Diesel Strategy Overview

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Revision History see version control tool

Abstract

This document describes the functionality contained in the diesel common rail engine control strategies, discusses where the strategies have been used, and answers common questions customers have about them.

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1. Introduction and Scope

This document serves as a software strategy product description, at a level of detail more specific than that shown in marketing fliers. However, this is not an engineering requirements document. Such detailed requirements, design, and Pi process documents for engine control are Pi intellectual property, which can be made available to customers according to specific business agreements.

2. Software Environment

All OpenECU engine control strategies are developed in Matlab Simulink. C language versions of the strategies are not available. The strategies are designed for use on OpenECU but can also be applied to other 3rd party ECUs. Use on 3rd party ECUs may require some software manipulation to meet the target ECUs operating system needs.

These strategies use floating point arithmetic and native Simulink blocks in the core of the application.

The strategies are intended to provide a solid foundation for any common rail diesel control system. They are readily extendable and configurable by either the customer or OpenECU to provide additional functionality required for any specific engine application.

3. Diesel Engine Components

The following is a generalized schematic diagram of the fuel flow within a diesel common rail injection system:

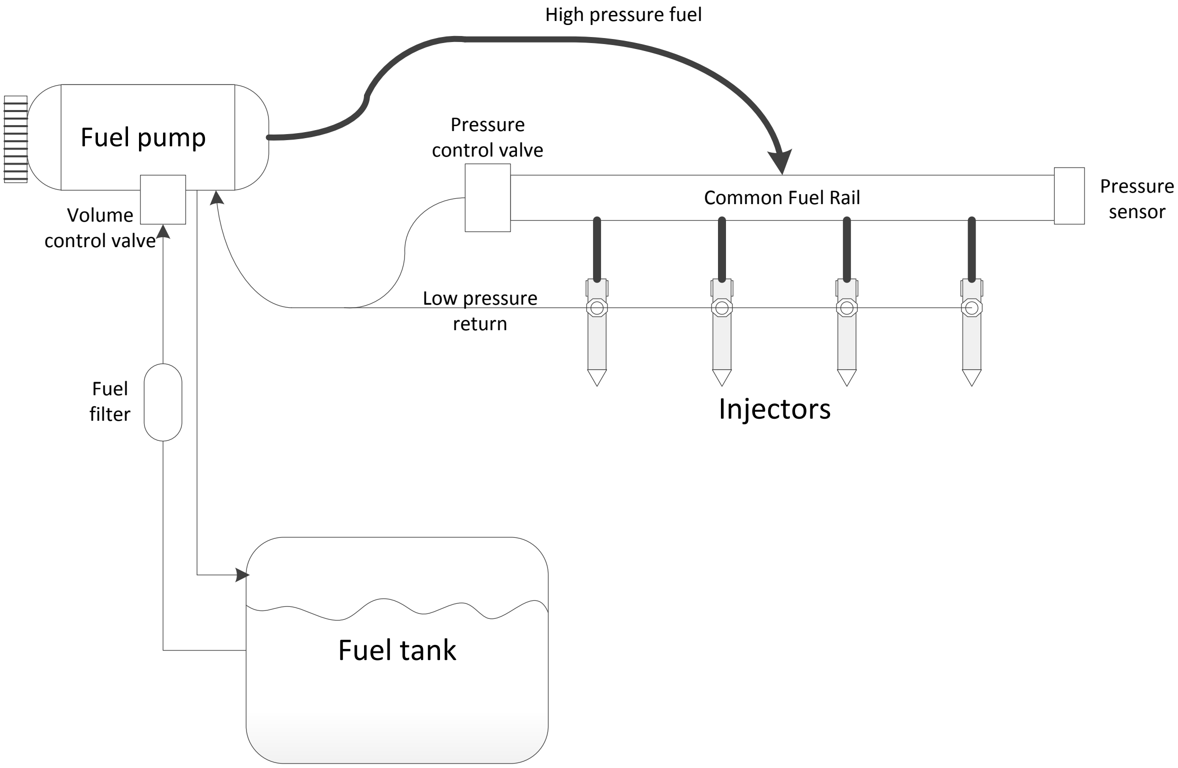

Figure 1: Common Rail Fuel System Components

The OpenECU diesel control strategies are capable of controlling the basic fuel injection components shown above together with the additional sensors and actuators typically found in the air path.

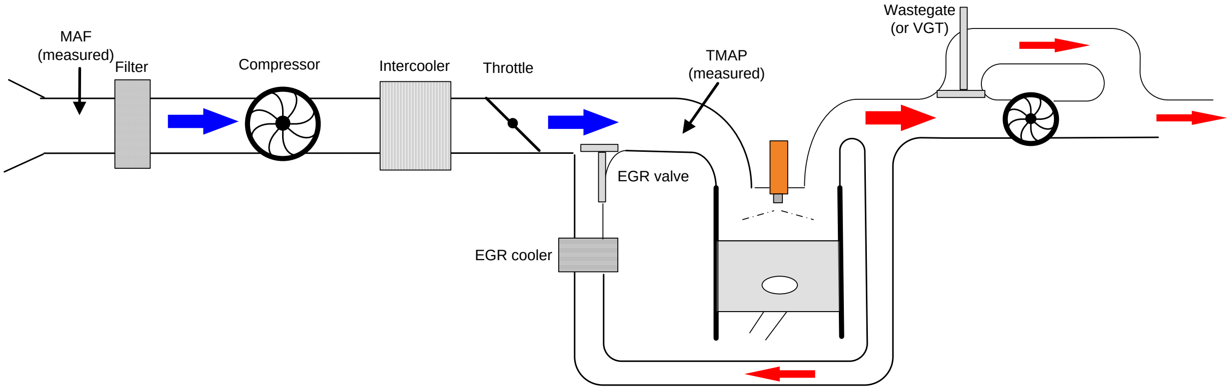

Figure 2: Typical Air Path & Components

4. Control Architecture

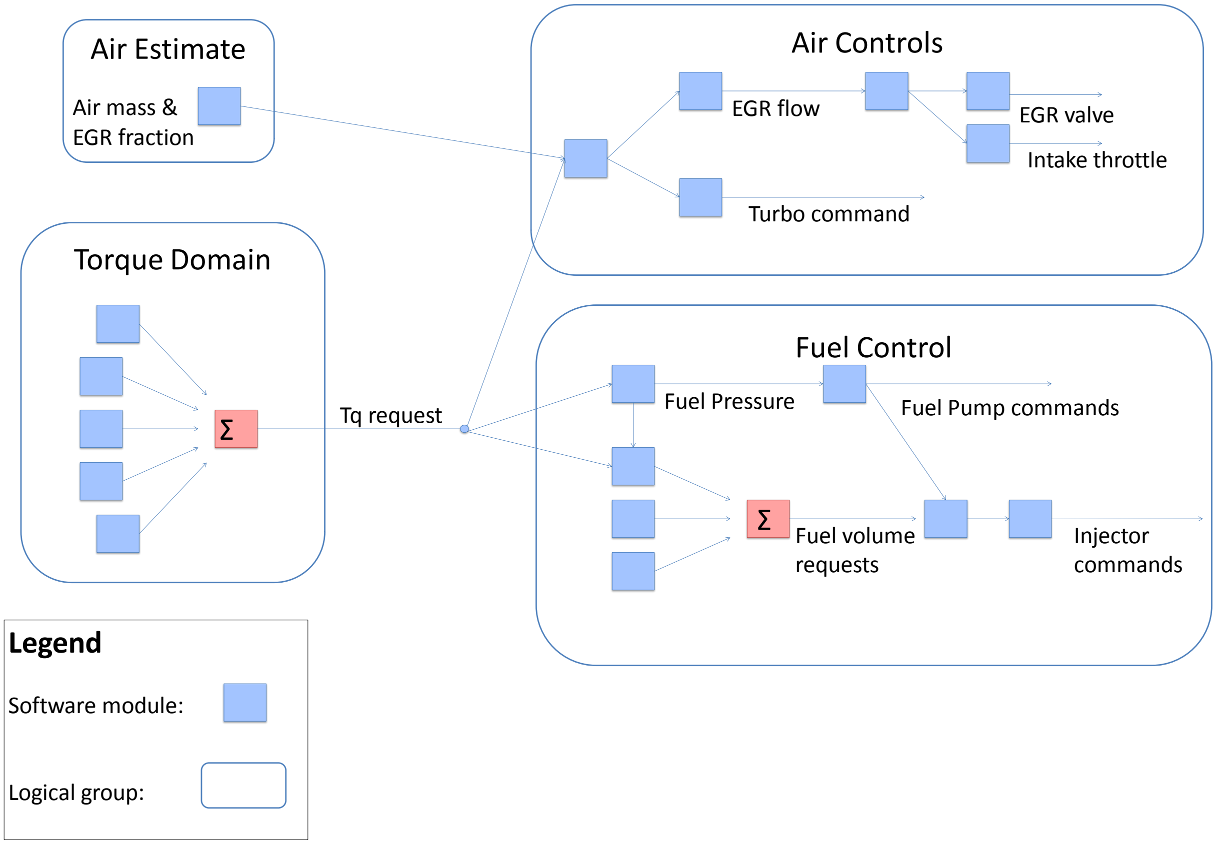

Figure 3: Control Architecture

The OpenECU strategies utilize a torque based control architecture as depicted in the figure above. This approach neatly distributes the different control responsibilities into groups of logic, and allows the user to focus on specific areas of development, according to their goals (basic engine running, startup, transient response, emissions, etc.)

5. Functional Behavior

The "software modules" shown in Figure 3 are described in further detail below, according to their logical grouping.

5.1 Torque Domain

5.1.1 Driver Request

The accelerator pedal position is validated and processed to indicate the overall driver requested torque. There are five gear maps provided, which allow the user to restrict torque in lower gear ratios to protect the transmission. They also allow the fine control of rate of change of torque for low speed maneuvering driveability.

5.1.2 Idle Speed Control

The idle control feature starts by determining at what state of idle the engine is operating.

- Closed loop idle
- Engine cranking
- Return to idle
- Driveability

The idle control logic works by adjusting torque demand to regulate the desired idle speed.

The desired idle speed for closed loop idle is determined by engine temperature, time since engine start and alternator load.

A feed-forward and feedback control scheme using a P+I controller is used to regulate the idle speed of the engine by modulating the torque demand (and subsequently fuel demand).

5.1.3 Engine Speed Limiter

The Engine Speed Limiter provides rev-limit functionality by reducing torque to provide a smooth limit rather than the sharp limit achieved by cutting cylinders.CAN Torque Requests

Requests from other vehicle systems (ACC, ESC, TCM) are also incorporated by the torque domain. These requests (typically originating from CAN messages) can be configured such that they are only able to reduce torque (ESC), or can have authority to increase torque (ACC).

5.1.4 Engine Loads Model

An Engine Loads Model is used to estimate the amount of torque the parasitic loads on the engine are consuming (aside from the transmission.) This includes an engine friction model, and accounts for engine temperature and loads from the auxiliary devices, such as the fuel pump, alternator, coolant pump, steering pump, air conditioning compressor, and any other accessories.

Using the Engine Loads Model in the torque domain provides improved drivability, and more consistent behavior and performance across different driving cycles.

The output of the torque domain logic is a total requested indicated torque. Here, "indicated torque" represents the total (average) torque produced by the combustion chambers. Note that some of this torque is lost to friction, or taken up by accessory loads, so therefore the "brake torque" observed on the dyno (or transmission) will be less than the indicated torque.

5.1.5 Torque Governor

Once the target indicated torque has been determined, the torque governor will produce set points for the EGR dilution, the fuel rail pressure, the pilot and main injection quantities and the boost pressure target (if controllable). The torque governor will limit the fuel demands based on the fresh air available to ensure that the resulting AFR will not produce excess smoke.

The system can provide up to six injections per cylinder per cycle. We allocate the first two of our six injections to being "pilot", the next three to "main" torque producing ones and assume that one is a late injection sufficient for aftertreatment purposes.

5.2 Air Charge Estimate

The strategy uses a combination of MAP, MAF and temperature measurements to determine the air mixture drawn into the cylinders. Ideal gas law equations based on inlet manifold pressure & temperature and lookup tables for volumetric efficiency are used to estimate the amount of inlet manifold gas mix which is trapped within the cylinders. The MAF sensor indicates the amount of fresh air drawn into the engine under steady state conditions. This is combined with an EGR flow model and a filtered version of the manifold model to estimate the fraction of fresh air versus EGR gas in the manifold under transient conditions given the air mixing effects within the inlet manifold. The result is an estimate of the gas mass currently in the cylinder (mg fresh air & EGR dilution, per cylinder, per firing.)

The air charge estimate can also be used to identify certain faults within the system. For example when an EGR valve is stuck partially open, then the air charge model will point to discrepancies in the measurements.

5.3 Air Controls

5.3.1 EGR Demand

The EGR flow demand is provided by the main torque governor. The EGR models use the EGR dliution estimate as a feedback parameter in to a PID controller on EGR flow. The output of the EGR flow control drives both the EGR valve position and the intake throttle position. Alternatively the EGR valve and the intake throttle valve may both have position sensors and individual position control loops or may be driven directly without position sensors.

5.3.2 Boost Pressure Control

The main torque governor may also provide a turbo boost pressure demand. In some cases, where there is a fixed geometry turbo-charger and a mechanical wastegate, then no control options are available. In other cases, there may be an electronically controlled wastegate or a variable geometry turbo-charger.

The Simulink control structure allows sufficient flexibility for each type of boost pressure control to be configured or derived from the base model.

5.4 Fuel Controls

5.4.1 Fuel Rail Pressure Control

This feature drives the valves that control low pressure fuel into the fuel pump and/or the pressure control valve on the fuel rail. Note that the number and position of the valves depends on the pump type. The main pressure control is a PID loop with feedforward terms which estimate the quantity of fuel in the rail by balancing the amount pumped in to the rail with the leakage and fuel injected from the rail.

There is also an adaptive current term for the main pressure control valve to learn the current required by the valve. This helps the system deal with the tolerances between one vehicle and the next without losing the speed of control.

5.4.2 Injection Quantities to Durations

The system first estimates the likely durations of each of the injections given the current fuel rail pressure. The proximities between injections are checked to ensure there is always a sufficient time delay between injections for the electronic boost drive circuit to re-charge and also for the fuel to stop flowing from the earlier injection. If there are insufficient delays, there can be unpredictable fuel quantities delivered to the engine.

If necessary, the algorithm can move injections, modify the start angles or even combine injections if there is a danger that the end of the main fuel injections is so late ATDC that it is likely to produce excess smoke.

The final injection quantity is passed to the OpenECU^{TM} platform code where additional fine trim is made with the very latest information about fuel rail pressure.

5.4.3 Cylinder Balancing

Cylinder balancing is a means to smooth out the engine particularly at idle speeds. The effectiveness of each cylinder is compared by measuring the engine acceleration immediately after each cylinder fires. The resulting change in speed is used to drive small adjustments between each cylinder's main injection to make fine adjustments to the torque being produced by that cylinder. The measurements are made close to idle and the resulting injection modifiers are used from idle up to medium engine speeds.

5.4.4 Deceleration Fuel Shut Off

This feature provides the ability to shut off fuel during overrun in order to improve fuel economy and driveability. The logic monitors the driver request throttle, engine speed, and engine runtime to enable DFSO.

5.4.5 Injector Compensation

The models include a placeholder to allow the user to add adjustments for each injector's fuel delivery characteristics. These are usually described by a numerical or QR code inscribed onto each injector at the end of manufacturing. The placeholder allows for adjustments in either the form of a time adjustment or a fuel quantity adjustment.

5.5 Miscellaneous Controls

5.5.1 Engine Running Mode

Stateflow based logic to process an enumeration to determine if the engine is:

- Stopped
- Cranking
- Running

This feature also provides an output of the time since engine start which is used elsewhere in the software to control start and post-start behavior.

5.5.2 Glow Plug Controls

Logic to drive the glow plugs before, during and after cranking is provided. This allows the glow plugs to be turned on for variable amounts of time depending on temperatures.

5.5.3 Cooling Fan Control

This logic monitors the engine coolant temperature and operates the low speed and high speed cooling fans. This logic also monitors battery voltage to ensure sufficient voltage is present to operate the fans. Additionally the cooling fan control conducts diagnostic tests of the fans to ensure they are operating normally.

5.5.4 Manual Calibration Override

All features have the ability to take manual calibration override to help the process of engine calibration and tuning.

5.5.5 CAN Communications

Some basic CAN messaging is built into the strategies currently. The strategies will output engine speed, vehicle speed, MIL state, odometer, fuel quantity, and ambient temperature. Additional CAN outputs can be easily configured using OpenECU CAN transmit blocks, as needed.

No CAN inputs are currently used in the strategies.

5.5.6 Diagnostics

5.5.6.1 Out of Range

All analog inputs are checked for out of range (OOR) low, high, and open circuit.

5.5.6.2 Rationality

All analog inputs are checked for slew rate.

Certain sensors have additional rationality checks:

- MAP vs. MAF vs EGR rationality (see air charge section)
- Accelerator pedal1 vs. Accelerator pedal2

5.5.6.3 Misfire detection

The speed measurements made for cylinder balancing (after each cylinder fires) are also used to perform misfire detection. This function has only been developed for the idle region, however full speed-load maps have been provided.

6. Frequently Asked Questions

6.1 Why is Common Rail diesel so complex?

A modern common rail diesel engine uses an engine driven fuel pump to create extremely high pressure fuel which is then precisely controlled through multiple injections into each cylinder. Each injection lasts for only a fraction of a milli-second, yet can deliver sufficient fuel to produce the high torques associated with diesel engines while maintaining good control of the engine out NOx and particulate emissions.

The common rail fuel pressure needs careful control by accurately modulating the pressure control valve(s). The ideal fuel pressure varies throughout the range of engine operating conditions and needs to be managed to reduce combustion noise while at the same time maximizing fuel spray atomisation. The pressure within the fuel rail can also vary along its length due to standing pressure waves created inside the rail. These are due to the large pressure pulsations in the fuel rail when an injector delivers fuel from the rail into a cylinder. The pressure in the fuel rail can vary by up o 10% over a full 720 degree engine cycle. The OpenECU^{TM} platform code includes a special function which reads the fuel rail pressure again immediately before every injection and then re-calculates the on-time for that injector given its characteristic fuel delivery map. This ensures that the very latest fuel pressure information is used for each of the six injections for each cylinder. This function does not appear within the Simulink model as it is required to operate extremely quickly within the eTPU co-processor.

6.2 Are the strategies production-ready?

Depends on what market or industry is being targeted. For modern production automotive applications the strategies are a great place to start but the diagnostic and OBD features required of modern automotive control systems would need to be added. The strategies are intended to jump start the development of production strategies and get a development team up and running quickly.

6.3 What emissions level can they achieve?

The diesel strategies were originally designed to meet Euro4 and Euro5 emissions. The basic strategies do not include any specific aftertreatment controls. The main change in moving from Euro4 to Euro5 is the aftertreatment and not the base injection strategies. The diesel strategies should be capable of meeting Euro6 emissions, given appropriate aftertreatment, but the level of diagnostics in the strategies is not sufficient for Euro6.

6.4 Do they have diagnostics?

The strategies have some basic diagnostics for sensor faults as well as some rationality checks. Misfire detection at idle has been provided, but further enhancements to the EGR flow checks and turbo boost checks would also be required in addition to aftertreatment diagnostics. There is no provision for monitoring the actual injection timing and duration (eg by using in-cylinder pressures), which is required to meet the latest legislation.

6.5 Do you support OBD?

OpenECU offers an OBD infrastructure handler separate from the diesel strategies. The OBD infrastructure handler can be integrated with the strategies to provide all of the service tool support and communications.

6.6 Can the strategies be used in other ECUs?

Yes. The strategies are built from Simulink and can thus be readily ported to other ECUs that support model based development.

6.7 What engines can they be used on?

The diesel strategies are currently configured for 4 cylinders, but could be reconfigured for use on engines matching the following configuration:

Number of cylinders:	1 to 8
Injector type:	Strategy independent, hardware dependant (solenoid only)
Crank wheel configuration	12 – 60 teeth with 1, 2, or 3 consecutive missing teeth
Cam wheel configuration	1 – 8 teeth
Number of cam wheels	1

6.8 How are the strategies sold or licensed?

The diesel strategies can be licensed with or without source code. Users can receive a pre-flashed ECU that can be calibrated and tuned via CCP tools, or they can receive source code enabling further updates and extensions to be added by the customer directly.

7. Terms and Abbreviations

ACC	Autonomous Cruise Control
AFR	Air Fuel Ratio
DFSO	Deceleration Fuel Shut Off
EGR	Exhaust Gas Recirculation
ESC	Electronic Stability Control
ETC	Electronic Throttle Control
IAC	Idle Air Control
IAT	Intake (manifold) Air Temperature
MAF	Manifold Air Flow
MAP	Manifold Absolute Pressure
OBD	On-board Diagnostics
OOC	Out of correlation
OOR	Out of range
RS	Recommended section
TCM	Transmission Control Module
TPS	Throttle Position Sensor