A Flux Balancing Strategy for 10-kV SiC-Based Dual-Active-Bridge Converter

Zihan Gao[1],Pengfei Yao[2], Haiguo Li[1], Fred Wang[1,3]
[1] The University of Tennessee, Knoxville [2] China Huaneng Group, Co, Ltd.
[3] Oak Ridge National Laboratory

BACKGROUND AND OBJECTIVES

- WBG device and novel magnetics enable single stage medium voltage dc/dc conversion.
- Dc/dc transformer may have flux unbalance due to control and device mismatch.
- Flux balancing in control transients has been well solved by modulation, but the balancing in steady-state may face challenges due to sensor/control resolution, etc.
- Current harmonics in dc/dc transformer can be used to detect the flux unbalance.

FERRITE GAP AND FLUX UNBALANCE

- In utility transformers, harmonics in magnetizing current have been modeled during saturation.
- Air gaps can be replaced with ferrite gaps to create partial saturation in nanocrystalline and amorphous transformer cores to detect flux unbalance.
- Piece-wise linear model used to model the different levels of the ferrite gap saturation.
- State-space model can be extracted in the combined platform of Simulink/MATLAB and PLECS.
- The steady-state current waveform can be calculated with augmented state-space matrices and matrix exponential.

$$\mathbf{x}_0 = \prod_{i=1}^{k} e^{\tilde{\mathbf{A}}_i t_i} \mathbf{x}_0$$

- With the adopted model, the current harmonics can be extracted for flux unbalance detection.

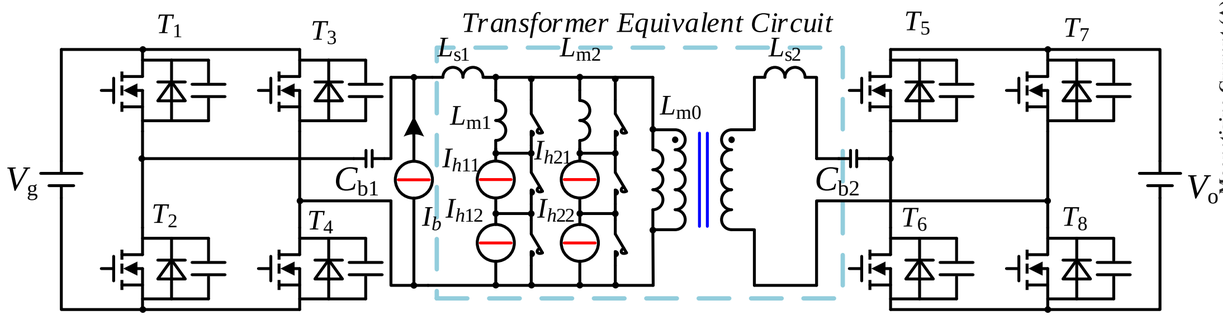

Fig. 2: State space model of DAB with transformer ferrite gaps

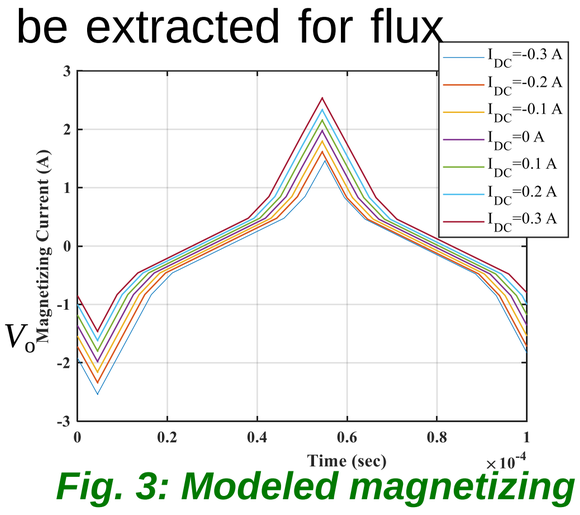

Fig. 3: Modeled magnetizing current with unbalance

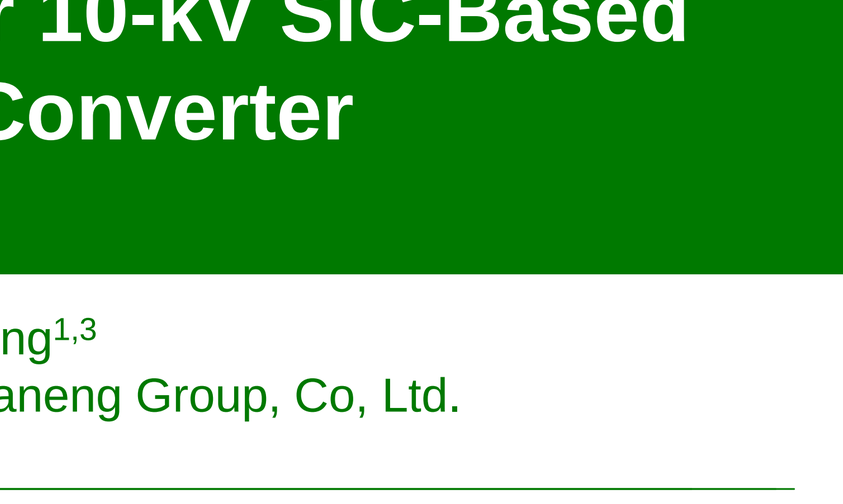

Fig. 1: Magnetizing current with balanced flux

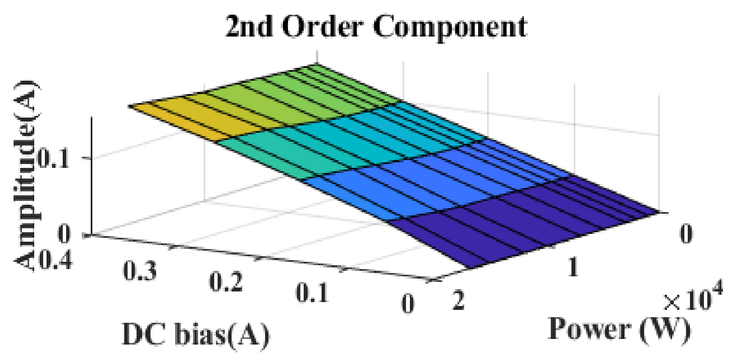

Fig. 4: Harmonic relation with flux DC bias and output power

EXPERIMENTAL TEST

- Amplifier gain designed for fractional winding turns ratio:

$$\frac{A_1}{A_2}\frac{A_{Hall,1}}{A_{Hall,2}} = \frac{N_1}{N_2}$$

- Duty cycle compensated on MV side H-bridge with PI controller.
- Flux balancing modulation used for transient flux balancing.
- Proposed strategy implemented in a 10-kV SiC MOSFET-based DAB converter.

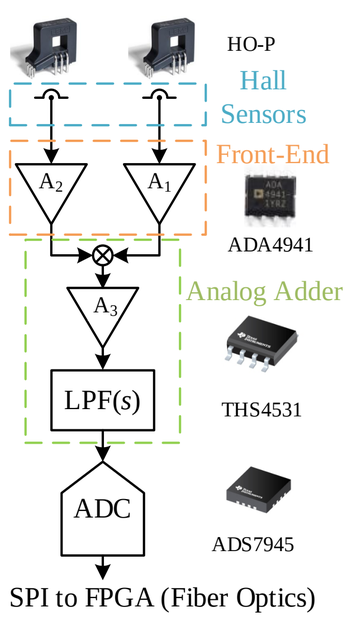

Fig. 5: Magnetizing current sensor

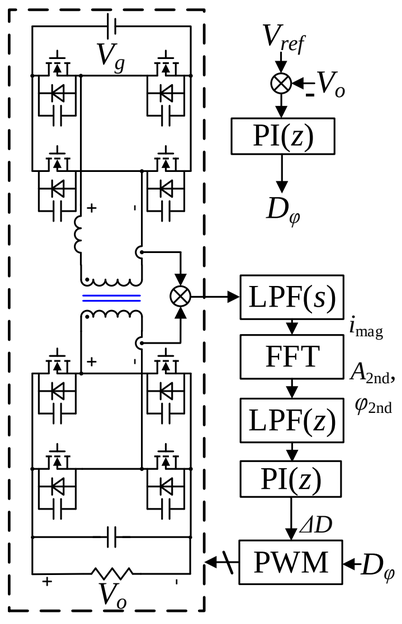

Fig. 6: Control scheme including flux balancing strategy

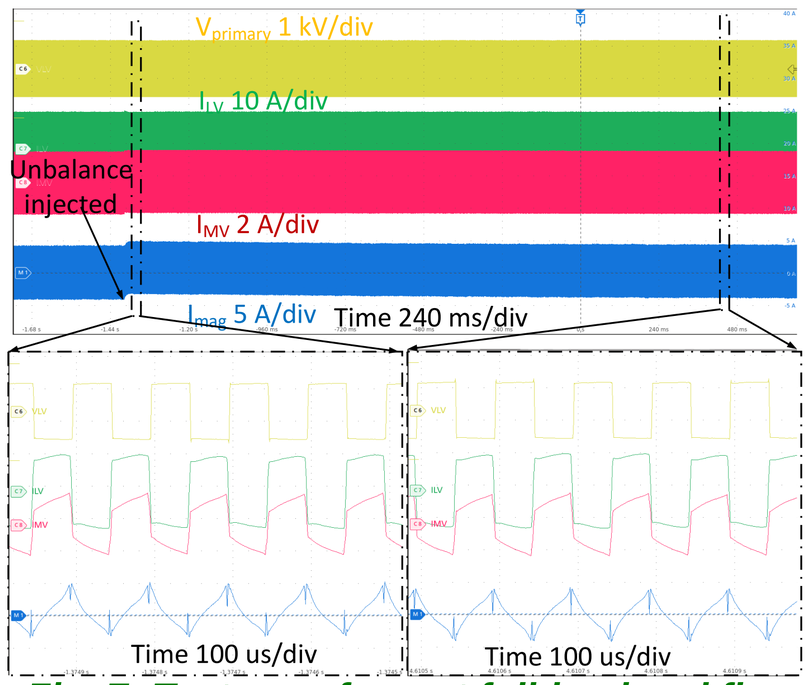

Fig. 7: Test waveform at full-load and flux unbalance disturbance

CONCLUSION

- The ferrite gap-based method can produce the partial core saturation and magnetizing current harmonics due to flux unbalance.
- The relationship can be found between current harmonics and flux unbalance.