Using cloud to develop and deploy advanced fault management strategies

next generation vehicle telemetry

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Abstract

Vantage Power designs and manufactures technologies that can connect and electrify powertrains in heavy-duty vehicles. Their technology appeals to fleet operators as a retrofit solution on existing vehicles, or to manufacturers as an OEM solution. Vantage Power's electrification technology comes connected to the cloud and extends the cloud platform to the vehicle, enabling new insights and capabilities can be accessed via a user interface. The platform is called VPVision and had been in place and operational for over 12 months by the time of writing.

In most cases, to electrify heavy-duty vehicles some typical systems and components will endure, such as hydraulic, pneumatic and cooling systems. This whitepaper provides an example of how a problem experienced by a component in one of these systems can be diagnosed using data stored in the cloud, how big data analytics can be used to assess and characterise the risk presented to the whole fleet, and how machine learning and edge-computing can be used to deploy updates to the vehicle that advance the fault management strategy and enable automatic damage limitation.

Introduction:

As we transition toward an electric low-carbon economy, vehicle OEM's and sub-tier suppliers are having to introduce new compatible technologies which, in some cases, are quite different from their standard product offering. Typically, deployments of new technology occur following extensive lab and track testing and low-volume pre-production trials, but regulations and a desire to keep pace with the competition demand new technology is brought to market in a shorter timeframe.

Technical issues occur on heavy-duty powertrains and ancillary systems for different reasons and at any time, from initial deployment up to many years later. Given the tight timeframes and new technology areas, not all issues can be tested and identified pre-production, so when new issues do occur its possible a robust on-board fault management strategy may not be in place to handle it.

Organisations respond to the emergence of new faults in different ways, but many will retrieve and analyse the effected component, refer to historical data from similar parts, analyse failure mode and effect analysis, conduct fleet-wide inspections and, if necessary, set up campaigns that may see hardware or software modified. This can be a disruptive, time-consuming and costly.

Vantage Power designed, built and in 2017 deployed heavy-duty hybrid powertrains that included lithium-ion batteries, motors and generators, power electronics and ancillary systems. The ancillaries were powered by the Ancillary Drive System (ADS) which is a mechanically complex part of the powertrain, this assembly ensures systems such as air-con, cooling circuits, 24volt charge and hydraulic circuits remain powered when the engine is off. As a result, the vehicle can operate in electric-only mode where the generator is used as a motor to drive the ADS and provide uninterrupted power to the ancillary systems.

After nearly a year in service a failure trend emerged as a subset of vehicles started to experience ADS drive belt issues. This specific failure was not preceded by a dashboard warning light which could have been used to trigger an inspection or service intervention. To understand the root cause, engineering investigations were conducted to look for wear and tear, assembly errors and component failures – but it was difficult to identify a cause. Analysis of data collected from the vehicle demonstrated the issue could be recognized approximately 10 minutes before a failure occurred by looking for anomalies from a speed sensor, but this short warning period was insufficient.

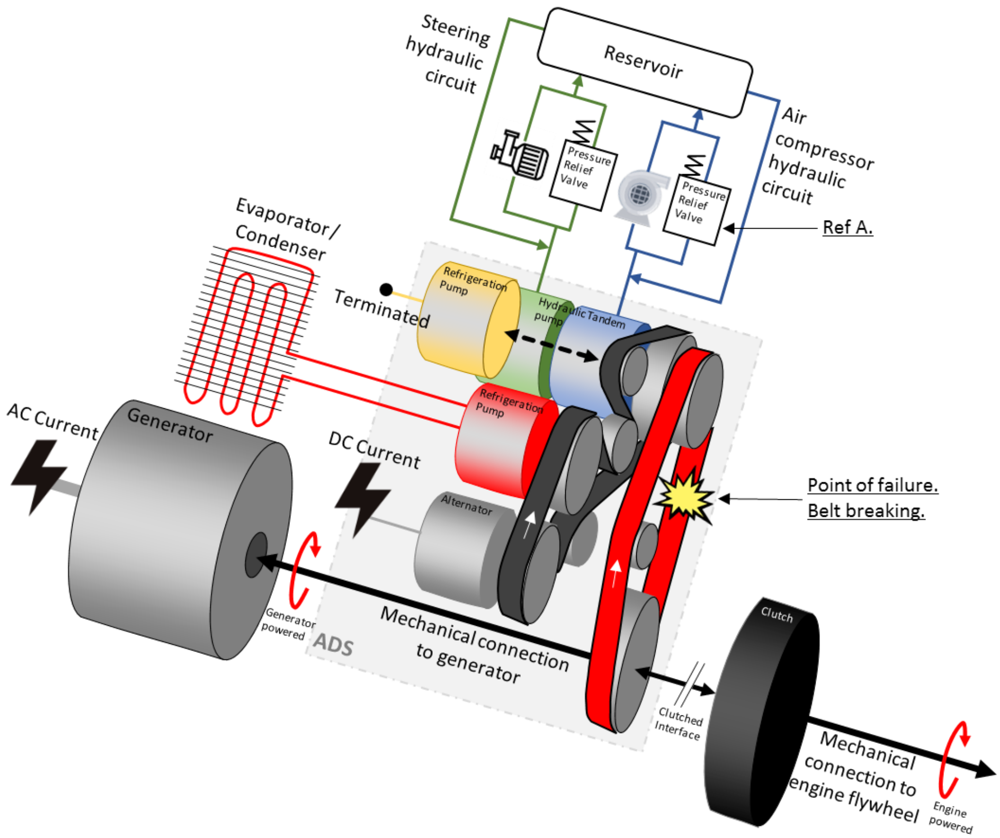

Figure 1: Illustration of the ADS – a 2 belt mechanical assembly driven by the engine or generator and powering multiple ancillary systems.

This problem required:

- An understanding of the root cause
- The risk presented to all vehicles in the fleet to be characterised / attending vehicles at risk
- A fault code(s) to be introduced
- Fault prognostics that provide advanced warning to be introduced
- Automatic steps to manage and control the risk of failure – If possible

Using VPVisions cloud architecture, this whitepaper demonstrates that analytical techniques can be applied to operational data from in-service vehicles and used to diagnose the root cause of mechanical failures, even from sensorless components. In addition, the risk presented by this failure mode can be characterized across all vehicles in a fleet, faster and cheaper than current methods allow.

The paper will go on to demonstrate the cloud provides the perfect environment to innovate new fault management strategies, which may include much more advanced fault codes and fault prognostics, and how historical and live streaming data can be used to validate new solutions across the fleet before being deployed to operate on-vehicle, which helps ensure accuracy and quality of the solution.

Finally, this paper shows how a solution can be quickly deployed to operate on-vehicle, which offers cost and performance benefits, and how new fault management techniques can interact locally with the vehicle control software, enabling modifications to the behavior of the powertrain which can automatically reduce the risk of failure.

Solution:

Operational data from the vehicle fleet was already being collected and stored in VPVision. The initial approach was to analyse historical vehicle data and overlay it with known fault events, from this a machine learning model would be trained in the cloud to identify patterns that preceded faults - by making refinements to this analysis the aim was to extend the warning period beyond ~10 minutes.

Training a model was possible because real-world vehicle data, which included the desired channels at a suitable frequency, had been collected during failure events. With data available, the cloud provided the toolset and processing power to innovate, creating and testing out multiple solutions in parallel that could automatically identify the problem. As a result of using machine learning and data visulisation techniques, a new data channel was identified as showing a strong correlation to the fault events, this channel recorded the pressure of a hydraulic circuit powered by the ADS. This signal would fluctuate with increasing frequency many months before a failure occurred.

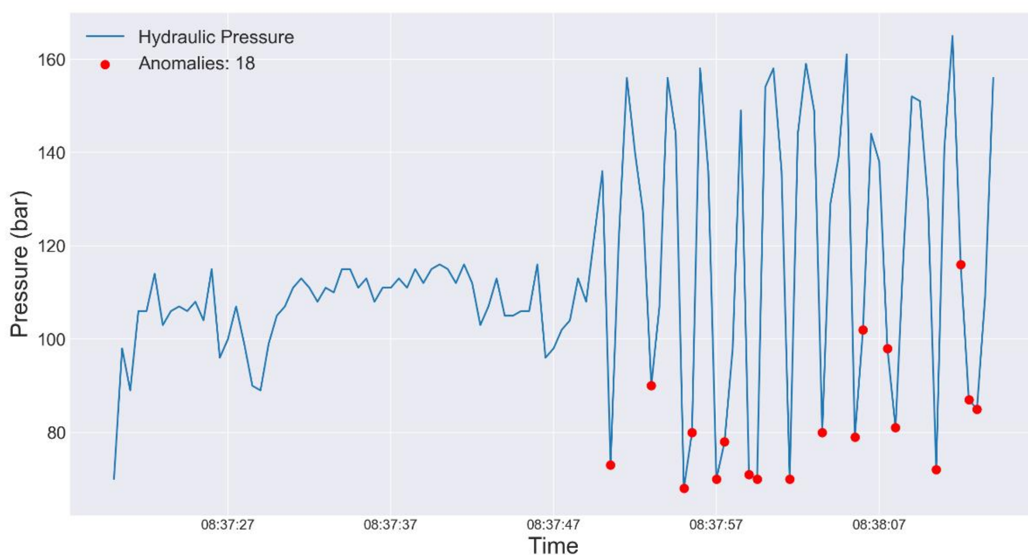

Figure 2: Hydraulic pressure trace with pressure release points flagged by the model marked in red

Root Cause: The new signal showed hydraulic pressure was dropping rapidly and recovering (see Figure 2). The sudden drop introduced a small shock wave that would transmit back to the ADS, jolting the system with higher loads and accelerating wear and tear of the belt. The duration and magnitude of the pressure drop matched the profile of pressure relief valve activation (Ref A in Figure 1), by returning to effected vehicles and testing the valve it was possible to demonstrate the activation point was drifting lower, resulting in undesired and frequent activations – this was the root cause of the belt failures.

Development: A new model was created and used to analyse historical data to count unexpected pressure relief valve activations, identifying which vehicles were operating with this issue and classifying the severity. As an example of big data analytics, 12 months of 1Hz data from a fleet of vehicles was analysed in seconds and the output pinpointed those operating at risk, allowing service interventions to be prioritised and scheduled as necessary.

Further refinement to the model meant it could be applied to live data as it was ingested into the cloud. This provided an ongoing assessment of risk across the fleet, live notifications and a severity rating. After the model was fine-tuned and validated in the cloud a decision was required on where to host it, either keeping it in the cloud or hosting on-vehicle. It was deployed on-vehicle, at the edge, for the following reasons:

- The model only required data generated by the vehicle
- A future development may see the model generate a fault lamp presented to the driver
- Connectivity issues would not hamper rapid analysis of emerging faults
- Notification to the cloud can happen only when an issue is detected, rather than uploading all data to perform the analysis in the cloud.
- Cloud compute and data transmission costs were avoided
- An interface with the vehicle controller software provides options to mitigate the problem locally.

Deployment of the model on-vehicle could be made remotely and at scale using a toolset provided by the cloud. Since the on-vehicle telemetry unit acts as an extension to the cloud platform, the model did not need to be modified or re-engineered – the validated model could be deployed directly. The toolset used to conduct the on-vehicle deployment maintains control, so if further development work to the model is required, updates across the fleet can be made easily.

Next Steps: By hosting the model on-vehicle, opportunities to further mitigate the fault become available. Since early signs of the fault can be detected, the model can be developed to output a message to the vehicle control software. The control software has authority over the operating pressures within the faulty hydraulic system, by marginally lowering the target pressure, within predefined safe limits, early signs of the fault can be temporarily fixed.

This means the vehicle can automatically self-heal for a period after early signs of the fault have been detected – also providing a notification to trigger a service intervention. This prevents any damage being inflicted on the vehicle between the detection point and the service intervention.

Conclusion

As OEM's and sub-tier suppliers move quickly to introduce new electrification technologies to market, they need the ability to closely monitor and continuously optimise in-service products. During the operational life, one area that will see ongoing development is the fault management strategy which can have a major impact on reliability and through life cost.

In the example given, the fault provided no more than 10 minutes warning by which time irreparable damage to the drivebelt was already done. The new solution presents a prognostic alarm more than 3 months in advance of a belt failure, that's enough time to resolve the issue in a cost-effective manner and at minimal disruption to the end customer.

The long-term solution to this problem is to replace the pressure relief valve with a design that does not drift – but making hardware changes to a large fleet of in-service vehicles is not always an option or one that can be deployed in the required timeframe or for the right price.

The approach adopted in this example can be applied to other components and failure modes. The ability to query vast quantities of data, historical and live, provides an ideal environment to rapidly diagnose issues. Using this unparalleled data access, a solution can be tested across a fleet, which includes many different operational scenarios and edge-cases, in place of lab or track testing, which is typically slower, more expensive and less representative.

Remote "virtual" validation of new fault strategies present zero risk to vehicle operation and provides a rapid feedback loop, this environment enables multiple ideas to be developed in parallel, stimulating innovation and making advanced and complex solutions more achievable. Some of the latest toolsets on cloud platforms enable fault management strategies and prognostic alarms to be deployed to operate on-vehicle following an established secure process. Operating on-vehicle can reduce costs, improve reliability and enable decisions to be taken automaticly and locally.

The deployed analysis can interact with the vehicle control software. This can be used to raise a fault light on the drivers dashboard, or in more advanced cases, modify calibratable parameters which could be used to transition the vehicle in to a damage-limitation mode of operation – minimising the damage inflicted by the fault, providing more time for a service to be scheduled and reducing disruption to vehicle operations.

The ability to respond to the belt failure mode in this way was possible for five reasons:

1.) The on-vehicle telemetry unit was sufficiently integrated to the vehicle.
2.) The correct vehicle data was being collected
3.) A toolset to analyse, test and deploy code is supported by the cloud and vehicle architecture
4.) Vantage Powers engineers know the meaning and context of the data received
5.) The vehicle control software enables calibratable parameters to be updated remotely

VPVision, which provides the architecture and toolset, is available as a standalone product that can be integrated with 3rd party components, systems and powertrains. Supplementary engineering services include integration and data analysis services, enabling customers to introduce new fault management strategies of their own – and innovate beyond the current limitations of legacy systems.