Three-level Flying-capacitor-based 100 W USB-C PD GaN Charger in Aircraft Applications

This paper provides the design and evaluation of a three-level, flying-capacitor-based 100 W USB-C Power Delivery (PD) GaN charger in aircraft applications. A proportional resonant compensation combined with input voltage feedforward is analyzed to accommodate the high line frequency of the aircraft. A two-step soft startup process is proposed to avoid possible overvoltage of the switching devices. The total harmonic distortion (THD) and electromagnetic interference (EMI) performance are evaluated with the experiment.

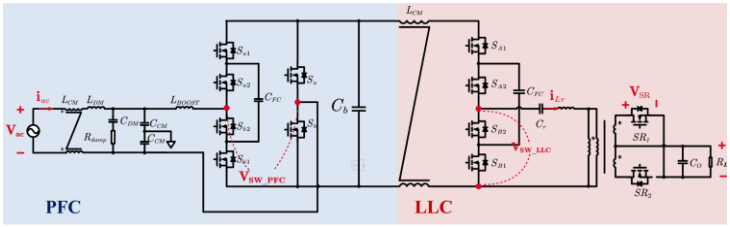

Fig.1. 100 W USB C PD GaN Charger topology

The schematics of the whole system are shown in Fig. 1. The front-end PFC stage utilizes the three-level flying capacitor phase-leg generating the high-frequency pulse-width modulation (PWM) waveforms. The phase-shifted PWM is applied to balance the flying capacitor voltage. The bus voltage is controlled at 200 V by PFC to satisfy the wide regulation range and decrease the step-down ratio of the dc-dc stage. Different from normal consumer electronics, the line frequency of the ac input on aircraft is almost 10 times higher. The phase-leading problem caused by the digital delay in the current loop compensation is more obvious under this low switching frequency and line frequency ratio. With the help of the proportional resonant (PR) compensator and input voltage feedforward, the phase-leading problem caused by the digital delay is greatly reduced and proven with an 800 Hz line frequency.

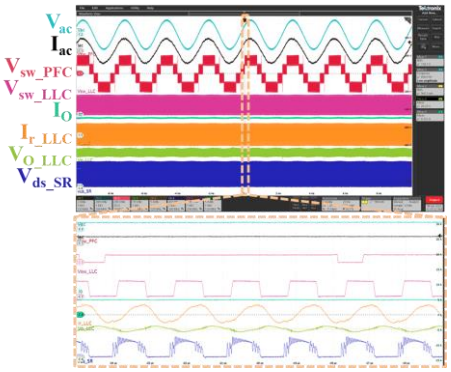

Fig. 2. Measurement waveforms of the charger under nominal outputs. Vac =115 V_{rms}, f=400 Hz. Output of LLC: 20 V/5 A.

The voltage divider of the LLC stage is the same as the PFC high-frequency phase-leg. Thanks to the three-level characteristics, the voltage divider can be operated in three-level flying capacitor mode (half bus mode) and two-level device series mode (full bus mode). The LLC stage achieves an efficiency of over 90% through the entire output range. Fig. 2 shows the experimental waveforms of the charger under nominal conditions with maximum output power.

To pass the THD requirement—especially the low limit for the even harmonics—the sampling frequency and the corner frequency of the filter in the signal processing circuit should be carefully selected. There is a trade-off between THD and power factor. Except for the ac side filter, a common-mode (CM) inductor is added on the dc bus, which provides an effective noise reduction in the middle-frequency range. Both THD and EMI pass the DO160 standard.