Elimination of the DC Bus Sixth Harmonic Component in Integrated Modular Motor Drives Using Third Harmonic Injection Method

Mesut Uur
Department of Electrical and Electronics Engineering
Middle East Technical University
Ankara, Turkey
Email: ugurm@metu.edu.tr

Ozan Keysan
Department of Electrical and Electronics Engineering
Middle East Technical University
Ankara, Turkey
Email: keysan@metu.edu.tr

***Abstract*—In this paper, a novel method to eliminate the harmonic component occurring on the DC bus which is six times the grid frequency is proposed. This harmonic component is present due to natural commutation of the passive diode bridge rectifier in motor drive applications. In conventional drives, bulky LC filters are utilized to reduce the effect of this harmonic component to the motor drive inverter. With this method, DC bus capacitance requirement can be minimized which will enhance the power density and decrease the cost of the overall system. Third harmonic injection is used with modular inverters in an integrated modular motor drive application. Both rectifier and inverter side analytical models are presented, the elimination of the sixth harmonic component is described analytically, and verified by simulations performed on MATLAB/Simulink. The possible adverse effects of third harmonic injection method are also discussed.**

I. Introduction

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A. Subsection Heading Here

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Most studies consider only one side for DC link characterisation or filter component optimization, although they should be considered simultaneously. This research aims at modeling the system as a whole, investigating the effect of harmonic components injected to the DC link from both sides and eliminating the low frequency harmonic due to the rectifier side by using the modular structure of the inverter side.

II. Problem definition

A conventional motor drive application block diagram is shown in Fig. 1. The rectifier and inverter are connected via the DC link, therefore a harmonic component injected from one side is reflected to the other side. For systems having two active converters on both sides such as back-to-back converters, the only fluctuations seen on the DC link voltage are high frequency components which are directly related to the switching frequency. On the other hand, in case of passive converters such as diode bridge rectifiers, low frequency components are emerge on the DC link voltage which are related to the grid supply frequency.

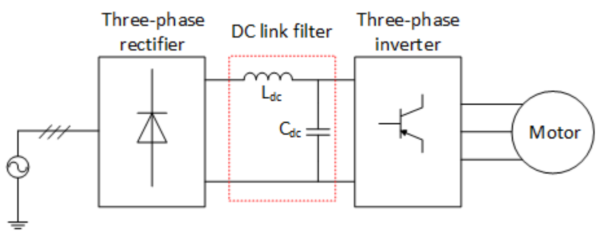

Fig. 1: A conventional motor drive block diagram

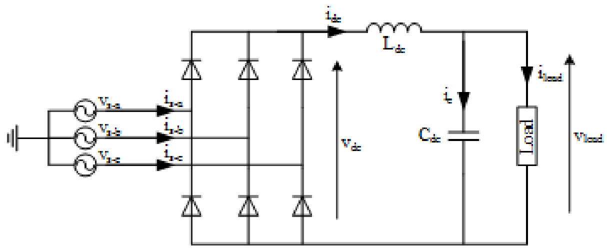

Fig. 2: Diode bridge rectifier circuit diagram

Diode bridge rectifier is a natural-commutated converter, circuit schematic of which is shown in Fig. 2. The supply voltages are shown in 5-7, where V_m is the RMS value of the supply voltage and f_s is the supply frequency.

$$v_{sa}(t) = \sqrt{2}V_m sin(2\pi f_s t) \tag{1}$$

$$v_{sb}(t) = \sqrt{2}V_m sin(2\pi f_s t - 2\pi/3) \tag{2}$$

$$v_{sc}(t) = \sqrt{2}V_m sin(2\pi f_s t - 4\pi/3) \tag{3}$$

With this configuration, integer multiples of sixth harmonic component are present on the rectifier output voltage in addition to the DC component as shown in 8.

$$v_{dc}(t) = \frac{3\sqrt{3}}{\pi}\left[1 - \sum_{k=1}^{\infty} \frac{2}{36k^2 - 1} cos(6k\omega_0 t)\right] \tag{4}$$

The purpose of the LC filter at the output is to decrease these harmonic components on the load side. The LC filter is bulky and costly.

Size of passives are very important for IMMD applications.

A set of voltage and current waveforms are shown in Fig. 3, for 400V line-to-line grid voltage at 50 Hz, filter inductance of 1 mH, filter capacitance of 3 mF and load resistance of 10 Ω. The three-phase rectifier output voltage and current has large harmonic components frequency of which is six times the grid frequency. This component is filtered by a second order LC filter resulting in a much smoother load voltage and current. Since the harmonic frequency is relatively low in comparison with conventional switching frequencies, large inductance and capacitance values are needed on the DC link filter. Those passive elements constitute a large portion of overall volume and cost, hence it is aimed to minimize their values.

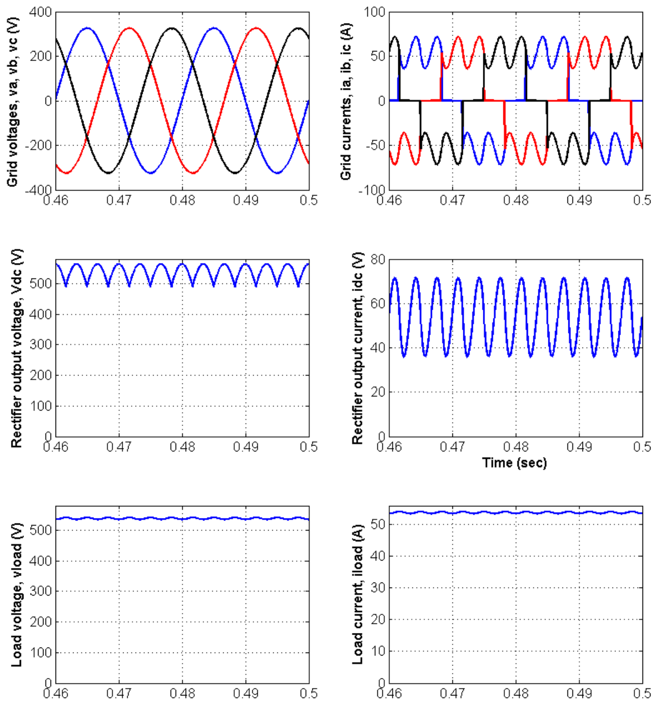

Fig. 3: Diode bridge rectifier input and output waveforms

III. Description of the Proposed Method

Proposed method: Sixth harmonic creation on the DC link with third harmonic injection (analytical)

Voltages and current expressions of one inverter module with zero sequence third harmonic injection are shown in 5-10.

$$v_a(t) = V_1 sin(2\pi ft - \phi_{1v}) + V_3 sin(6\pi ft - \phi_{3v}) \tag{5}$$

$$v_b(t) = V_1 sin(2\pi ft - 2\pi/3 - \phi_{1v}) + V_3 sin(6\pi ft - \phi_{3v}) \tag{6}$$

$$v_c(t) = V_1 sin(2\pi ft - 4\pi/3 - \phi_{1v}) + V_3 sin(6\pi ft - \phi_{3v}) \tag{7}$$

$$i_a(t) = I_1 sin(2\pi ft - \phi_{1i}) + I_3 sin(6\pi ft - \phi_{3i}) \tag{8}$$

$$i_b(t) = I_1 sin(2\pi ft - 2\pi/3 - \phi_{1i}) + I_3 sin(6\pi ft - \phi_{3i}) \tag{9}$$

$$i_c(t) = I_1 sin(2\pi ft - 4\pi/3 - \phi_{1i}) + I_3 sin(6\pi ft - \phi_{3i}) \tag{10}$$

Let us make the definitions shown in 11-18.

$$\phi_{11p} = \phi_{1v} + \phi_{1i} \tag{11}$$

$$\phi_{33p} = \phi_{3v} + \phi_{3i} \tag{12}$$

$$\phi_{13p} = \phi_{1v} + \phi_{3i} \tag{13}$$

$$\phi_{31p} = \phi_{3v} + \phi_{1i} \tag{14}$$

$$\phi_{11n} = \phi_{1v} - \phi_{1i} \tag{15}$$

$$\phi_{33n} = \phi_{3v} - \phi_{3i} \tag{16}$$

$$\phi_{13n} = \phi_{1v} - \phi_{3i} \tag{17}$$

$$\phi_{31n} = \phi_{3v} - \phi_{1i} \tag{18}$$

The instantaneous power expression for each phase are shown in 19-21.

$$\begin{aligned} p_a(t) = \frac{V_1 I_1}{2}\Big[cos(\phi_{11n}) - cos(4\pi ft - \phi_{11p})\Big] \\ + \frac{V_1 I_3}{2}\Big[cos(4\pi ft + \phi_{13n}) - cos(8\pi ft - \phi_{13p})\Big] \\ + \frac{V_3 I_1}{2}\Big[cos(4\pi ft - \phi_{31n}) - cos(8\pi ft - \phi_{31p})\Big] \\ + \frac{V_3 I_3}{2}\Big[cos(\phi_{33n}) - cos(12\pi ft - \phi_{33p})\Big], \end{aligned} \tag{19}$$

$$\begin{aligned} p_b(t) = \frac{V_1 I_1}{2}\Big[cos(\phi_{11n}) - cos(4\pi ft - 4\pi/3 - \phi_{11p})\Big] \\ + \frac{V_1 I_3}{2}\Big[cos(4\pi ft + 2\pi/3 + \phi_{13n}) - cos(8\pi ft - 2\pi/3 - \phi_{13p})\Big] \\ + \frac{V_3 I_1}{2}\Big[cos(4\pi ft + 2\pi/3 - \phi_{31n}) - cos(8\pi ft - 2\pi/3 - \phi_{31p})\Big] \\ + \frac{V_3 I_3}{2}\Big[cos(\phi_{33n}) - cos(12\pi ft - \phi_{33p})\Big], \end{aligned} \tag{20}$$

$$
\begin{aligned}
p_c(t) = \frac{V_1 I_1}{2}&\left[cos(\phi_{11n}) - cos(4\pi f t - 8\pi/3 - \phi_{11p})\right] \\
+ \frac{V_1 I_3}{2}&\left[cos(4\pi f t + 4\pi/3 + \phi_{13n}) - cos(8\pi f t - 4\pi/3 - \phi_{13p})\right] \\
+ \frac{V_3 I_1}{2}&\left[cos(4\pi f t + 4\pi/3 - \phi_{31n}) - cos(8\pi f t - 4\pi/3 - \phi_{31p})\right] \\
&+ \frac{V_3 I_3}{2}\left[cos(\phi_{33n}) - cos(12\pi f t - \phi_{33p})\right],
\end{aligned} \tag{21}
$$

The total instantaneous power becomes as in 22. As seen, all the frequency components which are two times and four times the fundamental frequency are cancelled, leaving two DC components and a component at six times the fundamental frequency.

$$
\begin{aligned}
p_{total}(t) = \frac{V_1 I_1}{2}\left[cos(\phi_{11n})\right] &+ \frac{V_3 I_3}{2}\left[cos(\phi_{33n})\right] \\
&+ \frac{V_3 I_3}{2}\left[cos(12\pi f t - \phi_{33p})\right]
\end{aligned} \tag{22}
$$

IV. Implementation of the method and practical issues

New IMMD scheme for third harmonic injection, practical considerations, effects on other components, torque ripple, copper loss etc.

V. Results

Simulation results

VI. Conclusion

The conclusion goes here.

Acknowledgment

The authors would like to thank...

References

[1] H. Kopka and P. W. Daly, *A Guide to LaTeX*, 3rd ed. Harlow, England: Addison-Wesley, 1999.