Analytical Characterization of Common-mode Voltage in A Three-level ANPC Inverter

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Abstract

In the motor drive system, the research on the analytical models for common-mode (CM) performance evaluation is important. However, such model for the 3-level inverter system is still largely missing. In this poster, an analytical model of CM voltage (CMV) in a 3-level active neutral point clamping (ANPC) inverter is presented using Double Fourier Integral (DFI). The model could be extended to different 3-level modulation schemes such as conventional space vector PWM (CSVM), nearest three space vectors modulation (NTSVM), and reduced common-mode voltage modulation (RCMVM). The impact of these three modulation schemes on the CMV is comprehensively compared across the full modulation index range. An 800V/50kW 3L inverter is built using off-the-shelf automotive-qualified 650V/60A GaN HEMTs to verify such model.

$$x(t)=\omega_s t+\theta_s$$

$$y(t)=\omega_0 t+\theta_0$$

$$f(x,y)=\frac{A_{00}}{2}+\sum_{n=1}^{\infty}\left\{A_{0n}\cos\left(n\left(\omega_0 t+\theta_0\right)\right)+B_{0n}\sin\left(n\left(\omega_0 t+\theta_0\right)\right)\right\}$$
$$+\sum_{m=1}^{\infty}\left\{A_{m0}\cos\left(m\left(\omega_s t+\theta_s\right)\right)+B_{m0}\sin\left(m\left(\omega_s t+\theta_s\right)\right)\right\}$$
$$+\sum_{m=1}^{\infty}\sum_{\substack{n=-\infty\\ n\neq 0}}^{\infty}\left\{A_{mn}\cos\left(m\left(\omega_s t+\theta_s\right)+n\left(\omega_0 t+\theta_0\right)\right)+B_{mn}\sin\left(m\left(\omega_s t+\theta_s\right)+n\left(\omega_0 t+\theta_0\right)\right)\right\}$$

Equation 1: DFI analysis of PWM, *m* is the carrier index variable, and *n* is the baseband index variable. $x(t)$ is the modulation.

CM Voltage Modeling

Compared with a two-level system, a 3-level inverter alleviates the CM noise by providing more vector redundancy, and some vector combinations even null the CMV. Using DFI analysis, the output voltage spectrum could be predicted analytically (equation 1). For CSVM, there are 8 sections for each fundamental cycle (Fig. 2). Especially, in sections 1, 2, 5, and 6, there are three integration areas while In sections 3, 4, 7, and 8 there is only one. Substituting different values for m and n in Equation 1, the carrier harmonics and sideband components of the CMV can be calculated and compared to the simulation.

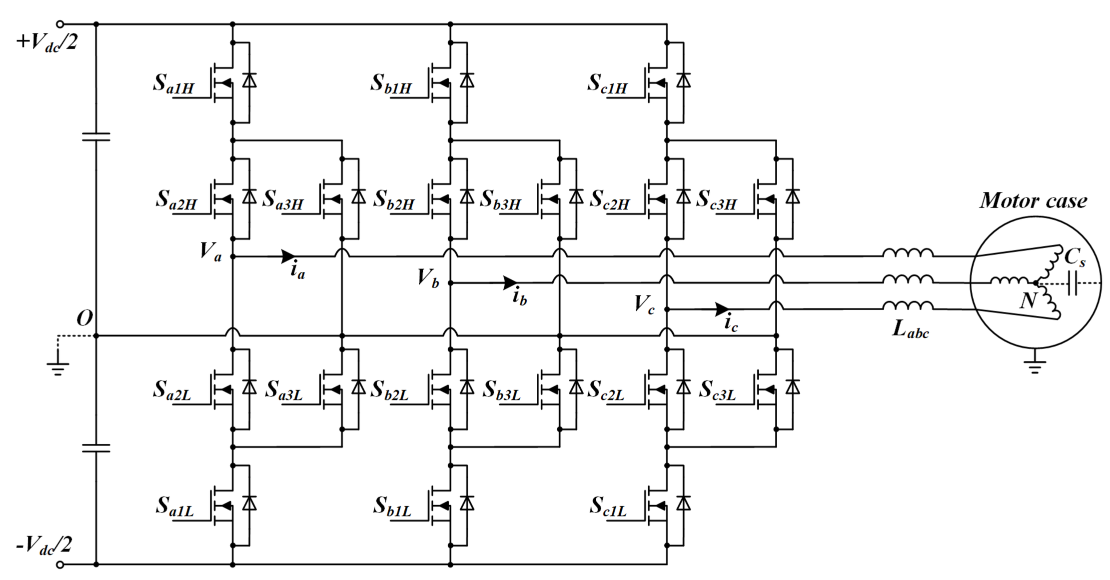

Figure 1: Three-level ANPC inverter motor drive system

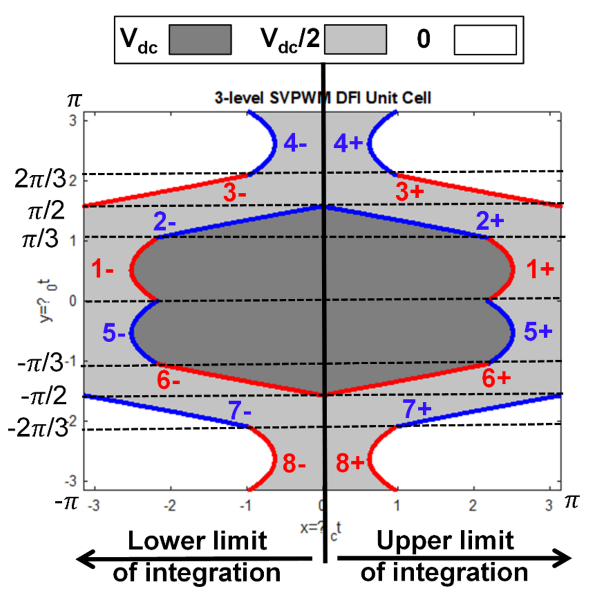

Figure 2: DFI integral bounds for CSVM

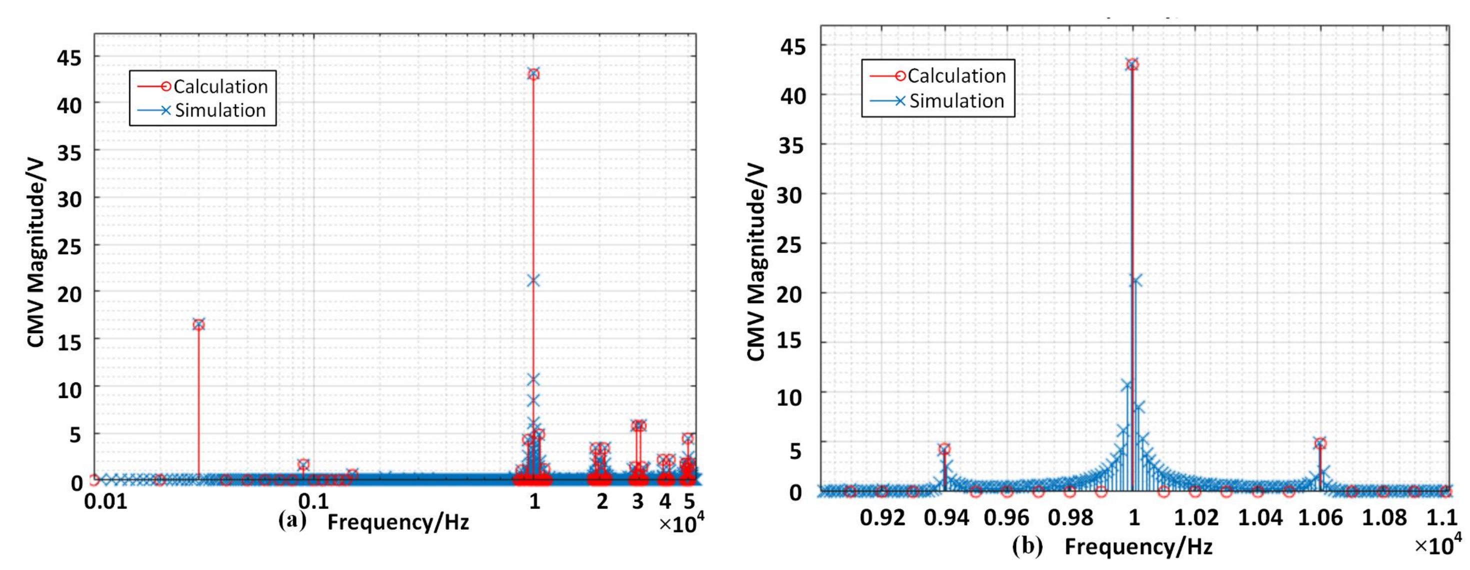

Figure 3: Comparison of DFI result and simulation for 3L-ANPC inverter. (a) Wide frequency range, (b) Zoomed-in view @f_s.

Experimental Validation

As shown in Fig. 3, the calculated carrier harmonics and the sideband component of both phase voltage and CMV are very close to the simulation. Therefore, the proposed analytical approach for CMV can be extended to multilevel scenarios, such as NTSVM and RCMVM (Fig. 4-5). We further built a three-level inverter using GaN and experimentally validate the effectiveness of the CMV analytical model, as shown in Fig.6-7.

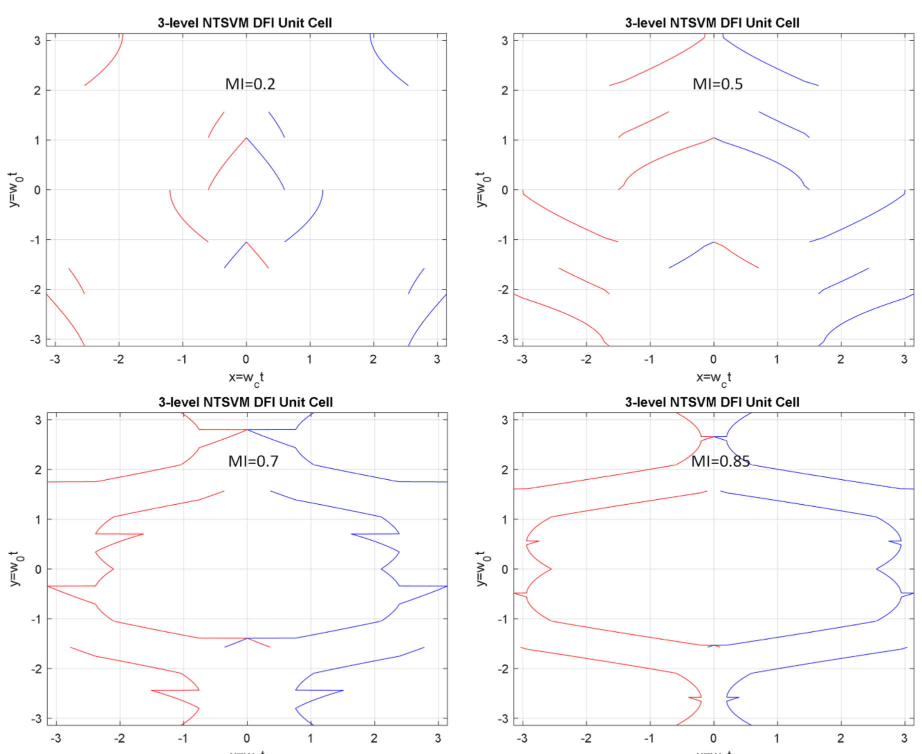

Figure 4a DFI integral bounds for NTSVM

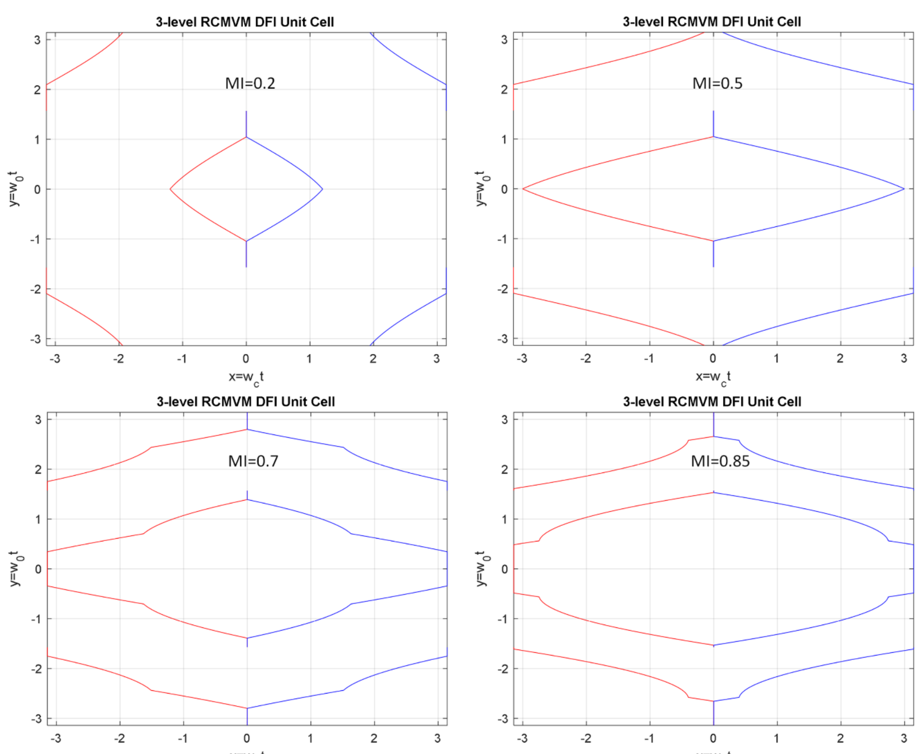

Figure 4b DFI integral bounds for RCMVM

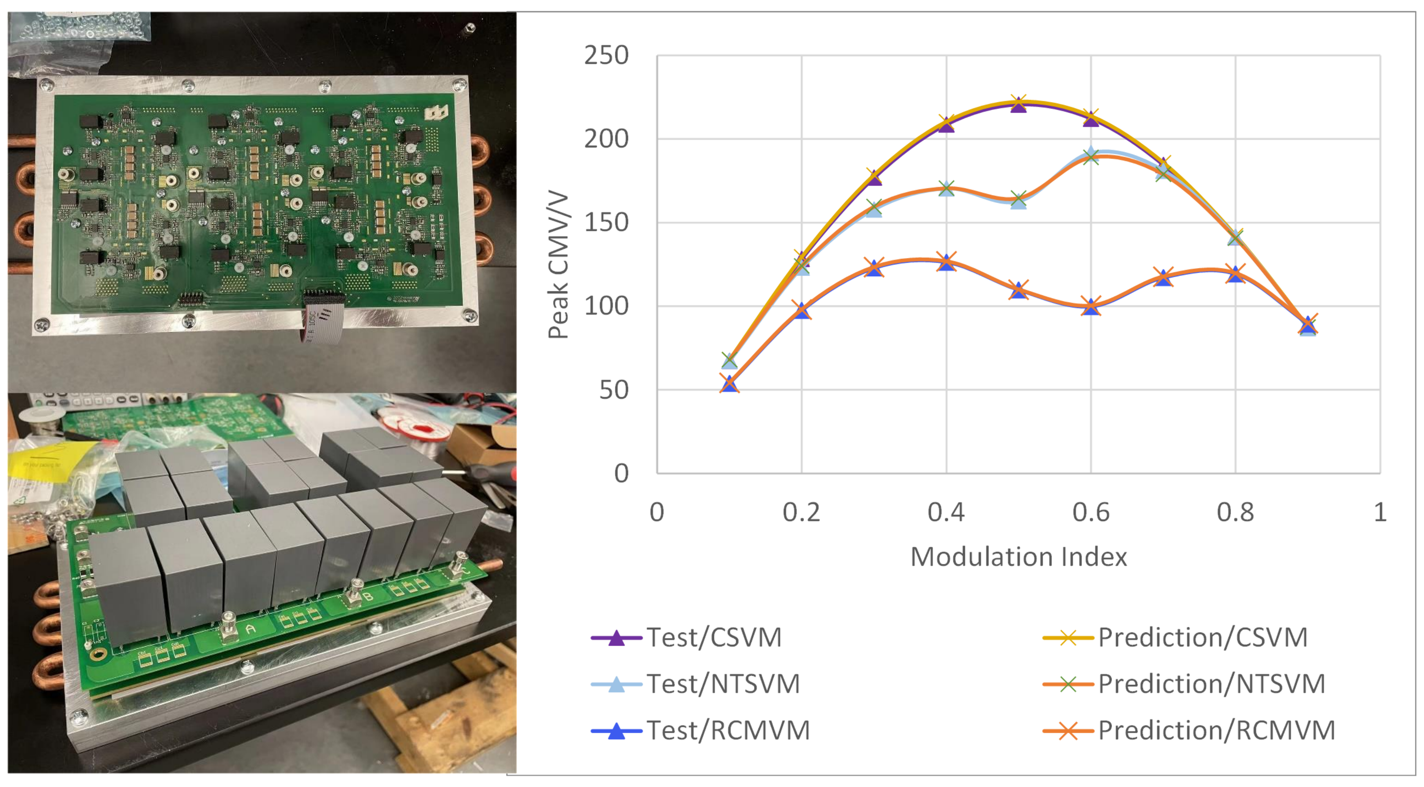

Figure 6 Comparison of CMV spectrum peak value between extrapolated experimental result and prediction result.

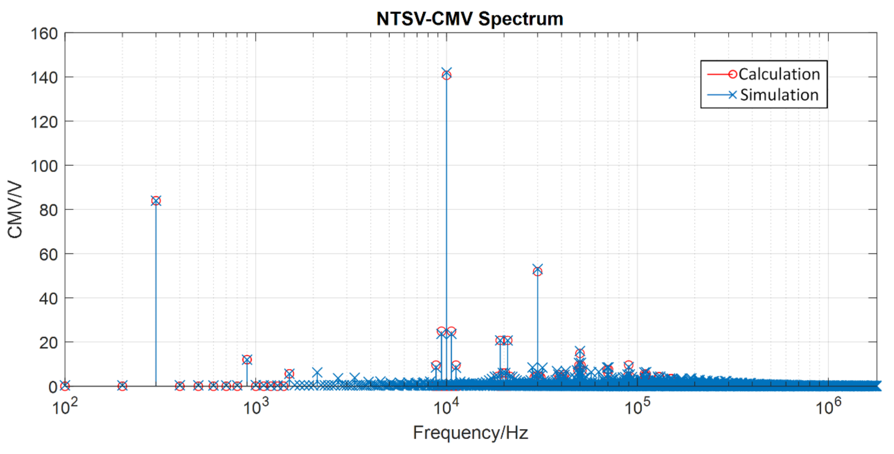

Figure 5a Comparison of DFI result and simulation for 3L-NTSVM.

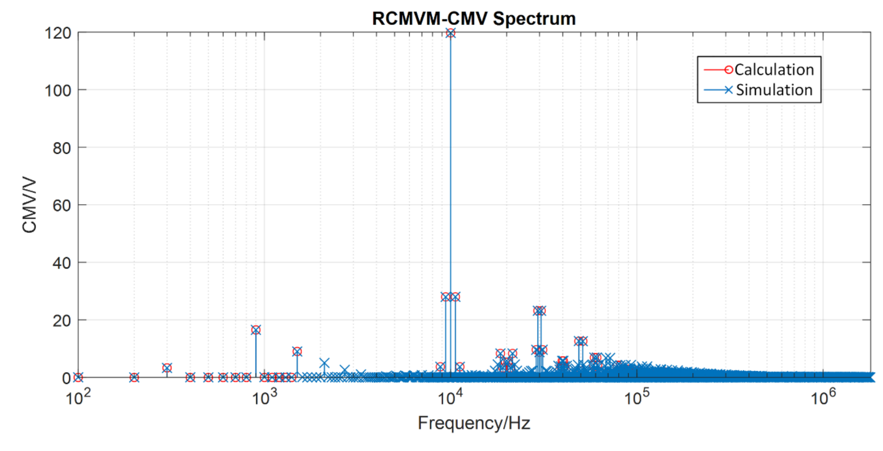

Figure 5b Comparison of DFI result and simulation for 3L-RCMVM.

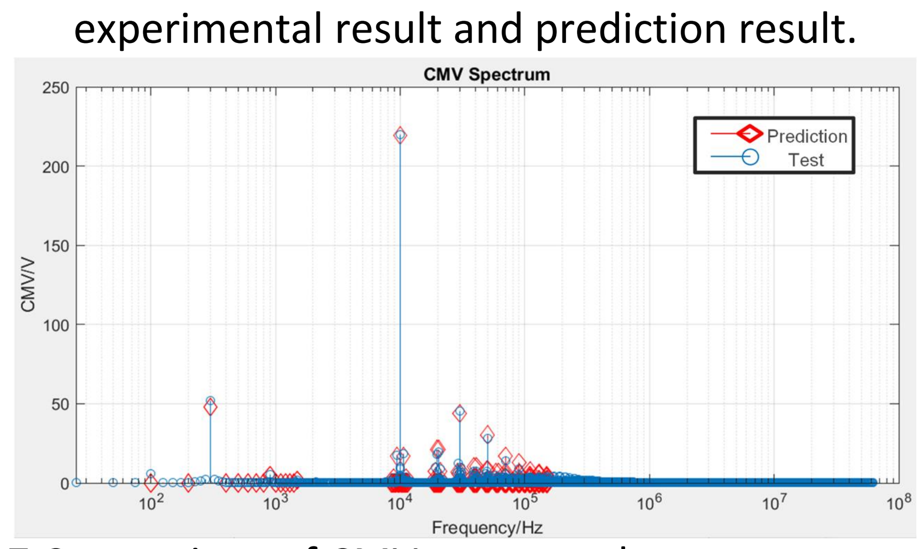

Figure 7 Comparison of CMV spectrum between extrapolated experimental result and prediction result for 3L-CSVM @MI=0.5.

Conclusion

To overcome the CMV issue that is worsened by the fast switched GaN devices, proper CM modeling is needed, which however is less studied in past research work. This paper successfully extended the proposed CMV prediction model to the 3-level inverter. Three different PWM methods are modelled and compared, using simulation and experiments. The computation results, simulation and experiments match very accurately. For the future work, we plan to run the GaN inverter to 800V and use more test data to support the CMV DFI model.

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