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Implementation of a PMDC Motor–Generator Based Winder Load Emulator

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Outline

- Introduction
- Winder Load Implementation
- Boost Converter Controller Design
- PLECS Simulation & Results
- Hardware Implementation & Results

Introduction

- **Objective** :
  - To emulate winder load characteristics using a PMDC motor–generator-based setup.

Winder System

- Winder systems are used to roll flexible materials such as paper, film, textile, and metal sheets onto a rotating spool
- The load torque in a winder system varies continuously with roll diameter and tension
- Maintaining constant tension and speed is essential for proper winding quality
- In winder system :
  - The **shaft speed decreases** as the **roll diameter increases**
  - The **load torque increases** as the **roll diameter increases**

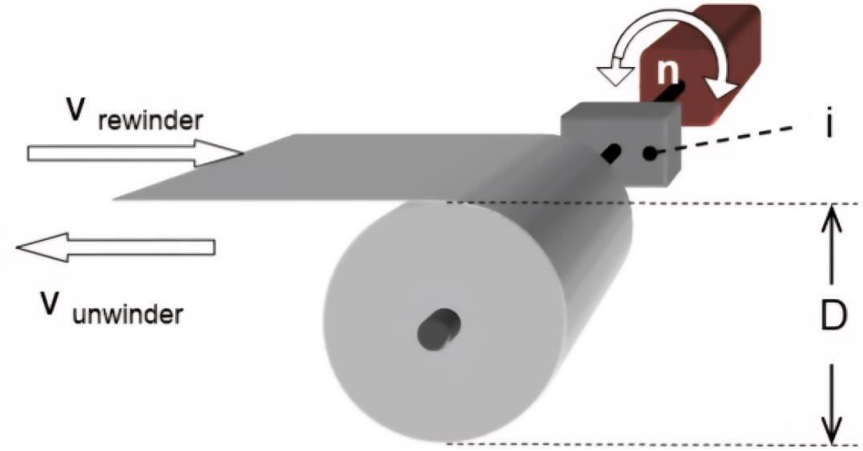
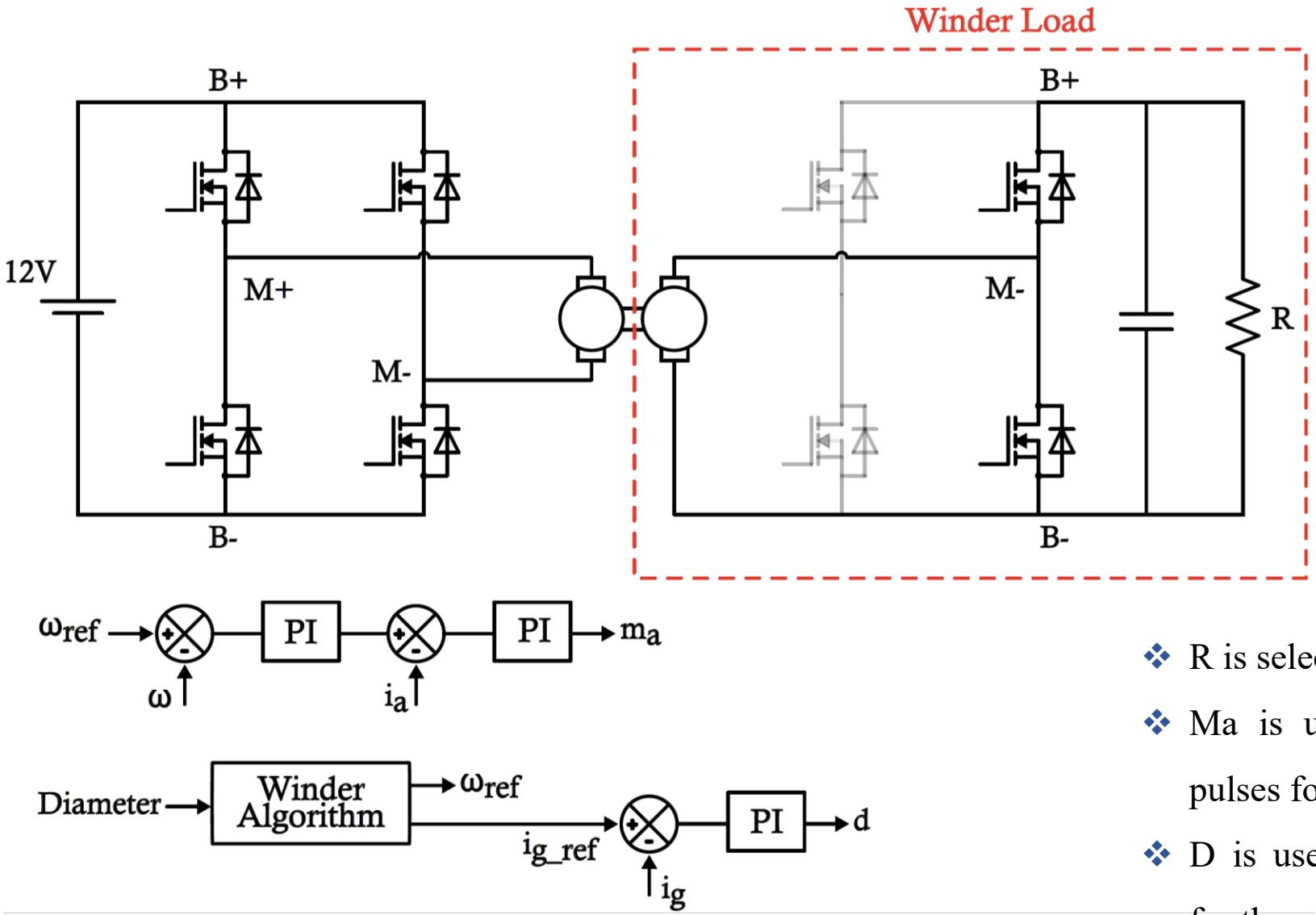


Illustration of a basic winder system [1]



Total system block diagram

- R is selected as 20 Ohm
- Ma is used to generate the gating pulses for the motor side H-Bridge
- D is used to generate gating pulses for the generator side boost converter

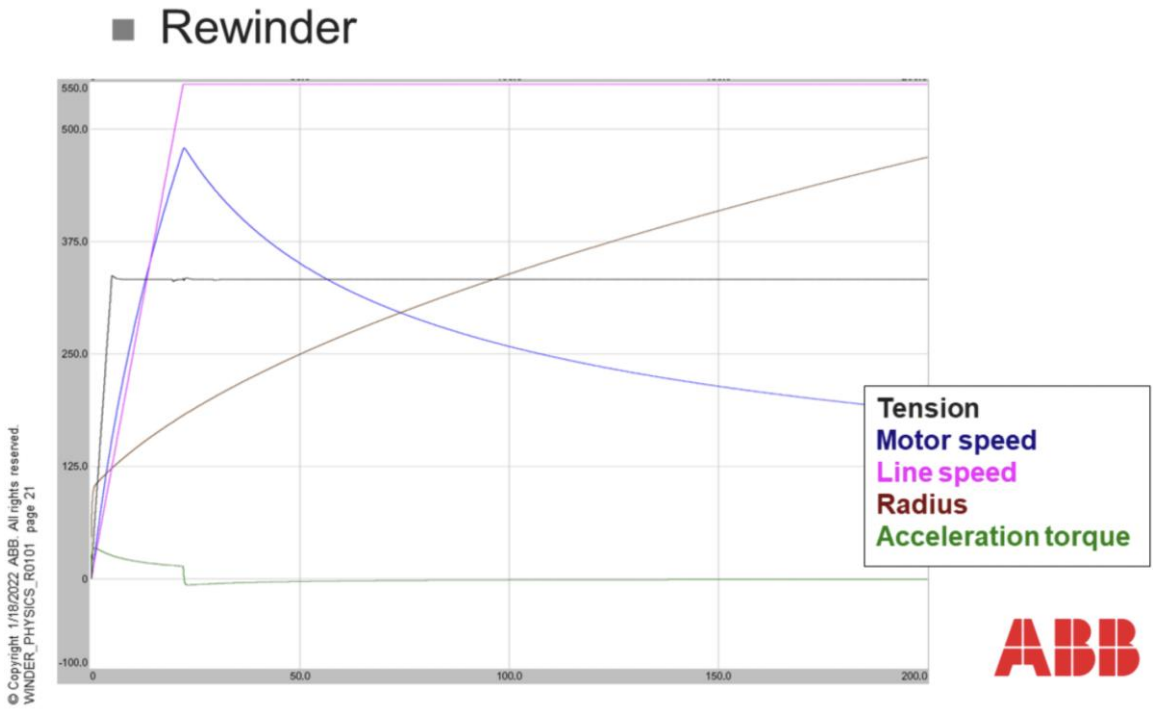
- D = Diameter of roll
- n = Motor speed
- v = Line speed

$$D = \frac{v}{n\pi}$$

- T_W = Winding torque
- F_W = Tension
- i = Gear ratio

$$T_W = \frac{F_W \cdot D}{2 \cdot i}$$

$$T_W = i_g \cdot k_b$$



Typical curves of a winder system [1]

- The line speed and tension are assumed constant, while the system variables are scaled to match the hardware specifications
- The max and min motor speed values are selected and accordingly other variables are calculated using the above equations
- The motor speed initially starts at **280rad/s** and gradually settles at **170rad/s**
- Accordingly, the generator current initially starts at **0.6A** and eventually settles at **0.98A**

When S1 is ON :

$$V_{in} = V_L + i_L R_L \Rightarrow \frac{di_L}{dt} = \frac{V_{in}}{L} - \frac{i_L R_L}{L}$$

$$0 = i_c + i_o \Rightarrow \frac{dV_c}{dt} = -\frac{V_c}{RC}$$

When S1 is OFF :

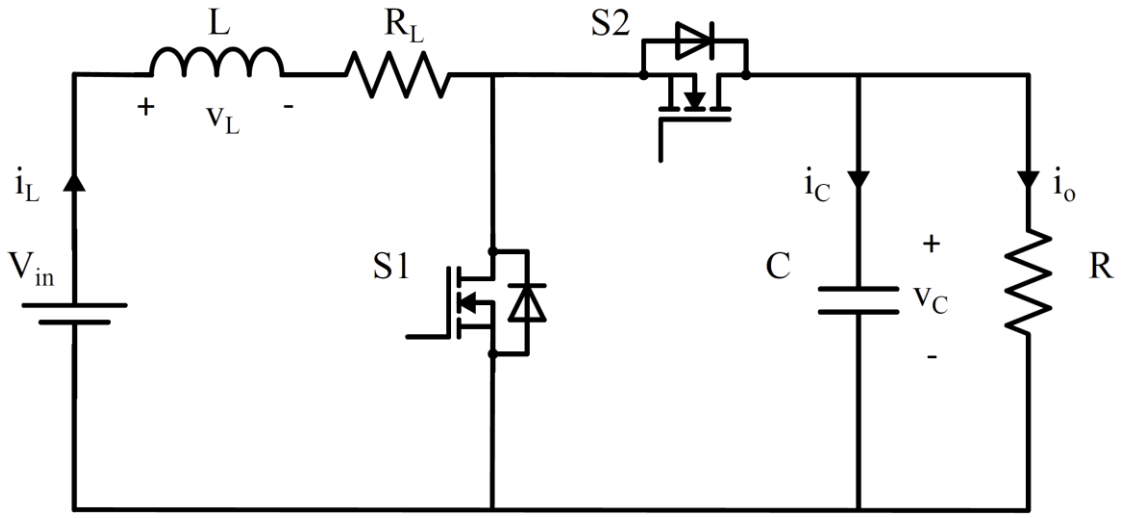
$$V_{in} = V_L + i_L R_L + V_o \Rightarrow \frac{di_L}{dt} = \frac{V_{in}}{L} - \frac{i_L R_L}{L} - \frac{V_c}{L}$$

$$i_L = i_c + i_o \Rightarrow \frac{dV_c}{dt} = -\frac{V_c}{RC} + \frac{i_L}{C}$$

Upon averaging over switching period :

$$\frac{di_L}{dt} = \frac{V_{in}}{L} - \frac{i_L R_L}{L} - \frac{(1-d)V_c}{L}$$

$$\frac{dV_c}{dt} = -\frac{V_c}{RC} + \frac{(1-d)i_L}{C}$$

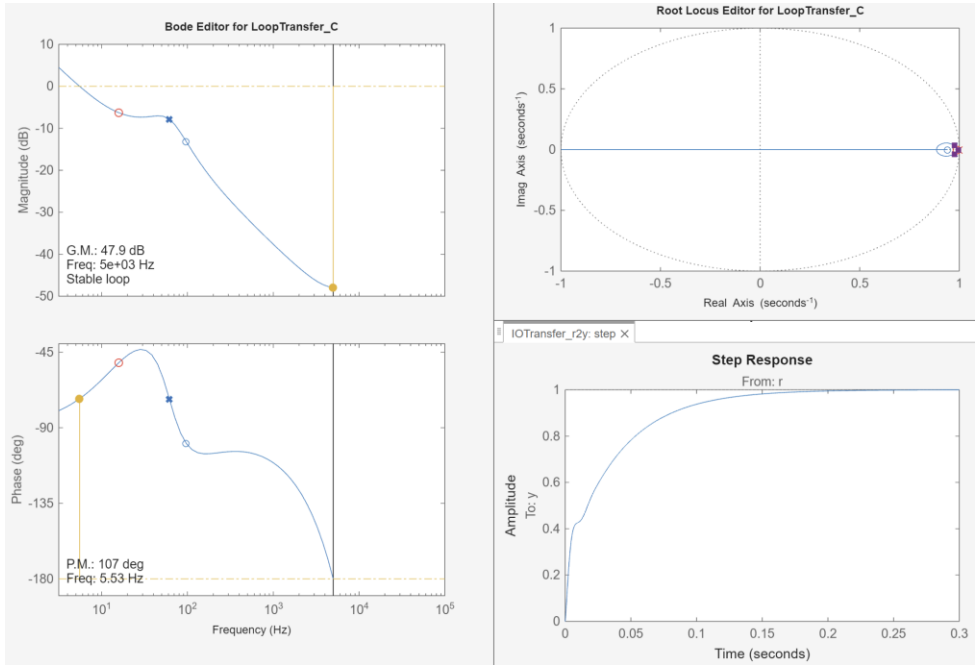


Circuit diagram of boost converter

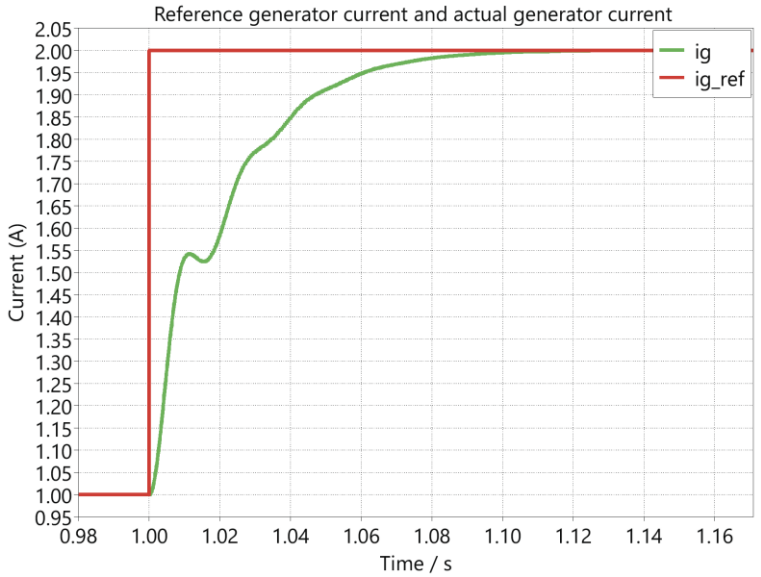
The variables are represented as the sum of steady-state values and small-signal perturbations, and the small-signal terms are separated.

$$\frac{d\Delta i_L}{dt} = \frac{\Delta V_{in}}{L} - \frac{R_L}{L}\Delta i_L - \frac{(1-D)\Delta V_c}{L} + \frac{V_c}{L}\Delta d$$

$$\frac{d\Delta V_c}{dt} = -\frac{\Delta V_c}{RC} + \frac{(1-D)\Delta i_L}{C} - \frac{I_L}{C}\Delta d$$



Different plots of $G_{id(s)}$ in sisotool with controller constants $k_p = 0.1$ & $k_i = 10$



Reference grid current and actual grid current for a step change in reference

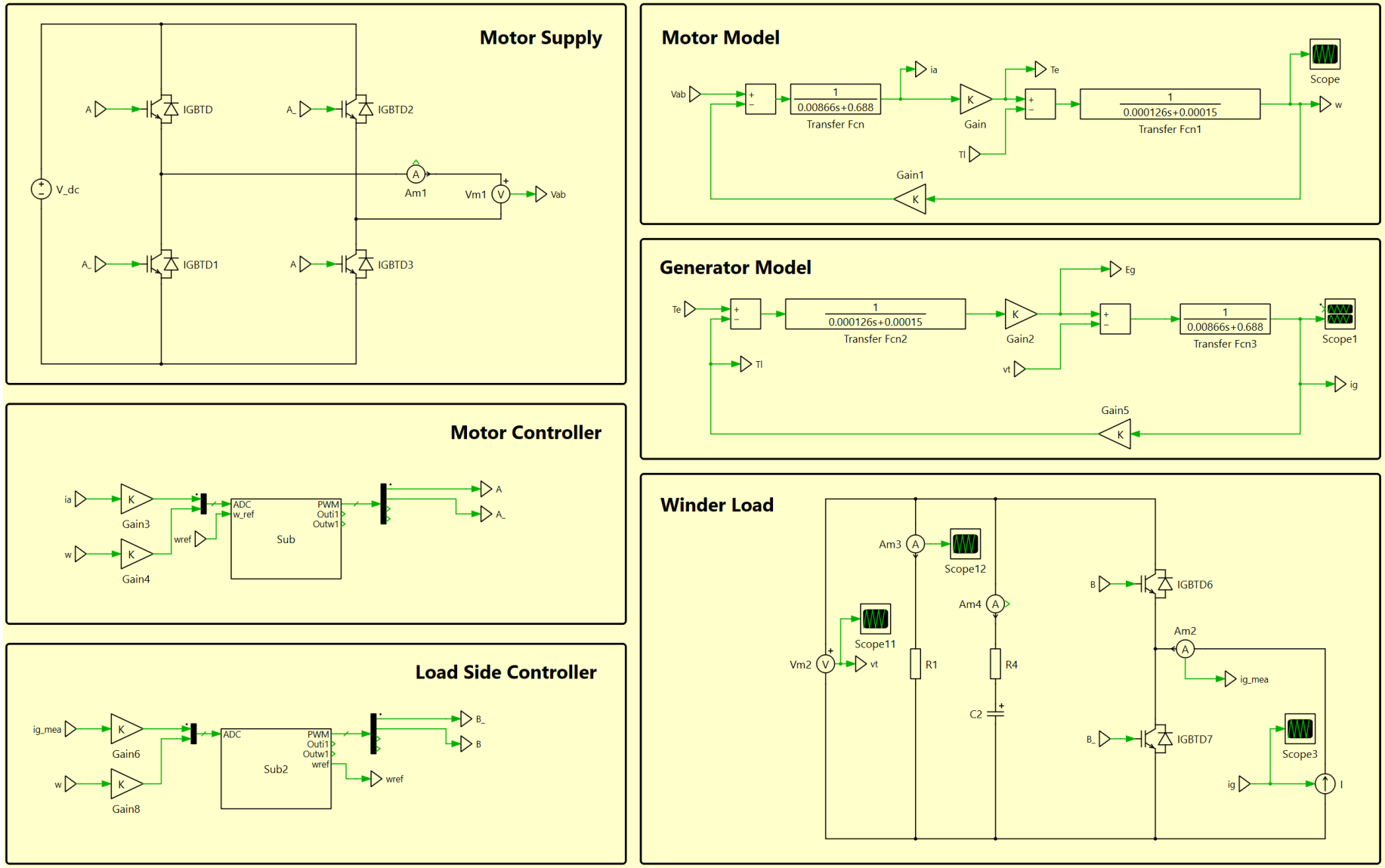
$$\begin{bmatrix} \frac{d\Delta i_L}{dt} \\ \frac{d\Delta V_c}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R_L}{L} & -\frac{(1-D)}{L} \\ \frac{(1-D)}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} \Delta i_L \\ \Delta V_c \end{bmatrix} + \begin{bmatrix} \frac{V_c}{L} \\ -\frac{I_L}{C} \end{bmatrix} \Delta d + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \Delta V_{in}$$

Taking LT with zero initial condition,

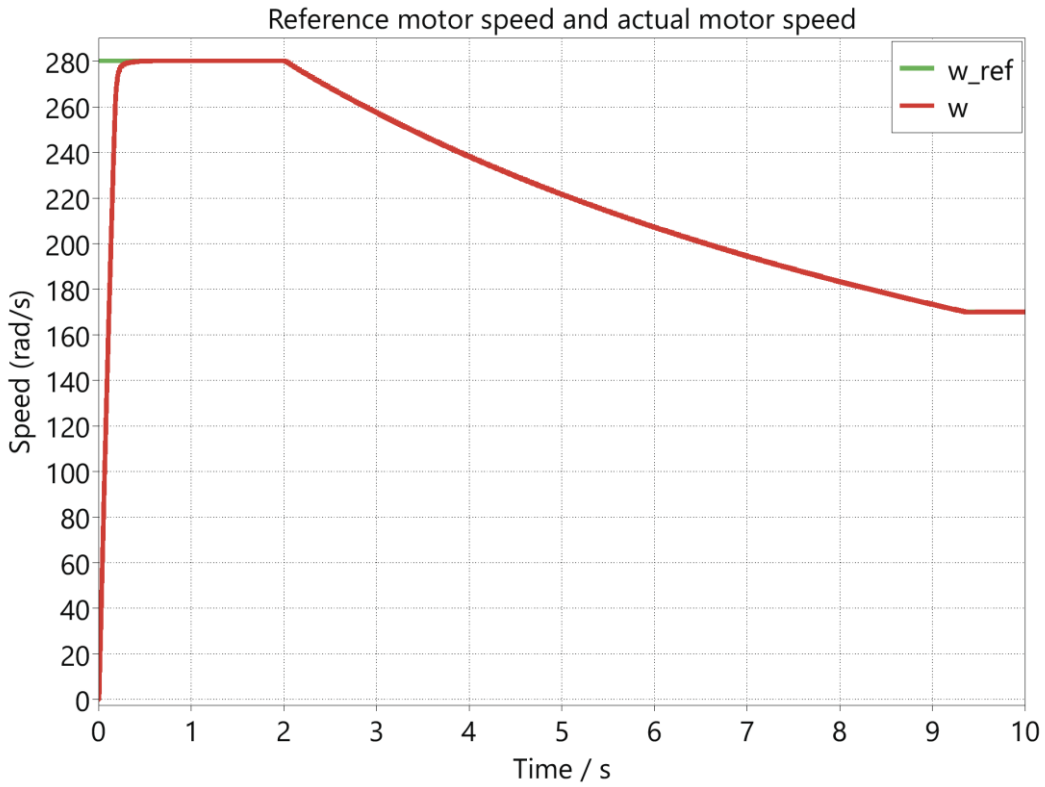
$$\Delta X(s) = (sI - A)^{-1} F\, \Delta d(s) + (sI - A)^{-1} B\, \Delta V_{in}(s)$$

$$\left.\frac{\Delta i_L}{\Delta d}\right|_{\Delta V_{in}=0} = \frac{\frac{V_{in}}{(1-D)L}\left(s + \frac{2}{RC}\right)}{s^2 + s\left(\frac{R_L}{L} + \frac{1}{RC}\right) + \frac{(1-D_0)^2 R + R_L}{LRC}}$$

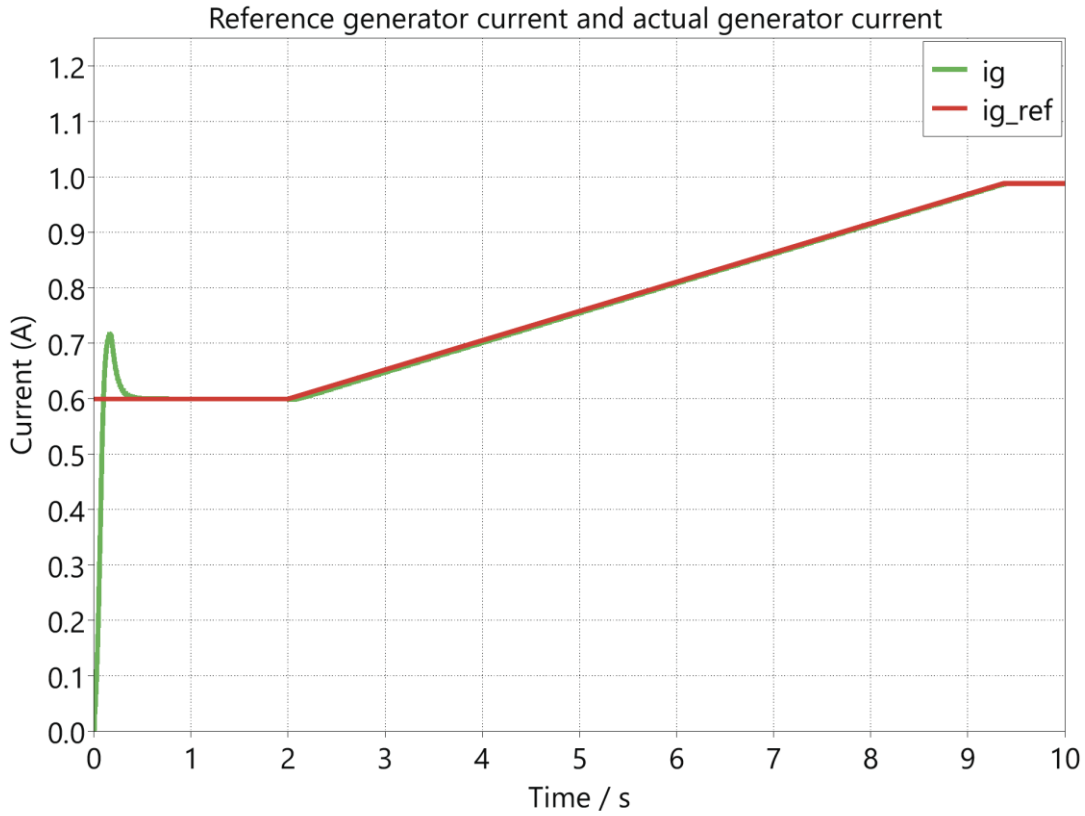
$$G_{id}(s) = \frac{\frac{2V_{in}}{(1-D)\left((1-D)^2 R + R_L\right)}\left(\frac{sRC}{2} + 1\right)}{\frac{s^2 LCR}{(1-D)^2 R + R_L} + \frac{s(L + RR_L C)}{(1-D)^2 R + R_L} + 1}$$



PLECS model of the motor–generator based winder emulator

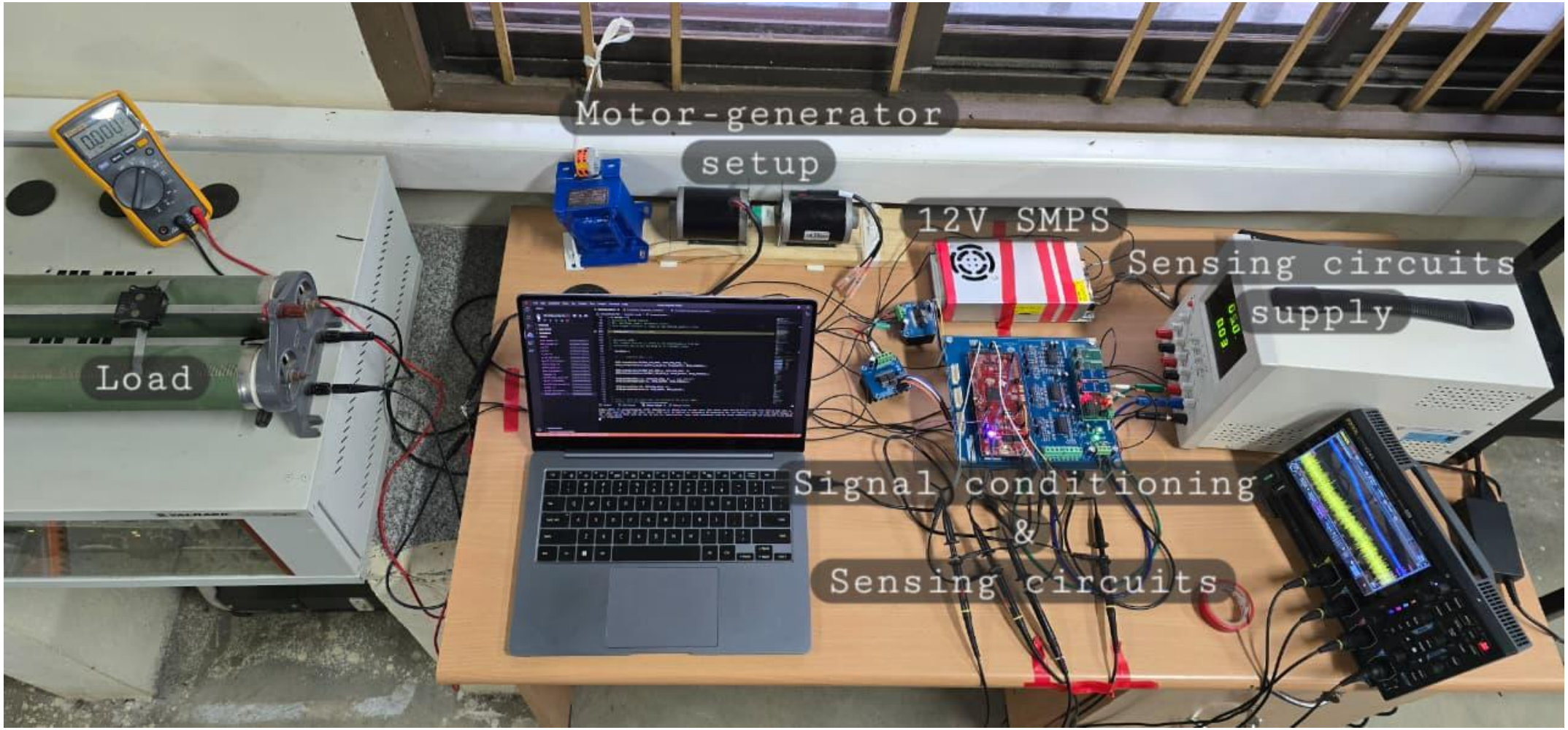


Refernce motor speed and actual moto speed



Reference generator current and actual generator current

- The motor is initially run at 280 rad/s and the generator current is set at 0.6A before the winder algorithm is turned ON
- After turning ON the winder algorithm, the speed reference eventually settles to 170 rad/s and generator current reference eventually settles to 0.98A

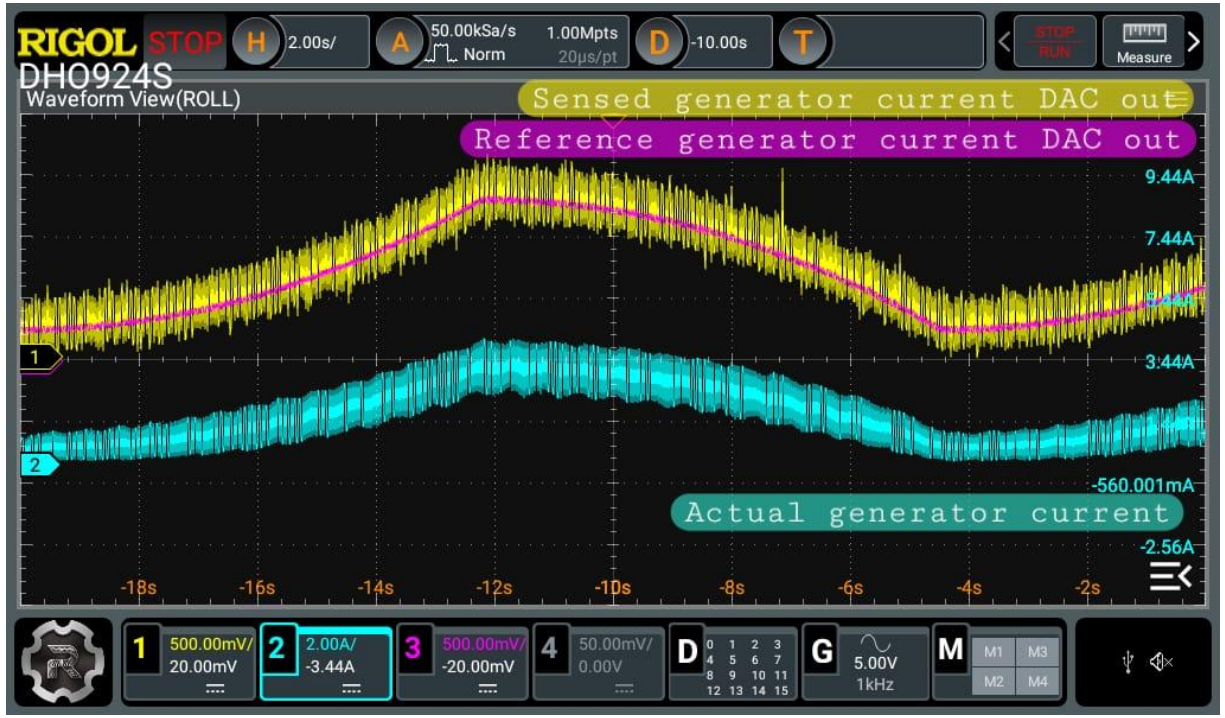


Hardware setup

- Generator current controller tracking performance



DSO waveforms of sensed generator current, reference generator current and actual generator current - Enlarged



DSO waveforms of sensed generator current, reference generator current and actual generator current

- Winder load speed and current profiles



DSO waveforms of sensed generator current, reference generator current and actual generator current



DSO waveforms of reference and sensed motor speed and generator current

Conclusion

- Designed and developed a current controller for the boost converter
- Simulated a PMDC motor-generator based winder system using PLECS
- Implemented the same system in hardware and experimentally verified the result

References

1. ABB, “**Winder – Physics**,” ABB Library, 2022
2. M. A. Abd-Elraouf, A. El-Shenawy and H. A. Ashour, "**Performance improvement of automatic tension control in multi coordinate drive systems for industrial paper winder**," 2017 Nineteenth International Middle East Power Systems Conference (MEPCON), Cairo, Egypt, 2017, pp. 1163-1169, doi: 10.1109/MEPCON.2017.8301329.

- Change in motor current with change in generator current



DSO waveforms of reference generator current, average motor current and actual motor current



DSO waveforms of reference generator current, sensed motor current and actual motor current

Thank You