ECE595s
Lab 10: Parameter Variation Effects on Indirect Field Oriented Control

- Group Members: Graham Mills, Jacob Turner
- Purpose: Examine estimated parameter variation on performance of Indirect Field Oriented Control
- Procedure: Use ACSL to simulate an IM and control of commanded torque and commanded rotor speed using IFOC. Then vary the IFOC's estimated parameters from the actual parameters of the IM.

Content

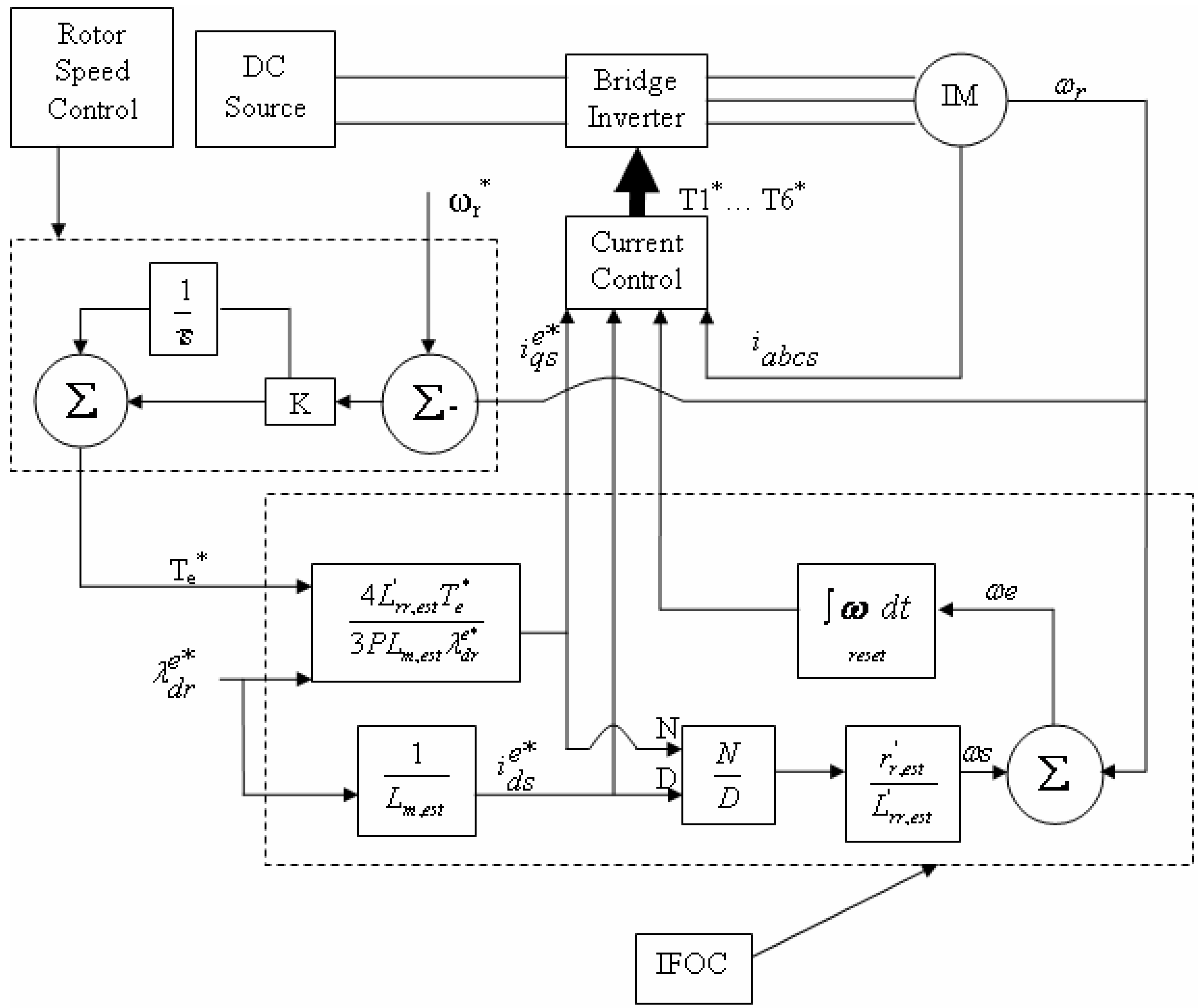
- Rotor Speed:
  - Steady State Error vs. Parameter Variation
  - Rise Time vs. Parameter Variation
- Torque Transducer:
  - Torque Waveform Curves vs. Parameter Variation
- Torque Steady State Response:
  - Steady State Error vs. Parameter Variation
- Conclusion:
  - Designer’s criteria for effectiveness of IFOC.

Justification of Estimated Parameter Variation

- Data points were taken under two operating conditions, cold startup and two-hour warm-up temperatures.
- It is observed that machines parameters increase with operating temperature, which justify the consideration of Parameter Estimation in the control.

	Cold Startup	Two Hour
Rs	2.125 Ω	2.515 Ω
Rr	1.081 Ω	1.344 Ω
Lrr	193.5 mH	196.3 mH
Lss	208.4 mH	213.5 mH
Lm	190.1 mH	194.1 mH

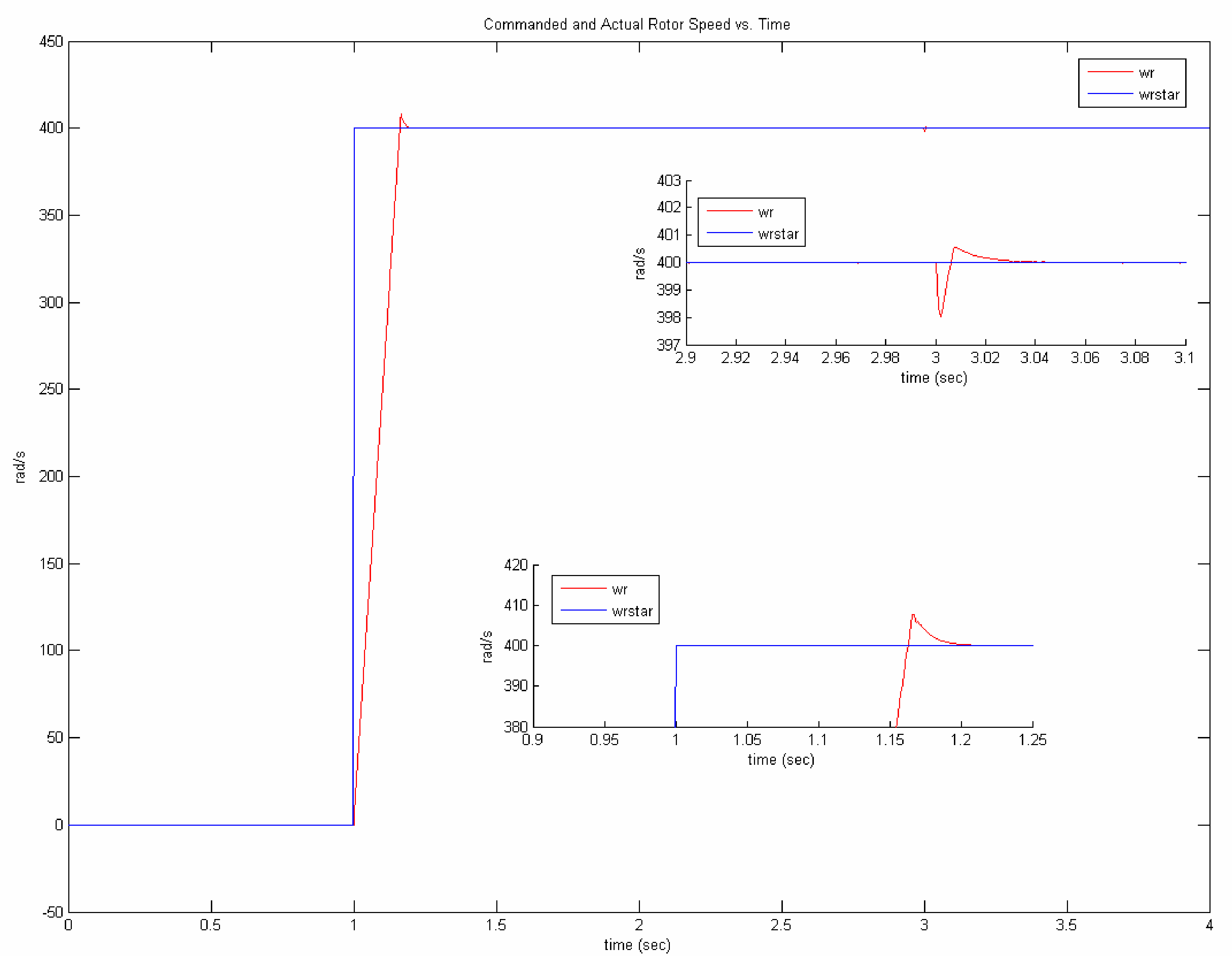
System Block Diagram

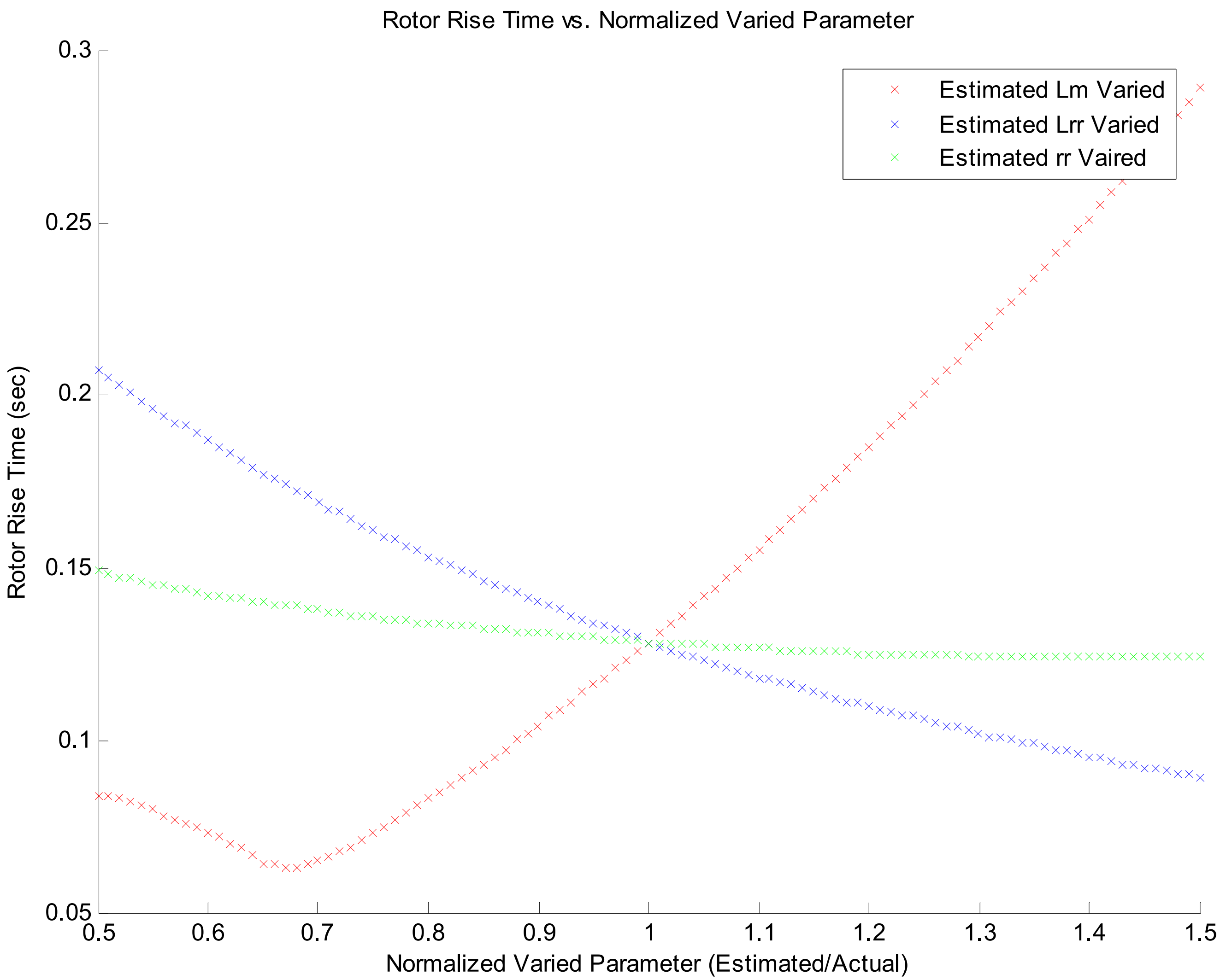


Operating Conditions for Rotor Speed Control Studies

- Initially no rotor speed commanded to stabilize the d-axis rotor flux.
- Applied a step change in ωr* to investigate rise time.
- Applied a step change in T_l to observe effects.

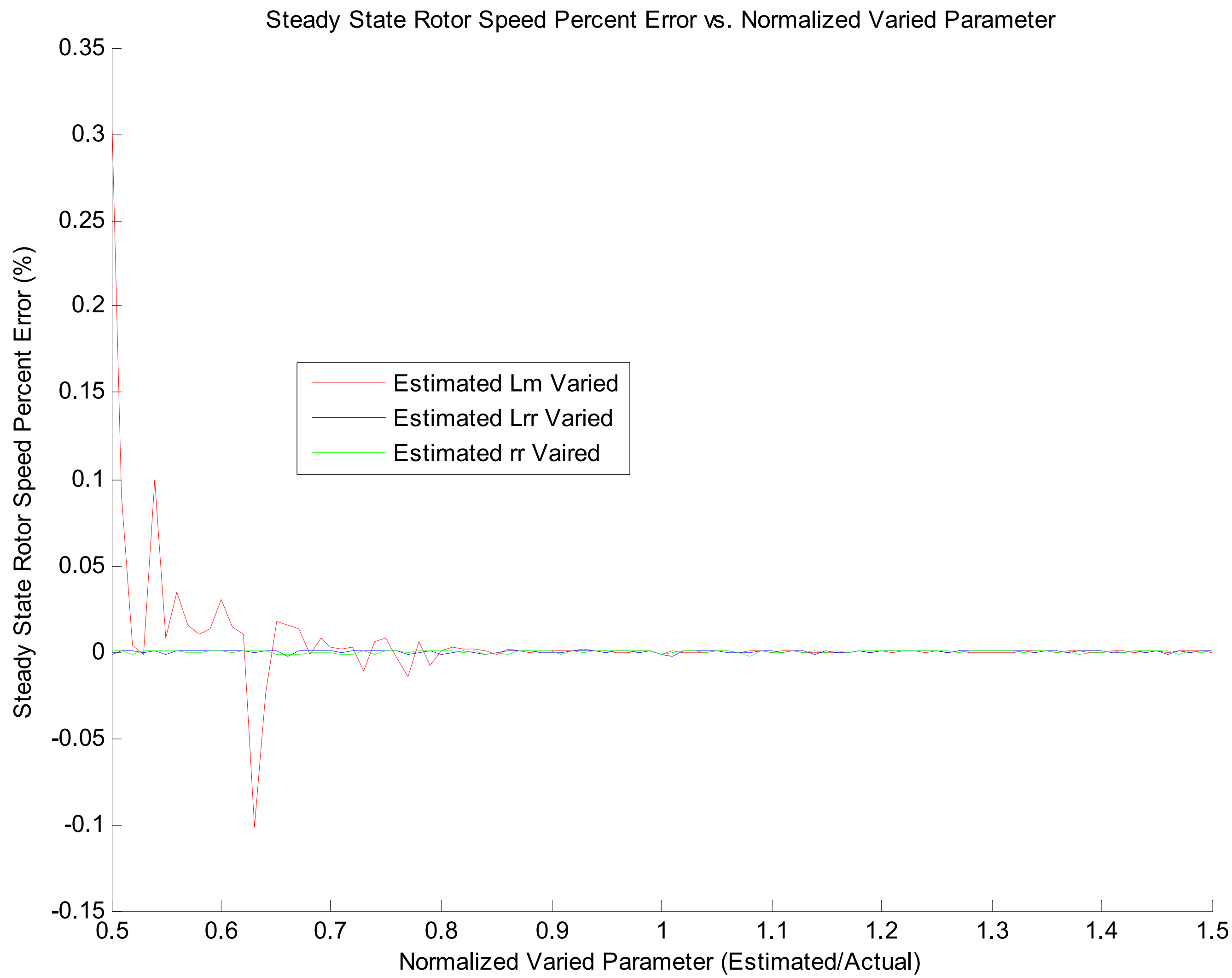
Time	0 sec	1 sec	3 sec
ω_r*	0 rad/s	400 rad/s	400 rad/s
T_l	0 Nm	0 Nm	3.0 Nm


Commanded and Actual Rotor Speed vs. Time
rad/s
time (sec)
wr
wrstar
450
400
350
300
250
200
150
100
50
0
-50
0
0.5
1
1.5
2
2.5
3
3.5
4
403
402
401
400
399
398
397
2.9
2.92
2.94
2.96
2.98
3
3.02
3.04
3.06
3.08
3.1
420
410
400
390
380
0.9
0.95
1
1.05
1.1
1.15
1.2
1.25


Rotor Rise Time vs. Normalized Varied Parameter
Estimated Lm Varied
Estimated Lrr Varied
Estimated rr Vaired
Rotor Rise Time (sec)
0.3
0.25
0.2
0.15
0.1
0.05
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Normalized Varied Parameter (Estimated/Actual)

Rotor Rise Time

- As can be seen the rise time of the rotor varies as the estimated parameters vary
- Mutual inductance seems to have the most effect on rise time, especially as the parameter is varied above the actual value
- Rotor resistance seems to have little effect on rise time
- Rotor inductance seems to have effect but not as severe as Lm does



Steady State Rotor Speed Percent Error vs. Normalized Varied Parameter
Steady State Rotor Speed Percent Error (%)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Normalized Varied Parameter (Estimated/Actual)
Estimated Lm Varied
Estimated Lrr Varied
Estimated rr Vaired

Rotor Steady State Error

- As noticed on the above plot estimated Mutual Inductance is the only parameter that seems to have effect on the Steady State Rotor Speed and not by any significant amount.

Here comes GRAHAM!!!!

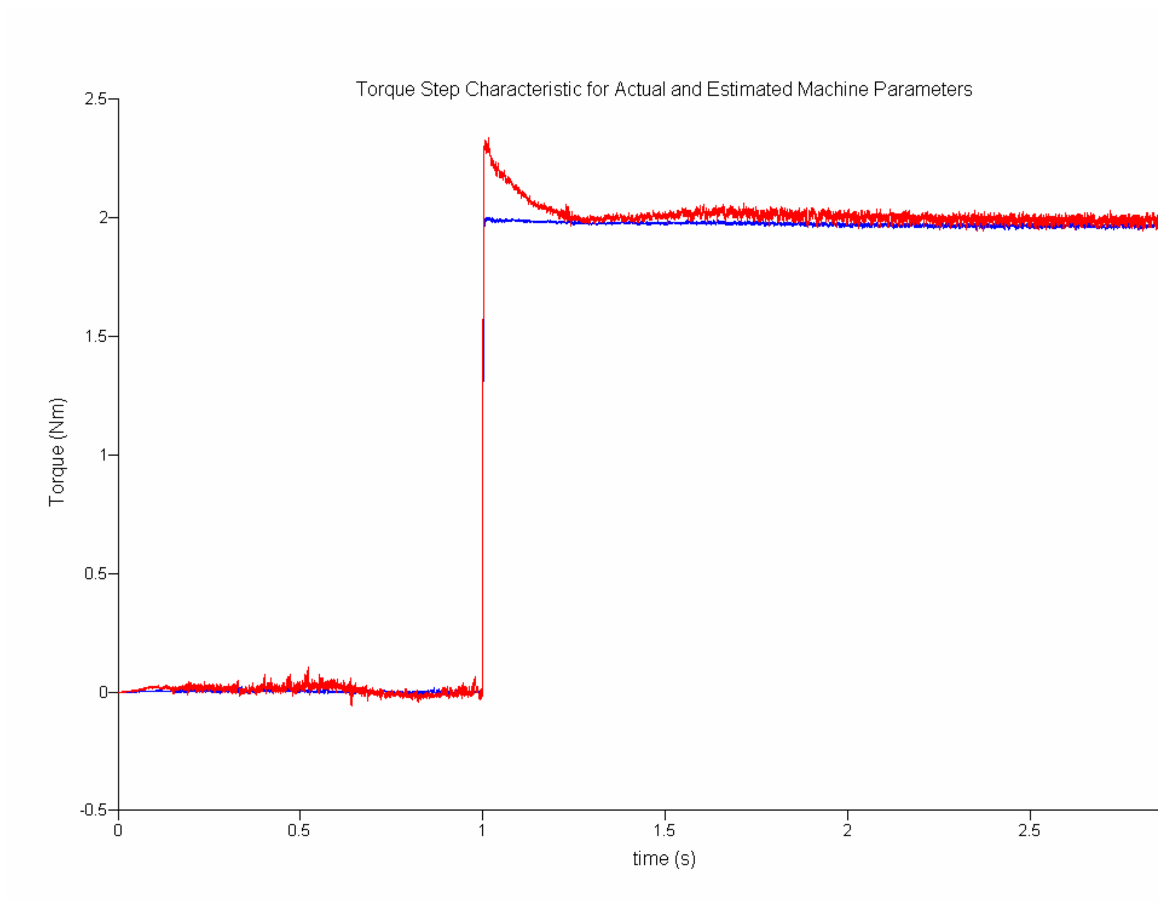
- To discuss Toque Transducer and Steady State effects from parameter variation.

Simulation Process

- Commanded torque step of 2 Nm applied at 1.0 second. Allows rotor flux to stabilize.
- Output torque was filtered using a single order LPF.
- ACSL Math used to acquire and process simulation data.
- ‘Hot’ and ‘Cold’ machine parameters are taken as bounds for the range of normal operating temperatures. Parameter variation investigated in this range.

Effect of Parameter Variation

Torque Waveform Produced for ‘Hot’ and ‘Cold’ Machine



Overshoot and Steady State Error for 'Hot' and 'Cold' Machine

- When the machine is cold the commanded torque waveform is reproduced exactly
  - Steady state error = 0.0555%
  - Overshoot = 1.7831%

  After warming up a steady state error and transient is evident
  - Steady state error = 0.4130%
  - Overshoot = 15.6070%

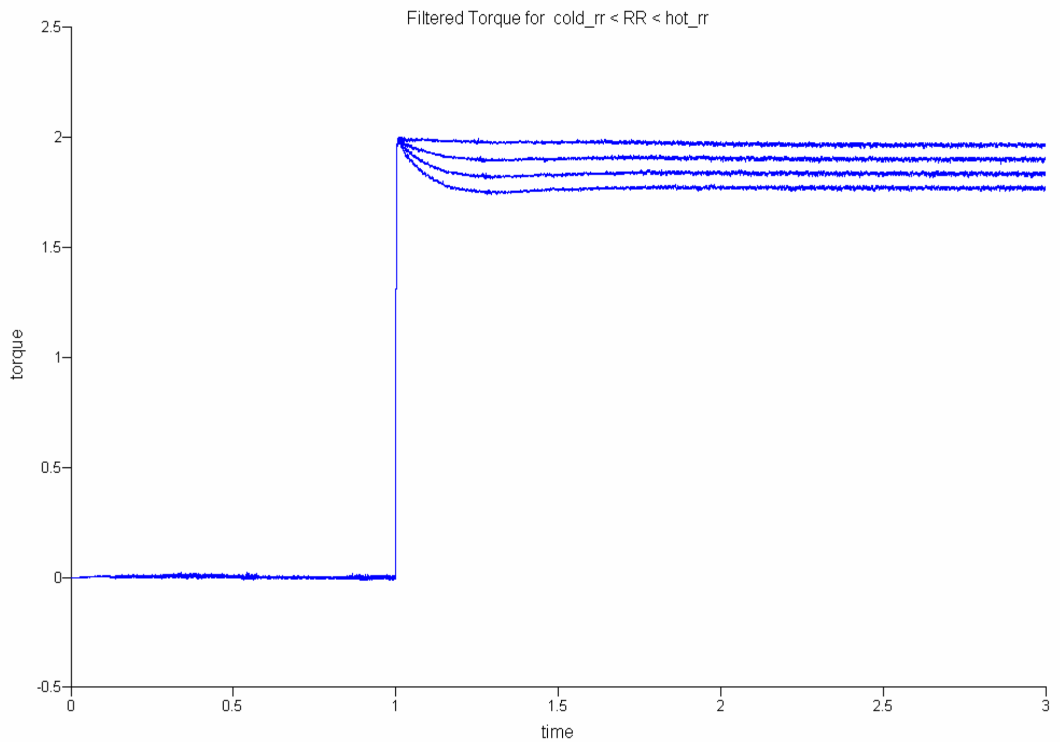
The over shoot is significant but the steady state error is not. Why?

Questions

- Which parameter is the steady state torque most sensitive to?
- Which parameters cause the transient effects?
- Which parameter is the torque least sensitive to?

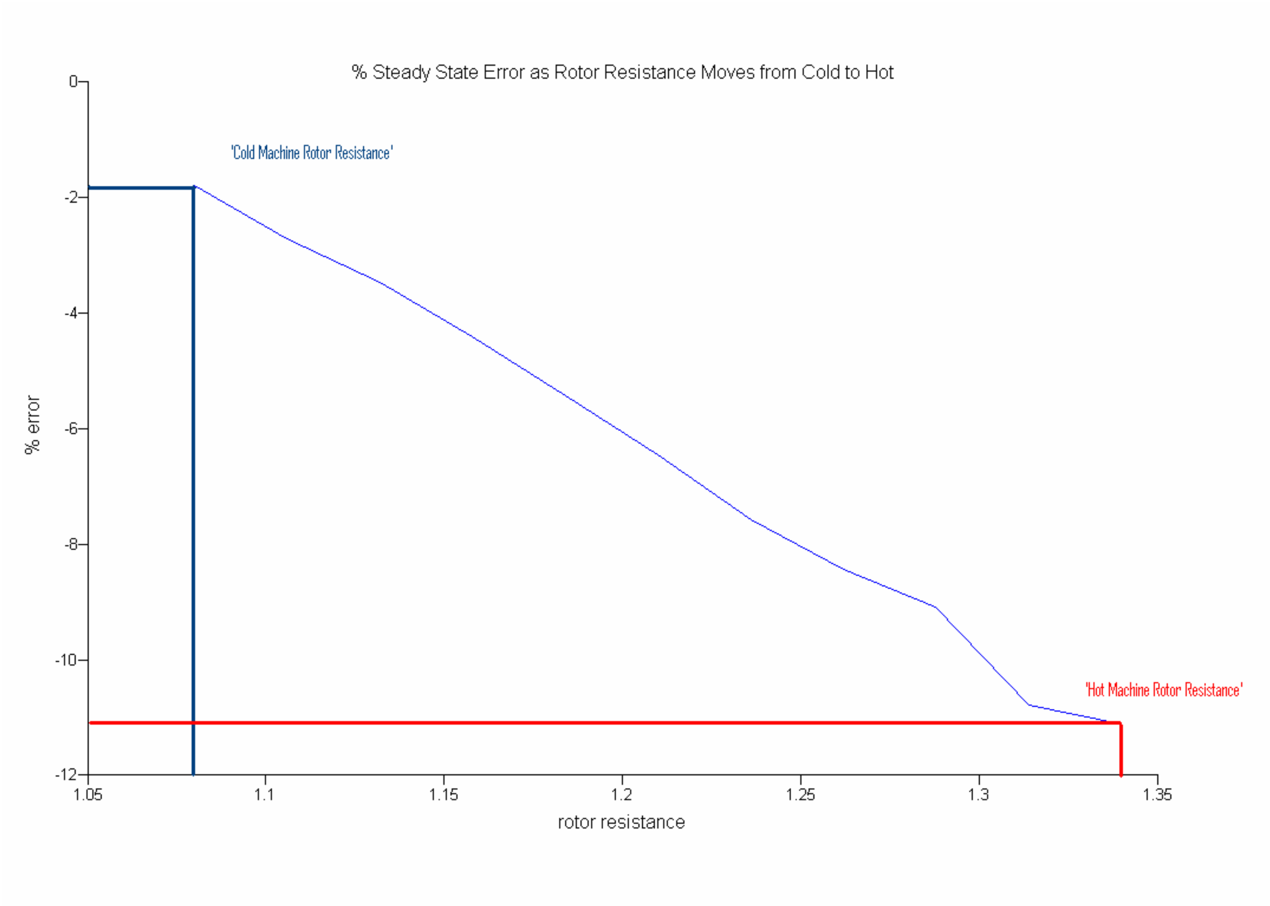
Effect of Varying Rotor Resistance

Torque Waveform as Rotor Resistance is Swept from Cold to Hot



Effect of Varying Rotor Resistance

Percentage Error in Steady State as Rotor Resistance is Swept from Hot to Cold

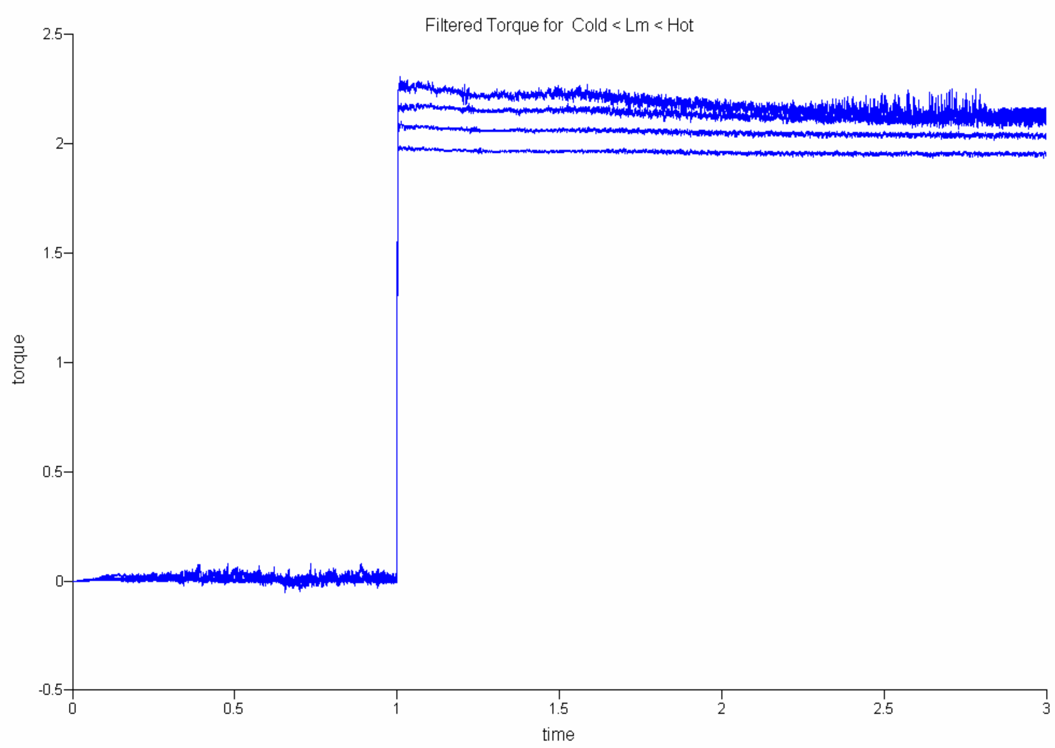


Effect of Varying Rotor Resistance

- Observations
  - The Torque is observed to initially arrive at commanded value before 'drooping' to the steady state value.
  - May be due to over estimate of slip frequency.
  - The steady state error is increasingly negative for higher values of rotor resistance.
  - Introduces 9.3342 % error into the steady state value.

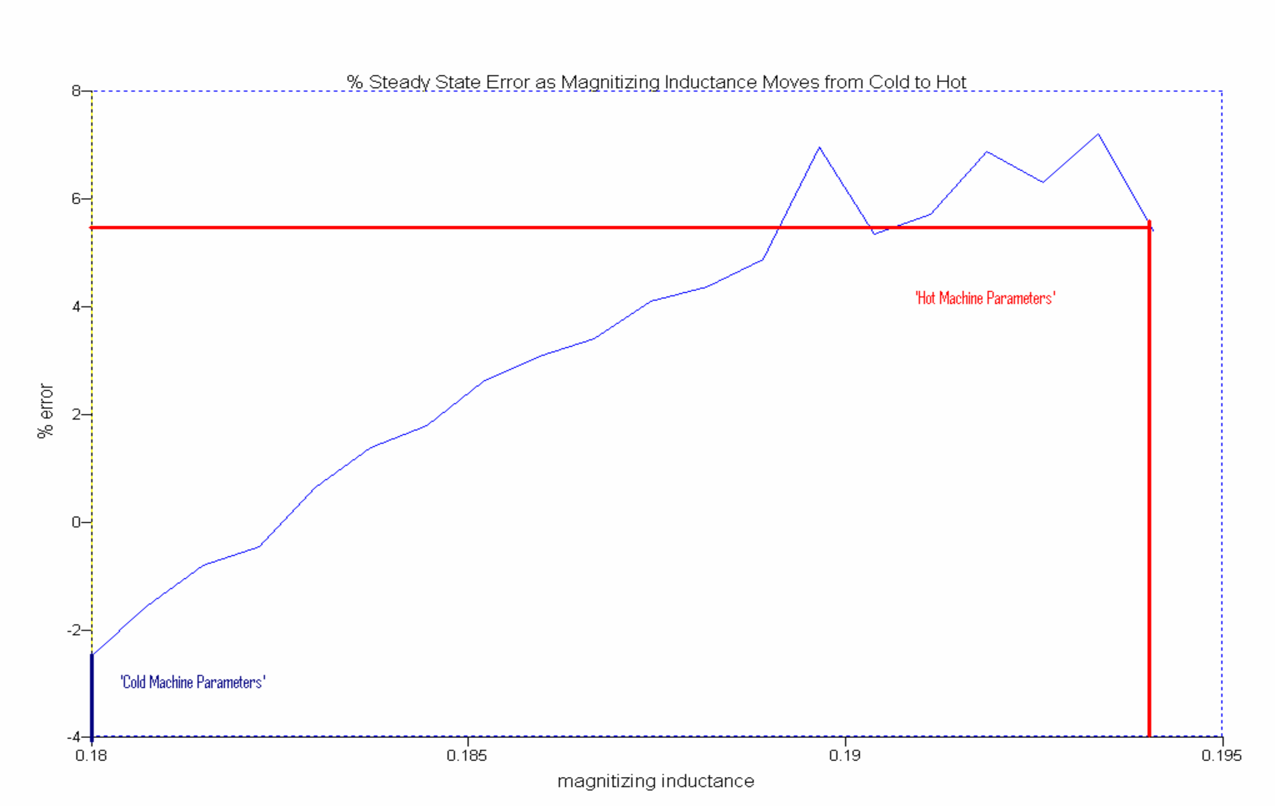
Effect of Varying Magnetizing Inductance

Torque Waveform as Magnetizing Inductance Swept from Cold to Hot



Effect of Varying Magnetizing Inductance

- Percentage Error in Steady State Value as Magnetizing Inductance is swept from hot to cold.



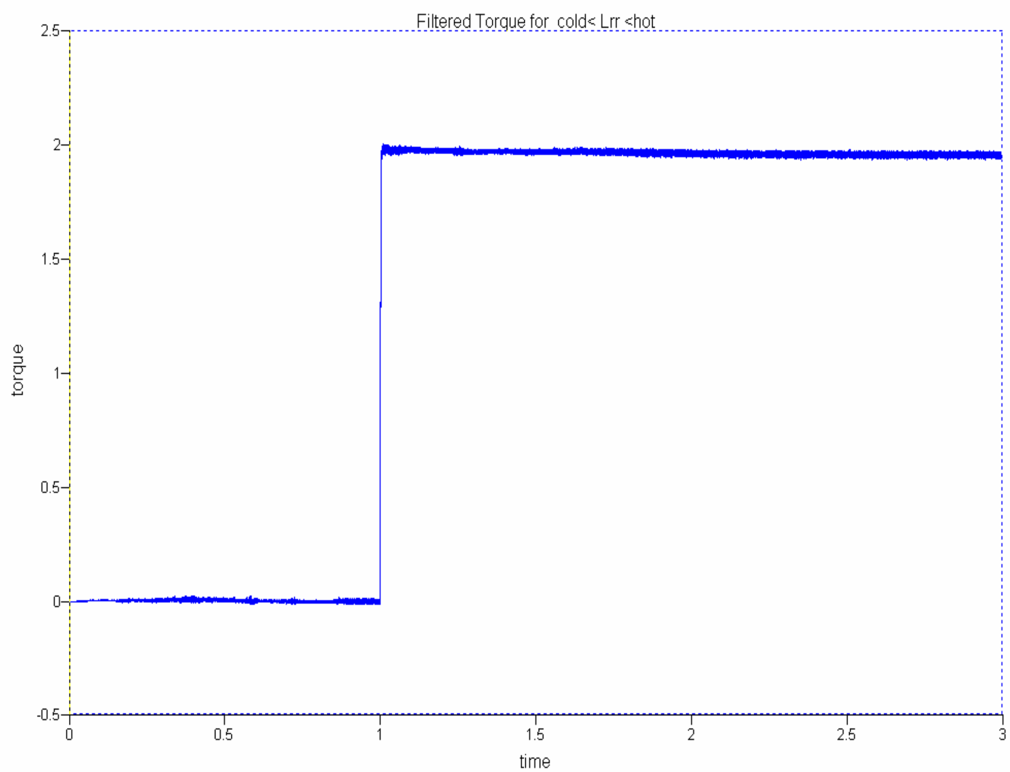
'Crunchiness' is due to torque ripple, stability at higher Lm

Effect of Varying Magnetizing Inductance

- Observations
  - Variation in the magnetizing inductance with increasing temperature increases steady state torque ~ 8%.
  - Stability becomes an issue for higher values of Lm
  - Torque shows significant sensitivity to changes in Lm over ‘standard operating range’.
  - No significant transient effects!

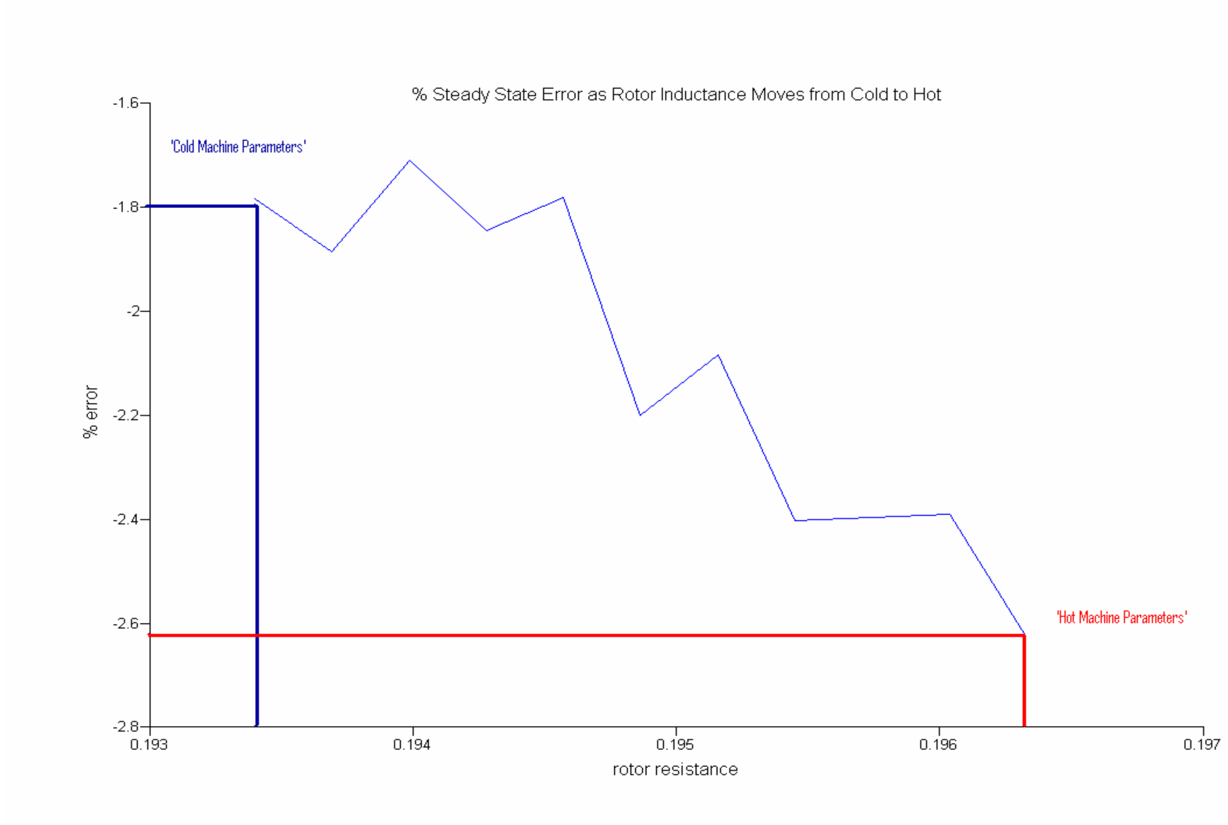
Effect of Varying Rotor Inductance

Torque Waveform as Rotor Resistance is Swept from Cold to Hot



Effect of Varying Rotor Inductance

- Percentage Error in Steady State Value



'Crunchiness' is due to torque ripple

Effect of Varying Rotor Inductance

- Observations
  - The effect of the change in rotor inductance as the machine heats up is small.
  - Additional -0.9174% steady state error introduced.
  - No perceptible transient effects.

Answers

- Which Parameter is the steady state torque most sensitive to?
  - Steady state torque shows significant sensitivity to Lm and Rr with Lm increasing steady state torque and Rr decreasing steady state torque. Hence they almost cancel each other out.
- Which parameter causes the transient effects?
  - The transient is contributed by the increase in rotor resistance. Neither the rotor or magnetizing inductances contribute.
- Which parameter is the torque least sensitive to?
  - The rotor Inductance doesn’t have much of an effect.