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Future Power Electronics Architectures for Magnetron-based RF systems

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1. Introduction And Background

In the widespread of industrial electrification, the magnetron has been employed as the heat generator to replace fossil fuels. However, the conventional power supplies in this field are large and heavy, due to the low switching speed and resonant circuits for lower losses. This project aims to design a new converter for a continuous wave magnetron for industrial processing with the power and voltage in excess of 100 kW and 20 kV, respectively. With the recent technological advances in switching devices and magnetic materials, power converters operating at 100 kHz without the need of resonant tank is possible to achieve. The project will carry out the converter design using SiC MOSFETs and new magnetic core materials, as well as the relevant control schemes.

2. Main Tasks for The Project

- Converter topology selection
- System modelling
- Control design
- Thermal design
- Magnetron emulator design
- Transformer design
- Component selection
- Practical experiment platform development

3. Converter Topology

Currently, the single active bridge (SAB) is adopted. Comparing to the full bridge DC-DC converter, the inductor in the SAB circuit is placed in the primary side. This can avoid the inductor working at high voltage and can also significantly reduce the inductance required. The 3-phase circuit has the best result for output current ripple cancellation, with 120° phase shift between each. Hence smaller output capacitor can be used to meet the output ripple requirement.

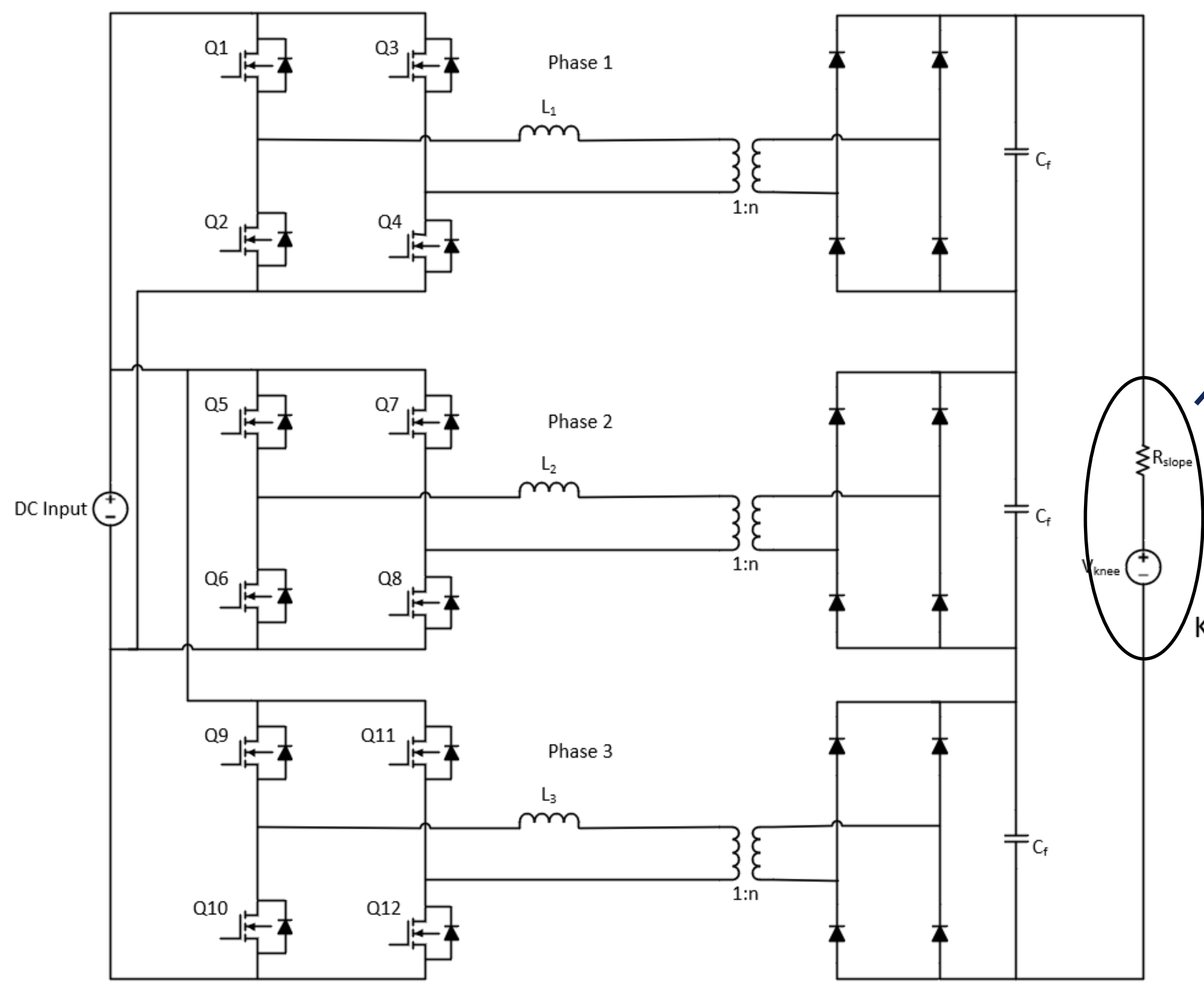

Figure 1: Converter topology

This represent the magnetron type load, which consists a slope resistor and a 'knee' voltage supply

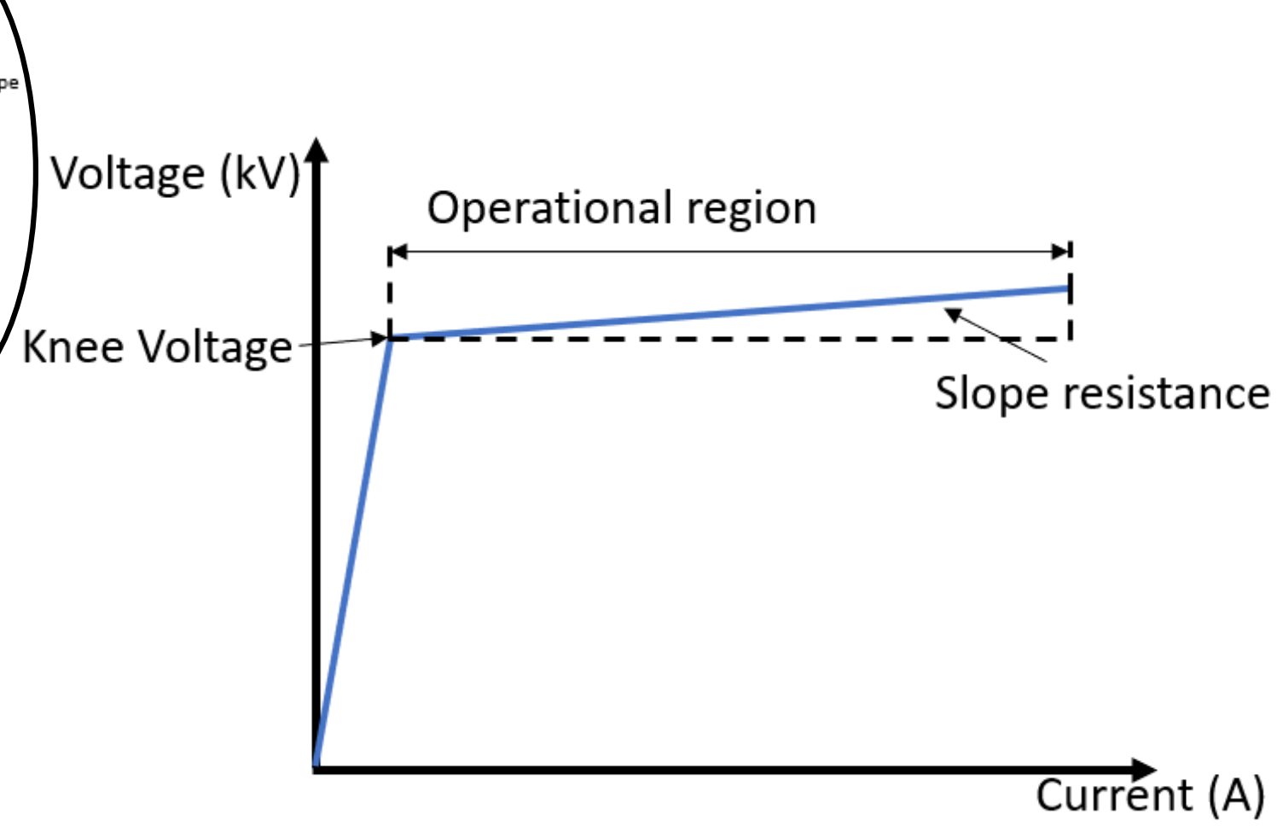

Figure 2: Typical magnetron type load characteristics

4. System Transfer Function And Control

The output current control is the main control scheme to be used for this converter. As the output current is mean inductor current over half switching cycle scaled by the transformer turns ratio, the system can be modelled as the absolute mean inductor current to the duty cycle in the H bridge. This makes the transfer function just a gain and thus an integral controller can be adopted. The controller outputs the gate signal without phase shift to use in phase one and the gate signals for the other two phases are derived from it.

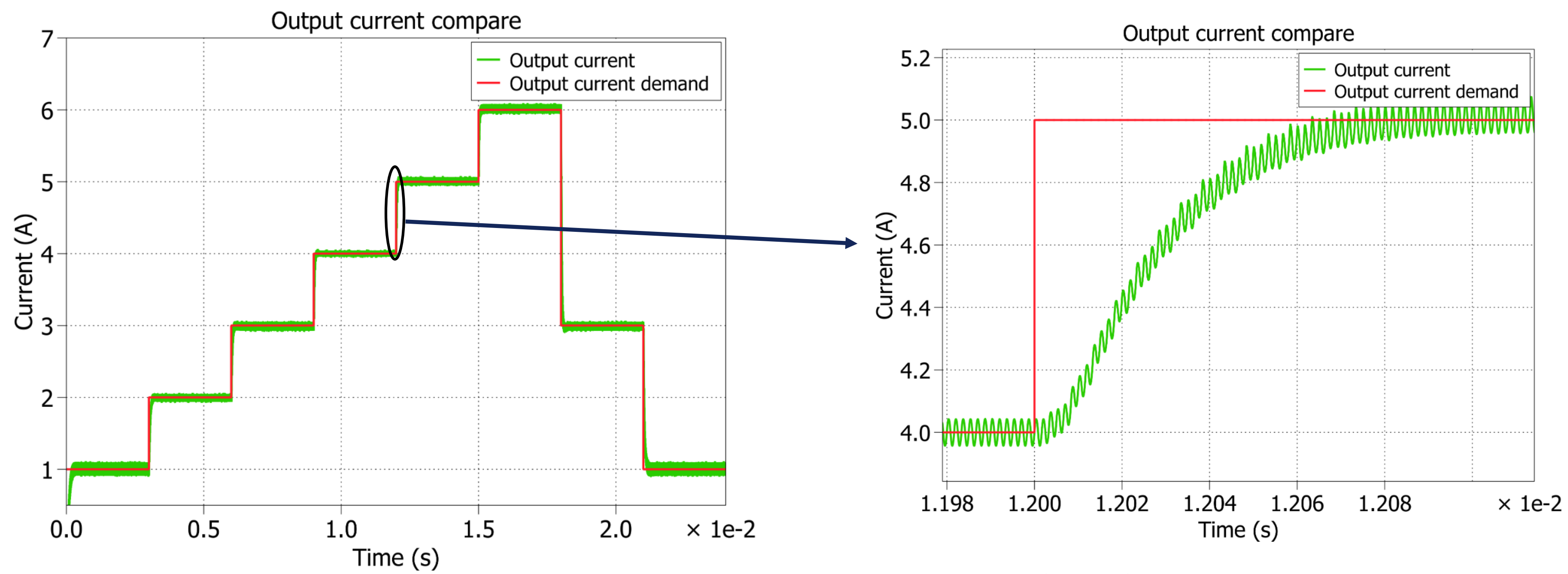

Figure 3 and 4: Output current control results

5. Transformer Design

The transformer design is another important part in the project. Since the circuit operates at 100 kHz, the parasitics and losses in the transformer becomes more significant. Thankfully, with the amorphous and nanocrystalline materials, the core loss can be reduced. Also, with the much higher saturation flux density, the size of the core, and hence the converter can be reduced, compared to using traditional ferrite materials. Currently, a scaled transformer is under development and its performance will be tested in the lab.

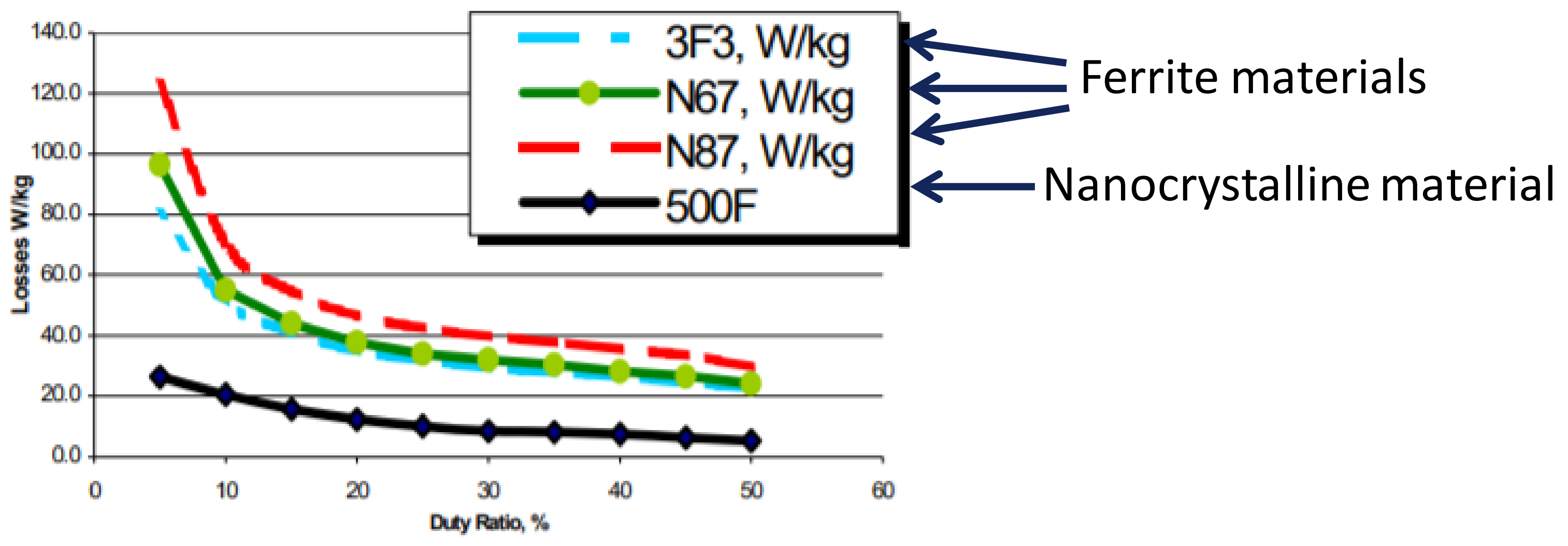

Figure 6: Core loss comparison at 100 kHz, 9kVA [1]

6. Conclusion and Future Works

Currently, the behaviour of the proposed converter has been analysed and controller designed, and the results match with the expectations. The converter is able to deliver the required 120 kW to the magnetron type load at 100 kHz and the output can be controlled accurately. For the next steps, the transformer will be studied in detail and thermal and loss simulations will be carried out. After acquiring satisfied result, experiment on the prototype power supply will follow.

7. References

[1]G. Nikolov and V. Valchev, "Nanocrystalline magnetic materials versus ferrites in power electronics", *Procedia Earth and Planetary Science*, vol. 1, no. 1, pp. 1357-1361, 2009. Available: 10.1016/j.proeps.2009.09.209 [Accessed 25 March 2021].

8. Acknowledgements

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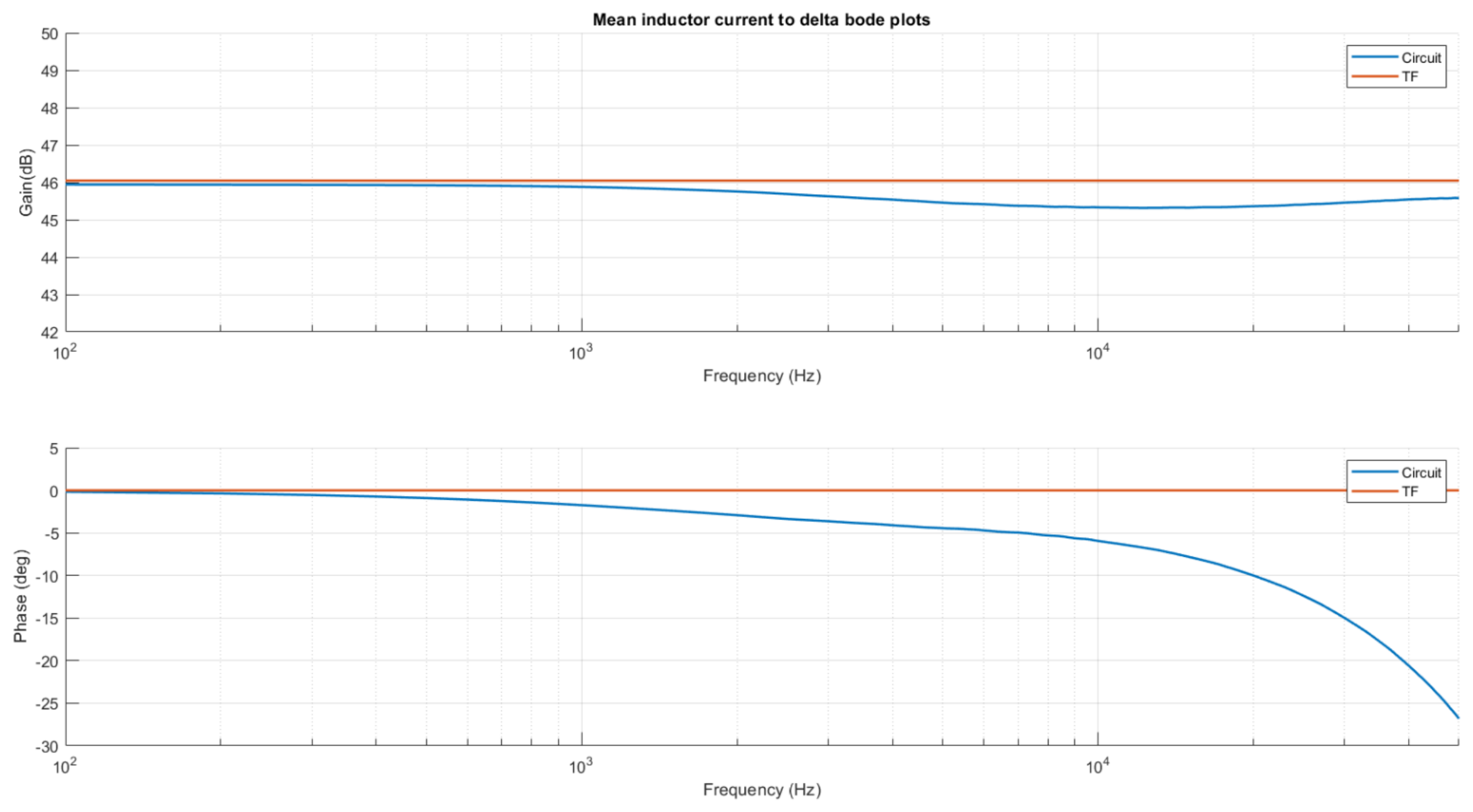

Figure 5: Bode plots for switching circuit and transfer function

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