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Effects of Parameter Error in Field Oriented Control

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Final Presentation
ECE 595 S
Fall 2005

Comparison Strategy

- Three Studies
  - Start-up response using a speed controller
  - Step change in torque command with motor at constant speed
  - Multiple step changes in torque command with motor at constant speed
- Three controllers were used for each study
  - Direct Field Oriented Controller (DFOC)
  - Robust version of the DFOC
  - Indirect Field Oriented Controller (IFOC)
- Two sets of parameters were used for each controller
  - Ideal measurements (both model and control use cold motor parameters)
  - Heated measurements (model uses warm motor parameters and control uses cold motor parameters)

Simulation Parameters

- All motor model parameters obtained through use of curve fitting impedances at multiple speeds using a genetic algorithm
- Motor model parameters obtained with a cold motor:

$$r_s = 2.515\ \Omega,\ r_r = 1.462\ \Omega,$$

$$L_M = 202.5\ \text{mH},\ L_{ls} = L_{lr} = 11.1\ \text{mH}$$

- Motor model parameters obtained with a warm motor:

$$r_s = 2.125\ \Omega,\ r_r = 1.291\ \Omega,$$

$$L_M = 195.1\ \text{mH},\ L_{ls} = L_{lr} = 11.9\ \text{mH}$$

- Measurements performed on a 4-pole, 230 V, 3.2 A, 1.0 hp induction motor.

Simulation Parameters

- Other parameters:

FOC's

$$\begin{cases} \lambda_{dr}^{e*} = 0.1 \\ \tau_{Te} = 0.01 \\ \tau_{\lambda} = 0.01 \end{cases}$$

Bridge Converter

$$\begin{cases} V_{dc} = 300 \text{ V} \\ V_{t,drop} = 0.0002\frac{i_t}{30} + 3.56\left(\frac{i_t}{30}\right)^{0.257} \\ V_{d,drop} = 0.27\frac{i_d}{30} + 1.45\left(\frac{i_d}{30}\right)^{0.136} \end{cases}$$

Flux Estimator

$$\{\tau_{\text{rfc}} = 1.0e-4$$

Delta Modulator

$$\{f_{\text{sample}} = 60 \text{ kHz}$$

Study Summary: Speed Control Comparison

- Used a simple PI controller to control the speed based on the torque
- Proportional Constant, K_p=0.050
- Integral Constant, K_i=0.001
- For the rotor dynamics, J=0.004 kg m^2
- Simulation ran to 0.5 s with a speed command of zero (to stabilize λ^e_{dr})
- Speed command then stepped to 1000 rpm
- Simulation ran an additional 0.5 s

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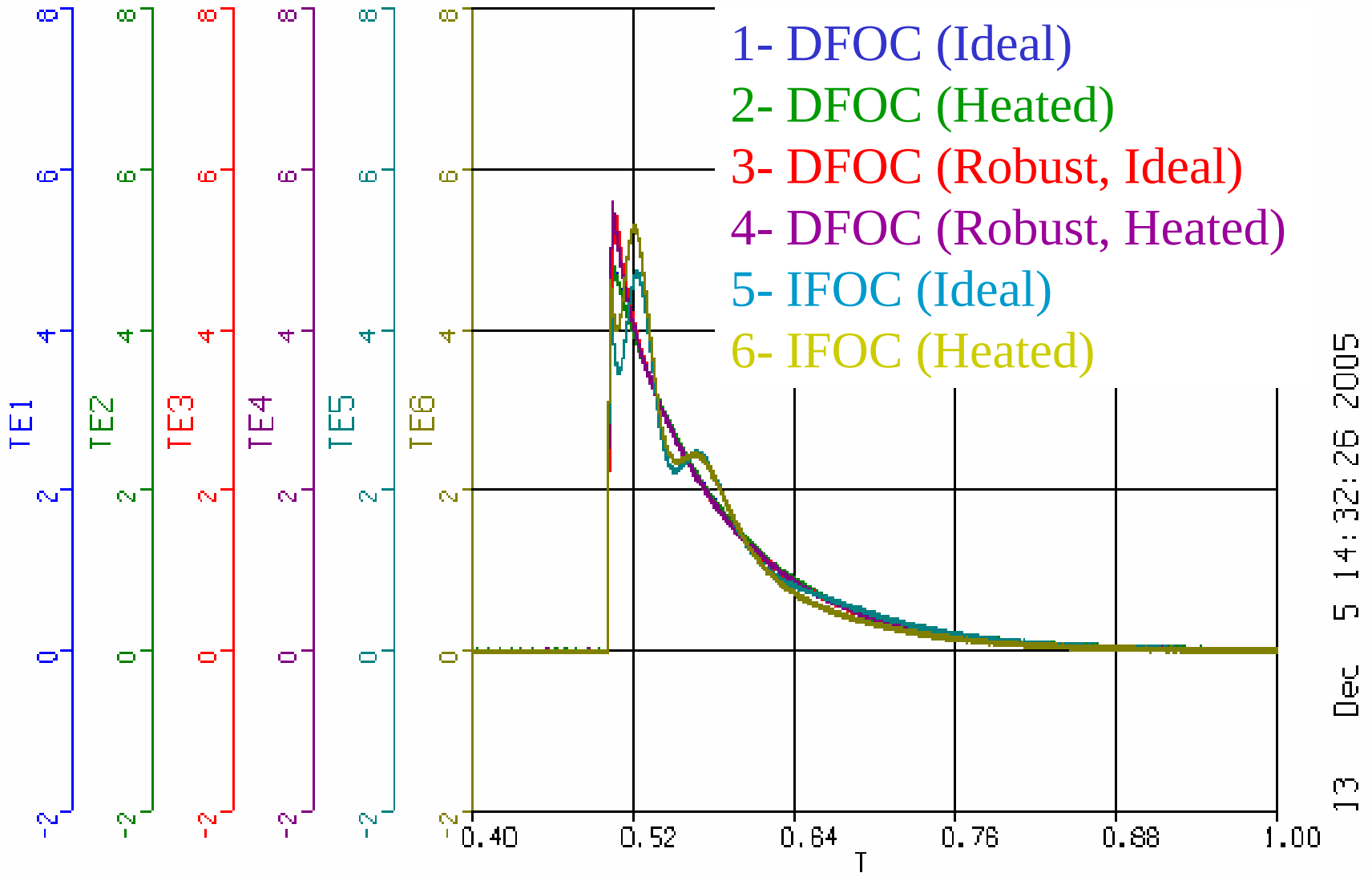
Speed Control Comparison



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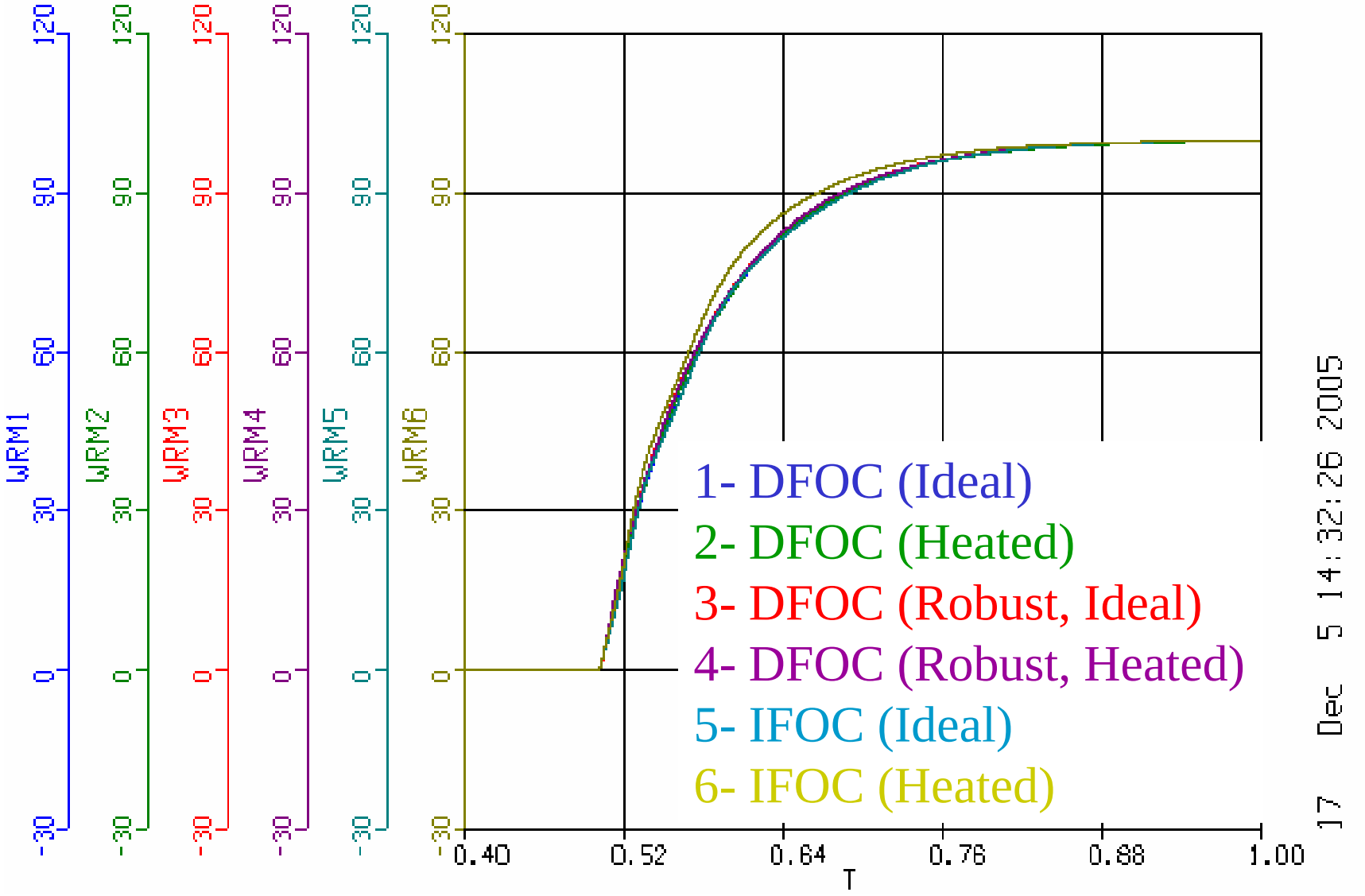
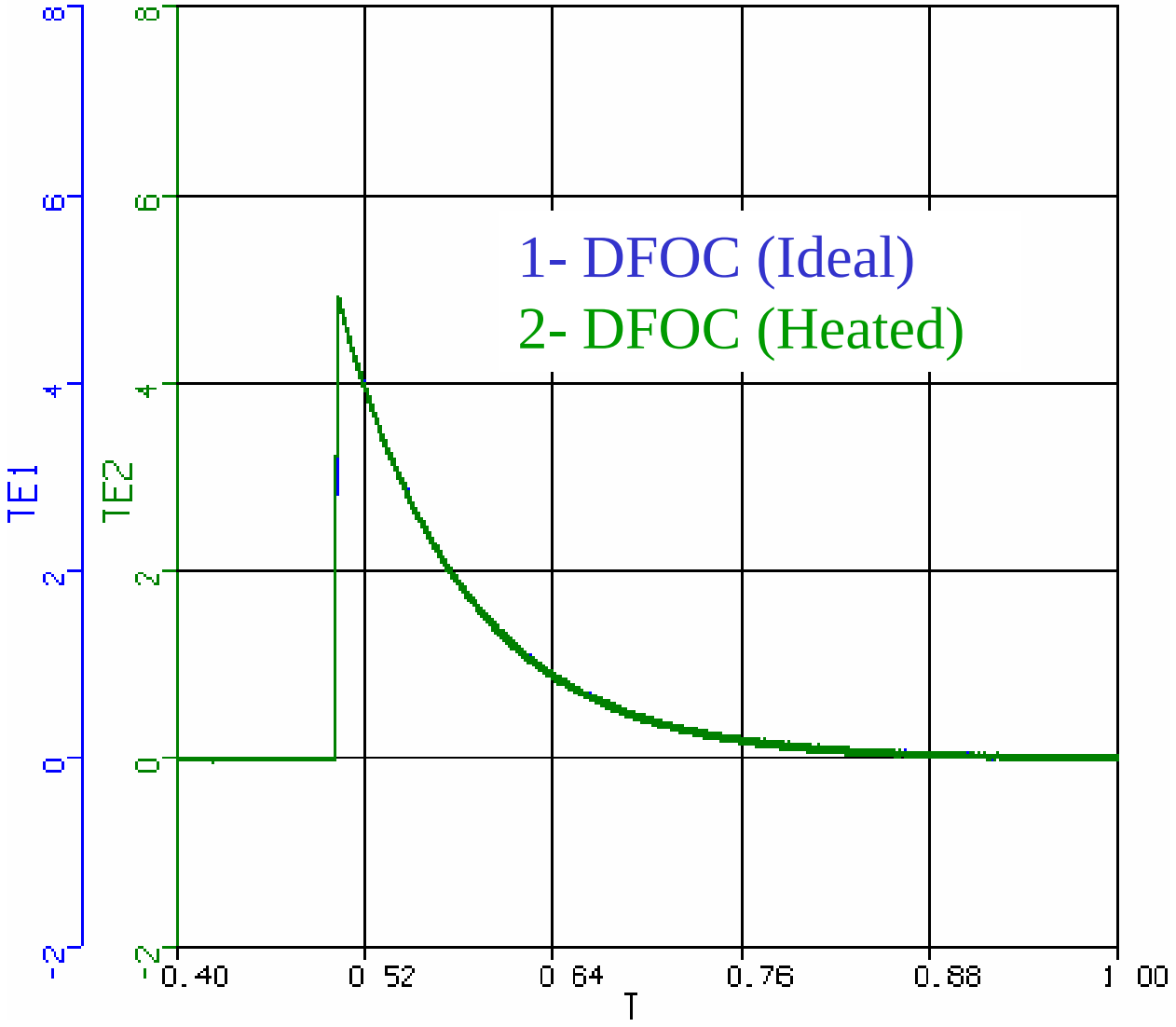
Speed Control Comparison

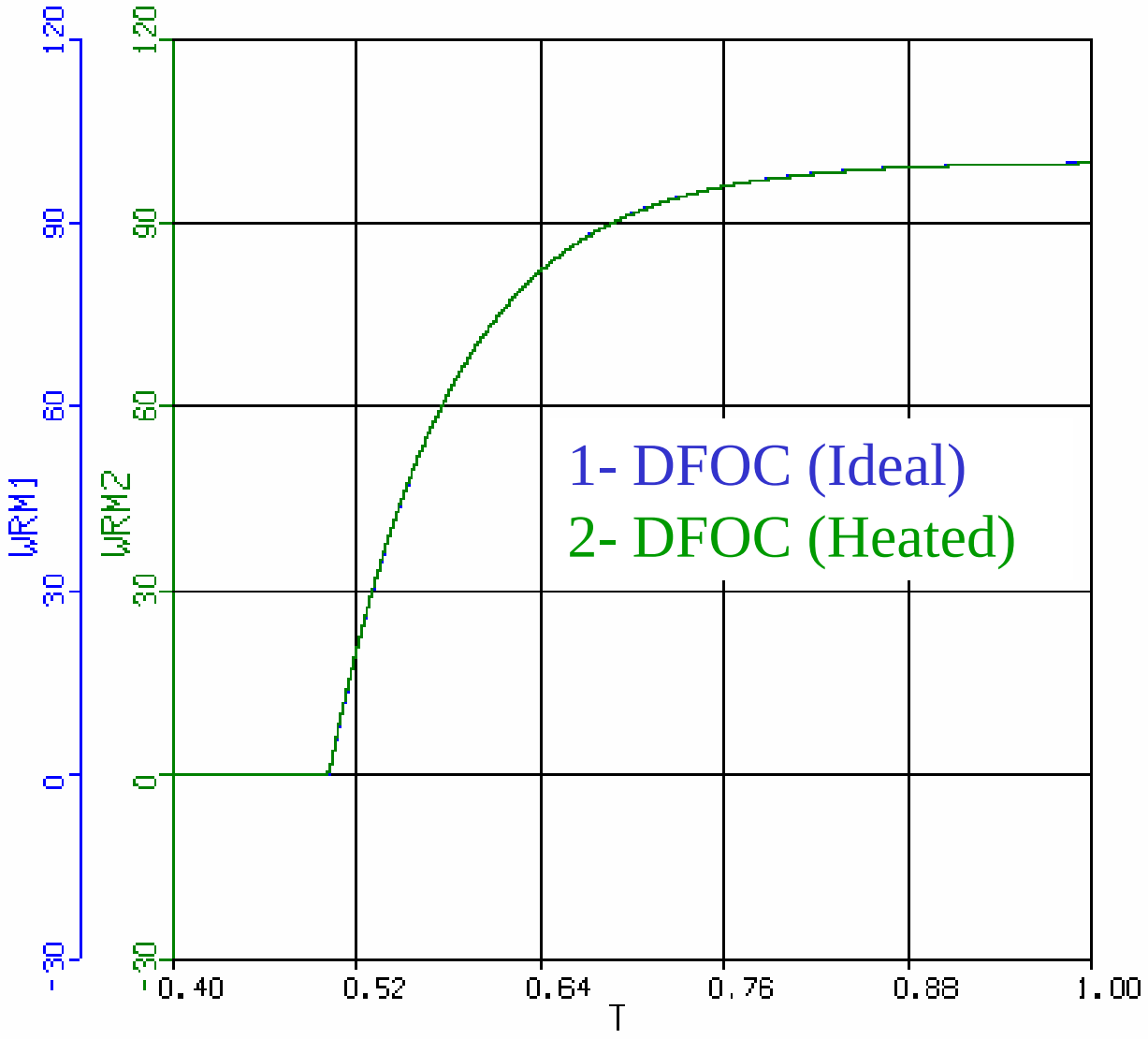


Speed Control Comparison



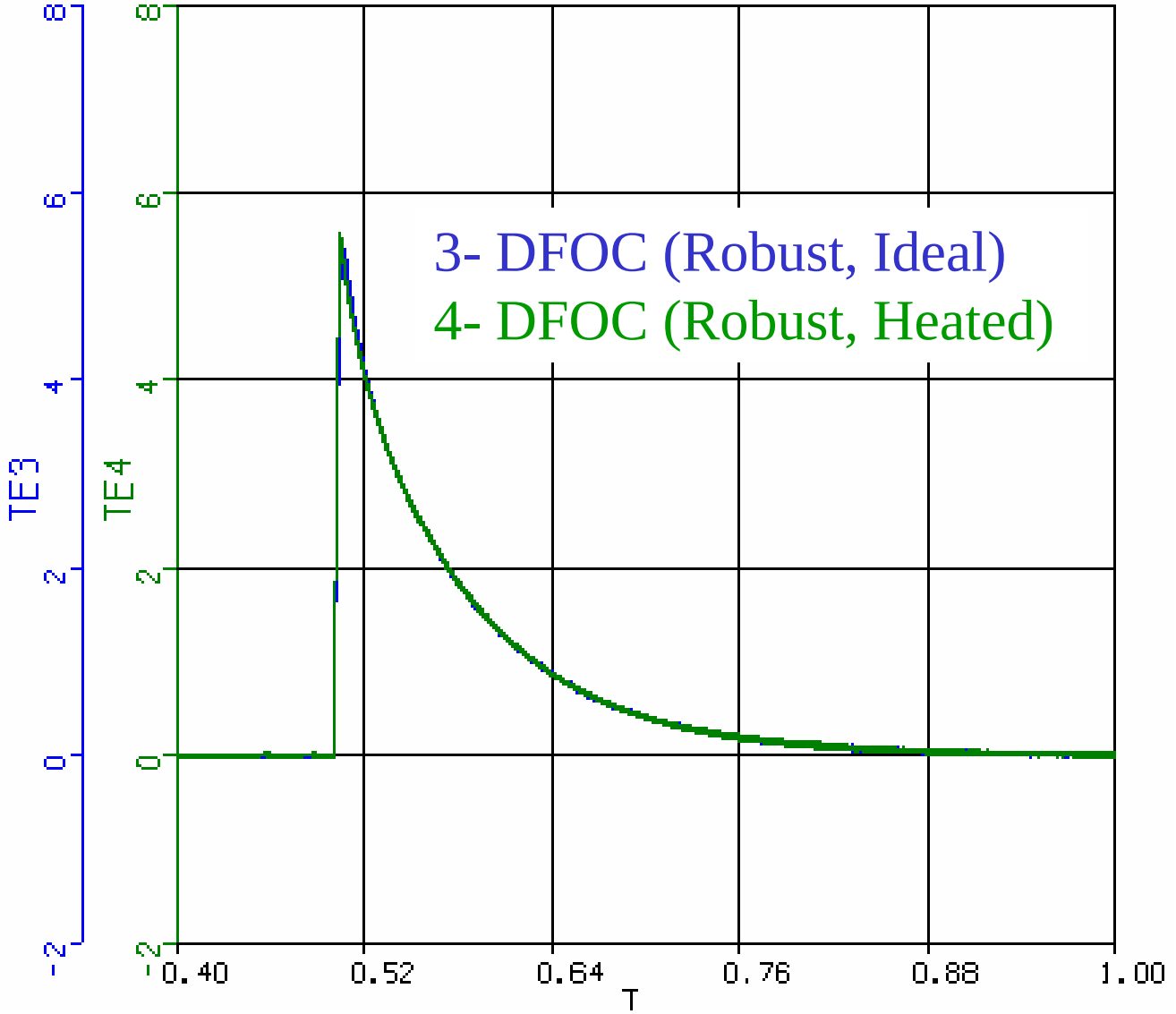
- Torques matched closely
- As speed approaches commanded speed, torque drops to zero

Speed Control Comparison



- Speeds matched closely

Speed Control Comparison



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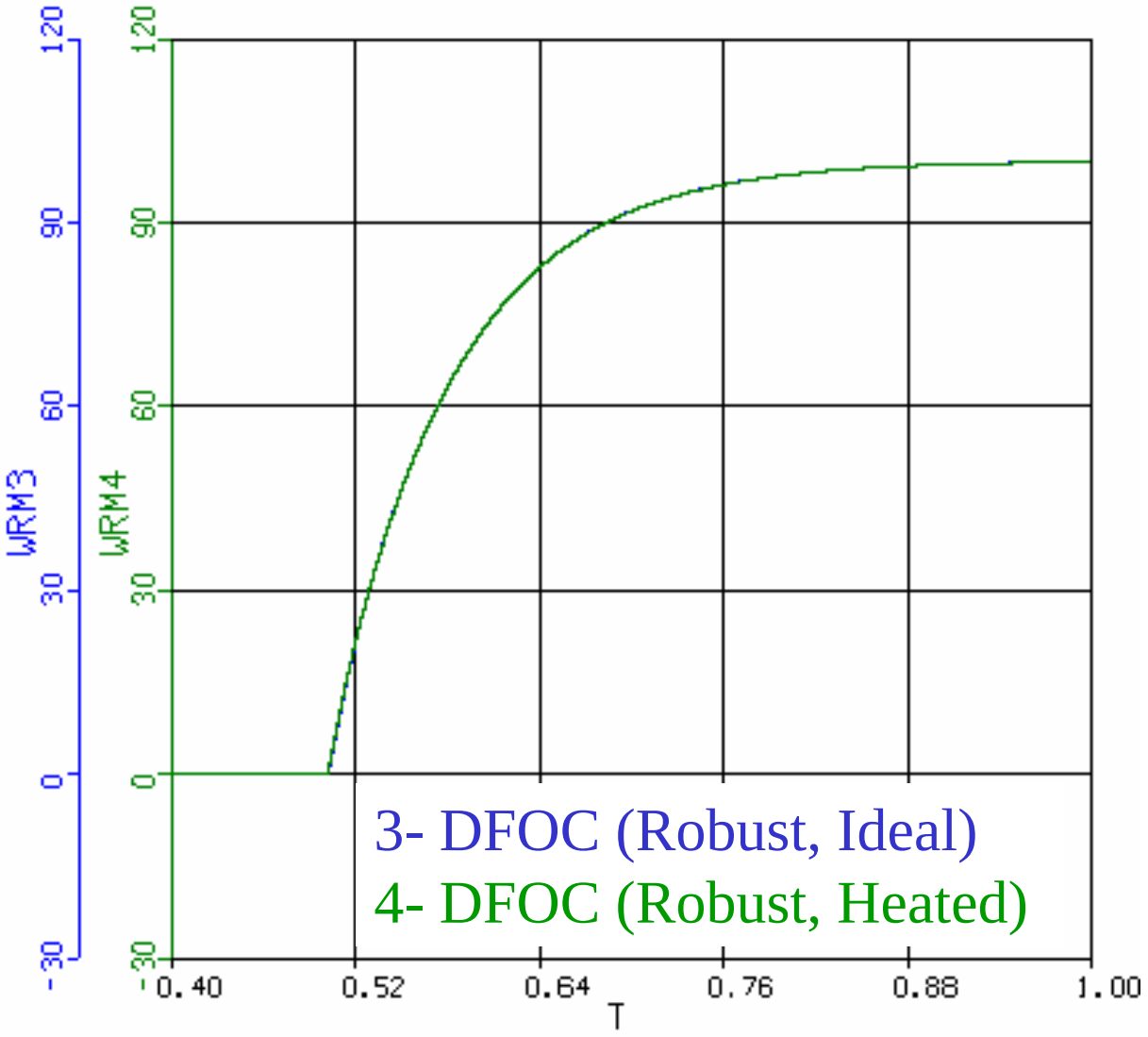

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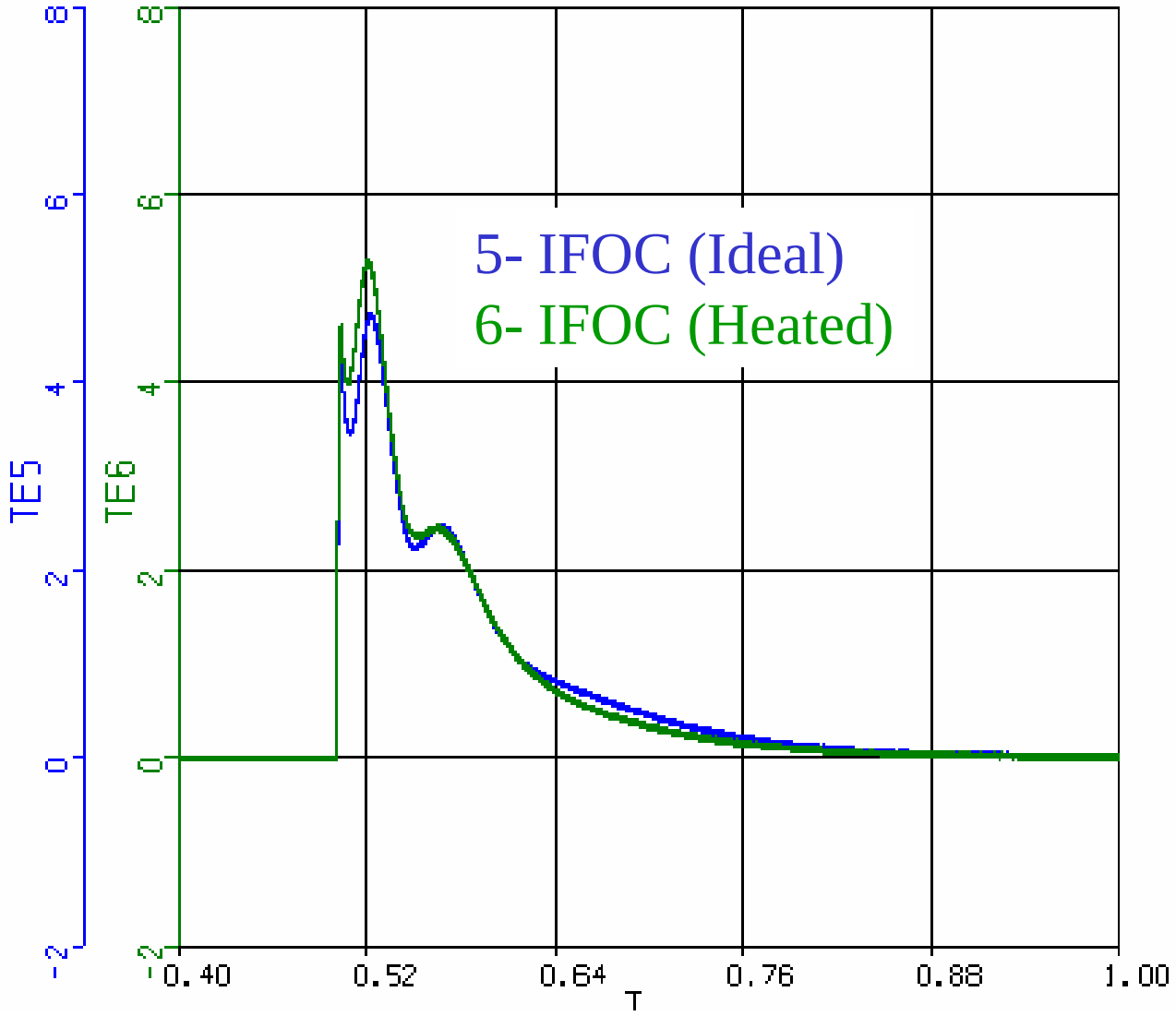
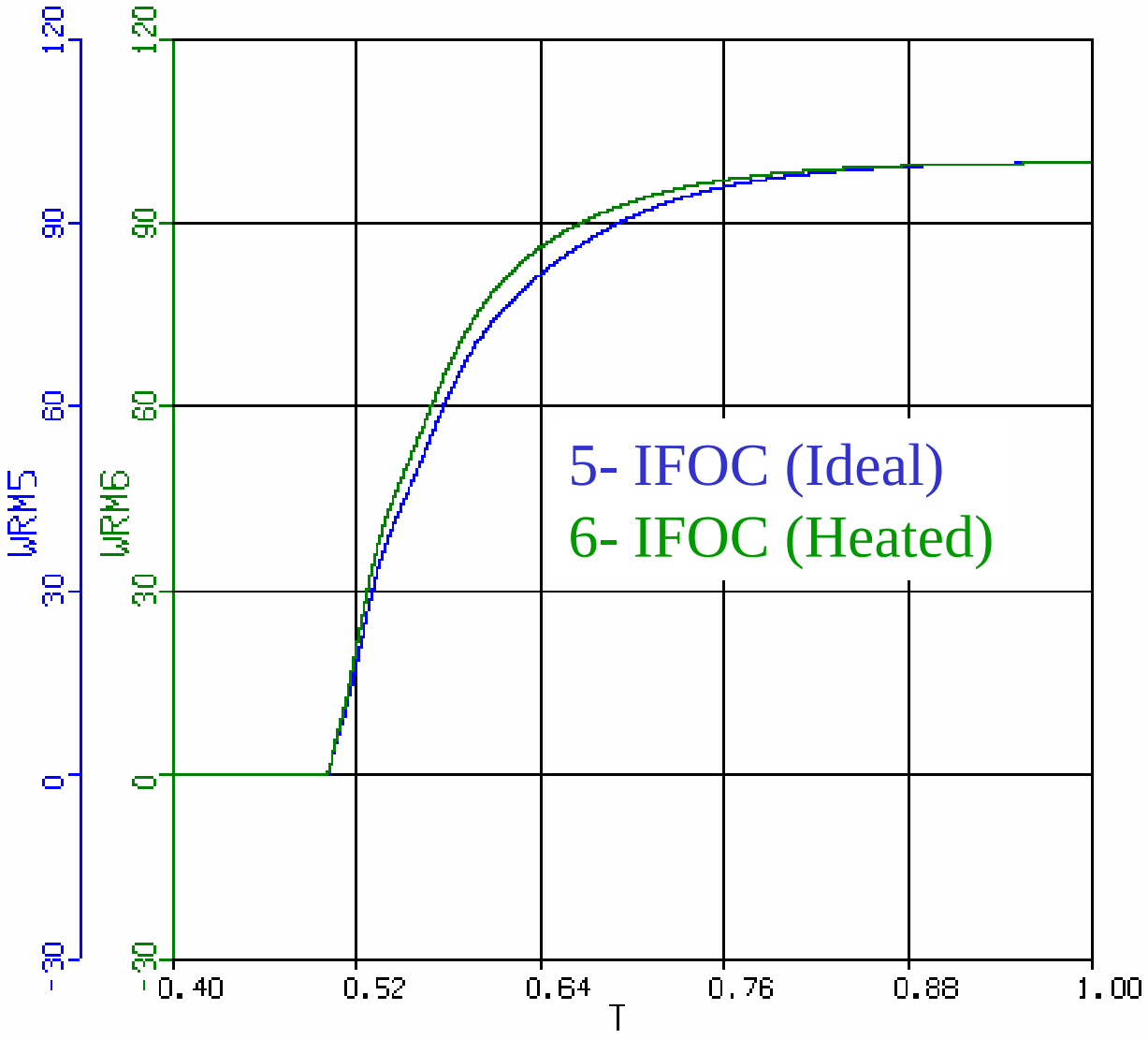
Speed Control Comparison



- Significant ripple exists in the torque as a result of using an approximated λ^{e}_{dr} in the controller
- Error in controller parameters produce a difference in torque output

Speed Control Comparison



- Error in controller parameters produce a difference in speed of the machine

Study Summary: Single Step Comparison

- Machine rotating at a constant 1000 rpm
- Torque command initially at 0.0 Nm (to stabilize λ^{e}_{dr})
- Torque command stepped to 1 Nm at 0.5 s
- Torque command stepped to 0 Nm at 1.0 s
- Simulation ended at 1.5 s

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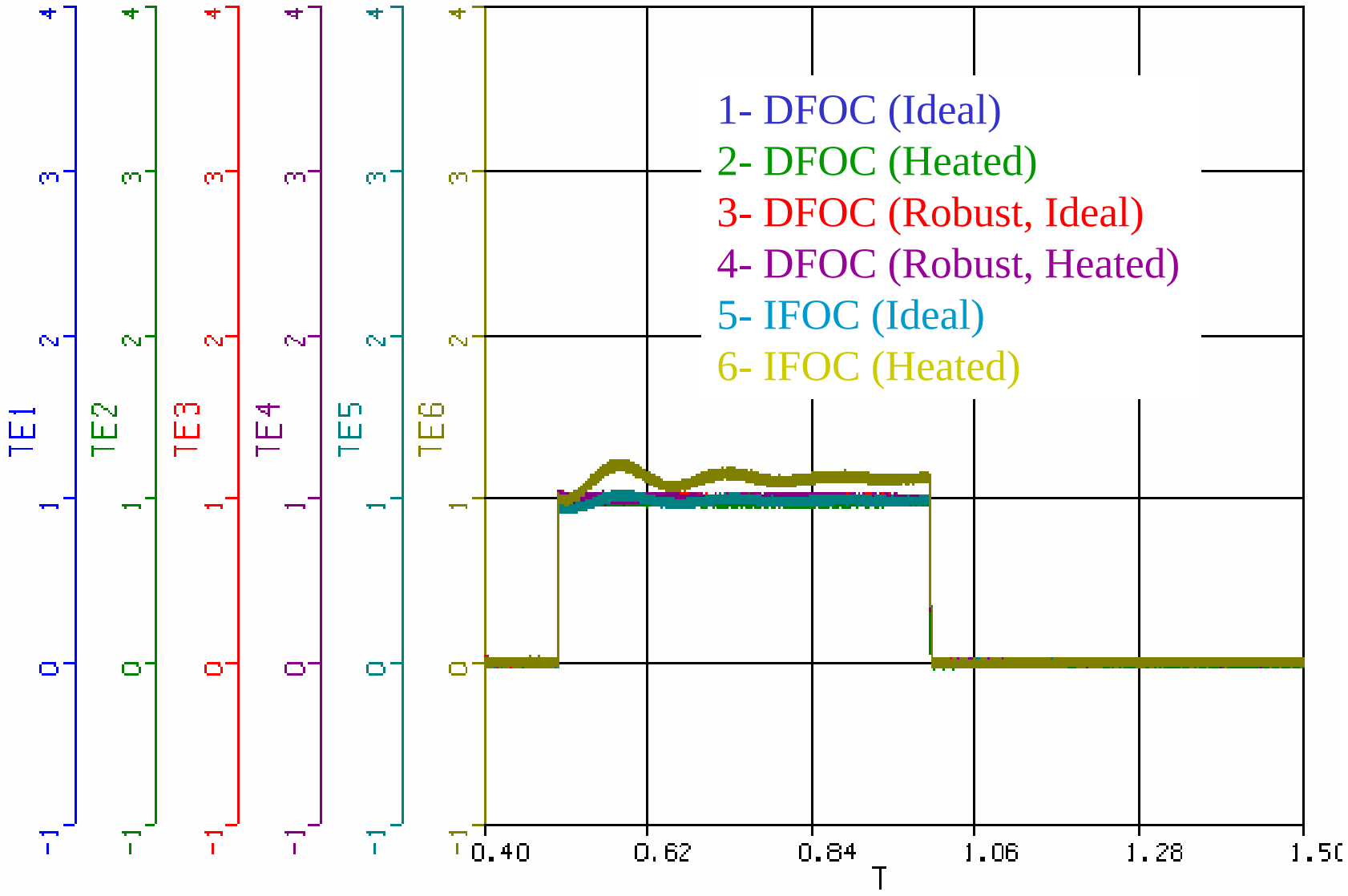
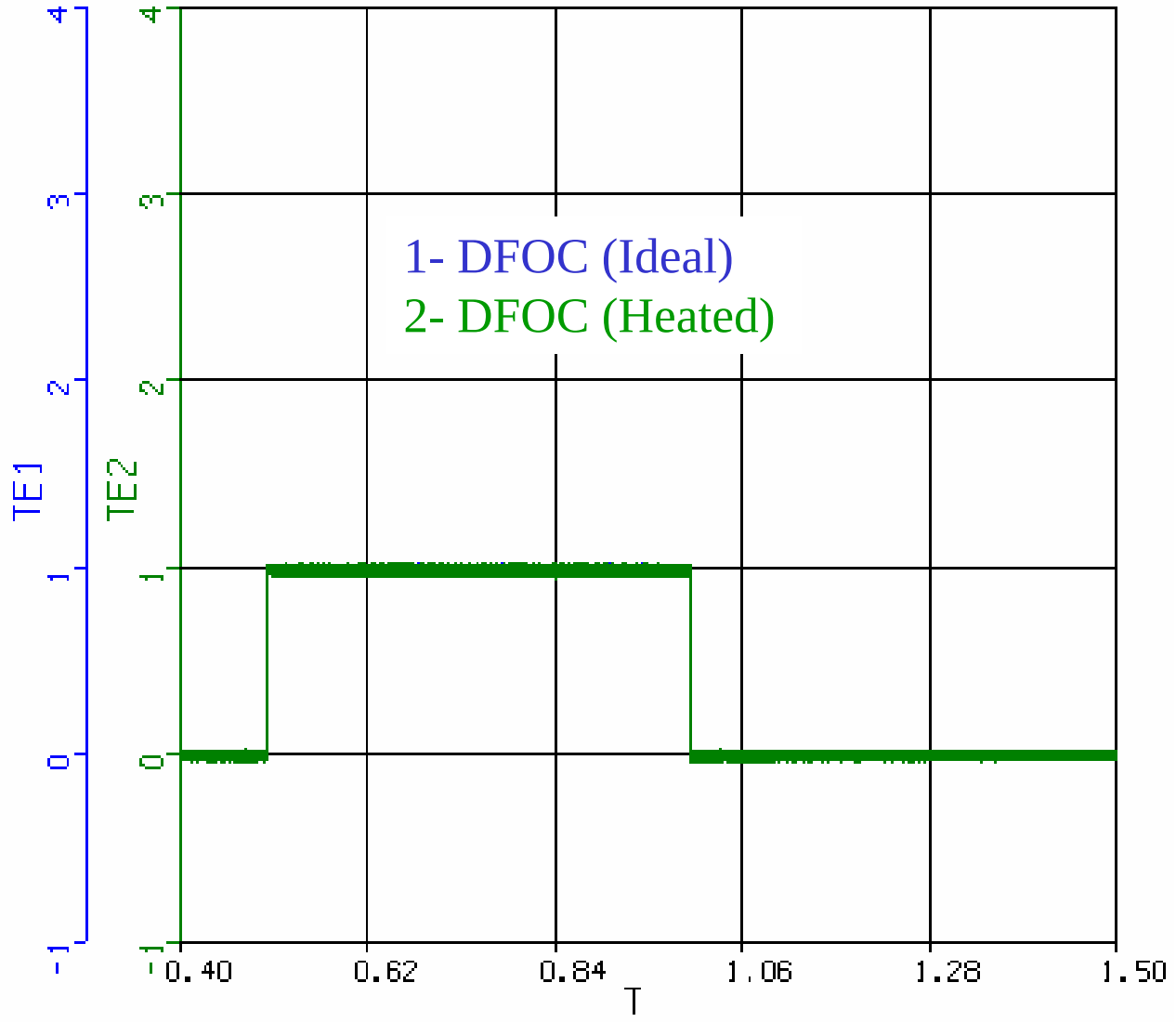
Single Step Comparison

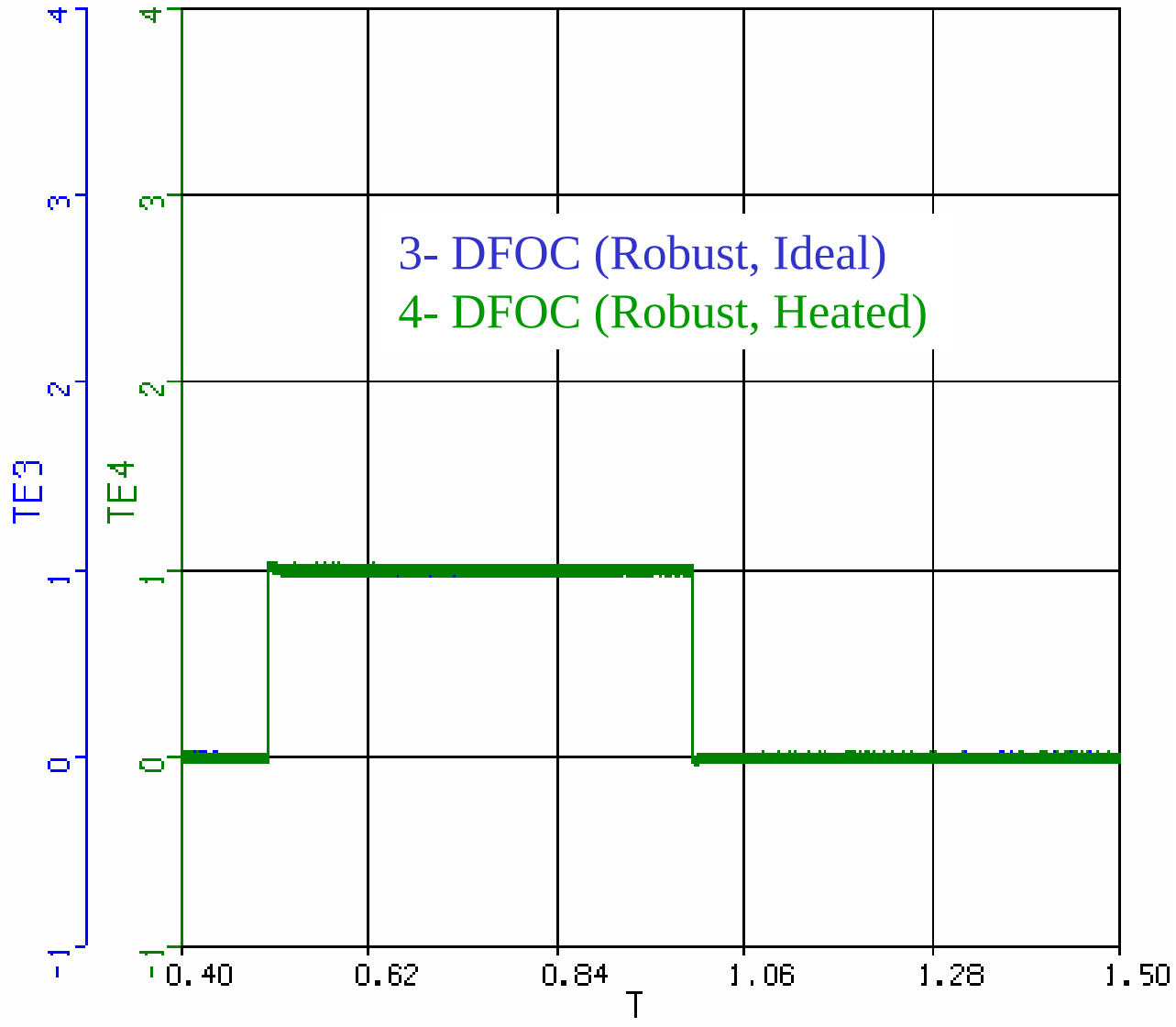


Single Step Comparison



- Torques matched closely

Single Step Comparison



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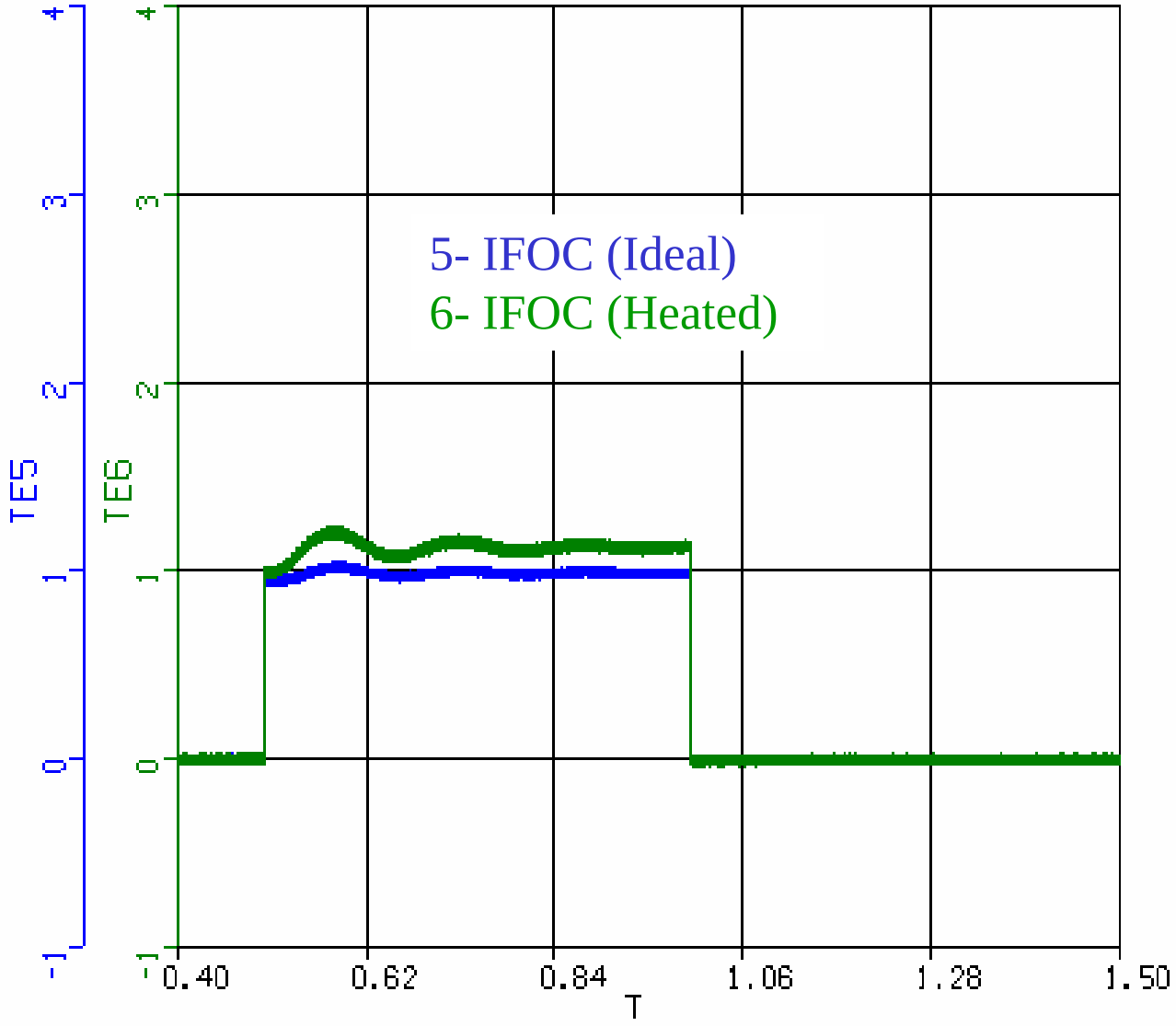
Single Step Comparison



- With ideal parameters, the commanded torque is achieved
- With error in the parameters, a significant offset in steady state torque exists
- Both sets have ripple, possibly due to error in λ^{e}_{dr}

Study Summary: Multiple Step Comparison

- Machine rotating at a constant 1000 rpm
- Torque command initially at 0.0 Nm (to stabilize λ^e_{dr})
- Torque commands are stepped according to the tables
- Simulation ended at 1.6 s

Torque Command [Nm]	Simulation Time [s]
1	0.5
-2	0.6
3	0.7
-4	0.8
5	0.9
-6	1.0
7	1.1
-8	1.2
9	1.3
-10	1.4
11	1.5

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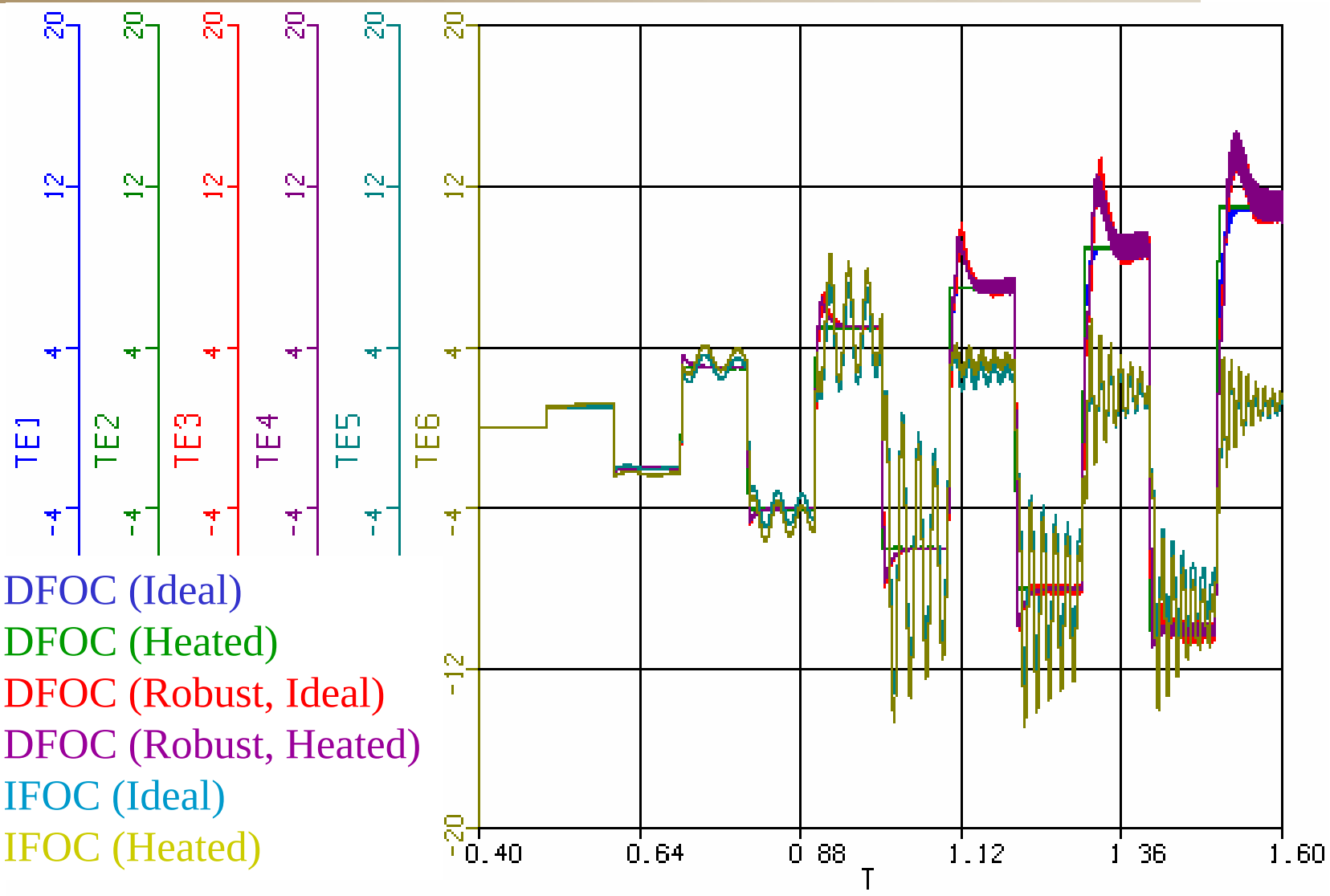
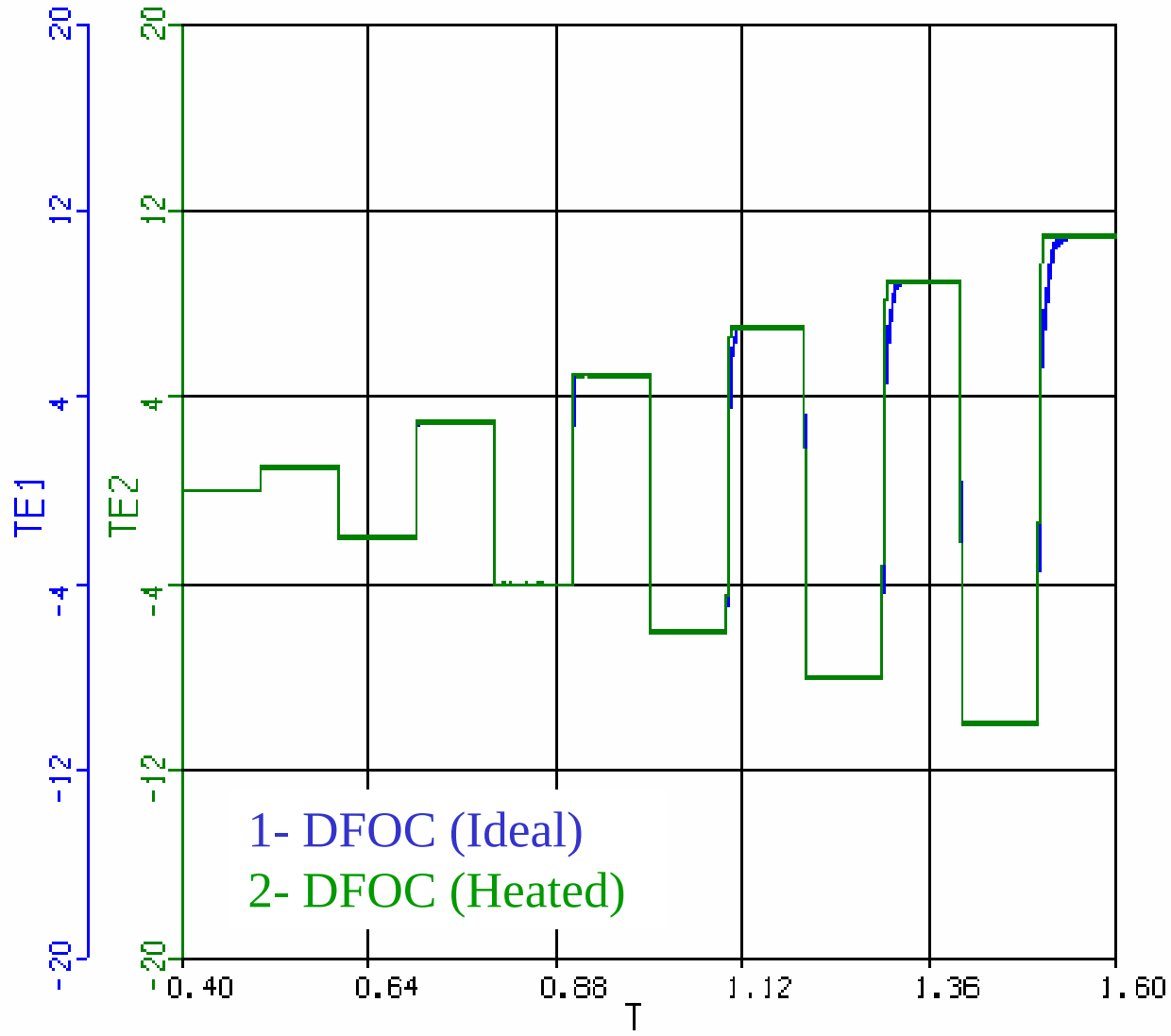
Multiple Step Comparison



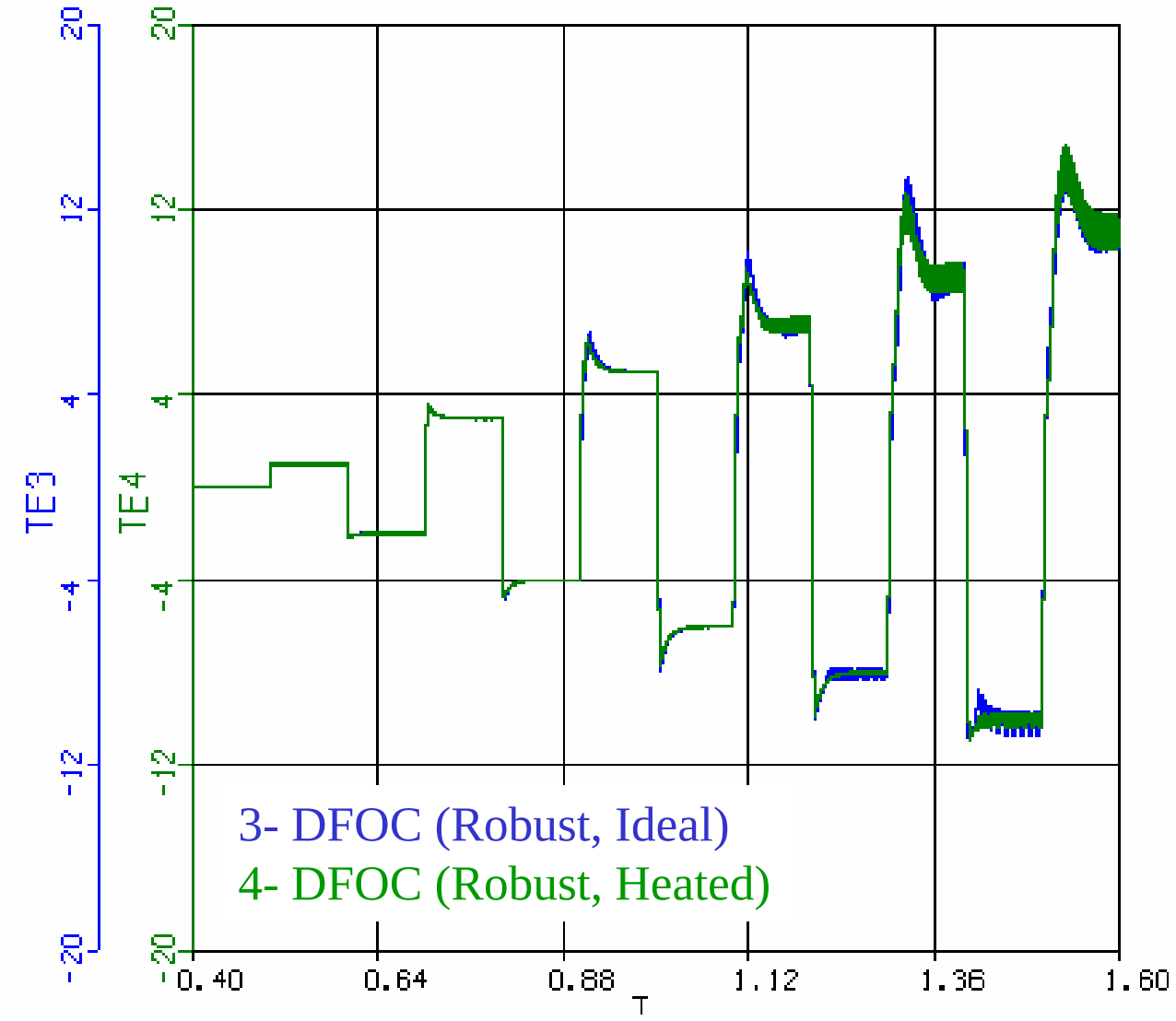
1- DFOC (Ideal)
2- DFOC (Heated)
3- DFOC (Robust, Ideal)
4- DFOC (Robust, Heated)
5- IFOC (Ideal)
6- IFOC (Heated)

Multiple Step Comparison



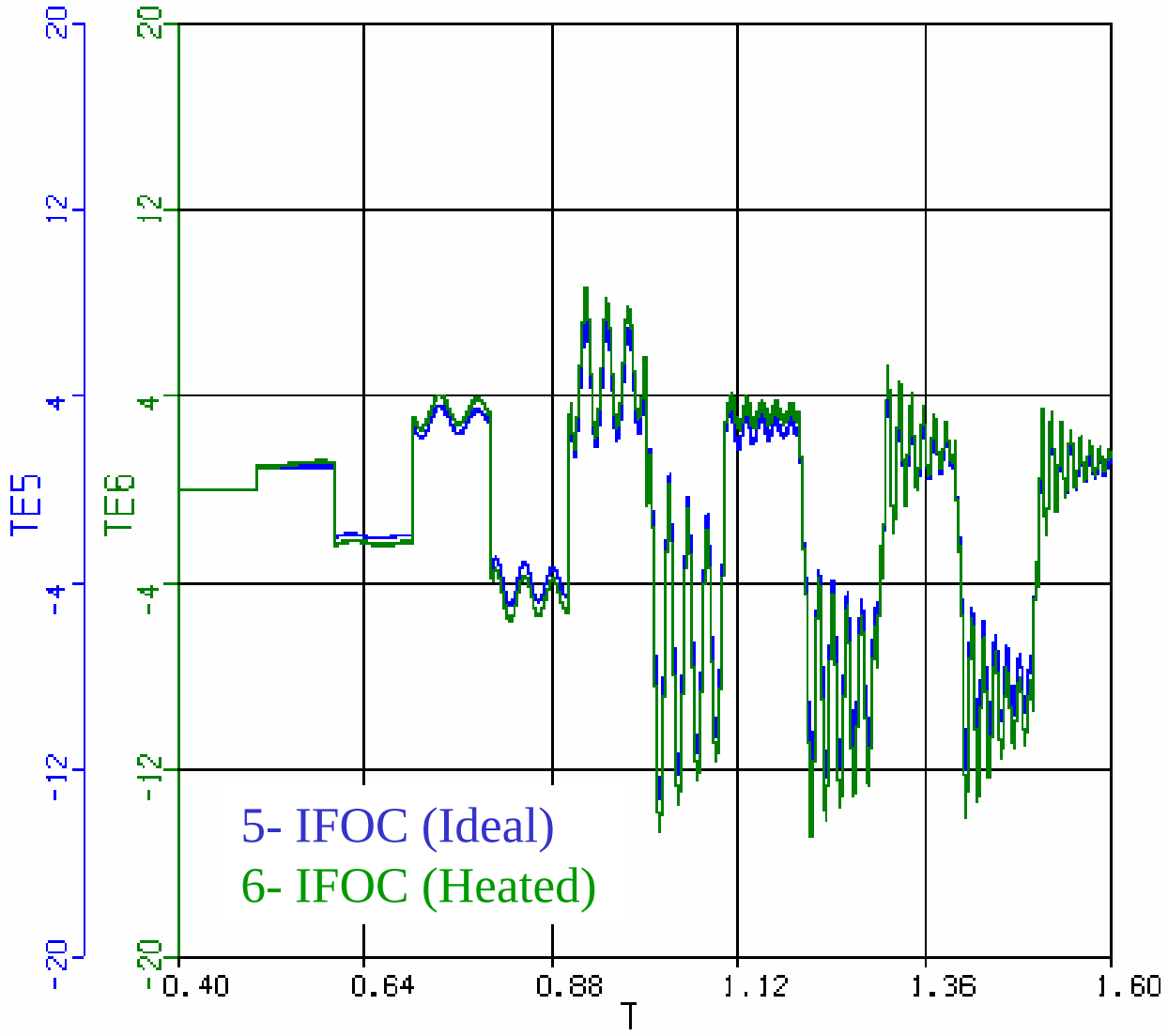
- Torques matched closely for the smaller steps in torque
- Very little error exists in the steady state torques
- The heated motor responds faster due to its decreased leakage inductance

Multiple Step Comparison



- Little error exists in the average steady state torques
- Overshoot and increased ripple may be due to improper setting of time constants

Multiple Step Comparison



- Significant error exists in the approximated value of λ^{e}_{dr}, which may cause the commanded current to be too large
- The error in steady state torque appears to be due to the large torque step
- The ripple exists because the torque command is changed before it is allowed to decay

Conclusions

- The DFOCs had less dependence on machine parameter variations
- The IFOC had a stronger dependence on machine parameter variations, namely due to rotor resistance
- All methods (except unmatched IFOC) could reasonably be used as a torque transducer up to a particular value of commanded torque, as long as the torque is changed reasonably slow
- The unmatched IFOC exhibited a steady state torque error of approximately 10% at 1.0 Nm
- With speed control, all methods reached the commanded speed in less than 0.5 s; however, the IFOC added significant ripple in the torque
- While the DFOC performed better, it is noted that it required additional inputs from the machine