close loop PMSM Drive has been used widely in many applications like, EVs, HEVs, Water Pumping and etc. Here a comparison of existing PI controller with FO controller has been presented. Fractional Order Controller provides smother transient response and better stability control the existing PI controller.

For the Future Scope, further research the purposed Fractional Order Controller may be used in many multi-order systems and with other Artificial Intelligent system.

## Conflict of interest

The author(s) has (have) no conflict of interest to declare.

## Funding

The author(s) received no specific funding for this work.

## References

Aijun, C., & Xinhai, J. (2017). A stable V/F control method for permanent magnet synchronous motor drives. In *2017 IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia-Pacific)* (pp. 1-5). IEEE.
https://doi.org/10.1109/ITEC-AP.2017.8080913

Ahmed, A., Sozer, Y., & Hamdan, M. (2017). Maximum torque per ampere control for buried magnet PMSM based on DC-link power measurement. *IEEE Transactions on Power Electronics*, *32*(2), 1299-1311.
https://doi.org/10.1109/TPEL.2016.2543663

Chandra, A., Datta, S., & Chowdhuri, S. (2015). Open loop speed control of a space vector PWM inverter fed PM synchronous motor. In *Michael Faraday IET International Summit 2015* (pp. 136-141). IET.
https://doi.org/10.1049/cp.2015.1620

de Castro, A. G., Guazzelli, P. R. U., de Oliveira, C. M. R., de Andrade Pereira, W. C., de Paula, G. T., & de Almeida Monteiro, J. R. B. (2020). Optimized current waveform for torque ripple mitigation and MTPA operation of PMSM with back EMF harmonics based on genetic algorithm and artificial neural network. *IEEE Latin America Transactions*, *18*(09), 1646-1655.
https://doi.org/10.1109/TLA.2020.9381808

Ge, H., Miao, Y., Bilgin, B., Nahid-Mobarakeh, B., & Emadi, A. (2016). Speed range extended maximum torque per ampere control for PM drives considering inverter and motor nonlinearities. *IEEE Transactions on Power Electronics*, *32*(9), 7151-7159.
https://doi.org/10.1109/TPEL.2016.2630051

Han, Z., & Liu, J. (2020). Comparative analysis of vibration and noise in IPMSM considering the effect of MTPA control algorithms for electric vehicles. *IEEE Transactions on Power Electronics*, *36*(6), 6850-6862.
https://doi.org/10.1109/TPEL.2020.3036402

Huang, K., Peng, W., Lai, C., & Feng, G. (2023). Efficient maximum torque per ampere (MTPA) control of interior PMSM using sparse Bayesian based offline data-driven model with online magnet temperature compensation. *IEEE Transactions on Power Electronics*, *38*(4), 5192-5203.
https://doi.org/10.1109/TPEL.2022.3230052

Kumar, D. M., Cirrincione, M., Mudaliar, H. K., di Benedetto, M., Lidozzi, A., & Fagiolini, A. (2021). Development of a Fractional PI controller in an FPGA environment for a Robust High-Performance PMSM Electrical Drive. In *2021 IEEE 12th Energy Conversion Congress & Exposition-Asia (ECCE-Asia)* (pp. 2427-2431). IEEE.
https://doi.org/10.1109/ECCE-Asia49820.2021.9479450

Lai, C., Feng, G., Mukherjee, K., Tjong, J., & Kar, N. C. (2018). Maximum Torque Per Ampere Control for IPMSM Using Gradient Descent Algorithm Based on Measured Speed Harmonics. *IEEE Transactions on Industrial Informatics*, *14*(4), 1424-1435.
https://doi.org/10.1109/TII.2017.2759812

Lee, J., & Choi, J. W. (2022). MTPA control method for MIDP SPMSM drive system using angle difference controller and P&O algorithm. *IEEE Transactions on Power Electronics*, *37*(12), 15382-15396.
https://doi.org/10.1109/TPEL.2022.3196400

Li, C., Chen, M., & Gao, S. (2014). Fractional order PI speed control for permanent magnet synchronous motor drives. In *Proceeding of the 11th World Congress on Intelligent Control and Automation* (pp. 4681-4685). IEEE.
https://doi.org/10.1109/WCICA.2014.7053504

Li, Z., Feng, G., Lai, C., Li, W., & Kar, N. C. (2019). Machine parameter-independent maximum torque per ampere control for dual three-phase PMSMs. *IEEE Transactions on Transportation Electrification*, *5*(4), 1430-1440.
https://doi.org/10.1109/TTE.2019.2953656

Li, F., Luo, Y., Luo, X., Chen, P., & Chen, Y. (2023). Optimal FOPI Error Voltage Control Dead-Time Compensation for PMSM Servo System. *Fractal and Fractional*, *7*(3), 274.
https://doi.org/10.3390/fractalfract7030274

Liu, J., Nondahl, T. A., Schmidt, P. B., Royak, S., & Rowan, T. M. (2017). Generalized stability control for open-loop operation of motor drives. *IEEE Transactions on industry applications*, *53*(3), 2517-2525.
https://doi.org/10.1109/TIA.2017.2661249

Pacha, M., & Zossak, S. (2019). Improved simple IF open-loop start-up of PMSM drives without speed or position sensor. In *2019 IEEE 10th International Symposium on Sensorless Control for Electrical Drives (SLED)* (pp. 1-6). IEEE. https://doi.org/10.1109/SLED.2019.8896231

Quadrant. *IEEE Transactions on Industrial Electronics*. https://doi.org/10.1109/TIE.2022.3217606

Qureshi, I., & Sharma, V. (2023). Analysis of different control schemes of PMSM motor and also a comparison of FOPI and PI controller for sensorless MSVPWMM scheme. *e-Prime-Advances in Electrical Engineering, Electronics and Energy*, *6*, 100359. https://doi.org/10.1016/j.prime.2023.100359

Rajasekhar, A., Jatoth, R. K., Abraham, A., & Snasel, V. (2011). A novel hybrid ABF-PSO algorithm based tuning of optimal FOPI speed controller for PMSM drive. In *2011 12th International Carpathian Control Conference (ICCC)* (pp. 320-325). IEEE. https://doi.org/10.1109/CarpathianCC.2011.5945872

Sun, D., Zheng, Z., Lin, B., Zhou, W., & Chen, M. (2017). A hybrid PWM-based field weakening strategy for a hybrid-inverter-driven open-winding PMSM system. *IEEE Transactions on Energy Conversion*, *32*(3), 857-865. https://doi.org/10.1109/TEC.2017.2676020

Tang, Z., & Akin, B. (2017). A new LMS based algorithm to suppress dead-time effects in PMSM V/f drives. In *2017 IEEE Applied Power Electronics Conference and Exposition (APEC)* (pp. 3156-3162). IEEE. https://doi.org/10.1109/APEC.2017.7931148

Thakar, U., Joshi, V., & Vyawahare, V. (2016). Fractional-order PI controller design for PMSM: A model-based comparative study. In *2016 International Conference on Automatic Control and Dynamic Optimization Techniques (ICACDOT)* (pp. 164-169). IEEE. https://doi.org/10.1109/ICACDOT.2016.7877571

Tu, W., Xiao, G., Suo, C., & Yang, K. (2017). A design of sensorless permanent magnet synchronous motor drive based on V/f control. In *2017 20th International Conference on Electrical Machines and Systems (ICEMS)* (pp. 1-5). IEEE. https://doi.org/10.1109/ICEMS.2017.8056032

Wang, B., Wang, L., Yu, Y., & Xu, D. (2022). Adaptive Overmodulation Strategy for PMSM Field-Weakening Control Based on Working Quadrant. *IEEE Transactions on Industrial Electronics*. https://doi.org/10.1109/TIE.2022.3217606

Xu, W., Ismail, M. M., Liu, Y., & Islam, M. R. (2019). Parameter optimization of adaptive flux-weakening strategy for permanent-magnet synchronous motor drives based on particle swarm algorithm. *IEEE Transactions on Power Electronics*, *34*(12), 12128-12140. https://doi.org/10.1109/TPEL.2019.2908380

Zhao, L., Ham, C. H., Han, Q., Wu, T. X., Zheng, L., Sundaram, K. B., ... & Chow, L. (2004). Design of an optimal V/f control for a super high speed permanent magnet synchronous motor. In *30th Annual Conference of IEEE Industrial Electronics Society, 2004. IECON 2004* (Vol. 3, pp. 2260-2263). IEEE. https://doi.org/10.1109/IECON.2004.1432151.

Zheng, Z., & Sun, D. (2019). Model predictive flux control with cost function-based field weakening strategy for permanent magnet synchronous motor. *IEEE Transactions on Power Electronics*, *35*(2), 2151-2159. https://doi.org/10.1109/TPEL.2019.2921361

Zheng, Z., Sun, D., Wang, M., & Nian, H. (2020). A dual two-vector-based model predictive flux control with field-weakening operation for OW-PMSM drives. *IEEE Transactions on Power Electronics*, *36*(2), 2191-2200. https://doi.org/10.1109/TPEL.2020.3007829

## Appendix

The Parameters used for the proposed 30kW PMSM motor drive scheme have been depicted in Table 2.

Table 2. Parameters of PMSM Drive and FOPI controller.

| Parameters | Value | Unit |
|---|---|---|
| Stator resistance | 2.98 | Ω |
| D-Q axis inductance | $7*10^{-3}$ | Henry |
| Flux Linkage | 0.125 | |
| Movement of inertia | $0.47*10^{-4}$ | $Kg.m^2$ |
| Value of fractional order | 0.5 | - |
| Kp | 3.62 | - |
| Ki | 26.61 | - |
| DC voltage | 240 | Volts |
| Reference speed | 300 | Rps |