Bulletin of Electrical Engineering and Informatics
Vol. 12, No. 5, October 2023, pp. 2682~2692
ISSN: 2302-9285, DOI: 10.11591/eei.v12i5.4554

Performance analysis of FOC space vector modulation DCMLI driven PMSM drive

Rakesh Shriwastava[1], Mohan P. Thakre[2], Jagdish Choudhari[3], Sunil Somnath Kadlag[4], Rahul Mapari[5], Deepak Prakash Kadam[6], Shridhar Khule[1]
[1]Department of Electrical Engineering, Matoshri College of Engineering and Research Center, Nashik, India
[2]Department of Electrical Engineering, SVERI's College of Engineering, Solapur, India
[3]Department of Electrical Engineering, Nagpur Institute of Technology, Nagpur, India
[4]Department of Electrical Engineering, Amrutvahini College of Engineering, Sangamner, India
[5]Department of Electrical Engineering, Pimpri Chinchwad College of Engineering and Research, Ravet Pune, India
[6]Department of Electrical Engineering, MET Institute of Engineering, Nashik, India

Article Info

Article history:

Received Sep 12, 2022
Revised Nov 2, 2022
Accepted Mar 24, 2023

Keywords:

Automatic voltage regulator
Field oriented control
Permanent magnet synchronous motor
Space vector modulation
Total harmonic distortion

ABSTRACT

The effectiveness of a permanent magnet synchronous motor (PMSM) drive managed by an automatic voltage regulator (AVR) microcontroller using field oriented control (FOC) with space vector modulation (SVM) and a diode clamped multilevel inverter (DCMLI) is investigated. Due to its efficacy, FOC would be widely implemented for PMSM speed regulation. The primary drawbacks of a 3-phase classic bridge inverter appear to be reduced dv/dt stresses, lesser electromagnetic interference, and a relatively small rating, especially when compared to inverters. PMSMs have a better chance of being adopted in the automotive industry because of their compact size, high efficiency, and durability. The SVM idea states that an inverter's three driving signals are created simultaneously. Using MATLAB simulations, researchers looked into incorporating a DCMLI with a resistive load on an AVR microcontroller. Torque, current, and harmonic analysis were evaluated between the SVM and the inverter-driven PMSM drive in this research. In comparison to the prior art, the proposed PMSM drive has better speed and torque management, less output distortion, and less harmonic distortion.

Corresponding Author:

Rakesh Shriwastava
Department of Electrical Engineering, Matoshri College of Engineering and Research Center
Nashik, India
Email: rakesh_shriwastava@rediffmail.com

1. INTRODUCTION

The characteristics of permanent magnet synchronous motor (PMSM) are the low value of cogging torque, ruggedness, high efficiency, high power to weight ratio, and additional reluctance torque. In an electric vehicle application, the motor, run to different load and speed profiles; hence it is used application. In PMSM, due to the magnet in the rotor and constant air gap, it is not needed to supply magnetizing currents through the stator flux. When at high speed, it gives high current and fewer switching losses. If put into practice, it would allow for a range of speeds by rapidly switching between low switching frequencies for slow speeds and high switching frequencies for fast speeds [1], [2]. Vector control is the most useful method for field oriented control (FOC). The FOC approach has replaced the direct torque control (DTC) method in AC drives [3], [4] because of its superior performance. The good-current regulation, high torque response, and simple construction have the advantages of FOC. Some of the advantages of multilayer inverters include increased efficiency, lower voltage distortion, lower harmonic content, and lower dv/dt at each switch. A pulse width modulation (PWM) controller multilayer inverter can switch to a lower frequency [5], [6]. The FOC is a vector control method based on the working principle of a separately excited d.c motor. This method can effectively control the motor torque and flux by controlling the stator reference currents, rotor angle, and torque of the alternating machine. In this paper, a novel space vector modulation (SVM) technique is designed for the FOC based diode clamped multilevel inverter (DCMLI) PMSM to drive for torque, speed, and stator current of PMSM [6].

The inverter switching vectors have been automatically constructed from the instantaneously sampled reference phase voltages [7], [8] without the need for lookup tables or difficult logical choices. In this study, we analyze DCMLI using a simulated SVM and then feed the results into a three-phase resistive load. It reduces switching losses and total harmonic distortion (THD). In this case, the automatic voltage regulator (AVR) microcontroller simulation results have been confirmed for use in actual projects. Pulses are generated by the atmega 8 and fed into the inverter.

FOC provides high-quality control capability in FOC SVM over the full range of torque and speed fluctuations [9]–[11].There are d & q current modes in FOC The q torque mode is run the desired torque from the PMSM. The d current mode is run with a zero to minimize the unwanted direct torque component [12]–[14]. To overcome this drawback in PWM, an SVM modulation technique is used.SVM selects vectors in a d-q stationary frame. Space vectors are based on induction machines magnetism. Three-phase amounts become two-phase [15], [16]. Space vectors can represent active and "0" switching [17]. V1-V6 forms a symmetric hexagon to diversify sectors (1 to 6). Each sector is 60° apart. SPWM compares sine waves to triangular waves [18]–[20]. Switching points result from the triangular carrier wave of frequency fc and the reference modulatory sine wave of frequency fm. This research presents MATLAB simulation and hardware validation of three-level DCMLI-fed FOC-PMSM drives using SVM and AVR microcontroller [21]–[25]. This paper follows this format. Section 1 covers the overview, section 2 the analytical approach, section 3 the virtual world assessment and outcomes, and section 4 the hardware configuration. section 5 is the experimental outcome and the conclusion of this paper is in section 6.

2. METHODOLOGY

Mathematical model analysis of PMSM is a concern, the *d*-axis-induced voltage is:

$$u_d = R_d i_d + \frac{d\lambda_d}{dt} - \omega_r \lambda_q \tag{1}$$

The *q*-axis induced voltage is:

$$u_q = R_q i_q + \frac{d\lambda_q}{dt} - \omega_r \lambda_d \tag{2}$$

$$\lambda_d = L_d i_d + \lambda_m \tag{3}$$

$$\lambda q = Lqiq \tag{4}$$

$$Ld = Lq \tag{5}$$

The torque equation is:

$$T_e = \frac{3}{2}\frac{\mathrm{p}}{2}(\lambda_\mathrm{d} i_q - \lambda_\mathrm{q} i_d) \tag{6}$$

Put in (7):

$$T_e = \frac{3}{2}\frac{\mathrm{p}}{2}[(\lambda_\mathrm{d} i_d + \lambda_m) i_q - \mathrm{L_q} i_q i_d] \tag{7}$$

$$T_e = \frac{3}{2}\frac{\mathrm{p}}{2}[(\mathrm{L_d} - L_q) i_d i_q + \lambda_m i_q] \tag{8}$$

$$Reluctancetorque = \frac{3}{2}\frac{\mathrm{p}}{2}(\mathrm{L_d} - L_q) i_d i_q \tag{9}$$

$$fieldtorque = \frac{3}{2}\frac{\mathrm{p}}{2} \lambda_m i_q \tag{10}$$

$$T_e = \frac{3}{2}\frac{\mathrm{p}}{2} \lambda_m i_q \tag{11}$$

$$Te=Ktiq \tag{12}$$

$$K_t = \frac{3}{2}\frac{p}{2} \lambda_m \tag{13}$$

Therefore, electromagnetic torque is:

$$T_e = T_l + B_{\omega_m} + J\frac{d\omega_m}{dt} \tag{14}$$

The primary goal of FOC is the control of torque and currents along the stator axis (d and q). By regulating the motor's torque and flux based on information from the stator currents and the rotor angle, FOC can accomplish desirable results such as high output and reduced torque ripple. The system consists of a current regulator, a direct-axis component, a q-axis component, and a speed regulator. The FOC method is depicted in block format in Figure 1.

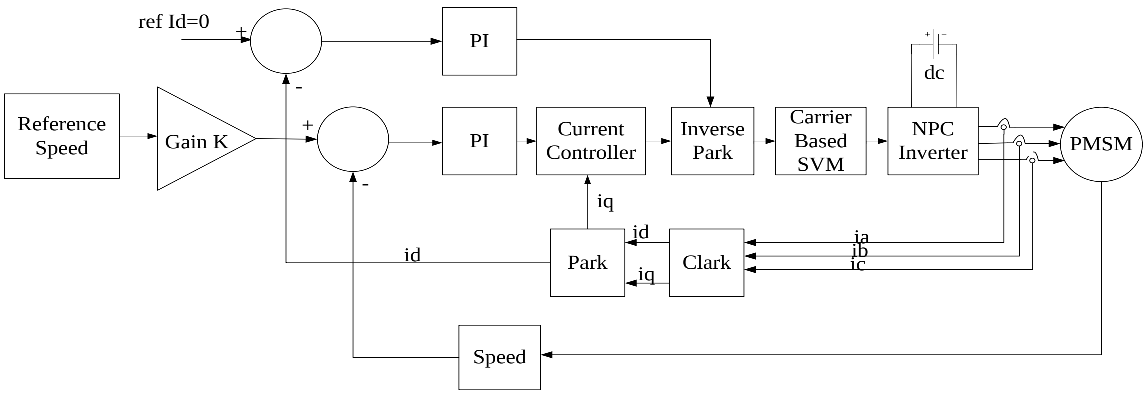


Figure1. Schematic illustration of FOC

Design of converter:

- Design of diode bridge rectifier

Voltage (input)=290 V, frequency=50 Hz, filter output voltage (rectifier)=380 Vdc

- Design of three-level diode clamp inverter, while selecting MOSFET, V_{dc}>0.707 xm_a Vdc [let m_a=1 (max)]>0.707×1×380>268.66 volts, V_{gs}>12 volts, I_d>I_{Lmax}>2 amps

Transition times should be minimized. IRFP460 is the MOSFET of choice, output voltage (inverter)=280 V, switching frequenc=2.5 KHz, inverter rating (KVA)=1.5 KVA

- Isolator drive and AVR microcontroller details

To regulate the output, there are twelve 7,812 ICs and twelve 4N35 optical couplers. The transformers have a rating of 230 volts to 12 volts and 500 milliamperes (12 No). The ATmega8 (28 Pin) is responsible for creating pulses, while the ATmega16 (40 Pin) is in charge of the control and monitoring circuit (40 Pin).

3. SIMULATION ANALYSIS AND DISCUSSION

The simulation diagram of FOC is shown in Figure 2. Design, simulation, and implementation of FOC SVM DCMLI-driven PMSM drive using an AVR microcontroller are investigated for the different speeds. It is shown in Figures 3-7. The frequency analysis of the inverter output and THD analysis are shown in Figures 8 and 9. The parameters of the motor and inverter have been listed in Tables 1 and 2. THD, torque, and current ripples of DCMLI are listed in Tables 3 and 4. Figures 3 and 4 shows inverter voltage and current respectively with less THD. Figures 5-7 show the performance of the PMSM drive using SVM.

The reference speed changed from 0 to 1,000 rpm for time t=0.05 s and speed are constant for the time of t=0.05 s to 0.3 s. Motor speed was 1,700 rpm for time t=0.3 s to 0.35 s. Speed reached the reference valuefor time t=0.6s as shown in Figure 6. The value of load torque is 0.2 N.m for time t=0s to 0.4s. It is decreased for time t=0.3s to 0.4sshown in Figure 6. The initial current of the motor was 1.4 amp and it reduces up to 1.3 amp for time t=0s to 0.1s as shown in Figure 7.

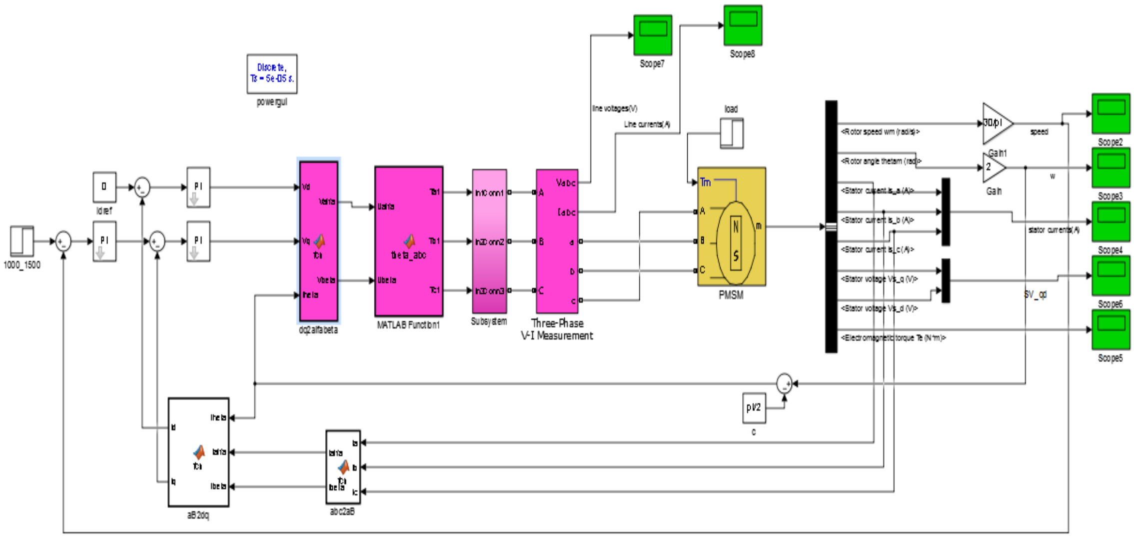


Figure 2. Simulation diagram of FOC

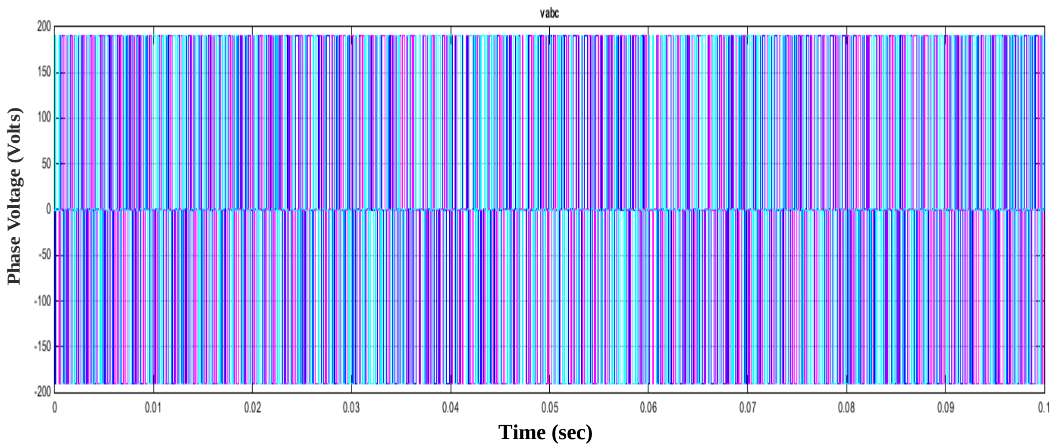


Figure 3. Output voltage of FOC-DCMLI

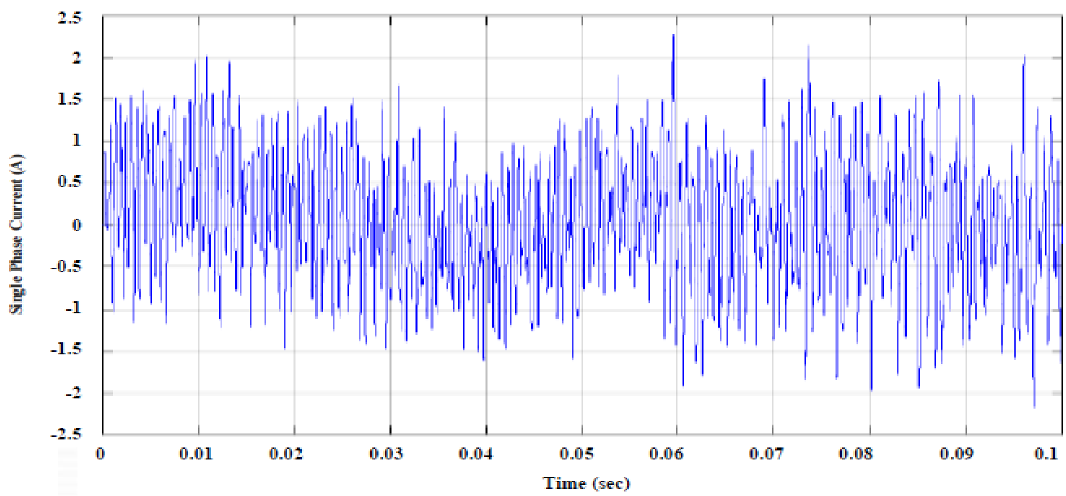


Figure 4. Output three-phase current FOC-DCMLI

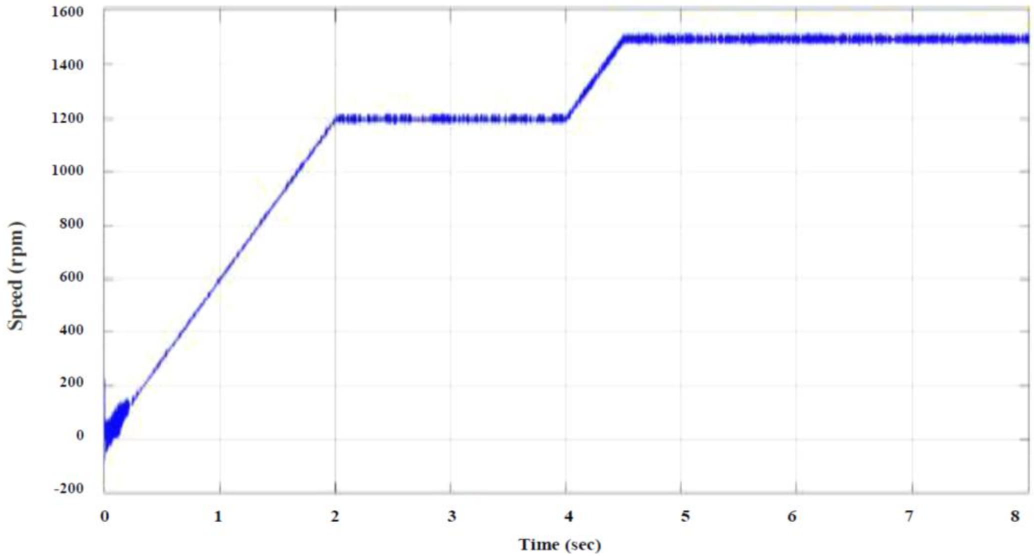


Figure 5. Output speed response of FOC-DCMLI

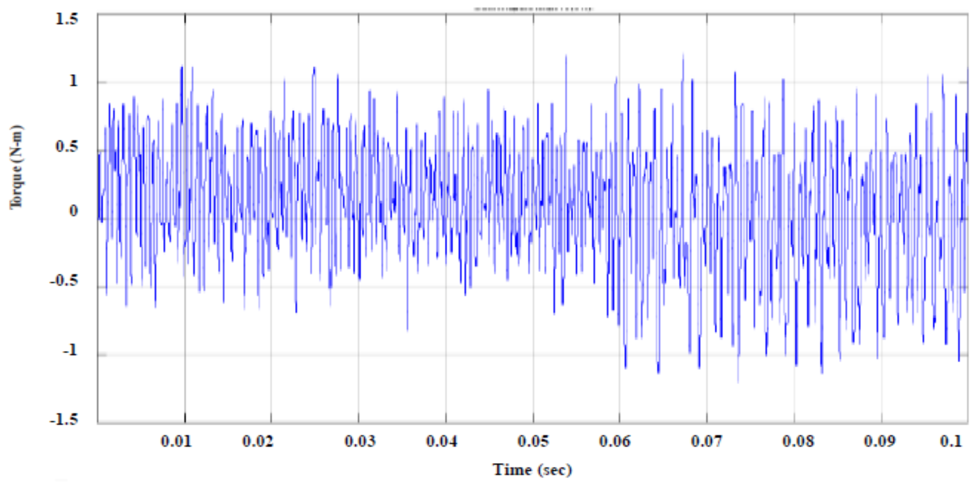


Figure 6. Output torque response of FOC-DCMLI

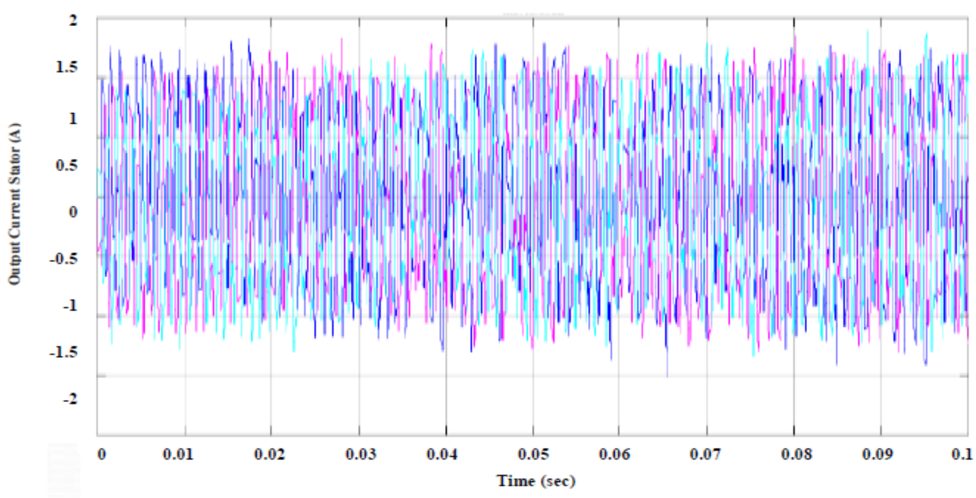


Figure 7. Output phase current FOC-DCMLI

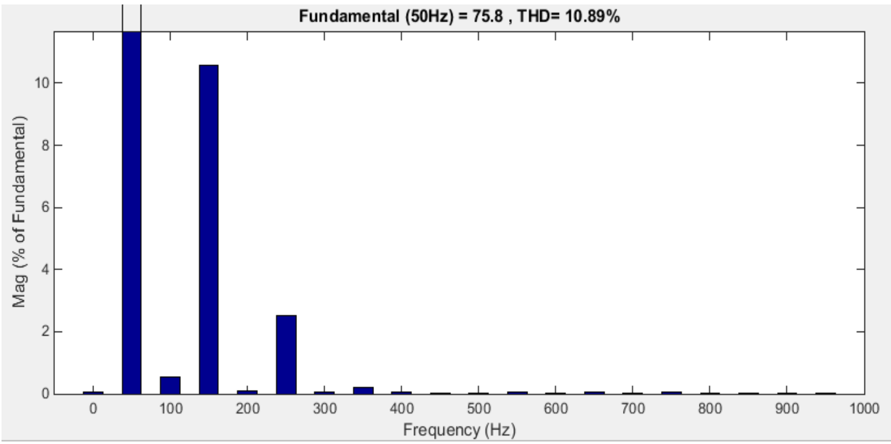


Figure 8. THD of the voltage of FOC-DCMLI

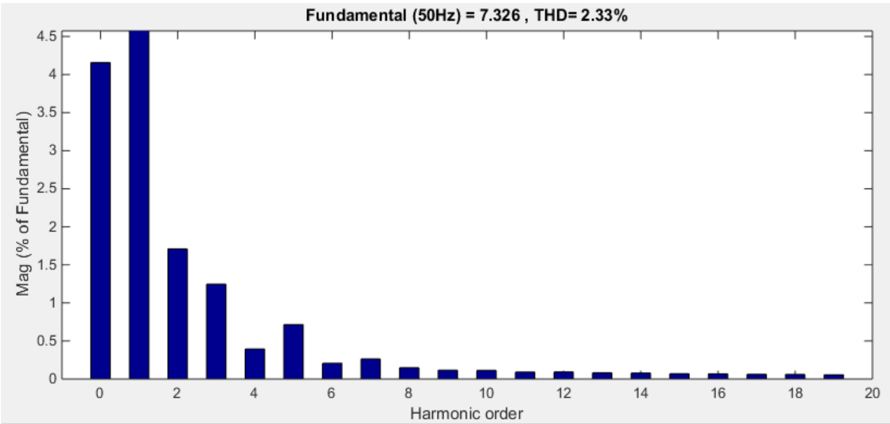


Figure 9. THD of current of FOC-DCMLI

Table 1. PMSM specification

Parameters	Values
Motor stator resistance (R_s)	4.865 Ω
Motor stator inductance (L_a)	0.0174 H
Motor torque (T_e)	0.544 N-m
Movement of inertia (J)	0.000114 Kg/m2
Viscous coefficient (f)	0.0000447 Nms
Number of pole(P) pair	2
Inductive load	PMSM

Table 2. Inverter parameter

Parameters	Values
Input voltage	280 V (rms)
Output filter voltage	380 Vdc
Supply frequency	50 Hz
Inverter voltage	270V
Switching frequency	2.5 kHz
Inverter rating	1.5 KVA
Resistive load	200 Watts

Table 3. THD analysis

Parameter	THD (%)
Voltage	10.89
Current	2.33

Table 4. Torque and current ripples

FOC	1100 rpm	1300 rpm	1600 rpm
Torque ripples	0.52 Nm	0.49 Nm	0.46 Nm
Current ripples	8.4 mA	7.8 mA	7.5 mA

4. HARDWARE ANALYSIS

The block diagram of the proposed AVR microcontroller-based three-level DCMLI with three-phase resistive load and real image for the experiment is shown in Figures 10 and 11 respectively. The three-level DCMLI is used to convert DC to three phases of AC. The generation of pulses using the SVM technique by the AVR microcontroller is shown. For triggering the insulated gate bipolar transistors (IGBTs), DCMLI generates gate pulses.

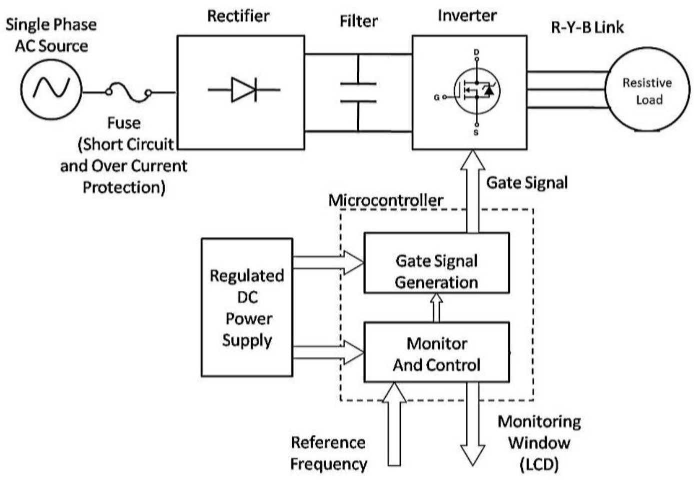


Figure 10. Block schematic of proposed FOC-DCMLI PMSM drive

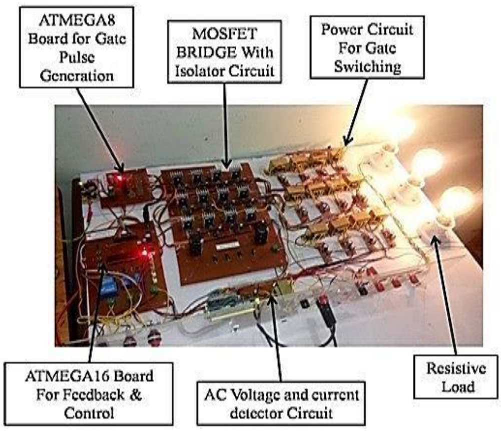


Figure 11. Real image for the experiment

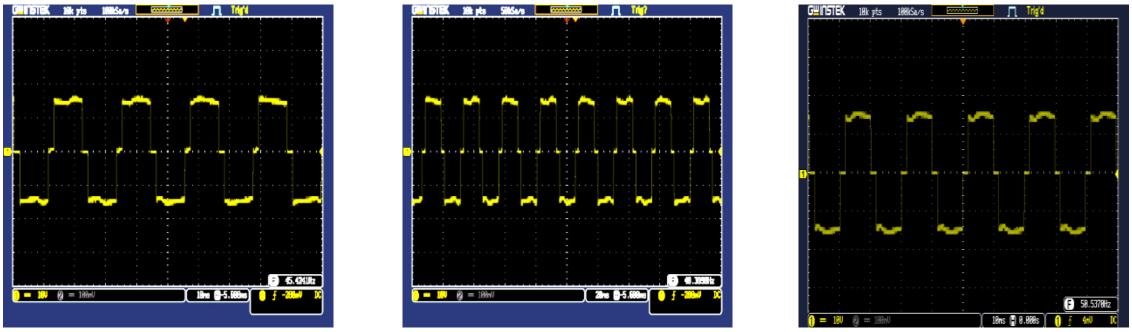
5. EXPERIMENTAL OUTCOME

A proposed method has been established by using AVR microcontroller. An empirical investigation has been carried out with a view to the validity of the presented AVR microcontroller premised SVM. Methods of regulation have been presented, and their efficacy with a 3 Nm load has been demonstrated. It has been experimentally looked into how fast each approach can respond. Load-related variations in the motor speed at constant modulating frequencies of 40 Hz, 45 Hz, and 50 Hz. Figures 12(a)-(c) display DCMLI phase voltages at 40 Hz, 45 Hz, and 50 Hz, respectively.

To verify the reliability of the suggested SVM approach, a three-tiered DCMLI was devised and implemented. DC-modulated multi-level interleaved-switched voltage modulation is superior to PWM. Figures 13(a)-(c) display the DCMLI line voltages at 40 Hz, 45 Hz, and 50 Hz, respectively.

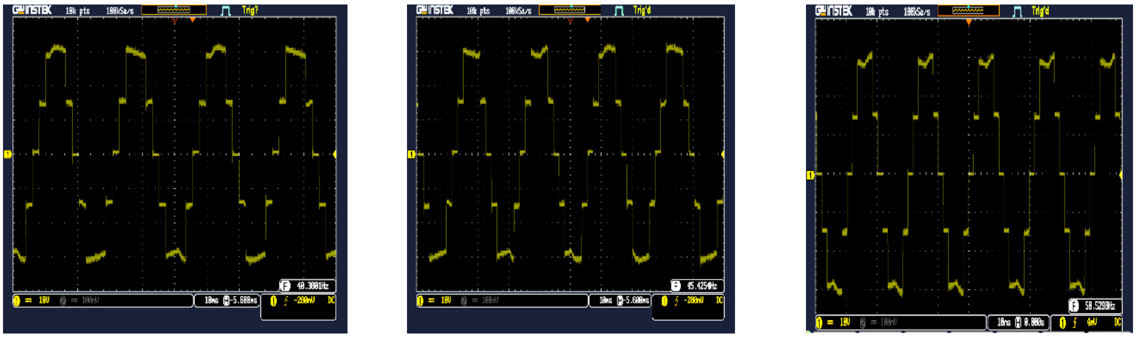
Observational data shows low levels of THD, ripple current (IR), and ripple torque (Tr). The evidence is in Tables 3 and 4. Tables 5 and 6 illustrate the load readings for 33 Hz and 59 Hz, respectively, at various motor speeds. Figure 14 shows waveforms of DCMLI current, speed-torque variation at 33 Hz and 59 Hz is seen in Figure 15.

There is no change in frequency or speed due to changes in load. Changing the inverter's frequency will also vary the motor's output. Power output vs torque is depicted in Figure 15(a) and load versus speed is depicted in Figure 15(b).



(a) (b) (c)

Figure12. DCMLI phase voltages: (a) at 40 Hz, (b)at 45 Hz, and (c) at 50 Hz



(a) (b) (c)

Figure 13. DCMLI line voltages: (a)at 40 Hz, (b) at 45 Hz, and (c) at 50 Hz

Table 5. Motor speed-load reading at 33 Hz

Sr. No.	Weight (gm)	Actual speed (rpm)	Calculated speed (rpm)	Voltage (volts)
1.	600	998	1011	272
2.	1100	998	1011	272
3.	1600	998	1011	272
4.	2100	998	1011	272
5.	2600	998	1011	272
6.	3200	998	1011	272

Table 6. Motor speed-load reading at 59 Hz

Sr. No.	Weight (gm)	Actual speed (rpm)	Calculatedspeed (rpm)	Voltage (volts)
1.	600	1770	1792	268
2.	1100	1770	1792	268
3.	1600	1770	1792	268
4.	2100	1770	1792	268
5.	2600	1770	1792	268
6.	3200	1770	1792	268

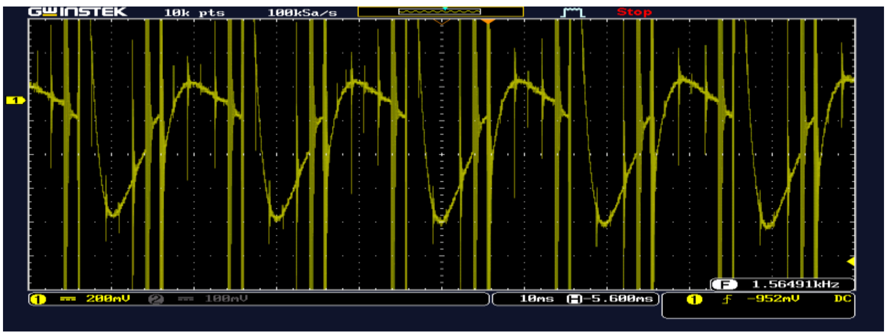
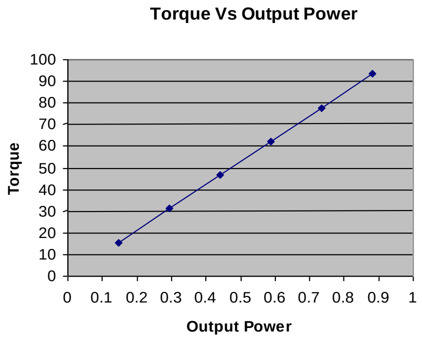
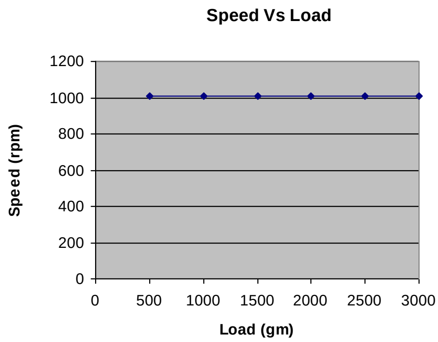


Figure 14. Waveforms of DCMLI current



(a)



(b)

Figure 15. Speed-torque variation: (a) at 33 Hz and (b) at 59 Hz

6. CONCLUSION

In this study, we analyze the efficiency of a PMSM drive controlled by a FOC SVM DCMLI and driven by an AVR microcontroller. This evaluation is predicated on an AVR microcontroller-driven PMSM motor and is controlled by a DCMLI. The inverter-driven PMSM drive with SVM was compared in terms of torque, current, and harmonic analysis. Less harmonic distortion is achieved as a result of using DCMLI. Improved steering efficiency in terms of speed and torque response, in addition to better dynamic characteristics, less contorted output, and reduced costs are provided by the proposed AVR microcontroller-based DCMLI-driven PMSM drive. Since it can adapt to changes in speed quickly and has a lower load ripple than conventional inverters, it is well suited for use in the automotive industry.

REFERENCES

[1] V. T. Ha, "Torque Ripple Reduction of the SRM Motor Using Nonlinear Controller for Electric Vehicles Application," in *2022 11th International Conference on Control, Automation and Information Sciences (ICCAIS)*, Nov. 2022, doi: 10.1109/iccais56082.2022.9990491.

[2] Z. Alqarni, "Improved Control Strategy for 4 WD Electric Vehicle Using Direct Torque Control Technique with Space Vector Modulation," in *2022 IEEE 12th Annual Computing and Communication Workshop and Conference (CCWC)*, Jan. 2022, doi: 10.1109/ccwc54503.2022.9720858.

[3] K.-B. Lee, J.-H. Song, I. Choy, and J.-Y. Yoo, "Torque ripple reduction in DTC of induction motor driven by three-level inverter with low switching frequency," *IEEE Transactions on Power Electronics*, vol. 17, no. 2, pp. 255–264, Mar. 2002, doi: 10.1109/63.988836.

[4] L. Romeral, A. Arias, E. Aldabas, and M. G. Jayne, "Novel direct torque control (DTC) scheme with fuzzy adaptive torque-ripple reduction," *IEEE Transactions on Industrial Electronics*, vol. 50, no. 3, pp. 487–492, Jun. 2003, doi: 10.1109/tie.2003.812352.

[5] R. G. Shriwastava, M. P. Thakare, K. V. Bhadane, M. S. Harne, and N. B. Wagh, "Performance enhancement of DCMLI fed DTC-PMSM drive in electric vehicle," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 4, pp. 1867–1881, Aug. 2022, doi: 10.11591/eei.v11i4.3714.

[6] M. S. Merzoug and F. Naceri, "Comparison of Field-Oriented Control and Direct Torque Control for Permanent Magnet Synchronous Motor (PMSM)," *International Journal of Electrical and Computer Engineering*, vol. 2, no. 9, pp. 1797–1802, Sep. 2008, doi: 10.5281/zenodo.1330719.

[7] Y. Li, W. Liu, Z. Fu, and D. Gerling, "The control of stator flux and torque in the surface permanent magnet synchronous motor direct torque control system," in *2009 4th IEEE Conference on Industrial Electronics and Applications*, May 2009, doi: 10.1109/iciea.2009.5138554.

[8] R. G. Shriwastava, S. S. Hadpe, S. B. Patil, R. S. Kadam, and M. P. Thakre, "Voltage Flicker Control in EAF Using P-Q Power Compensation Through STATCOM," in *Advances in Intelligent Systems and Computing*, Springer Nature Singapore, 2022, pp. 601–615, doi: 10.1007/978-981-16-7330-6_46.

[9] Y. Li, D. Gerling, J. Ma, J. Liu, and Q. Yu, "The Comparison of Control Strategies for the Interior PMSM Drive used in the Electric Vehicle," *World Electric Vehicle Journal*, vol. 4, no. 3, pp. 648–654, Sep. 2010, doi: 10.3390/wevj4030648.

[10] Z. Zhang and J. Shu, "Matlab-based permanent magnet synchronous motor vector control simulation," in *2010 3rd International Conference on Computer Science and Information Technology*, Jul. 2010, doi: 10.1109/iccsit.2010.5563610.

[11] K. Huang, W. Peng, C. Lai, and G. Feng, "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*, vol. 38, no. 4, pp. 5192–5203, Apr. 2023, doi: 10.1109/tpel.2022.3230052.

[12] Y. Li, M. Jian, Y. Qiang, and L. Jiangyu, "A Novel Direct Torque Control Permanent Magnet Synchronous Motor Drive used in Electrical Vehicle," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 1, no. 2, Nov. 2011, doi: 10.11591/ijpeds.v1i2.141.

[13] L. Y. L. Yaohua, L. Jingyu, M. J. M. Jian, and Y. Q. Y. Qiang, "A Simplified Voltage Vector Selection Strategy for Direct Torque Control," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 9, no. 3, Dec. 2011, doi: 10.12928/telkomnika.v9i3.746.

[14] L. M. Masisi, S. Williamson, and P. Pillay, "A comparison between A 2-level and 3-level inverter for a permanent magnet synchronous motor drive under different inverter switching frequencies," in *2012 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, Dec. 2012, doi: 10.1109/pedes.2012.6484370.

[15] M. P. Thakre, J. A. Gangurde, R. Shriwastava, D. P. Kadam, S. S. Kadlag, and H. S. Sonawane, "Investigative uses of overmodulation techniques in modular multilevel cascaded converter," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 6, pp. 3147–3156, Dec. 2022, doi: 10.11591/eei.v11i6.3958.

[16] P. Ramana, B. S. Kumar, K. A. Mary, and M. S. Kalavathi, "Comparison of various pwm techniques for field oriented control vsi fed pmsm drive," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 2, Jul. 2013.

[17] P. Yunhao, Y. Dejun, and H. Yansong, "The stator flux linkage adaptive SVM-DTC control strategy of permanent magnet synchronous motor," in *2021 6th Asia Conference on Power and Electrical Engineering (ACPEE)*, Apr. 2021, doi: 10.1109/acpee51499.2021.9437101.

[18] R. G. Shriwastava, D. R. Bhise, and P. Nagrale, "Comparative Analysis of FOC Based Three Level DCMLI Driven PMSM Drive," in *2019 International Conference on Innovative Trends and Advances in Engineering and Technology (ICITAET)*, Dec. 2019, doi: 10.1109/icitaet47105.2019.9170242.

[19] M. Haris, M. K. Pathak, and P. Agarwal, "Comparison of SPWM multilevel inverter fed PMSM drive with two level inverter fed drive," in *International Conference on Recent Advances and Innovations in Engineering (ICRAIE-2014)*, May 2014, doi: 10.1109/icraie.2014.6909123.

[20] S. Devabhaktuni and R. G, "Performance analysis of three-phase and five-phase inverters with different PWM strategies," in *2019 Innovations in Power and Advanced Computing Technologies (i-PACT)*, 2019, doi: 10.1109/i-pact44901.2019.8960210.

[21] S. D. Lakshmi and S. Dasan, "Analysis of Newly Developed Third Harmonic Injection Mothod with Ovpmw Method for a PV System Connected Through 3-Level Diode Clamped Inverter to an Induction Motor," in *2018 International Conference on Current Trends towards Converging Technologies (ICCTCT)*, Mar. 2018, doi: 10.1109/icctct.2018.8551049.

[22] M. Saeedian, J. Adabi, and S. M. Hosseini, "Cascaded multilevel inverter based on symmetric–asymmetric DC sources with reduced number of components," *IET Power Electronics*, vol. 10, no. 12, pp. 1468–1478, 2017, doi: 10.1049/iet-pel.2017.0039.

[23] A. Taghvaie, J. Adabi, and M. Rezanejad, "A Self-Balanced Step-Up Multilevel Inverter Based on Switched-Capacitor Structure," *IEEE Transactions on Power Electronics*, vol. 33, no. 1, pp. 199–209, Jan. 2018, doi: 10.1109/TPEL.2017.2669377.

[24] K. K. Gupta, A. Ranjan, P. Bhatnagar, L. K. Sahu, and S. Jain, "Multilevel Inverter Topologies With Reduced Device Count: A Review," *IEEE Transactions on Power Electronics*, vol. 31, no. 1, pp. 135–151, Jan. 2016, doi: 10.1109/TPEL.2015.2405012.

[25] Z. Du, B. Ozpineci, L. M. Tolbert, and J. N. Chiasson, "DC–AC Cascaded H-Bridge Multilevel Boost Inverter With No Inductors for Electric/Hybrid Electric Vehicle Applications," *IEEE Transactions on Industry Applications*, vol. 45, no. 3, pp. 963–970, May 2009, doi: 10.1109/TIA.2009.2018978.

BIOGRAPHIES OF AUTHORS

Dr. Rakesh Shriwastava obtained Ph.D. Degree in Electrical Engineering specializing in Power Electronics and Drives from RTM Nagpur University, India in 2017. He occupied various positions to serve the Engineering Institutes for about 24 years. He is currently working as Professor at Department of Electrical Engineering, Matoshri College of Engineering and Research Center, Nashik. His research interests include the analysis and control of electrical drives, particularly in hybrid and electric vehicle applications. He has several publications in national and international journals. He attended International and National conferences and also worked as a jury member. He is a member of professional bodies such as ISTE and IAENG. He can be contacted at email: rakesh_shriwastava@rediffmail.com.

Dr. Mohan P. Thakre received the B.Tech. and M. Tech degrees in Electrical Power Engineering from Dr. Babasaheb Ambedkar Technological University (Dr. BATU), Maharashtra, India, in 2009 and 2011 respectively, and the Ph.D. degree in Electrical Engineering from Visvesvaraya National Institute of Technology, (VNIT), Nagpur, Maharashtra, India in 2017. Currently, he is an Associate Professor at the Department of Electrical Engineering, SVERI's College of Engineering, Pandharpur, Maharashtra, India. His research interests include FACTS and power system protection. He can be contacted at email: mohanthakre@gmail.com.

Jagdish Choudhari completed his Bachelor of Electrical Engineering and Master of Engineering in Electrical Power System from Government College of Engineering in 1999 and 2002 respectively. He has completed his Ph.D. in the area of Electrical Drives and Control in 2019 from Rashtrasant Tukadoji Maharaj Nagpur University. He has published 60 plus papers in National and International Journal and Conferences and granted 01 International and 01 National Patent. He is a member of LMISTE, MIE, QCFI and IAENG. He is working as Associate Professor and Head, Department of Electrical Engineering from June 2018 and Dean Academics from September 2022 at Nagpur Institute of Technology, Nagpur, Maharashtra (India). He can be contacted at email: jagdishchaudhari260878@gmail.com.

Dr. Sunil Somnath Kadlag received B.E in Electrical Engineering from Dr. received B.E in Electrical Engineering from Dr. Babasaheb, Ambedkar, Marathawada University, Aurangabad (Dr B.A.M.U) in 1997 and M.E in Electrical Engineering (Control System) from Government College of Engineering Pune (Pune University) in 2005 and Ph.D. in Electrical Engineering from Suresh Gyan Vihar University Jaipur (Rajasthan) in 2021. His research area is electric vehicles. He is presently working as an Associate Professor and Head, of the Department of Electrical Engineering, Amrutvahini College of Engineering, Sangamner, Savitribai Phule Pune University, Pune, Maharashtra, India. He can be contacted at email: sunilkadlag5675@gmail.com.

Dr. Rahul Mapari received a bachelor's degree and master's degree in Electronics Engineering from Savitribai Phule Pune University, India, in 2004 and 2007 respectively, and a Ph.D. degree in Electronics andTelecommunication Engineering from Amravati University, India in 2016. He has a total of 17 years of experience in various reputed Technical Institutes. He is working as a Professor in the Department of Electronics and Telecommunication Engineering of Pimpri Chinchwad College of Engineering and Research, Pune since 2017. His research interests include power converters and power electronics. He can be contacted at email: rahul.mapari@pccoer.in.

Dr. Deepak Prakash Kadam received a B.E from the Government College of Engineering, Amaravati, and M.E degrees in Electrical Power Systems from Walchand College of Engineering, Sangli, Maharashtra, India, in 1997 and 2005 respectively, and the Ph.D. degree in Electrical Engineering from Savitribai Phule Pune University, Pune Maharashtra, India in 2015. Currently, he is an Associate Professor at the Department of Electrical Engineering, Bhujbal Knowledge City, MET Institute of Engineering, Nashik, India. His research interests include renewable energy technology, power quality, and power system. His total teaching experience is around 23 years. He can be contacted at email: dpkadam@gmail.com.

Dr. Shridhar Khule obtained Ph.D. Degree in Electrical Engineering specializing in power systems from Sant Gadge Baba Amravati University, Amravati, Maharashtra, Indiain 2021. He occupied various positions to serve engineering institutes for about 20 years. He is currently working as Professor in the Electrical Engineering Department of Matoshri College of Engineering and Research Center, Nashik. His research interests power system. He attended International and National conferences. He is a member of professional bodies such as ISTE and IET. He can be contacted at email: shridhar.khule@matoshri.edu.in.