International Journal of Applied Power Engineering (IJAPE)
Vol. 14, No. 1, March 2025, pp. 235~243
ISSN: 2252-8792, DOI: 10.11591/ijape.v14.i1.pp235-243

DTC analysis of DCMLI driven PMSM-SVM drive

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Article Info

Article history:

Received Jan 8, 2024
Revised Sep 13, 2024
Accepted Oct 23, 2024

Keywords:

Direct torque control
Dual-cell modular multilevel inverter
Permanent magnet synchronous motor
Space vector modulation
Total harmonic distortion

ABSTRACT

The paper focuses on a comparative analysis of direct torque control (DTC) space vector modulation (SVM) based permanent magnet synchronous motor (PMSM) drive. This comparative analysis is based on a conventional inverter and a 3-level dual-cell modular multilevel inverter (DCMLI) using the SVM technique using MATLAB simulation. The present DTC-PMSM drive consists of flux and torque hysteresis comparators and has a problem of switching frequency and torque ripple. The problems are solved by using SVM to provide more inverter voltage and it compensates for torque and flux error in a DTC. A reference voltage space vector is calculated every time using the algorithm on the basic of torque error and stator flux angle. It was proposed to control torque, torque angle, and stator flux in DTC-PMSM. From the detailed comparison, the DTC-DCMLI PMSM drive has an exact solution of problem-solving of switching frequency and torque ripple due to less distorted output. Proposed drives can be applicable for hardware implementation in automotive applications.

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1. INTRODUCTION

In hybrid electric vehicles (HEVs), electric motors (EMs) and generators are the primary workhorses. The batteries and operate the motors and generators. To drive the wheels, motors produce the required torque in HEVs. The permanent magnet is used [1]-[5]. Electric propulsion systems are the main part of electric vehicles (EV). It consists of electric motors, power converters, and electronic controllers [6]-[12]. DTC method is proposed to maintain constant switching frequency and also reduce torque and current ripple [13]-[18]. This paper focuses on a novel method of DTC-based dual-cell modular multilevel inverter (DCMLI) using SVM techniques used in electrical vehicles [19]-[21].

The DTC method has excellent dynamic performance, robust and simple in nature. The drawbacks of the DTC are variable switching frequency, flux ripples, and relatively high torque in the case of Induction motors. The results of the DTC of PMSM can be improved by maintaining a fixed switching frequency, and reducing the torque ripples and flux using the novel technology of SVM [22]-[25]. This paper presents a DTC-based 2-level and 3-level DCML inverter using SVM techniques. In section 3, the direct torque control principle is explained. In sections 4 and 5, control topology is presented. In section 6, the simulation results are presented.

2. PMSM MATHEMATICAL MODEL ANALYSIS

Following are the PMSM mathematical model analysis in d-q coordinate system, the torque equations are (1)-(4).

$$\lambda_D = L_D I_D + \lambda_R \quad (1)$$

$$\lambda_Q = L_Q I_Q \quad (2)$$

$$\lambda_s = \sqrt{(\lambda_D^2 + \lambda_Q^2)} \quad (3)$$

$$T_{EM} = \left(\frac{3}{2}\right) P\left(\lambda_D I_Q - \lambda_Q I_D\right) \quad (4)$$

The d-q current equations are (5) and (6).

$$I_D = \frac{\lambda_D - \lambda_Q}{L_D} \quad (5)$$

$$I_D = \frac{\lambda_D}{L_Q} \quad (6)$$

The flux linkage equations are (7) and (8).

$$\lambda_D = \lambda_S cos\delta \quad (7)$$

$$\lambda_{DQ} = \lambda_S sin\delta \quad (8)$$

Put in the torque expression as shown in (9).

$$T_{EM} = \left(\frac{3}{2}\right) P \frac{|\lambda_S|}{2L_D I_Q}\left(2\lambda_R L_Q sin\delta - |\lambda_S|\left(L_Q - L_D\right) sin2\delta\right) \quad (9)$$

3. PROPOSED METHODOLOGY

A DTC PMSM drive is shown in Figure 1. Stator voltage vectors are used for torque control and hysteresis stator flux. For the selection of voltage vectors, hysteresis comparators are used. In hysteresis, comparators are replaced by error measurements, torque, and estimators. It gives a good dynamic performance having less torque and flux ripple. For getting more inverter output voltage in effective time a novel CB-SVM method is used. In CB-SVM, inverter gating signals are used in a simple form using a time relocation algorithm. All the motor parameters are converted in one form to another by using the park and Clark transformation.

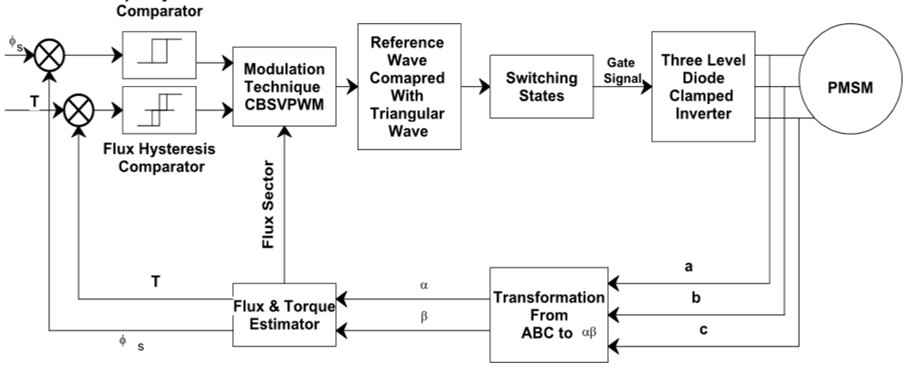


Figure 1. Proposed DTC PMSM drive

4. SIMULATION RESULTS ANALYSIS

With MATLAB software, the investigations on DTC-based conventional and three-level inverter PMSM drives have been done. The SVM method has been applied to the conventional and multilevel inverter-driven PMSM drive. Figures 2 and 3 show the Simulink model of DTC-based conventional and multilevel inverter PMSM drive. Figures 4 and 5 show the inverter voltage and current output of conventional and three levels using SVM. Figures 6-8 show the speed, electromagnetic torque, and stator rotor flux response respectively. Figures 9 and 10 show the total harmonic distortion (THD) analysis of voltage and current. Tables 1 and 2 show the THD analysis and torque ripple analysis of DTC-based conventional and three-level inverter PMSM drive. The specification of PMSM as in Table 3.

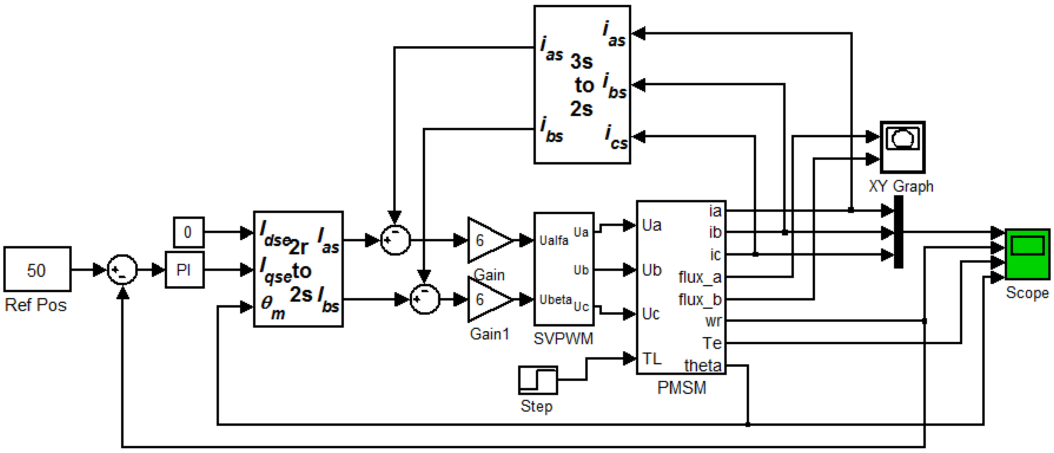


Figure 2. Simulink model of DTC based conventional inverter PMSM drive

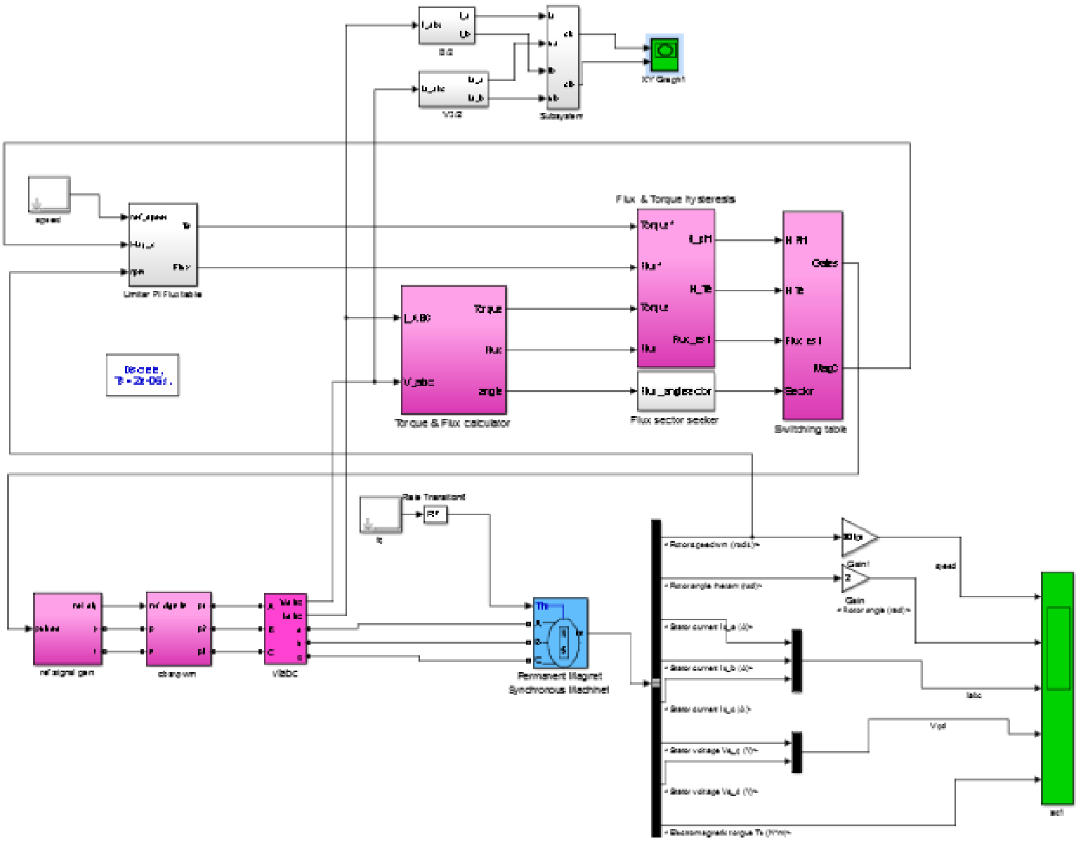
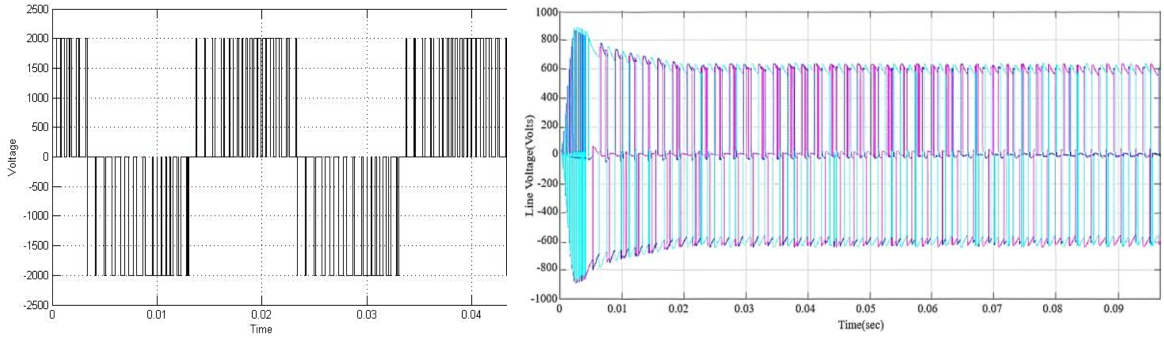
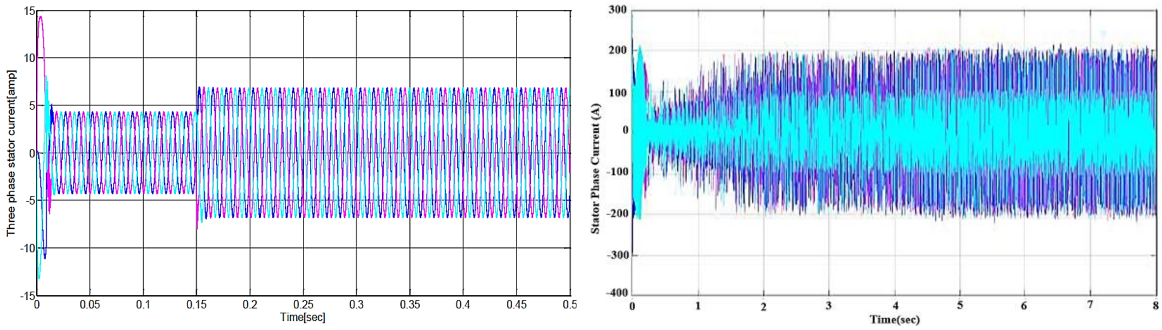


Figure 3. Simulation model of DTC based DCMLI PMSM drive



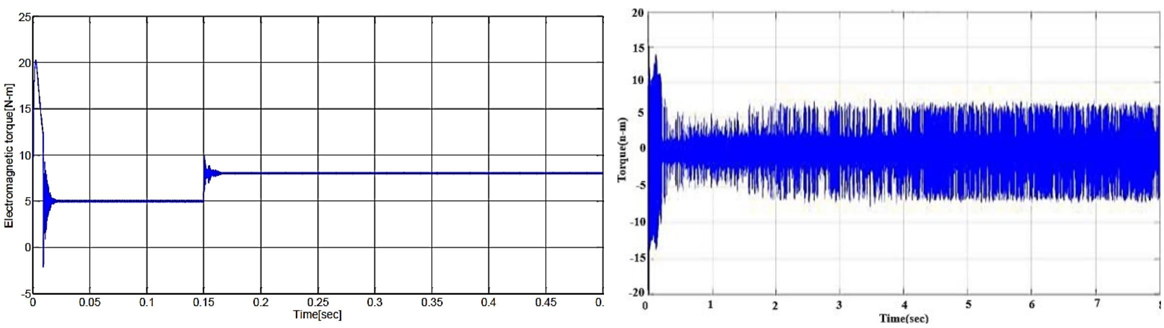
(a) (b)

Figure 4. Voltage response of (a) two-level and (b) multilevel inverter



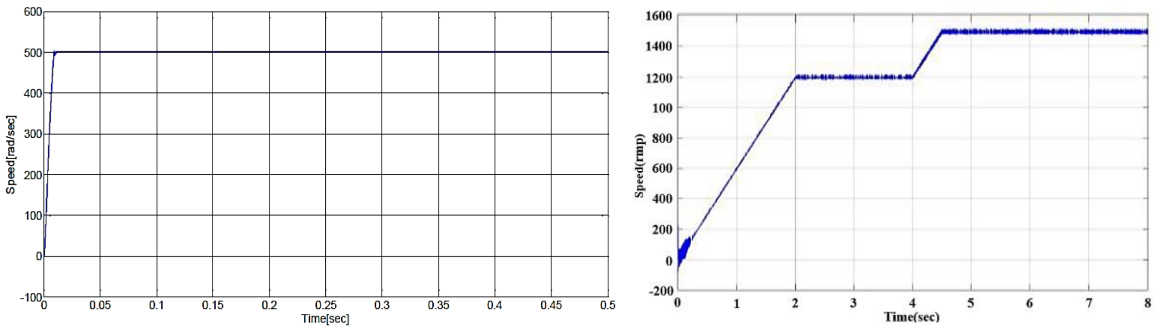
(a) (b)

Figure 5. Stator current response of (a) two-level and (b) multilevel inverter



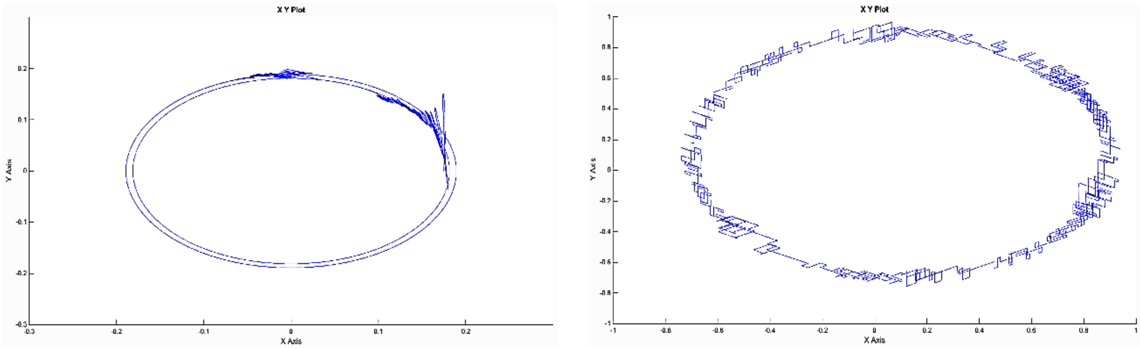
(a) (b)

Figure 6. Torque response of (a) two-level (b) multilevel inverter



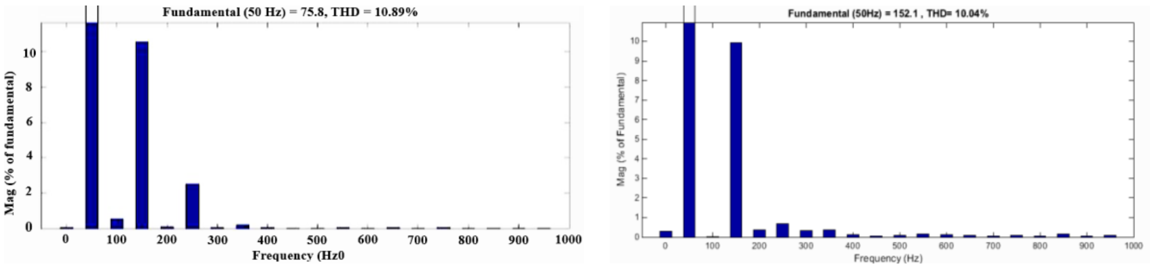
(a) (b)

Figure 7. Speed response of (a) two-level and (b) multilevel inverter



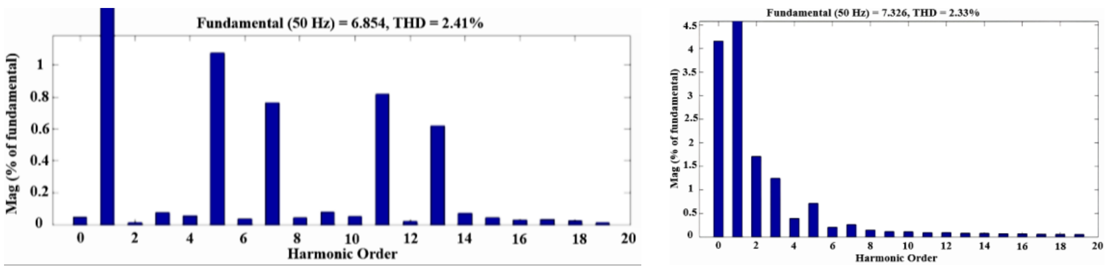
(a) (b)

Figure 8. Motor flux response: (a) two-level and (b) multilevel inverter



(a) (b)

Figure 9. FFT response of stator voltage: (a) two-level and (b) multilevel inverter



(a) (b)

Figure 10. FFT response of stator current: (a) two-level and (b) multilevel inverter

Table 1. THD analysis

THD	Two level with SVM	Three -level with SVM
Line voltage	10.89%	10.04%
Line current	2.41%	2.33%

Table 2. Torque ripple analysis

Controller speed	Two-level with DTC- SVM	Three-level with DTC- SVM
500 rpm	21.58%	18.5449%
1000 rpm	20.54%	17.26%
1500rpm	18.27%	15.86%

Table 3. Specification of PMSM

Sr. No.	PMSM parameter	Value	Sr. No.	PMSM parameter	Value
1.	Stator resistance	2.885 Ω	5.	q-axis inductance	8.5×10^{-3} H
2.	PM flux	0.185 Wb	6.	Torque	0.051 Nm
3.	No of pole pairs	4	7.	Movement of inertia	2.26×10^{-5} Kg/m^2
4.	d-axis inductance	8.5×10^{-3} H	8.	Viscous coefficient	1.349×10^{-5} Nms

5. HARDWARE MODEL AND EXPERIMENTAL RESULTS

Figure 11 shows the hardware design of the DTC-PMSM drive Figure 12 shows inverter phase voltages of DTC-SVM at (a) 40 Hz, (b) 45 Hz, and (c) 50 Hz. Figure 13 shows inverter line voltages of DTC-SVM at (a) 40 Hz, (b) 45 Hz, and (c) 50 Hz. Figure 14 shows the motor inverter current response.

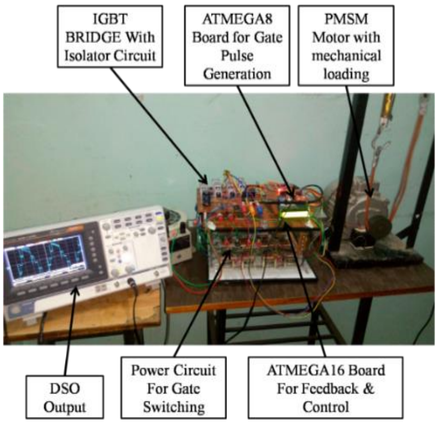


Figure 11. Hardware design of DTC-PMSM drive

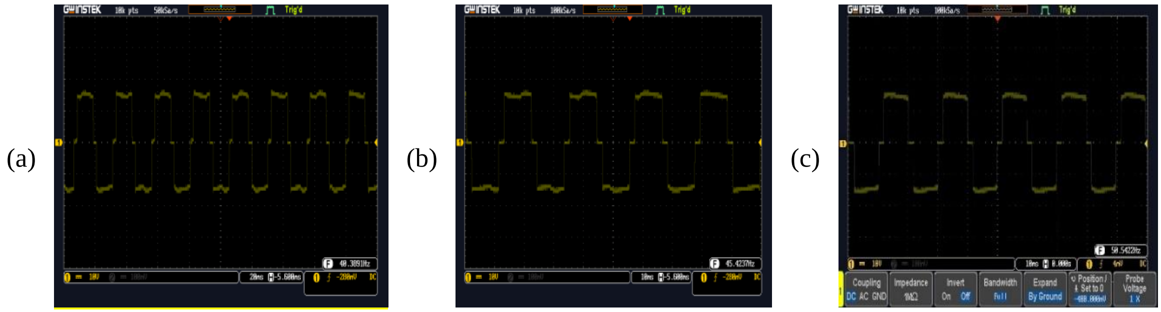


Figure 12. Inverter phase voltages of DTC-SVM at (a) 40 Hz, (b) 45 Hz, and (c) 50Hz

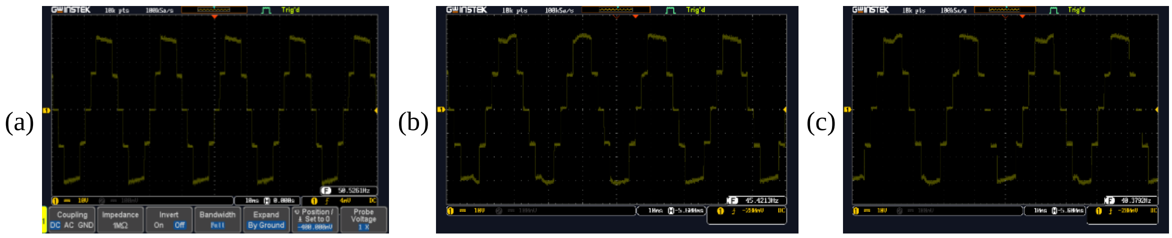


Figure 13. Inverter line voltages of DTC-SVM at (a) 40 Hz, (b) 45 Hz, and (c) 50 Hz

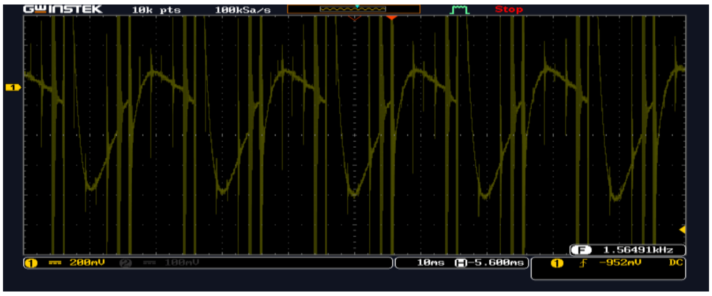


Figure 14. Motor inverter current response

6. CONCLUSION

This paper presents *a* DTC analysis of a DCMLI-driven PMSM-SVM drive using MATLAB software. The SVM method provides a better steady-state response of DCMLI-driven PMSM drive as compared to a conventional inverter. SVM is easy and the fastest method for torque ripple and THD reduction. The proposed multilevel inverter PMSM drive gives lesser harmonic distortion, distorted output, torque ripple, and better control performance. Also, the driving performance of multilevel inverter-driven PMSM drives is better compared to conventional inverter-driven PMSM drives and hence It is suited for EV applications.

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