Digitalization in Variable Speed Motor Systems

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Abstract. Variable-speed drives have been utilized for many years to achieve energy savings. In recent years, the variable speed drive has also been seen as a valuable source of data, given its current and voltage sensing capabilities. These capabilities can be leveraged, within the aim of digitalization in motor drive systems, to improve both energy and operational efficiency of such systems.
In this paper, we will dive into the concept of using the drive as a sensor, as well as the role of Industrial Internet-of-Things (IIoT) in data collection, visualization and analysis. This allows for the monitoring of energy usage and eventual deviations due to wear-out and other operating conditions. In the final chapter, our paper will share the experiences of the last five years and highlight opportunities and challenges.
There is a myriad of opportunities within efficiency, maintenance and problem root cause analysis empowered by the data and these new systems.

Keywords: Variable Speed Motor Drives, Digitalization, Energy Efficiency.

1 The Intelligent Drive

1.1 Digitalization and Industry 4.0

Since the introduction of microprocessors to control the drives, additional functionality has been added to the original function – which is that of a power processor. For instance, drives are able to perform motion control, control several pumps in a cascade system in water pumping applications and by-pass certain frequencies to avoid resonances. The advance of digitalization and Industry 4.0 has given an additional boost to these auxiliary functions. As digitalization deals with information and networking, the drives – given their native processing capabilities - naturally become usable as smart and networked sensors.

1.2 The intelligent drive concept

The drive plays an important role in the automation network and is characterized by some enabling features [1] (Figure 1):

- Drive as a sensor – using motor current and voltage signature analysis for sensing the motor and application
- Sensor hub – collecting external sensor data of the process controlled by the drive

- Drive as a controller, replacing the PLC whenever the application constraints allow
- Secure connectivity to other elements in the network (PLCs, sensors) and cloud

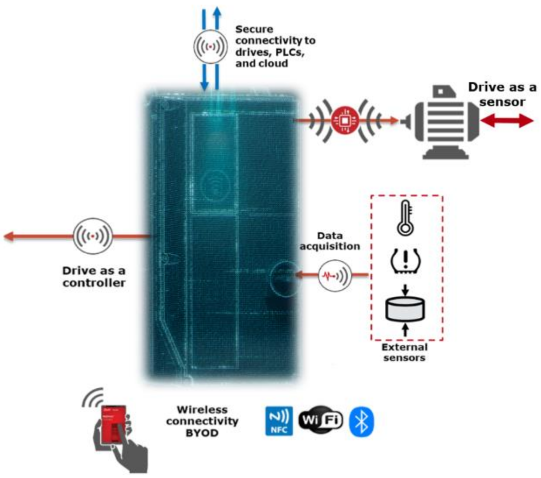

Fig. 1. The intelligent drive

1.3 The drive as a sensor

The availability of microprocessors and bus communication options in the drive combined with current and voltage sensors opens previously untapped opportunities [2]. Moreover, additional sensors (such as vibration and pressure sensors) can be connected to the drive at almost no cost. This allows the drive to be used as a smart sensor (Figure 1). The data collected from this multitude of sensors can be used to explore various use cases, such as drive as a controller (where the drive controls the process given its ability to read the system feedback from the connected sensors), system optimization, energy efficiency optimization, and condition-based maintenance [5,6].

1.4 Data categories

The information available from the drive can be structured on three levels: instantaneous signals, processed signals and analyzed information (Figure 2).

Instantaneous signals are raw signals measured by sensors (for example voltage and current), online estimated signals (like power and torque) or controller signals (speed reference). These signals are present in the drive with a high sampling rate, typically in the kHz range. It is rather unusual to read the instantaneous signals at their original sampling rates out of the drive because of bandwidth constraints. This data is used for troubleshooting and corrective service.

The processed data layer consists of signals which have been processed in some manner. There are many possibilities: simple RMS value calculation, statistical representation of the signals or even a full frequency analysis. The processing is done on the edge (that means, within the drive) and since the data is compressed and calculated at slower rates (typically in the Hz range), it can be continuously read out of the drive.

The analytics can be anything from very simple constant thresholds to advanced Machine Learning (ML) algorithms.

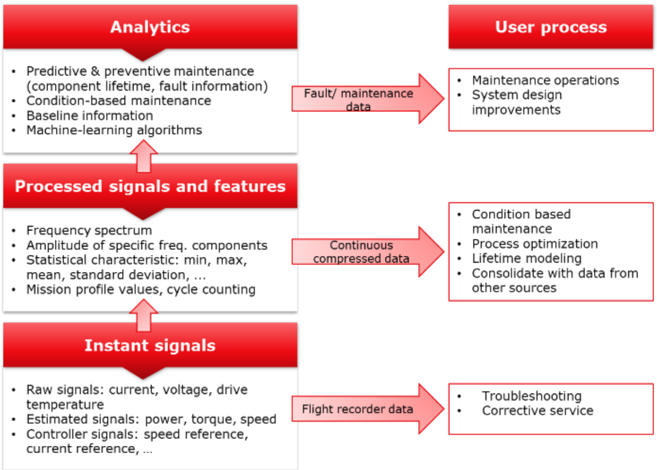

Fig. 2. Information layers in the drive as a smart sensor

1.5 Edge vs. cloud

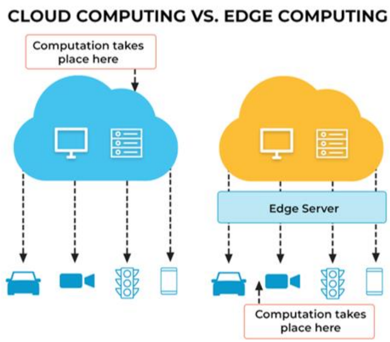

Fig. 3. Representation of cloud and edge architectures. Source: Toolbox™

When considering the digitalization of variable speed motor drives, the "edge" and "cloud" are often presented as a dichotomy (Figure 3). Indeed, the drive (the edge device) has processing and communication capabilities offering near real-time response times. It provides increased security and data privacy, without the need for external communication. On the other hand, the cloud offers large scaling of computing power and storage. The data in the cloud is easily accessible, is highly available and redundant and can be stored for historical analysis. Furthermore, the cloud provides capabilities that are otherwise very limited on the edge, such as simple back-up and recovery, fleet (group of drives) analysis and comparison and aggregation among different attributes.

However, it turns out this is not an either/or discussion. The best results are obtained combining the edge device capabilities with the opportunities offered by the cloud. We can combine the drives' capabilities for sensing, processing and (limited) analytics with the cloud's data visualization, ad-hoc analysis and advanced Artificial Intelligence (AI) / Machine Learning (ML). This architecture saves bandwidth and reduces complexity. The analysis ran on the cloud can be then, in certain cases, transferred back to the device for automated and real-time insights and actions.

2 Use cases

2.1 Digitalize own production – a good starting point

A good starting point for the digitalization journey is your own production facilities. Having control over the facility enables to learn and grow confidence on a data and analysis collection systems. In this paper we share our learnings in our own production, which have been fundamental to developing and maturing our digital products for increased customer value.
In this case, digitalization meant implementing various measures and technologies both on the edge and in the cloud. On the edge, we have updated the software in the variable speed drive to include functions related to condition monitoring. A number of sensors were also installed and connected to the drives (mostly vibration and pressure sensors). For the cloud connectivity we have connected all drives to our own IIoT platform.
The benefits started showing up immediately after these measures were implemented. The simple visualization of the drives' operating parameters (raw data) immediately revealed underlying issues which were not observed before. In nearly 50% of the motor systems, various issues have been uncovered during the commissioning of the digitalization solution. Some examples of these issues we have encountered were: wrong configuration of the drives which lead to sub-optimal operation, resonances which prevent running at full load, applications with variable speed drives running at fixed speed, incorrect operation of rotary heat exchanger in an air handling unit, incorrect control of the application with too frequent start/stops cycles. It could be argued that these issues are small and have relatively low impact, but on the other hand, the cumulative (and long-term) effect of these issues is not to be understated. Furthermore, if we could identify and solve simple issues by just connecting and reading raw data, then the potential of more advanced functions is truly immense.
After the commissioning and connection of the drives to the IIoT, we focused on two main use cases: energy efficiency and operational efficiency.

2.2 Energy Efficiency

IIoT makes it possible to monitor the energy use at the individual motor level, by reading the connected variable speed drive's data. This is a radical change in the granularity of energy data, allowing improvement potential at both motor and installation levels.
Another very important aspect is to visualize the energy savings by operating at variable speed vs. fixed speed (direct on-line). This visualization is simple and very important for determining the return of investment in the case of a retrofit from fixed to variable speed.
Moreover, visualizing and documenting energy usage before and after an upgrade aimed to reduce energy consumption becomes very easy. We have used the energy visualization to monitor and determine the real savings from upgrading several ventilation systems by replacing old centrifugal fans with new high-efficiency axial fans and also replacing the old induction motors with new IE5 class permanent magnet motors.

Another very important aspect is CO_2 emissions [3], [4]. We have realized a CO_2 dashboard that uses the energy consumption of the drives and multiplies it with the actual CO_2 intensity which is based on live data from the Danish grid operator Energinet.
The result is a visualization of the actual CO_2 emissions. A future step being in the research phase is a control algorithm that aims at reducing the CO_2 emissions. Besides visualizing the CO_2 emissions, also the emissions abated by using variable speed operation are quantified.

2.3 Operational efficiency

In production environments, maintenance is a must and there is, consequently a choice of maintenance strategy to keep the production equipment running at its best performance. The most common maintenance strategies in increasing order of complexity and operational efficiency are: corrective maintenance (triggered by a failure), preventive maintenance (triggered by a pre-defined static schedule) and condition-based maintenance (triggered by actual conditions of equipment, estimated in real-time). Figure 4 shows a typical degradation pattern, also known as PF-curve: this is something that we cannot control. However, we can control the maintenance strategy to address this degradation.

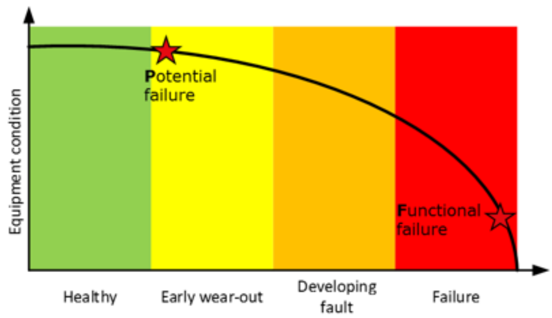

Fig. 4. P-F curve representing the condition of a component over time until functional failure

There is a link between degradation and energy efficiency. Poor maintenance leads to excessive wear-out and degradation which can in turn lead to increased energy use. For example, poor lubrication (in mechanical systems) and clogged air filters (in air handling units) can lead to increase energy use. An incorrect maintenance strategy can be too conservative (leading to an unnecessarily high degree of redundancy) or too lackadaisical (leading to equipment failure and unexpected downtime). Therefore, it becomes important to choose the right maintenance strategy. The preventive maintenance concept can often be sub-optimal given that it only considers assumptions of the usage of the equipment and not its actual usage. As opposed to this, the idea of condition monitoring is to detect the potential failure based on the actual use of the equipment. For this purpose, key "conditions" indicating the health condition of the equipment are used (calculated based on data collected from the drive and connected sensors).

On one hand, condition monitoring is a more complex maintenance strategy, but on the other it delivers a highly beneficial maintenance strategy delivering benefits such as: reduction of downtime, elimination of unexpected production stops, maintenance optimization, reduction of spare part stock, and others.
In the case of variable speed motor systems, condition monitoring covers electrical motor faults (winding faults), mechanical faults in the motor and load (vibration), load/torque and other relevant operating parameters.

2.4 Lessons learned: Challenges and Opportunities

There were many challenges and lessons taken from our digitalization journey. Here we name the most important ones:

1. It is very important to clearly specify the data requirements for the intended end-use functionality. Parameters such as data variables, sampling rates, resolutions, aggregation, etc have to be considered and specified (as close to the needs as possible) to get an understanding of the IIoT system requirements. Vague or non-existing data requirements may result in building a platform that captures insufficient or low-quality data that cannot be used for further processing and analysis, and eventually a failure in implementing such systems.
2. Involve the concerned stakeholders from the first day and have them contribute to the process of designing and using the platform. This increases the probability of success of implementing such data collection and analysis systems. In our case, involvement of R&D, IT, factory operation management and Product Management was essential. The human factor is perhaps more important than the technical factor and hence it is important to demonstrate value and gain commitment across different departments in the organization. A lack of engagement might alienate the people who may find the platform valuable.
3. In an existing installation there is often complexity which needs to be dealt with. As various systems were implemented in time, we had to deal with different field-bus communication systems and a mix of new and legacy devices. Therefore, it is essential to build a flexible and robust architecture.
4. Data collection and analysis systems can be costly and have a high RoI. It is therefore important to work in a multi-discipline team in small iterations to be able to generate value at each iteration early in the development process.

We have identified and realized many opportunities: analytics and ML/AI for energy and process optimization of drive-systems. More opportunities lie within metric optimization (ex: comfort of passengers powered by drive-systems), assisted servicing, etc. These identify opportunities are enabled by the data already available in the drives.

Acknowledgements

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