Performance Evaluation of Conventional Inverters Driven PMSM Drive using Microcontroller

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***Abstract*:**
This paper focues on Performance evaluation of conventional inverters driven PMSM drive using microcontroller. The purpose of this paper is to decrease the ripples in torque of Micro controllers based PMSM drive. The innovative method consists of conventional inverters, switched-mode power supply (SMPS), PMSM motor and Microcontroller. It is used to maximize fundamental component of torque also. The both the results of the suggested Micro controller are compared on the basis of torque and speed and improves that reduces the torque ripple and improve the dynamic response of the system in comparative analysis. This paper organizes introduction, mathematical model of the PMSM, proposed Microcontroller technique, hardware and simulation results and conclusion in different sections.

***Keywords*: Switched-mode power supply (SMPS), conventional inverters, Microcontroller, Permanent magnet synchronous motors (PMSM), EPROM, Clock generator.**

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I. INTRODUCTION

In industrial application, Electric motors (EMs) and generators are the primary workhorses. The generators convert energy transformation to charge the batteries for motor operation. Required torque developed by motors for drive the wheels. The permanent magnets, switched reluctance, and induction motors are used in industrial application [1-4].This paper explains Simulation and Hardware Implementation of VSI -Fed PMSM drives for automotive application. For the speed &torque control,VSI fed PMSM drive is one of the method used. The VSI fed PMSM drive system is designed, simulated and implemented using Microcontroller. A hardware setup is designed and implemented based on a Four-pole 0.25 HP PMSM. The control hardware consists of, Main power circuit, Control circuit, Isolator and driver circuit and PMSM [5-11]. The fixed dc voltage is obtained from three phase rectifier circuit and uses shunt capacitor for filter purpose. The output of three phase rectifier circuit is given to MOSFET bridge inverters in power circuit [12].The function of control circuit is to turn the MOSFET by using Gating pulses Isolator and driver circuit is used for proper isolation by using opt isolator [25-26].The steps involved in any drive system are design, building its hardware and its testing. Once the system is designed, depending on designed values of various components, the system hardware is developed. Once the assembly of hardware is completed then it is tested by carrying out various experiments on the developed system to test whether the system is working satisfactory or not. If it is not working properly then the error must be removed and the system must be updated and modified. The drive developed here is operating variable frequency mode. The theme of the paper is Simulation and Hardware analysis of torque ripple minimization of PMSM drive for automotive application.

II. MATHEMATICAL MODEL OF PMSM

A. PMSM modeling in rotor reference frame

There are two stator windings in the dq reference frame and field winding is absent in rotor of PMSM. The direct-axis winding is along with the axis of magnetic pole. If PMSM running in anti-clockwise direction, at the speed of ‘ωr’,

The induced voltage in the direct-axis winding:

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

Where, *‘id’* and *‘Rd’* are called direct-axis stator current and resistance respectively

The induced voltage in the quadrature-axis winding:

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

Where, 'Rq' and '*iq*' are called the quadrature -axis resistance and current of stator.

$$\lambda_d = L_d i_d + \lambda_m \quad (3)$$

λd = flux-linkage in the direct-axis of stator in webers,λm is the PM rotor flux

$$\lambda_q = L_q i_q \quad (4)$$

λq = flux-linkage in the quadrature-axis stator (Wb)

In this case of quadrature-axis, there are no magnets so λm is absent.

Considering round rotor PMSM, we have

$$L_d = L_q \quad (5)$$

The PMSM torque equation is given by:

$$T_e = \frac{3}{2}\frac{p}{2}(\lambda_d i_q - \lambda_q i_d) \quad (6)$$

Substituting for *'λd'* and *'λq'* in the torque equation of PMSM,

$$T_e = \frac{3}{2}\frac{p}{2}[(\lambda_d i_d + \lambda_m) i_q - L_q i_q i_d] \quad (7)$$

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

The two components of torque developed are:

$$Reluctance\ torque = \frac{3}{2}\frac{p}{2}(L_d - L_q) i_d i_q \quad (9)$$

$$field\ torque = \frac{3}{2}\frac{p}{2}\ \lambda_m i_q \quad (10)$$

$$T_e = \frac{3}{2}\frac{p}{2}\ \lambda_m i_q \quad (11)$$

In a round rotor PMSM the electromagnetic torque present is the field torque present due to the PM flux linkage, *λm*. For a chosen PMSM, the PM rotor flux-linkage *(λm)* and the number of poles (*p*) is constant. Hence, for the round-rotor PMSM, the electromagnetic torque equation is

$$T_e = Kt\ i_q \quad (12)$$

Where, Kt = Torque constant

$$K_t = \frac{3}{2}\frac{p}{2}\ \lambda_m \quad (13)$$

Therefore, electro-magnetic torque is given by

$$T_e = T_l + B\ \omega_m + J\ \frac{d\omega_m}{dt} \quad (14)$$

ωm = rotor's mechanical speed, *ωr* = rotor's electrical speed

III. SIMULATION RESULT

The simulation response of Voltage source inverter-fed PMSM drives at different speed range is shown in figure 5 to figure 9.

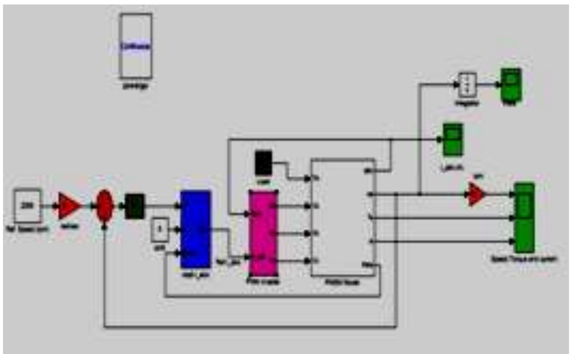

Figure 1.Simulation diagram

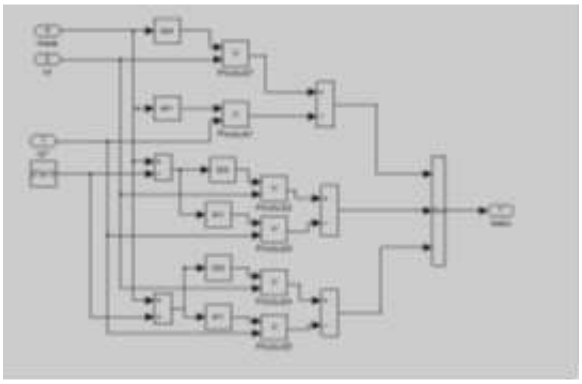

Figure 2.D-axis &Q-axis Currents model

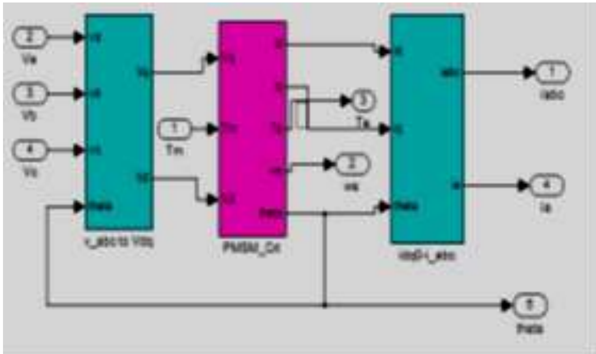

Figure 3.PM Synchronous Motor model

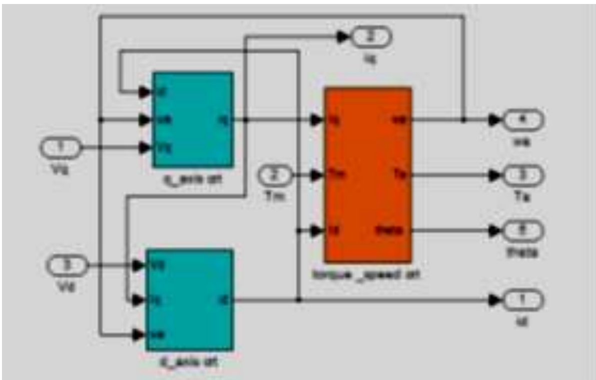

Figure 4. PMSM Characteristics diagram

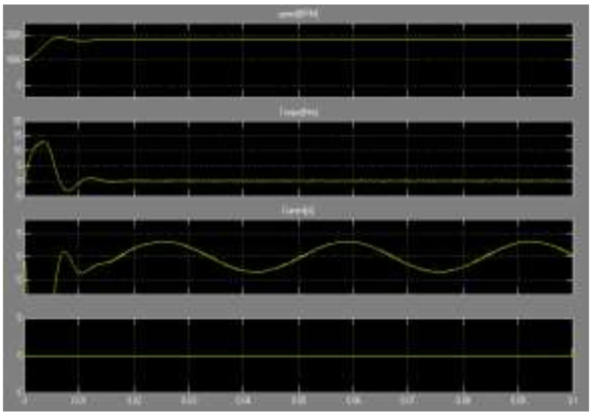

Figure 5.Speed, torque and Current response at 1000 to 1800 rpm

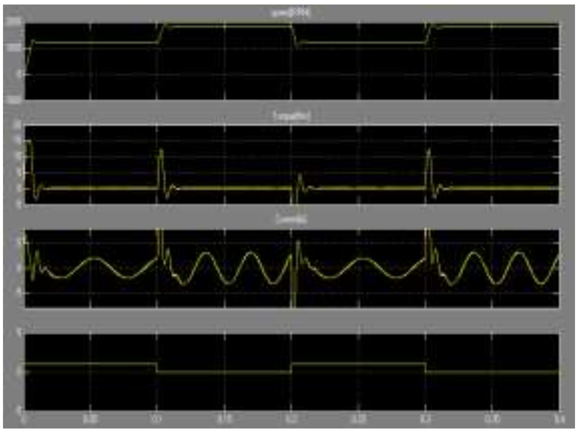

Figure 6.Speed, torque and Current response at 1200 to 1800 rpm

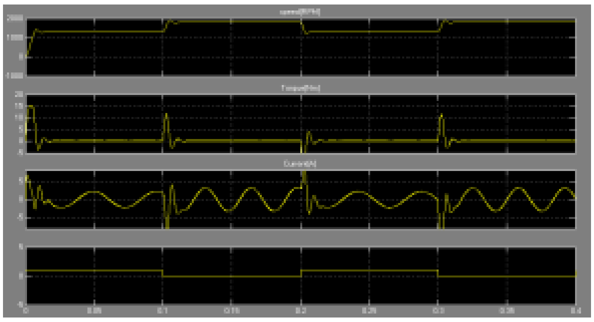

Figure 7.Speed, torque and Current response at 1400 to 1800 rpm

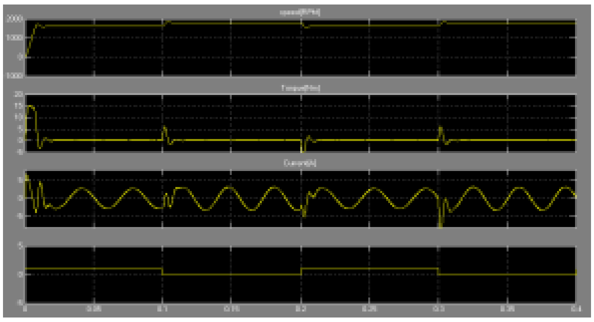

Figure 8.Speed ,torque and Current response at 1600 to 1800 rpm

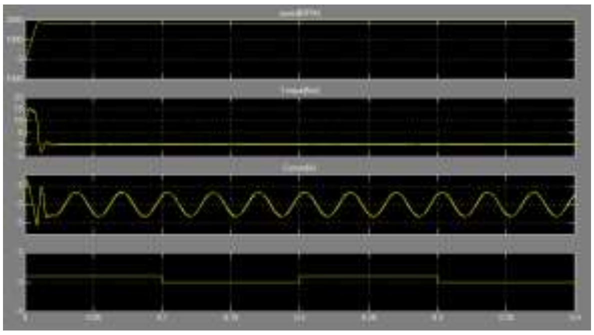

Figure 9.Speed, torque and Current response at 1800 rpm

IV. HARDWARE RESULT ANALYSIS

Initially the drive operation was worked on dummy load (3 phase star connected lamps) by connecting the motor to the drive. Various outputs are taken out from the control card on the drive. Firstly the frequency knob on the drive was kept at its minimum position. The converter card was then switched on. The power supply status was indicated by all the LEDs inside the unit. By using CRO probes, the waveforms at various test points were observed.

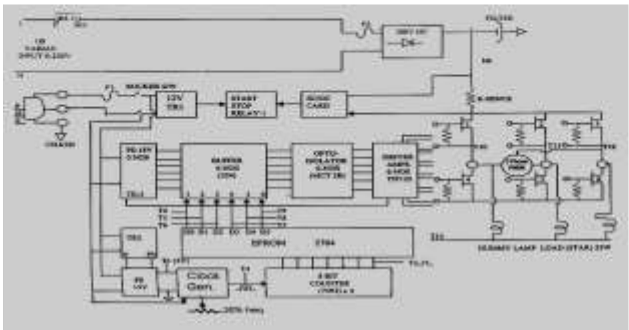

Figure 10.Block diagram of conventional inverters driven PMSM

While observing the waveforms on CRO, care was taken to use the unearthed CRO only. The basic timer IC 555 output frequency was observed at the test point. This frequency can be changed by changing the position of frequency knob. The pulses for various gate drives were observed at the test points. The output frequency was observed at the test point. The minimum and maximum frequency was noted and tabulated in the result table. The frequency knob position was slowly changed along with the set speed pot. Slowly the lamps were turned on as the soft start in the result table. The output line and phase voltage waveforms for the three phases were observed on the CRO at the corresponding test points. After observing the satisfactory performance of the control card then the motor was connected to the drive. The dummy lamp load was now removed and the motor was connected in the output connector. Thus the motor runs at variable speed depending on the frequency. After testing the various test points the dummy star connected load is removed and across the output of the bridge inverter PMSM is connected. Then gradually increasing the load on the shaft of the motor for different values of frequency speed of the motor is measured.

TABLE NO.1: MOTOR SPEED VARIATION BY FREQUENCY

Sr. No .	Time (m.s.)	Frequency (Hz)	Actual Speed (rpm)	Measu red Speed (rpm)	Voltage (Volts)
1	30	33.4	995	1005	260
2	25	40.1	1250	1219	265
3	22	45.5	1462	1370	265
4	20	50.2	1530	1518	265
5	18	55.6	1765	1672	265
6	17	59.2	1785	1795	265

TABLE NO.2: MOTOR SPEED VARIATION BY LOAD AT 33.4

Sr. No.	Load (gm)	Frequency (Hz)	Actual Speed (rpm)	Expected Speed (rpm)	Torque (N-m)	Output Power (W)
1	500	33.4	1110	995	0.15715	16.59
2	1000	33.4	1110	995	0.2743	35.28
3	1500	33.4	1110	995	0.4814	48.99
4	2000	33.4	1110	995	0.6186	65.45
5	2500	33.4	1110	995	0.8357	79.98
6	3000	33.4	1110	995	0.9829	99.49

TABLE NO.3: MOTOR SPEED VARIATION BY LOAD AT 50.2HZ

Sr. No.	Load (gm)	Frequency (Hz)	Actual Speed (rpm)	Expected Speed (rpm)	Torque (N-m)	Output Power (W)
1	500	50.2	1500	1540	0.16715	25.89
2	1000	50.2	1500	1540	0.3043	49.96
3	1500	50.2	1500	1540	0.4814	76.45
4	2000	50.2	1500	1540	0.6886	99.79
5	2500	50.2	1500	1540	0.7857	125.51
6	3000	50.2	1500	1540	0.9229	148.78

TABLE NO.4: MOTOR SPEED VARIATION BY LOAD AT 59.2 HZ

Sr. No .	Load (gm)	Frequ ency (Hz)	Actual Speed (rpm)	Expecte d Speed (rpm)	Torque (N-m)	Output Power (W)
1	500	59.2	1700	1770	0.1571	29.64
2	1000	59.2	1700	1770	0.3243	58.16
3	1500	59.2	1700	1770	0.4914	89.73
4	2000	59.2	1700	1770	0.6588	115.33
5	2500	59.2	1700	1770	0.7957	142.90
6	3000	59.2	1700	1770	0.9229	172.49

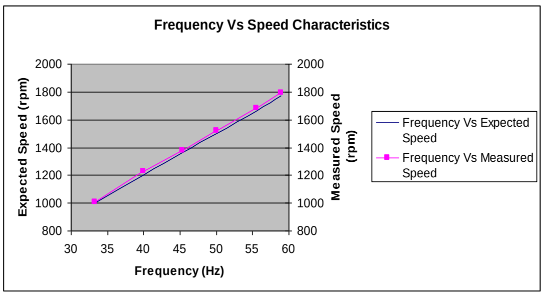

Figure 11.Speed- Frequency characteristics

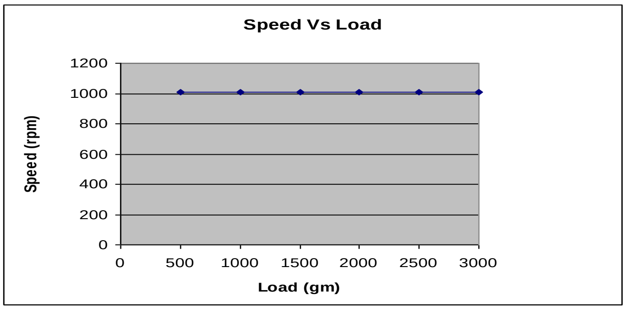

Figure 12.Load -Speed Characteristics at 33.3 Hz

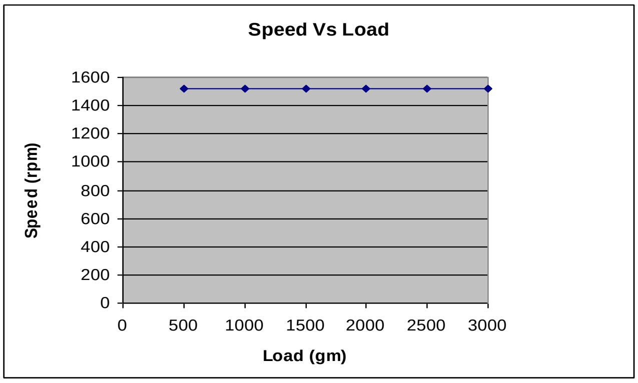

Figure 13.Load -Speed Characteristics at 50 Hz

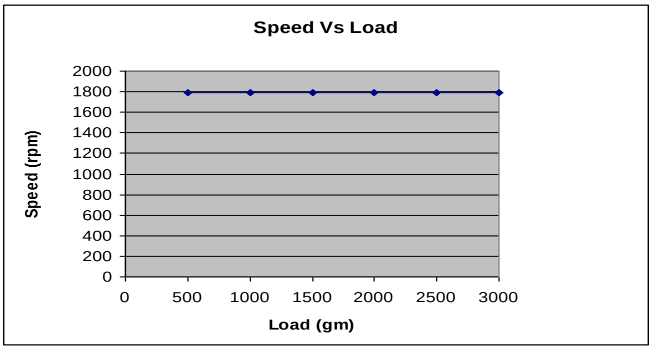

Figure 14.Load -Speed Characteristics at 59 Hz

CONCLUSION

This paper focuses on simulation and hardware analysis of conventional inverters driven PMSM drive using microcontroller. A detailed Simulink model of torque minimization of PMSM drive has being developed. It is observed that, at constant frequency, speed remains constant irrespective of load. The motor runs at synchronous speed. Speed also gets changed accordingly the inverter frequency .The overall motor performance can be very well judged from the performance characteristic shown. Finally we conclude that simulation results and hardware implementation shall give better performance analysis. Hence it is used in automotive application.

REFERENCES

[1] B.K.Bose, Modern Power Electronics an AC Drives (Prentice-Hall, 2002.

[2] Ward Leonhard, Control of Electrical Drives (Springler-Verlag, 1990).

[3] M. Ehsani, et al., "Propulsion system design of electric and hybrid vehicles," IEEE Transactions on Industrial Electronics, vol. 33, pp. 19-27, Feb. 1997.

[4] W. P. Jung, et al., "Improvement of control characteristics of interior permanent-magnet synchronous motor for electrical vehicle,". IEEE Transactions on Industry Application, vol. 37, pp.1754-1760, Nov. 2001.

[5] L. Zhong, et al., "Analysis of direct torque control in permanent magnet synchronous motor drives," IEEE Transactions on Power Electronics, vol. 12, pp. 528-536, May 1997.

[6] L. Zhong, et al., "A direct torque controller for permanent magnet synchronous motor drives," IEEE Transactions on Energy Conversion, vol. 14, pp. 637-642, Sep. 1999.

[7] M. F. Rahman, et al., "A direct torque-controlled interior permanent magnet synchronous motor drives incorporating field weakening," IEEE Transactions on Industry Application, vol. 34, pp. 1246-1253, Nov./Dec. 1998.

[8] G. Buja, et al., "Direct torque control of PWM inverter-fed AC motors-a survey," IEEE Transactions on Industrial Electronics, vol. 51, pp. 744-757, Aug. 2004.

[9] D. Casadei, et al., "FOC and DTC: two viable schemes for induction motors torque control," IEEE Transactions on Power Electronics, vol. 17, pp. 779-787, Sep. 2002.

[10] M. F. Rahman, et al., "Problems associated with the direct torque control of an interior permanent-magnet synchronous motor drive and their remedies," IEEE Trans. Industrial Electronics, vol. 51, pp. 799-809, Aug. 2004.

[11] Y. H. Li, "Direct Torque Control of Permanent Magnet Synchronous Machine," Shaker Verlag Gmbh, 2011.

[12] Y. H. Li et al., "Simulation study on the effect of voltage Vector on torque in direct torque control system of permanent magnet synchronous motor," in Proc.2007 IEEE Industrial Electronics and applications Conf., pp. 1521-1525, 2007.

[13] Y. H. Li, et al., "A novel switching table to suppress unreasonable torque ripple for the PMSM DTC drives," in Proc.2008 IEEE Electrical Machines and Systems Conf., pp. 972-977, 2008.

[14] Y. H. Li, et al., "The control of stator Flux and torque in the surface permanent magnet synchronous motor direct torquecontrol system," in Proc.2009 IEEE Industrial Electronics and applications Conf., pp. 2004-2009, 2009.

[15] Y. H. Li, et al., "A Simplified Voltage Vector Selection Strategy for the Permanent Magnet Synchronous Motor DirectTorque Control Drive with Low Torque Ripple and Fixed Switching Frequency," in Proc.2010 IEEE Electrical Machines and Systems Conf., pp. 674-679, 2010.

[16] Y. H. Li, et al., "The Comparison of Control Strategies for the interior PMSM drive used in the Electric Vehicle," in Proc.the 25th World Electric Vehicle Symposium and Exposition, paper 4C-7, 2010.

[17] F. Heydari, A. Sheikholeslami, K. G. Firouzjah amd S. Lesan. Predictive Field-Oriented Control of PMSM with Space VectorModulation Technique Front. Electr. Electron. Eng. China(2010).

[18] M. S. Merzoug and F. Naceri,Comparison of Field-Oriented Control and Direct Torque Control for Permanent Magnet Synchronous Motor (PMSM) World Academy of Science, Engineering and Technology 45(2008).

[19] Jorge Zambada, Microchip Corporation, Sensorless Field Oriented Control of PMSM Motors. Microchip Technology Inc., 2007.

[20] D Sun, F Weizhong, H Yikang, Study on the Direct Torque Control of Permanent Magnet Synchronous Motor Drives. IEEE/ ICEMS. 571-574(2001)

[21] Dr.R.G.Shriwastava, Dr. M. B. Daigavane,Dr. N.B.Wagh, "Comparative Analysis of Three Phase 2-Level VSI with 3-Level and 5-Level DCMLI Using CB-SVM",Published in IEEE International Conference on Electrical, Electronics, Computers, Communication, Mechanical and Computing (EECCMC-2018),at Priyadarshini Engineering College, Chettiyappanur, Vaniyambadi - 635751, Vellore District, Tamil Nadu, India. Conference records no 978-1-5386-4304-4/18/$31.00 ©2018 IEEE.

[22] Dr.R.G.Shriwastava, Dr. M.B. Daigavane,Dr. N.B.Wagh, "Performance Investigations of PMSM Drive using Various Modulation Techniques for Three Level NPC Inverter ", Published in 5th International Conference on Computing for Sustainable Global Development(INDIACOM-2018), IEEE Conference at Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM), New Delhi with Conference record no INDIACom-2018; ISSN 0973-7529; ISBN 978-93-80544-28-1 Page no-1038-1042

[23] N. P. Matale, "Alleviation of Voltage Sag-Swell by DVR Based on SVPWM Technique," 2020 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS), Chennai, India, 2020, pp. 1-6, doi: 10.1109/ICPECTS49113.2020.9336972.

[24] Sanda Victorinne Paturca," Direct Torque Control of Permanent Magnet Synchronous Motor (PMSM) - an approach by using Space Vector Modulation (SVM)", Proc. of the 6th WSEAS/IASME In Conf. on Electric Power Systems, High Voltages, Electric Machines, 16-18(2006).

[25] Dr.R.G.Shriwastava,Dr. Nandkumar Wagh,Dr.Santaji K.Shinde "Implementation of DTC-Controlled PMSM Driven By A Matrix Converter", published in International Journal of Recent Technology and Engineering (IJRTE) Volume-8 Issue-5, January 2020,PageNo:4420-4424,ISSN:2277-3878,Retrieval Number: E6641018520/2020©BEIESP DOI:10.35940/ijrte.E6641.018520,.

[26] Dr.R.G.Shriwastava, Mr. D.R.Bhise,Dr. Mr. Pravin Nagrale "Comparative Analysis of FOC Based Three Level DCMLI Driven PMSM Drive", Published in IEEE Explore ICITAET 2019 Conference record no ISBN -978-1-7281-1901-4 Page no-26-31

[27] P. S. Borse, "Analytical Evaluation of FOC and DTC Induction Motor Drives in Three Levels and Five Levels Diode Clamped Inverter," 2020 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS), Chennai, India, 2020, pp. 1-6, doi: 10.1109/ICPECTS49113.2020.9337015.

[28] Marian P. Kazmierkowski and Luigi Malesani, "Current control techniques for three-phase voltage-source PWM converters: A survey," IEEE Trans. on Ind. Electronics, Vol.45, N0.5, pp.691-703, October 1998.

[29] Dr.Rakesh G. Shriwastava, Mohan P. Thakre,Manoj D. Patil, Digamber R.Bhise " Performance Analysis of CB-SVM Three-Phase Five-Level DCMLI Fed PMSM Drive", published in Turkish Journal of Computer and Mathematics Education Vol.12 No.12 (2021), 887-89

[30] T. Gaidhani, "HVDC Fault Current Reduction Through MMC and DCCB Coordination," 2020 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS), 2020, pp. 1-6, doi: 10.1109/ICPECTS49113.2020.9337020.

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