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MEEM 5812: AUTOMOTIVE CONTROL SYSTEMS

SPRING 2023

TITLE: FUEL CONTROL IN A SPARK IGNITION ENGINE WITH PORT AND DIRECT FUEL INJECTORS

By

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[1.1] A/F = 14.64

1. Plot of lambda measured (without feedback, i.e only transient fuel is added to the fuel controller)

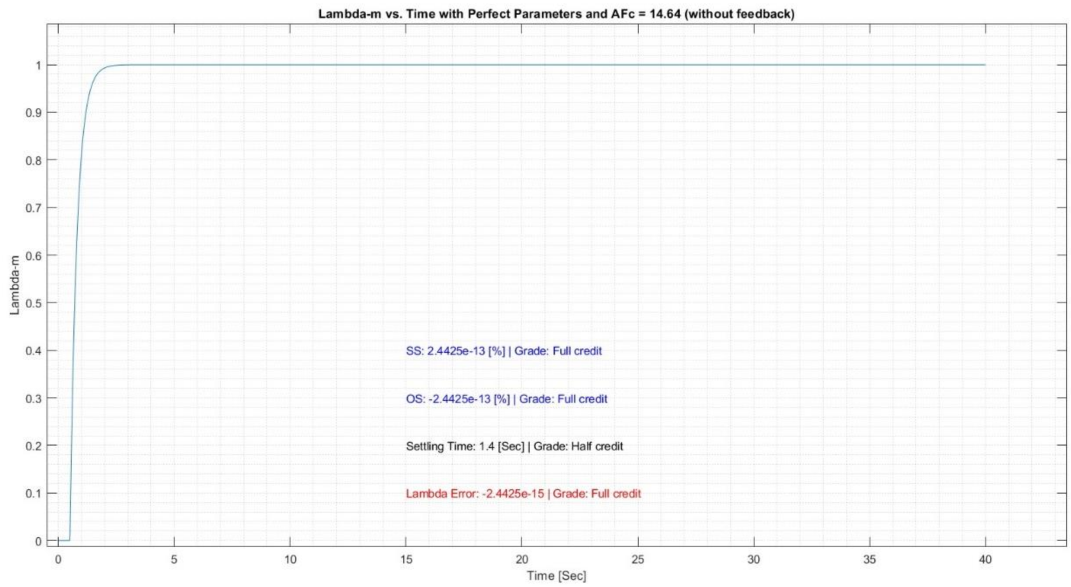

Fig 1. 1 Lambda measured vs time (without feedback, A/F=14.64)

2. Plot of Lambda measured (with feedback) (PI/Smith controller are connected to transient fuel)

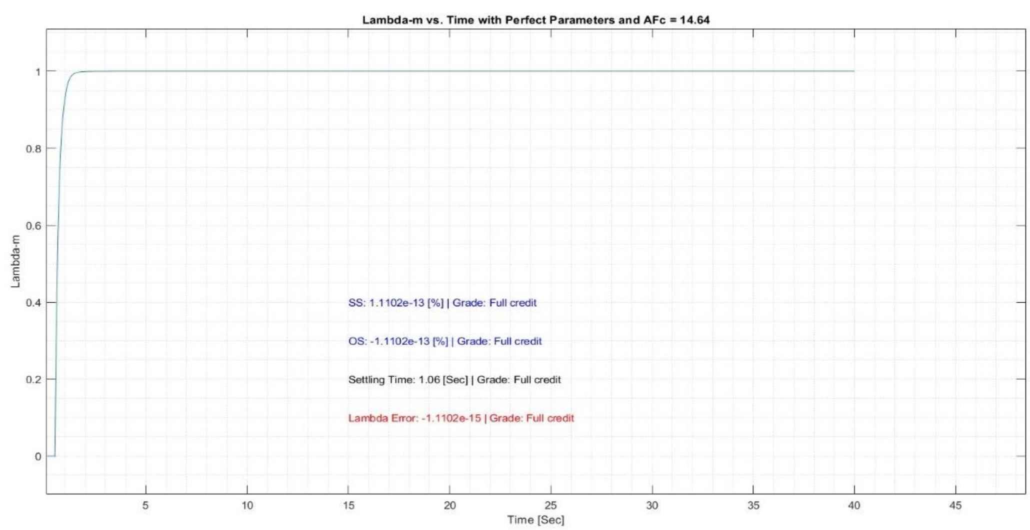

Fig 1. 2 Lambda measured vs time (with feedback, A/F=14.64)

3. Plot of normalized fuel and injected fuel vs time (PI/Smith controller are connected to transient fuel)

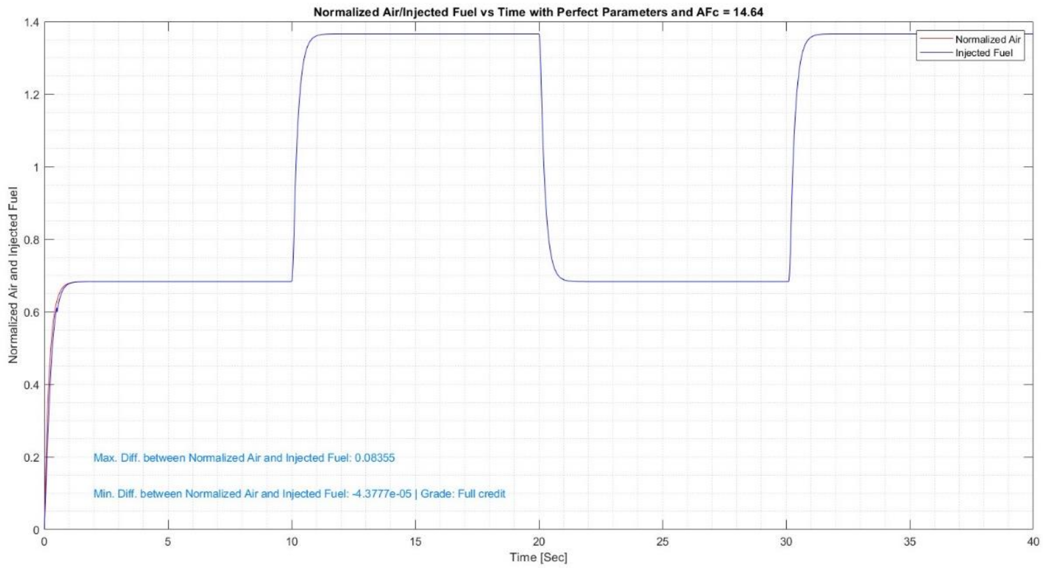

Fig 1. 3 Normalized air and Injected Fuel vs time (A/F =14.64)

[1.2] A/F = 14.4

1. Plot of lambda measured (without feedback, i.e only transient fuel is added to the fuel controller)

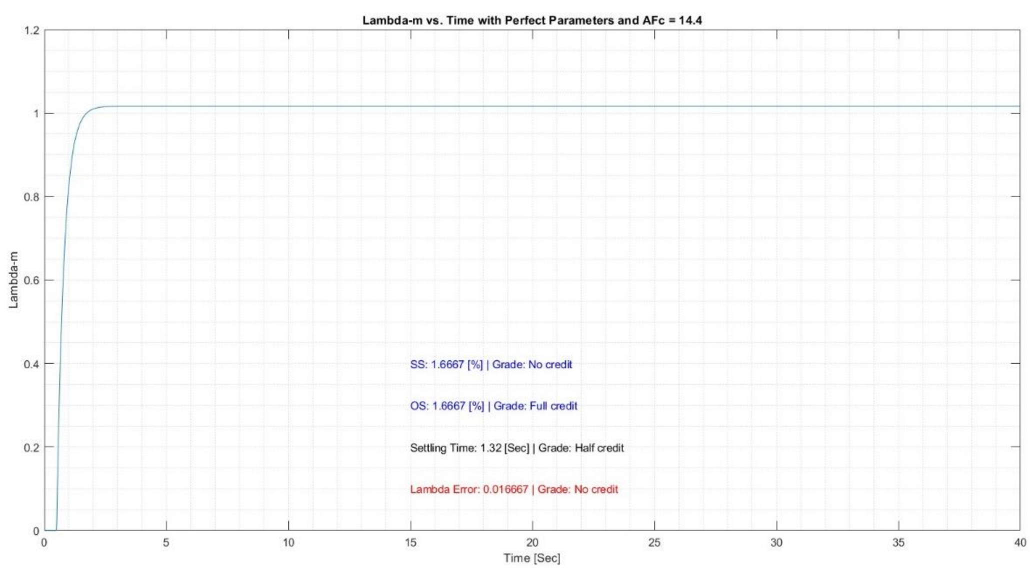

Fig 1. 4 lambda measured vs time (without feedback A/F=14.4)

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2. Plot of lambda measured (with feedback) (PI/Smith controller are connected to transient fuel)

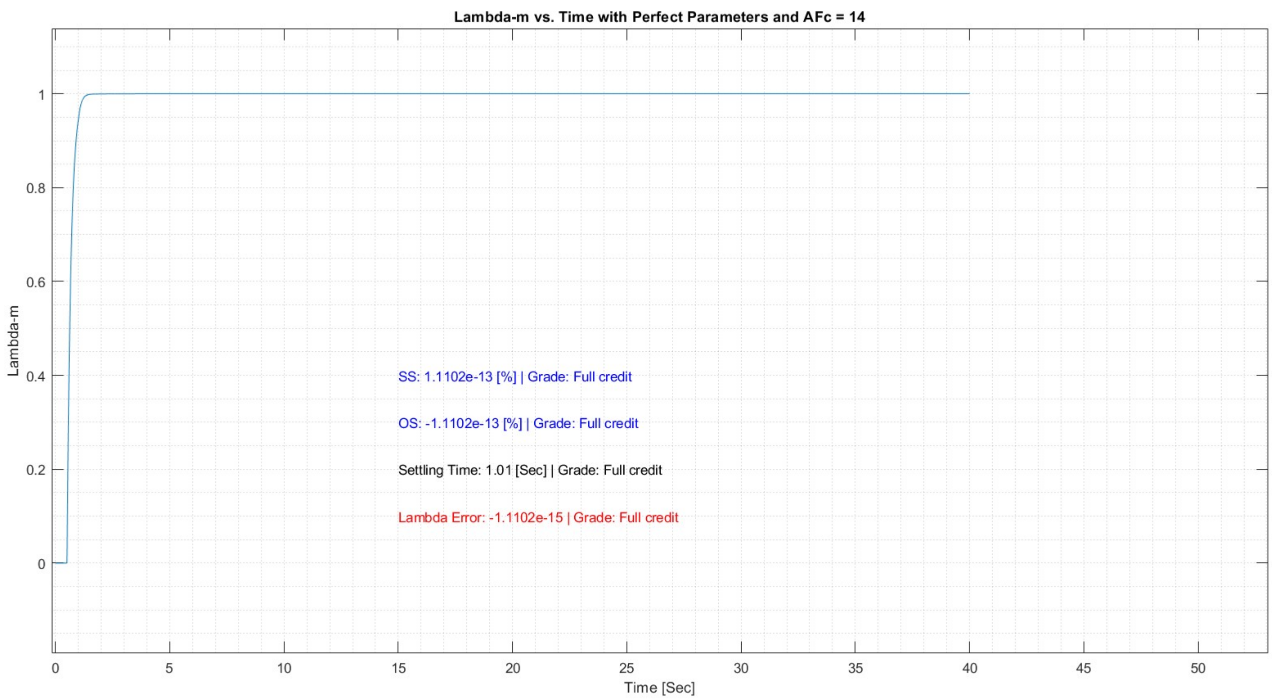

Fig 1. 5 lambda measured vs time (with feedback A/F= 14.4)

3. Plot of normalized air and injected fuel vs time(PI/Smith controller are connected to transient fuel)

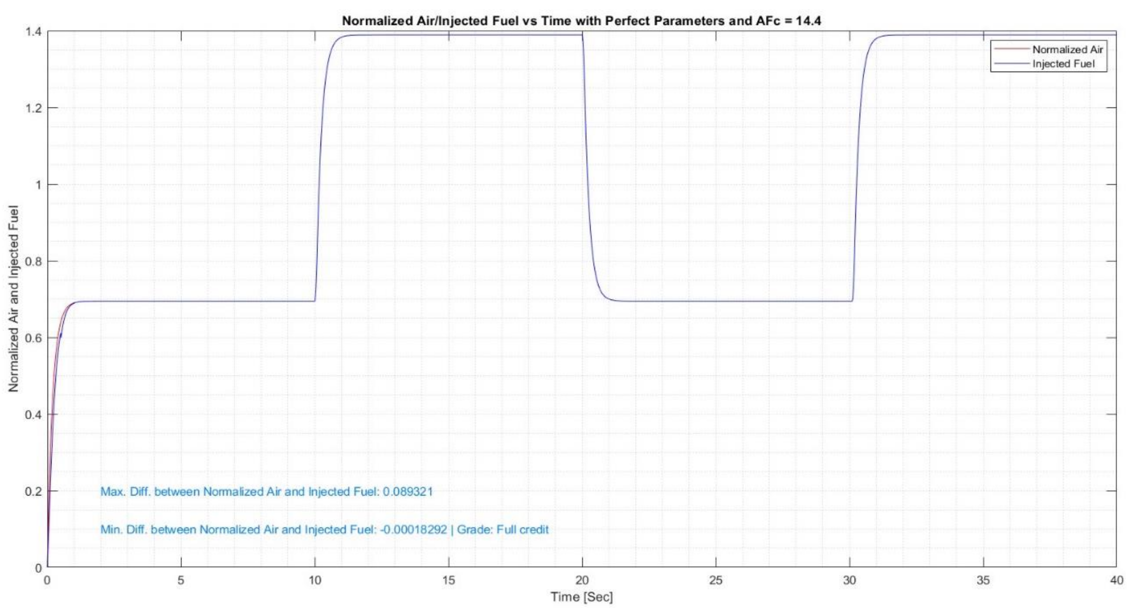

Fig 1. 6 Normalized air and Injected fuel vs time (A/F = 14.4)

[2] IMPERFECT PARAMETERS

[2.1] A/F= 14.64

1. Plot of lambda measured (with feedback) (PI/Smith controller are connected to transient fuel)

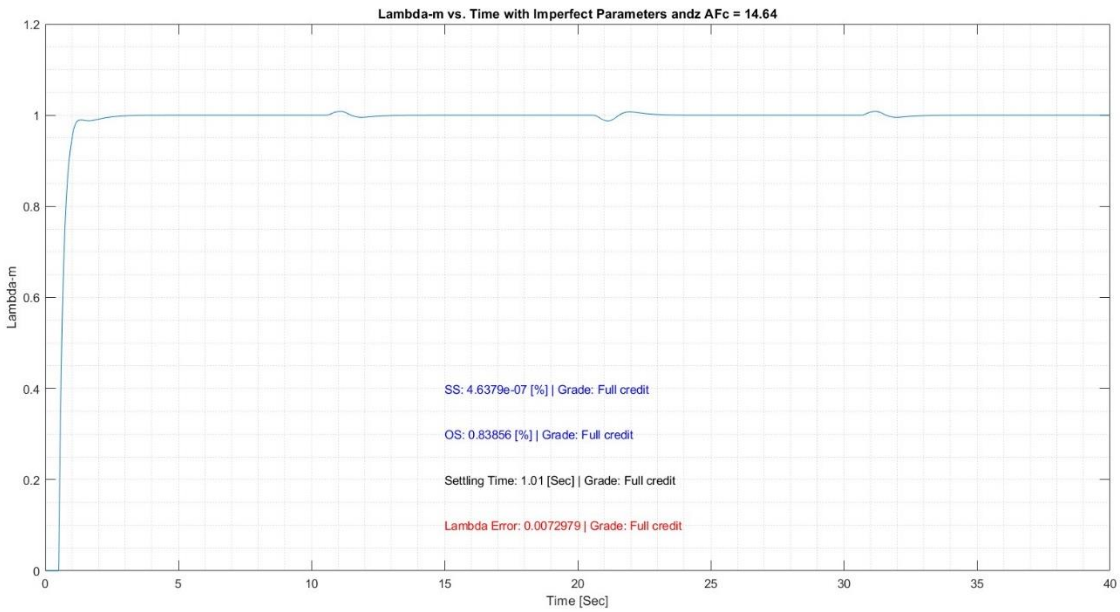

Fig 2. 1 Lambda measured vs time (A/F=14.64)

2. Plot of normalized air and injected fuel vs time (PI/Smith controller are connected to transient fuel)

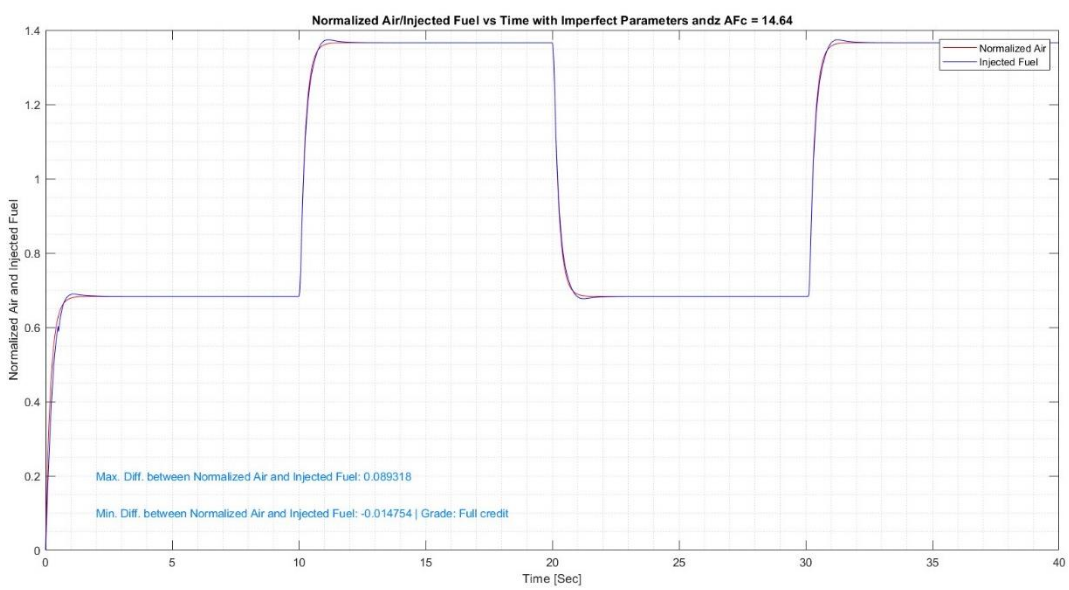

Fig 2. 2 Normalized air and Injected fuel vs time (A/F=14.64)

[2.2] A/F = 14.4

1. Plot of Lambda measured (PI/Smith controller are connected to transient fuel)

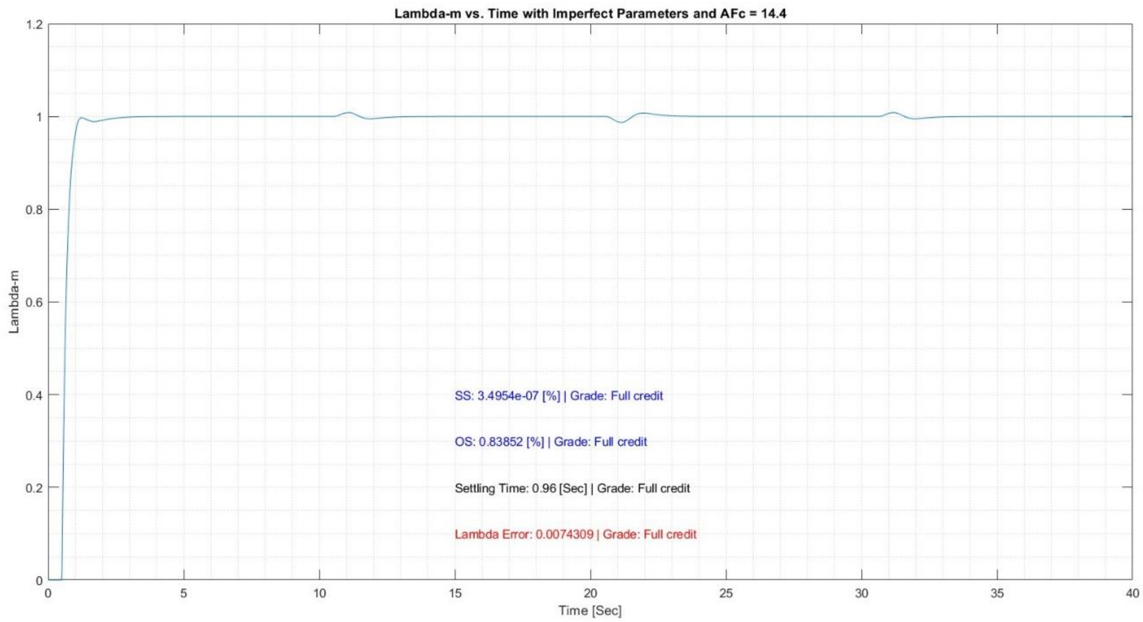

Fig 2. 3 lambda measured vs time (A/F=14.4)

2. Plot of Normalized air and Injected fuel vs time (PI/Smith controller are connected to transient fuel)

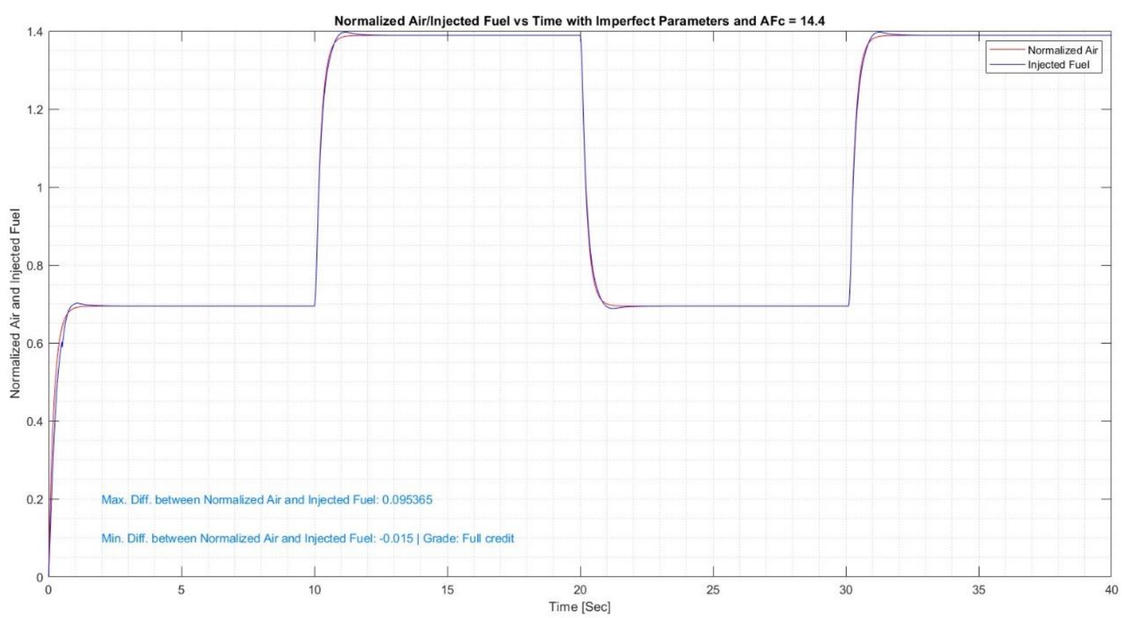

Fig 2. 4 Normalized air and Injected fuel vs time (A/F = 14.4)

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[3] DISCUSSIONS

- Adding transient fuel gets rid of the puddles and transients occurring in the lambda measured because of real-world fuel dynamics.
- However, to keep the lambda measured value equal to one, we need to add a PI controller and a smith predictor to compensate for the time delay introduced in the EGO sensor.
- The PI controller has proportional gain, kp=1.8, and integral gain,ki=5.55.
- For A/F =14.64 the transient fuel works perfectly, and the lambda measured reaches 1. However, when the A/F is changed to 14.4, the transient fuel alone is unable to get the lambda measured back to 1. (See fig 1.4)
- When A/F = 14.4 (with perfect parameters) lambda measured exceeds 1. This is because the transient fuel is a feedforward system and is unable to adjust the input value to keep the lambda-measured value equal to 1.
- After adding the PI controller/smith predictor in the fuel controller and connecting it to transient fuel, lambda measured for A/F=14.4 steadies at 1. (See fig 1.5)
- In the case of imperfect parameters, transients remain in the curve even after adding PI/smith predictor and transient fuel. This is because the control parameters are different from the parameters used for air-fuel dynamics. This is also because the fuel controller only reduces the transients occurring due to real-world dynamics and cannot eliminate them completely.
- In the case of perfect parameters, the controller parameters are the same as the parameters used for air-fuel dynamics. Thus, the controller works perfectly, and we see no transients in the lambda measured vs time curve.

[4] SHORT ANSWERS

1. The transient occurs for imperfect parameters because in this case, the controller parameters are different from the parameters used for air-fuel dynamics. This is also because the fuel controller only reduces the transients occurring due to real-world dynamics and cannot eliminate them completely. In the case of perfect parameters, the controller parameters are the same as the parameters used for air-fuel dynamics. Thus, the controller works perfectly, and we see no transients in the lambda measured vs time curve.
2. The difference in the shape of the fuel injected curve and normalized air curve is due to the presence of disturbances occurring because of real-world dynamics. The difference is also because the controller tries to keep the A/F ratio equal to stoichiometric ratio and causes initial transient which in turn results in disturbance in fuel injected curve.
3. When A/F = 14.4 (with perfect parameters) lambda measured exceeds 1. This is because the transient fuel is a feedforward system and is unable to adjust the input value to keep the lambda-measured value equal to 1. To keep the A/F ratio equal to the stoichiometric ratio we implement the PI/smith controller in addition to the transient fuel.
4. The steady-state error for the designed controller is approximately 1.1102×10^{-13} % (for perfect parameters) and 3.8×10^{-7} % (for imperfect parameters) which implies that the controller keeps the equivalence ratio within the above-mentioned percentage error range.

5. The project was very insightful, and I got a chance to implement the smith predictor in real world applications. I also enjoyed tuning of the PI controller to satisfy all the conditions. The tuning process taught me how the systems react to changes in each of the PI gains.