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# Torque ripples analysis of three-level inverters in DTC drives

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**ABSTRACT** – Multilevel inverter is one of the applications method applied in direct torque control drives. In this paper, the mapping voltage vectors of conventional and three-level inverter is performed by using analytical expression. Indeed, the hexagonal of mapping vector performed by three-level inverter is larger than conventional inverter. Finally, an analysis of torque ripple is presented by comparing the performance between conventional inverter and classic three-level inverter applications in DTC for induction machine.

## 1. INTRODUCTION

Takahashi and Noguchi [1] introduce direct torque control (DTC) strategy that performs a circular trajectory of stator flux in 1986. Simple and robust implementation of DTC become the prior attraction in AC drive rather than field oriented control (FOC) which depends on parameter variation and transformation [2]. Nevertheless, DTC contributes several disadvantages such poor stator flux regulation, variable switching frequency and higher ripple of torque and flux (Kumar, Iqbal and Lenin, 2018).

Multilevel inverter is an interest method among others in order to minimize the ripple of torque and flux produced by conventional DTC. The key point of this topology is the high number degree of freedom particularly in finding the optimum voltage vector in the DTC [3], [4]. Also, multilevel inverter is applied for reducing dv/dt of switches, harmonics and producing sinusoidal output voltage rather than conventional inverter [5]. Several ideas of using multilevel inverter in DTC have been implemented by several authors [3], [6], [7] The common three-level inverters are introduced as Flying Capacitor (FC), Neutral Point Clamped (NPC) and Cascaded H-Bridge (CHB).

Thus, this paper presents the mapping voltage vector of conventional inverter and three-level inverter by using analytical expression. Then, it is followed by the analysis of torque ripple in DTC for induction machine.

## 2. MAPPING VECTOR OF TWO-LEVEL AND THREE-LEVEL INVERTER

The analysis of dynamic behavior of induction machine is necessary in order to identify the mapping voltage vector. Initial equation of three-phase quantities of stator voltage vector is derived from (1) to obtain the transformations of d-q voltage vector for two-level inverter ((2) and (3)) and three-level inverter ((4) and (5)) [8]. Finally, the hexagonal of mapping vector of two-level and three level inverter are shown in Figure 1 and 2.

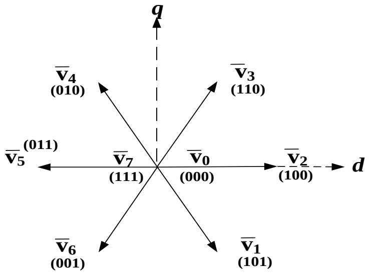
$$\bar{v} = \frac{2}{3}\left(v_{aN} + \bar{a}v_{bN} + \bar{a}^2 v_{cN}\right) \tag{1}$$

$$v_{sd} = \frac{V_{DC}}{3}\left[2S_a{}^{+} - S_b{}^{+} - S_c{}^{+}\right] \tag{2}$$

$$v_{sq} = \frac{V_{DC}}{\sqrt{3}}\left[S_b{}^{+} - S_c{}^{+}\right] \tag{3}$$

$$\begin{aligned} v_{sd} = \frac{V_{DC}}{3}\Big[2\left(S_{a1}{}^{+} - S_{a2}{}^{+}\right) \\ - \left(S_{b1}{}^{+} - S_{b2}{}^{+}\right) \\ - \left(S_{c1}{}^{+} - S_{c2}{}^{+}\right)\Big] \end{aligned} \tag{4}$$

$$v_{sq} = \frac{V_{DC}}{\sqrt{3}}\left[\left(S_{b1}{}^{+} - S_{b2}{}^{+}\right) - \left(S_{c1}{}^{+} - S_{c2}{}^{+}\right)\right] \tag{5}$$



(a)

Figure 1 Mapping vector of two-level inverter.

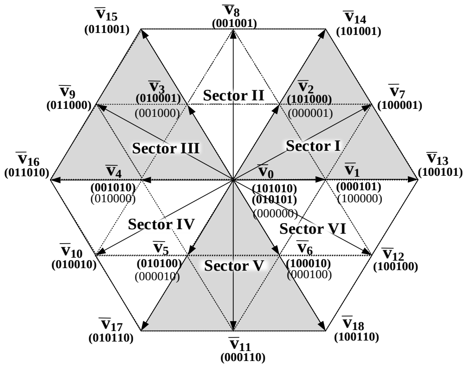
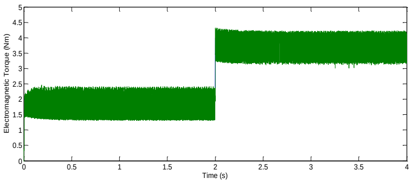
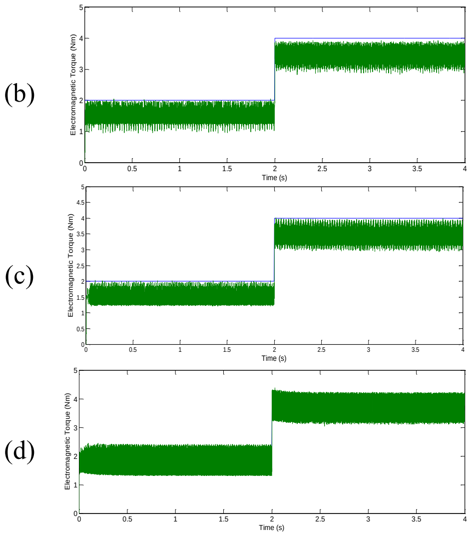


Figure 2 Mapping vector of three-level inverter.



(a)



**Reference torque: Blue waveform*
**Estimated torque: Green waveform*

Figure 3 Simulation results of torque response of DTC by using (a) Conventional inverter, (b) Flying Capacitor inverter, (c) Neutral Point Clamped inverter, and (d) Cascaded H-Bridge inverter circuit

## 3. RESULT AND DISCUSSION

All of the inverters in DTC implementation is simulated by using MATLAB/Simulink. The simulation result of torque ripple in DTC implementation is illustrated in Figure 3. The step response imposed to the reference torque is set at initial of 2 Nm and final at 4 Nm. All of the torque performance is well regulated follows the reference as displayed from the result.

In Figure 3(a), the conventional or two-level inverter achieves 33.36% of torque ripple. As for flying capacitor inverter in Figure 3(b), the torque ripple reaches 32.7%. Although the estimated torque follows the dynamic response of the reference torque, but it is a slight far to reach the steady state of torque at 4 Nm. Fortunately, the estimated torque keep maintained at initial of 2 Nm torque. The neutral point clamped which it has almost similar configuration of flying capacitor produces 30.18% of torque ripples. It is the lowest reduction of torque ripples among topologies as shown in Figure 3(c). In addition, it is better than flying capacitor through the estimated torque that almost reaches the final value of torque.

Although cascaded H-bridge has the lowest number of components, but it requires the separated DC-link on each cascaded bridge. In contrast with neutral point clamped and flying capacitor inverter, they only need single DC-link. As applied cascaded H-bridge in DTC drives, the torque ripples of 32.97% is achieved. Furthermore, the reference torque is followed well by the estimated torque.

## 4. CONCLUSION

In conclusion, the multilevel inverter application in DTC drives could produce the acceptable torque ripple almost similar with the conventional inverter. As comparison the torque ripples among three-level inverter, the neutral point clamp topology produce the lowest torque ripple reduction with 30.18%. Moreover, the dynamic response is achieved well except the flying capacitor inverter where its estimated torque is a bit far from steady state of 4 Nm. Luckily, the torque result is better at 2 Nm.

## ACKNOWLEDGEMENT

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