Small-signal Characterization of Selective Harmonics Elimination (SHE) Modulation and its Impact on Passivity-based Impedance Analysis

High-power converters often operate at low switching frequencies to enhance overall efficiency, yet this approach introduces elevated low-order harmonics under sinusoidal pulse width modulation (SPWM). Selective harmonics elimination (SHE) precisely manipulates switching angles within a line cycle, effectively mitigating specific low-order harmonics. This paper studies the impact of SHE on converter impedance characterization. It was revealed that the SHE has an amplifying and uncontrolled effect on certain high-frequency points, which becomes more pronounced when utilizing input voltage feedforward control. This phenomenon is the cause for the simulated terminal impedance of the studied converter to exceed 90˚ at the corresponding frequency points, which violates the passivity criterion.

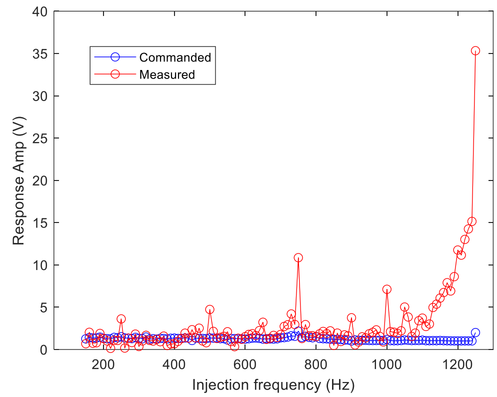

Fig.1. Frequency response results of the SHE

To characterize the small-signal response of the SHE, a perturbation is injected successively into the duty cycle of a closed-loop converter. The fast Fourier transform (FFT) results of the switching terminal voltage and the commanded signal are shown in Fig. 1. The horizontal axis is the perturbation frequency, and the vertical axis is the response voltage amplitude at each perturbation frequency. An amplified effect at high frequencies is observed. Fig. 2 shows the extracted impedance of the converter and the impedance of the input filter. For the case without the 50 Hz zero-order-hold (ZOH), the impedance exceeds 90˚ at high frequencies, especially above 1.2 kHz. This corresponds to the frequency range where the SHE block has significant amplifying effects in Fig. 1. With a 50 Hz ZOH, the simulated impedance follows the impedance of the LCL filter and is within -90˚ and 90˚.

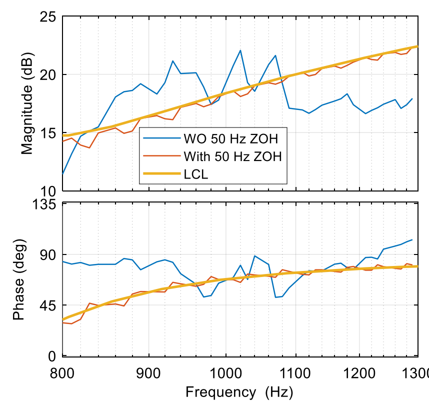

Fig.2. Z_{qq} simulation results

If the input voltage feedforward control is removed, the impact of SHE on impedance at high frequency also becomes smaller. This is because the low-bandwidth current loop reduces the input perturbation of the SHE block to a very small amount. However, with the input voltage feedforward, the perturbation will pass to the SHE block directly.

A potential solution to mitigate this impact is to update the angle and modulation index of the SHE scheme at a slower rate, such as the fundamental frequency, and to avoid the use of feedforward terms; alternatively, switching to SPWM-type modulation schemes also helps alleviate this problem.