Designing an interleaved boost converter along with thermal model

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Problem statement:

Design an interleaved boost converter of 1.5 Kilo watt . Input voltage variation (80V-150V) current ripple 1% voltage ripple 5% and Fsw is 80 kHz. Develop a thermal model and evaluate the conduction and switching loss . Validate this in PLECS software.

Software used: PLECS

Theory:

An interleaved boost converter is a power electronics topology that utilizes multiple converter stages operating in parallel to share the load, thereby reducing input and output current ripple while increasing power handling capabilities and efficiency. This technique is commonly employed in various applications where efficient voltage step-up is required, such as in renewable energy systems, electric vehicles, and power supplies.

1. Interleaved Operation:

Interleaved boost converters operate by interleaving multiple converter stages or phases together. Each phase consists of its set of switches, inductors, and capacitors, often controlled by a central control system. The switching of these phases is staggered in time, reducing the overall ripple current and stress on components.

2. Reduction of Ripple Current:

By distributing the load among multiple phases, interleaved converters effectively reduce input and output current ripple. Lower ripple current leads to decreased electromagnetic interference (EMI), improved efficiency, and better voltage regulation.

3. Improved Efficiency:

The sharing of load among multiple phases lowers the current flowing through each phase, reducing losses in individual components like switches, inductors, and capacitors. Lower losses contribute to improved overall efficiency compared to a single converter handling the entire load.

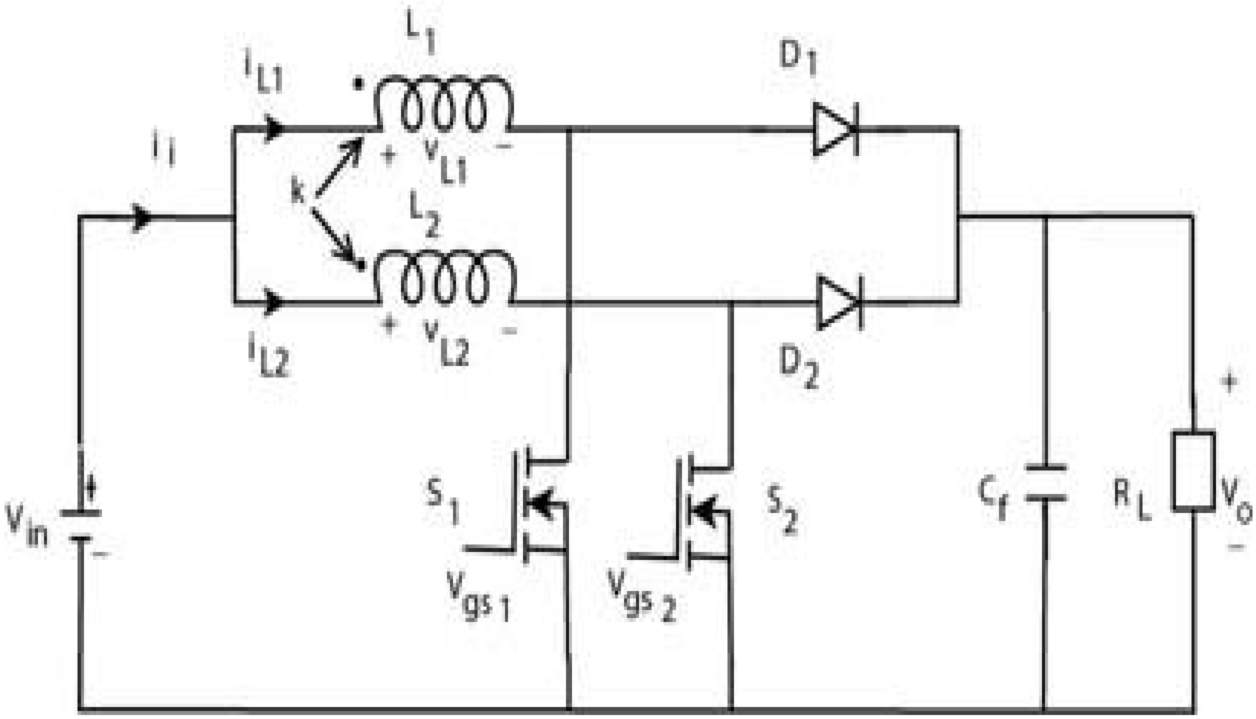
4. Synchronization and Control:

Proper synchronization and control of the interleaved phases are crucial for optimal performance. Control circuits or algorithms ensure that the phases operate in sync, preventing issues like imbalances, excessive current sharing, or instability.

5. Design Considerations:

Component selection, such as switches with low on-state resistance and low switching losses, inductors with low core losses, and capacitors with appropriate voltage and capacitance ratings, is vital for efficient operation. Careful consideration of the phase relationship, timing, and control strategy is necessary to achieve effective interleaving.

Model:



schematic diagram of interleaved boost converter

Here the gate pulses for the switches are given by using pulse generator, and we are using the duty cycle as 0.5, the switches are working under the frequency of 80khz, the pulse generator for the second mosfet has a phase delay 1/160 msec.

Theoretical calculations:

Let $D = 0.5$ $\quad \frac{V_0}{V_{in}} = \frac{1}{1-D} \Rightarrow V_0 = \frac{V_{in}}{1-D} = \frac{150}{0.5} = 300\,V$

If we take $V_{in} = 80\,V$

then $D = \frac{300\,V - 80\,V}{300\,V} = 0.7 = D_{max}$

→ Load current $I_o = \frac{P_o}{V_o} = \frac{1.5 \times 10^3}{300} = 5A$

→ Average inductor current $\Rightarrow I_{L(avg)} = \frac{I_o}{1-D} = \frac{5A}{0.5} = 10$ Amp.

→ current ripple $= 1\% = \frac{1}{100} \times 10 = 0.1$ Amp.

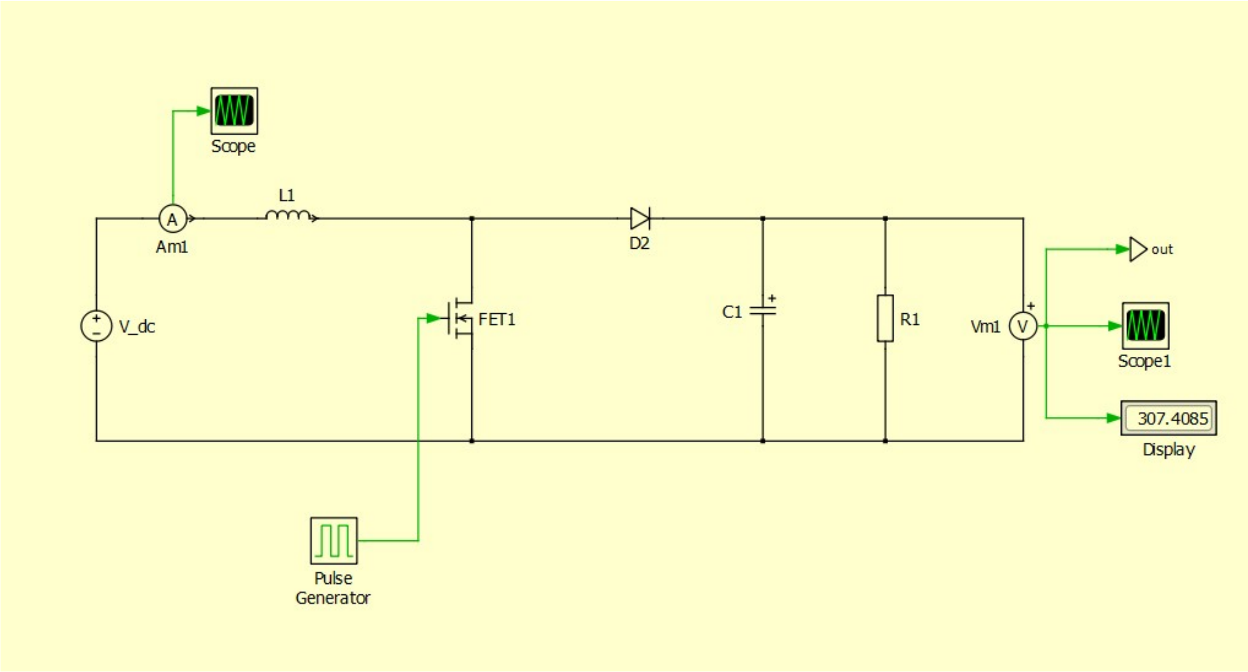
→ $R = \frac{V_o}{I_o} = \frac{300V}{5A} = 60\,\Omega$.

→ $L = \frac{V_{in}\,D}{\Delta I_L\, f} = \frac{150 \times 0.5}{80 \times 10^3 \times 0.1} = 9.375 \times 10^{-3}$

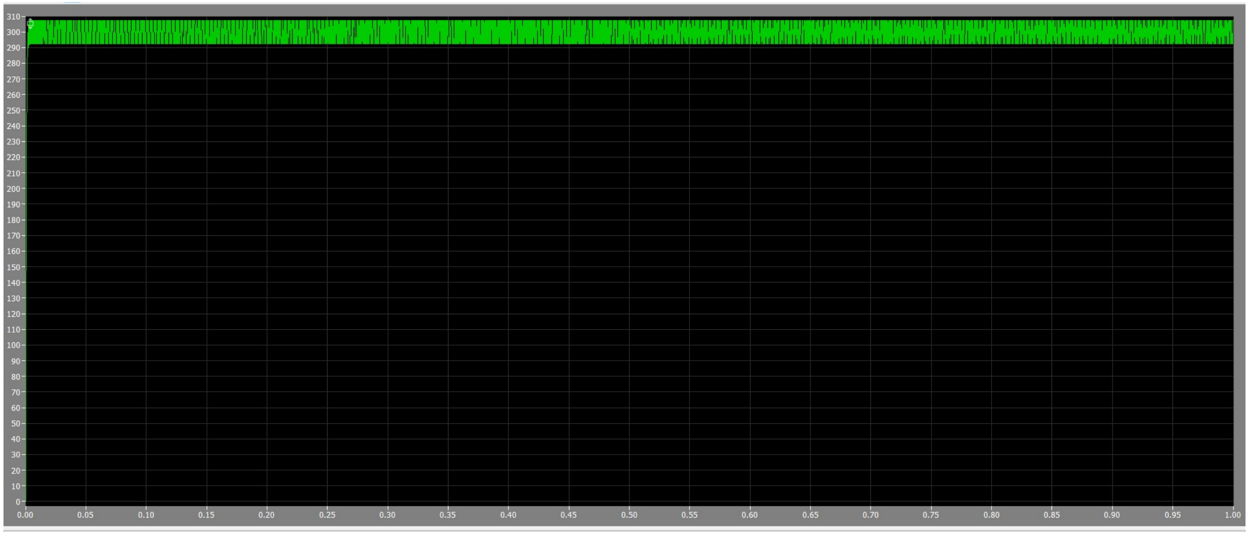
→ $\Delta V_c = 5\% = \frac{5}{100} \times 300 = 15\,V$

→ $C = \frac{I_o\,\alpha}{f\,\Delta V_c} = \frac{5A \times 0.5}{80 \times 10^3 \times 15} = 2.0834\,\mu F$

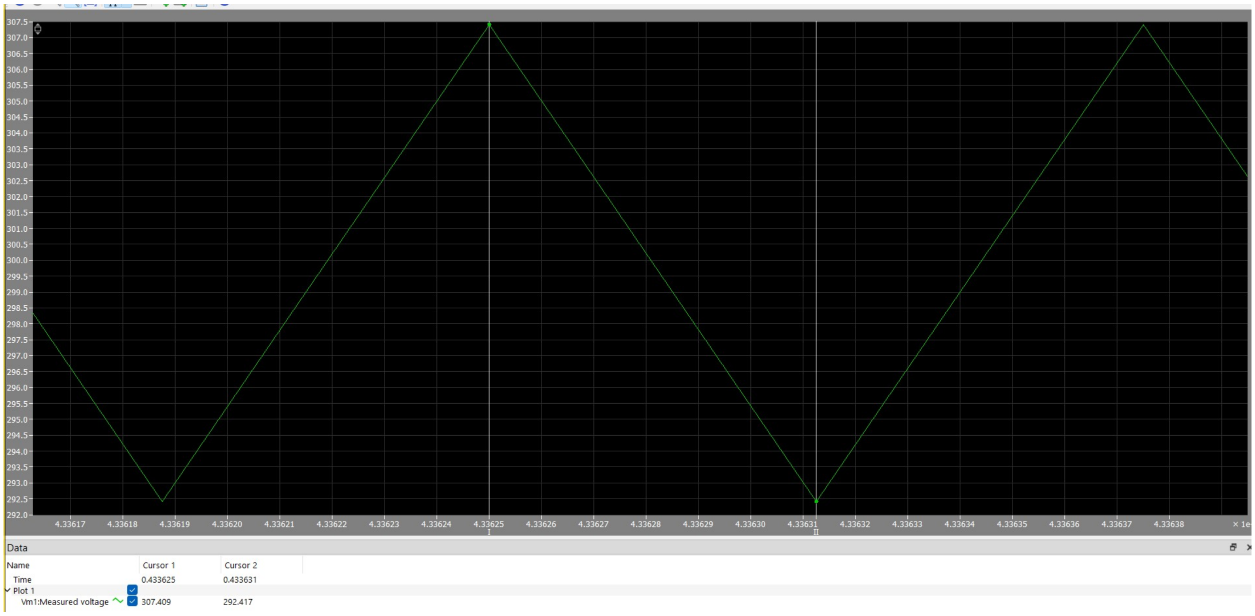
Boost converter:



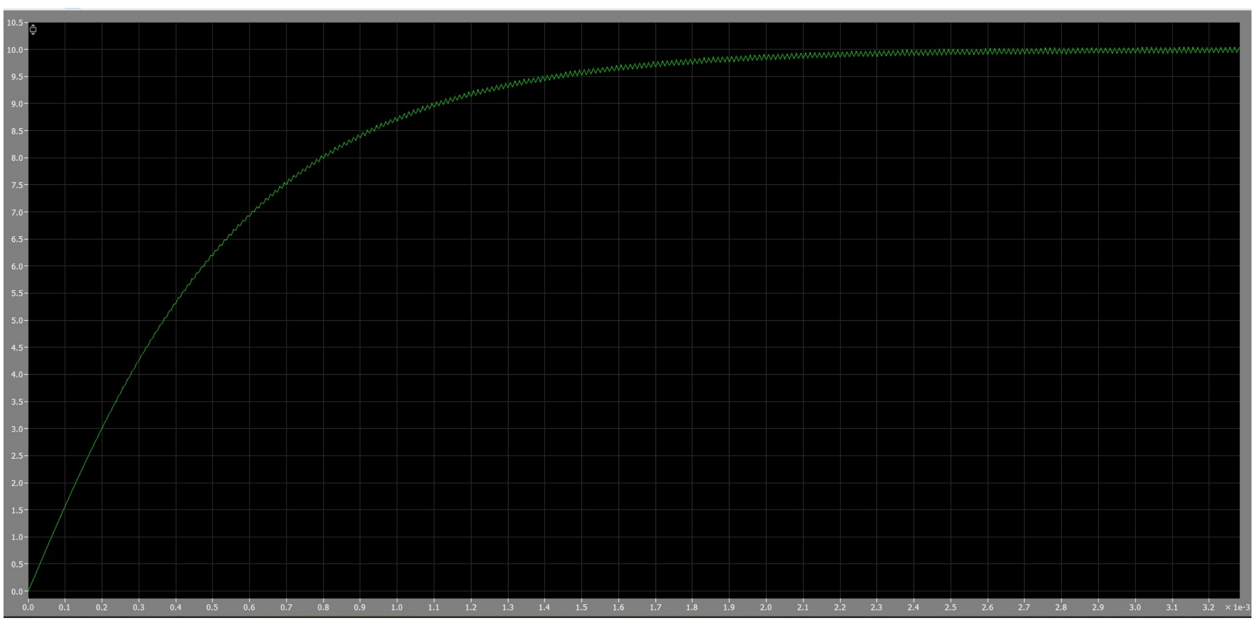
Schematic figure of boost converter in PLECS software



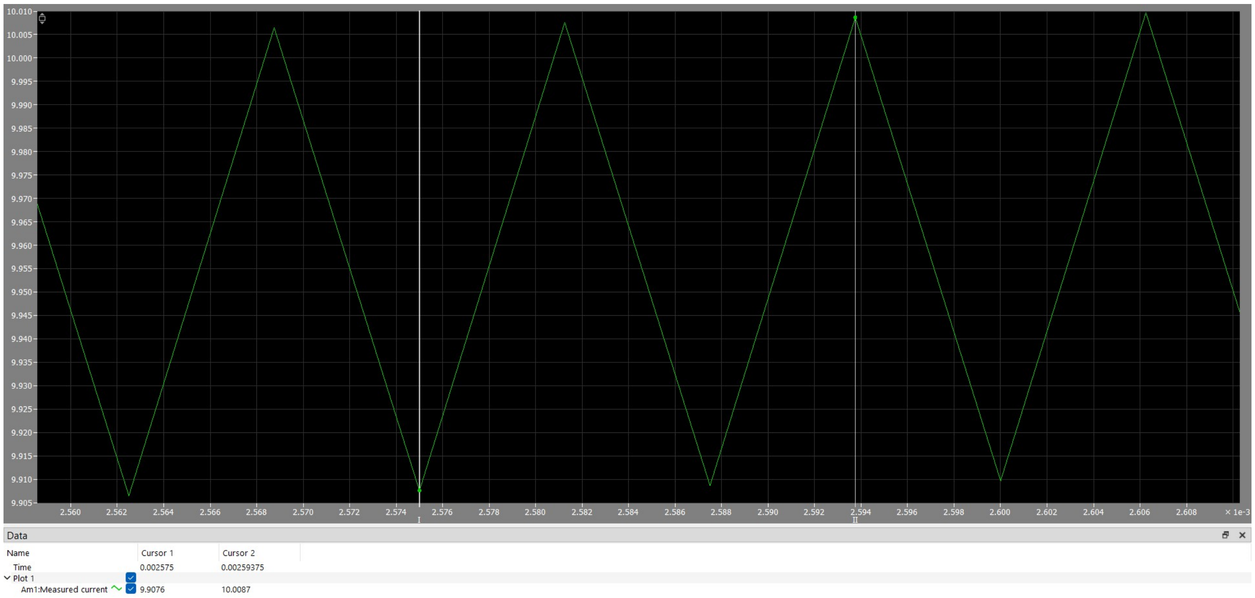
Output voltage of the boost converter



Output Voltage ripple of the boost converter = 14.992 volts



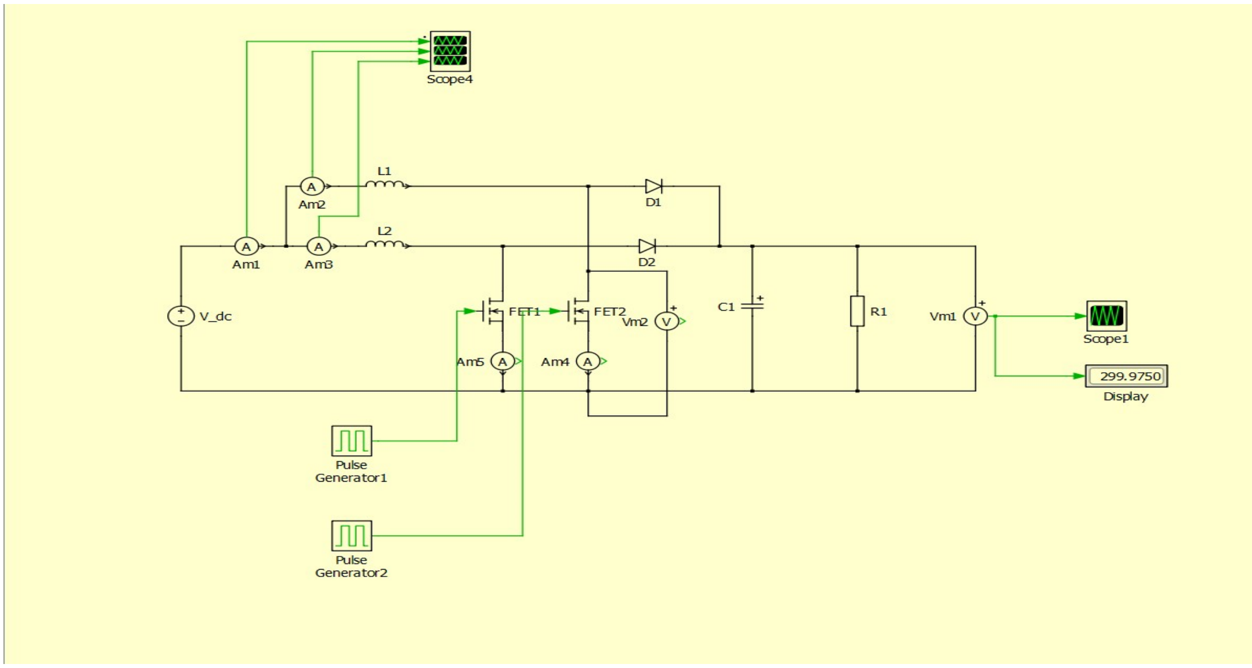
Inductor current waveform of the boost converter



Ripple current in the inductor waveform=0.101 amperes

We can observe that there was a huge ripple in both output voltage and inductor current, to reduce this ripple we use interleaved boost converter and from the results of interleaved boost converter we can observe that there will be reduction in the output ripple voltage.

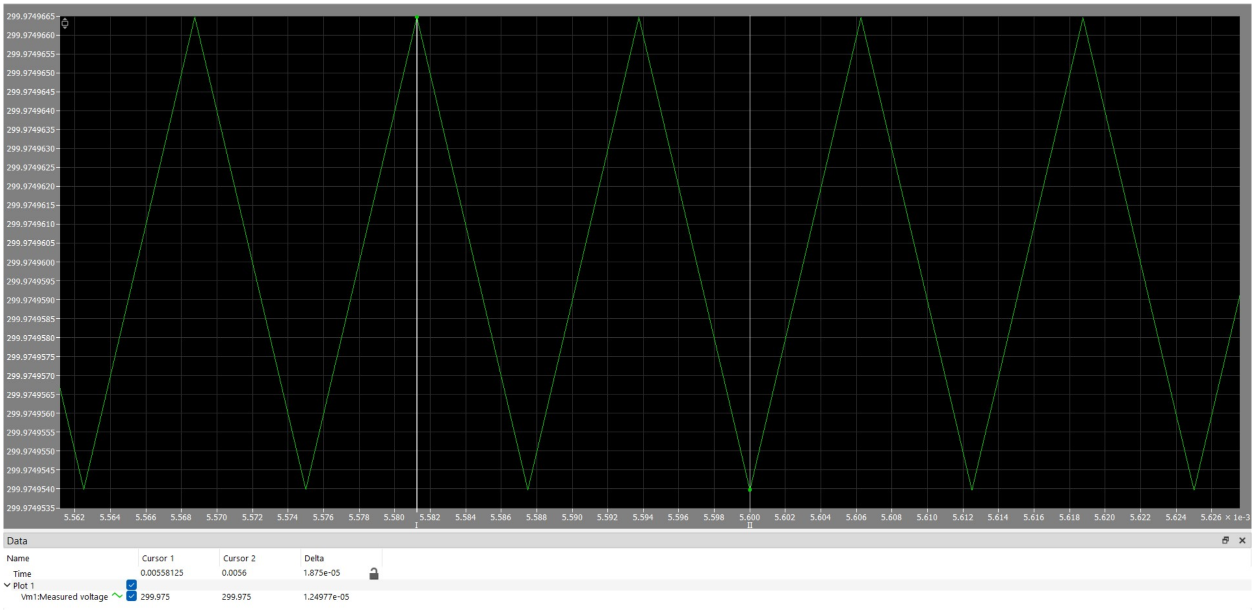
Interleaved boost converter:



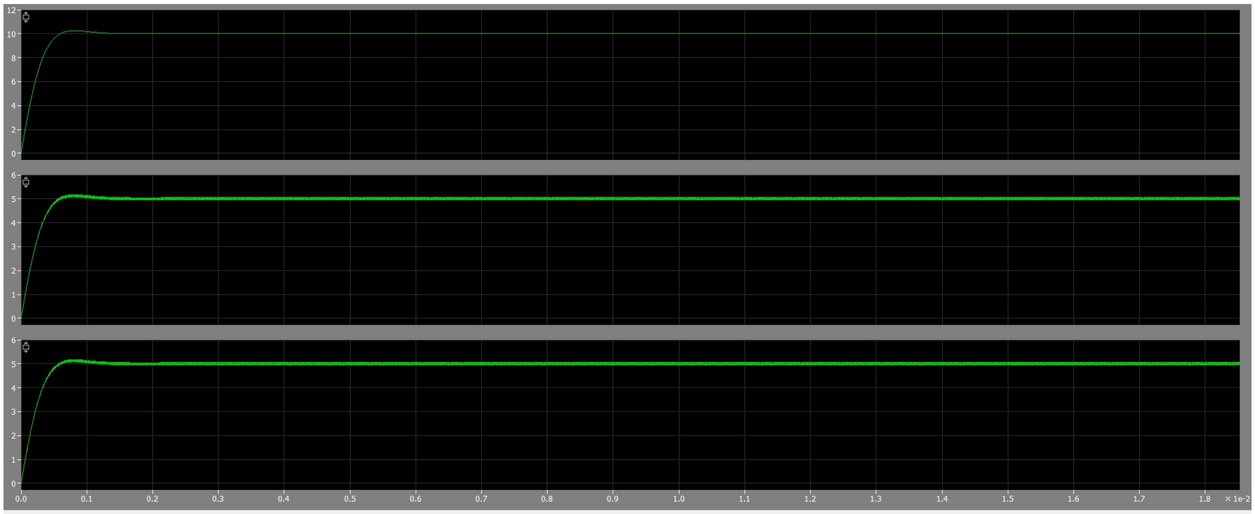
Schematic figure of interleaved boost converter

Waveforms:

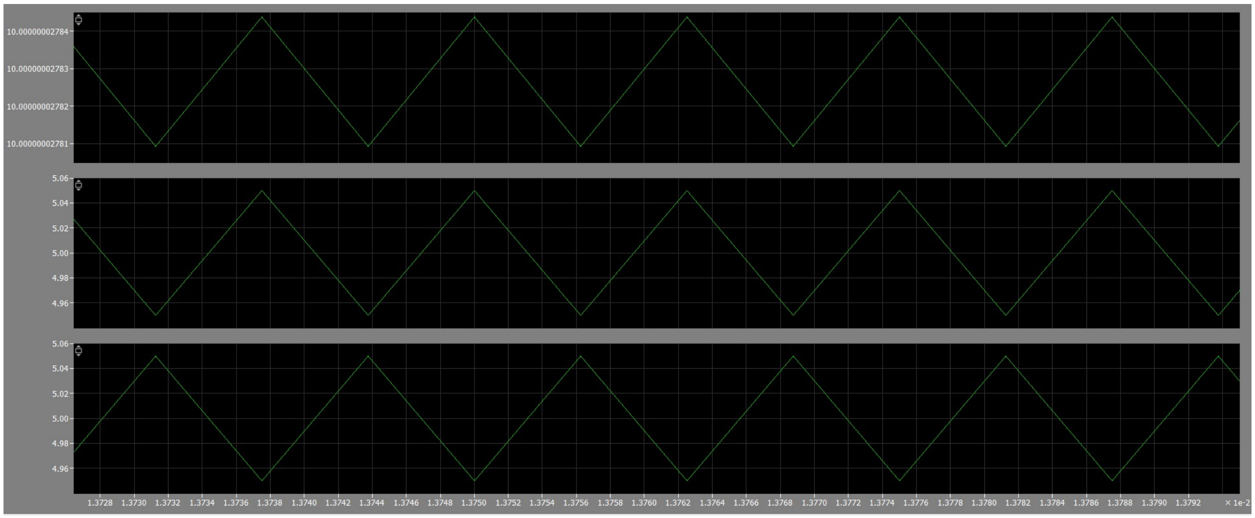
Output voltage of the interleaved boost converter



Output ripple of the interleaved boost converter



Current waveforms in interleaved boost converter



Current ripple in interleaved boost converter

Advantages of interleaved boost converter:

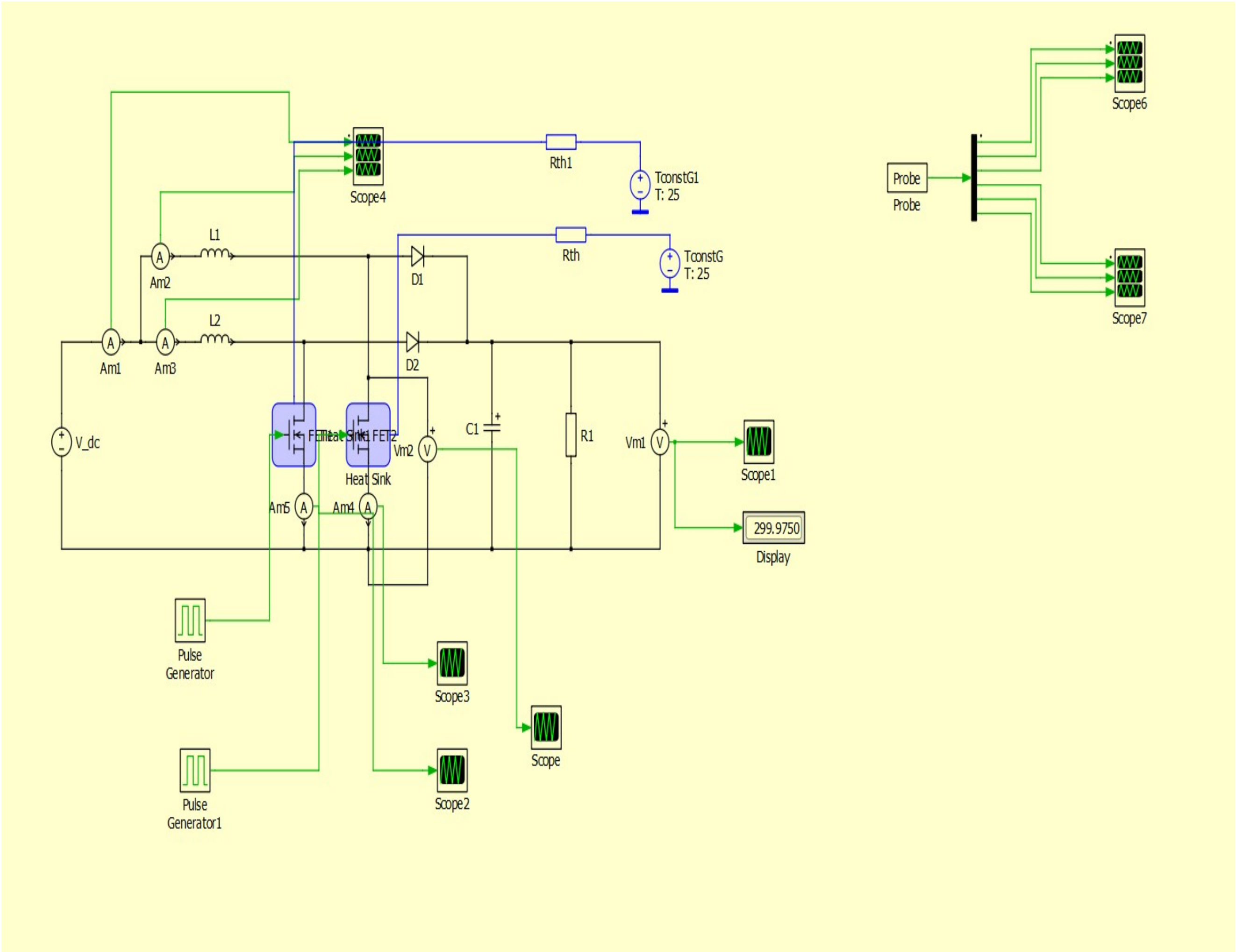
1) Ripple Reduction: Interleaved boost converters significantly reduce input and output current ripple compared to standard boost converters.
2) Efficiency: Interleaved boost converters tend to be more efficient due to lower ripple and shared load among phases.
3) Complexity: Interleaved boost converters are more complex in terms of control and synchronization due to multiple stages operating in parallel.

Applications: While standard boost converters are suitable for low to moderate power applications, interleaved boost converters are preferred for high-power systems demanding reduced ripple and higher efficiency.

Thermal model of the interleaved boost converter:

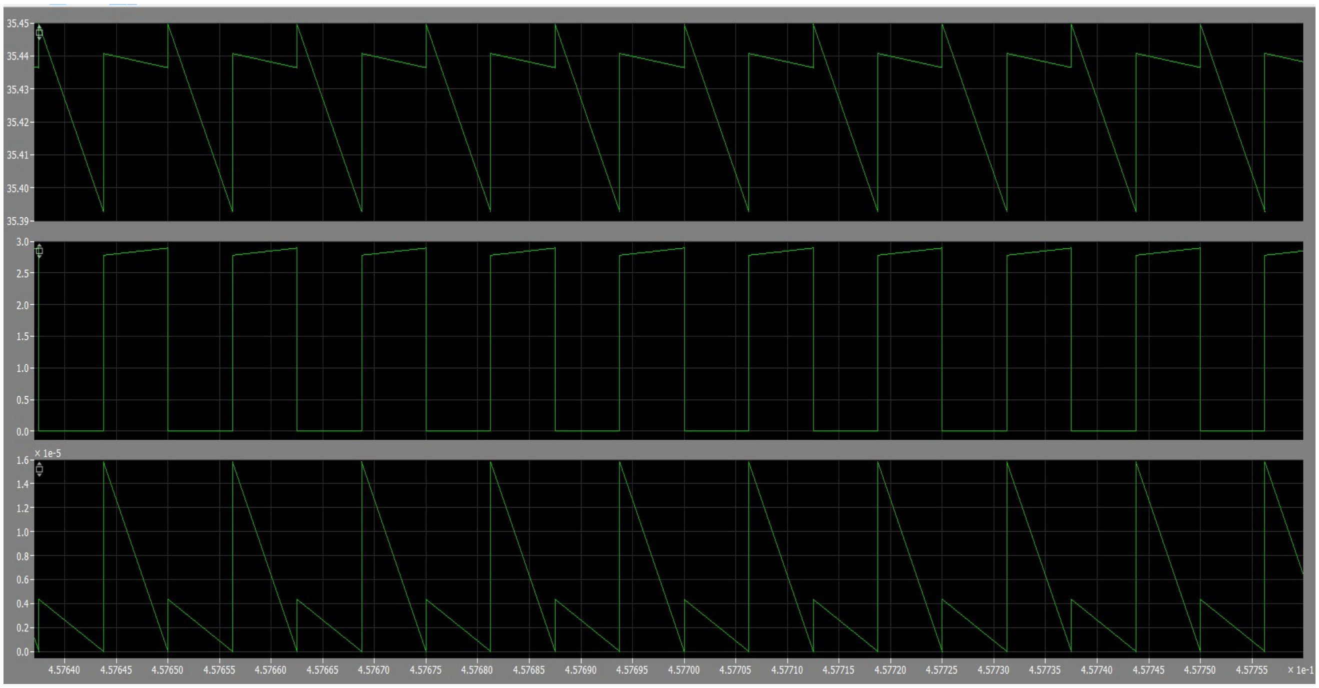
Thermal modeling helps in predicting the temperature distribution within the converter components such as switches, inductors, capacitors, etc. By understanding the temperature profile, engineers can assess the reliability of these components and prevent overheating, which could lead to premature failure. selecting appropriate components with the required thermal characteristics. Components with higher temperature ratings or better thermal properties can be chosen to ensure reliable operation under expected operating conditions. Thermal models assist in predicting the converter's performance under different loads and environmental conditions. They help in understanding how the system behaves concerning temperature changes and how efficiency might be affected. By predicting component temperatures, maintenance schedules can be devised to avoid operating components at temperatures close to their thermal limits, thereby extending the overall system lifespan. Heat is a form of energy loss. A thermal model helps in identifying areas of excessive heat dissipation and inefficiencies within the converter. This insight can lead to design modifications aimed at improving overall efficiency. A thermal model enables validation of simulation results against actual thermal measurements, ensuring the accuracy and reliability of simulation tools used in the design process. Developing a thermal model for an interleaved boost converter allows engineers to design, optimize, and operate the system more effectively by considering thermal aspects alongside electrical and control considerations. This holistic approach ensures better performance, reliability, and longevity of the converter system

Circuit diagram:



Thermal model of the interleaved boost converter

Output waveforms:



Junction temperature, conduction loss and switching loss of the converter of the switch 1 and 2

Conclusion:

The interleaved boost converter stands as a robust solution for applications demanding high efficiency, reduced ripple, and increased power handling capabilities. While it poses challenges in terms of control complexity and design considerations, its advantages in efficiency, scalability, and EMI reduction make it a preferred choice for various high-power systems where these benefits are crucial. Through careful design, control, and consideration of thermal aspects, the interleaved boost converter proves to be an efficient and reliable power conversion solution.

Thank you