



Vaasan yliopisto  
UNIVERSITY OF VAASA

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# Utilizing the Value of Smart Sensor Data in Motor Manufacturing

Tekniikan ja innovaatiojohtamisen akateeminen yksikkö  
Diplomityö  
Tieto- ja automaatiotekniikan koulutusohjelma

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<b>Tekijä:</b>	Vili Auranen		
<b>Tutkielman nimi:</b>	Älykkäiden antureiden tuottaman datan hyödyntäminen moottorivalmistuksessa		
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<b>Työn ohjaaja:</b>	Jouni Lampinen		
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**TIIVISTELMÄ:**

Diplomityön aiheena on kohdeyrityksen älykkään anturin tuottama lisäarvo yhtiön Vaasan moottoritehtaan moottorivalmistuksessa. Kohdeyritys on valmistanut älykkäitä antureita asiakkaille myytäväksi jo useita vuosia ja on nyt käyttöönottamassa tuotteen omassa prosessissaan. Työssä tutkitaan älykkään anturin tuottaman datankäytön mahdollisuuksia kohdeyrityksen Vaasan yksikössä, määritellyn pilotin avulla. Pilottiin valittiin moottorit käyttötarkoituksen mukaan. Tavoitteena on tunnistaa kehittämiskohteita älykkäälle sensorille kappaletavaratuotannossa sekä luoda suunnitelma sensoridatan käytölle ja sen kehittämiseen. Datan tehokkaan käytön tavoitteina on pienentää suunnittelemattomia käyttökatkoksia, parantaa työturvallisuutta ja minimoida moottorien viivästyneiden toimitusten aiheuttamat lisääntyneet rahti ja muut ylimääräiset kustannukset. Lisäksi datankäytön tuomalla lisäarvolla pyritään kehittämään huolto- ja varaosatoimintaa, sekä määrittelemään käytössä olevien moottorien soveltuvuus nykyiseen käyttötarkoitukseensa. Konkreettisenä tavoitteena on luoda toimeksiantoyritykselle raportointityökaluja.

Työ alussa on kirjallisuuskatsaus anturien, älykkäiden anturien ja sähkömoottoreiden perusteisiin. Erityisesti tarkasteltiin kohdeyrityksen älykkäitä antureita ja sen kilpailijoita. Näitä vertailtiin toisiinsa saatavilla olevan tiedon avulla. Älykkään anturin pilottiasennuksen perusteella tehtiin johtopäätöksiä antureiden soveltuvuudesta kappaletavaratuotantoon esimerkkiyrityksen kautta. Pilotin perusteella pyrittiin analysoimaan tuotteen käyttöönoton kannattavuutta kohdeyritykselle. Lopuksi luotiin tiekartta antureista saatavan datan analysoinnille, tallettamiselle ja esittämiseksi.

Työn tuloksena syntyi Power BI raportointipohjia ja fleet report sekä kehitysehdotuksia jatkotoimenpiteille. Lisäksi työssä havaittiin, että ABB:n Ability Smart Sensor TM on tuotteena kilpailijoita hieman edellä tuotteen ominaisuuksien ja käytettävyyden osalta. Työssä havaittiin, että pelkkä datan mittaaminen sensoreilla ei itsessään tuo lisäarvoa yritykselle, vaan data pitää muuttaa ymmärrettäväksi informaatioksi ja vasta sen jälkeen se tuo lisäarvoa kohdeyritykselle. Edellisten lisäksi pilotissa havaittiin, että anturien tuottaman datan perusteella voidaan tehdä toimenpiteitä, jotta tuotannon suunnittelemattomia katkoksia pystyttäisiin vähentämään käyttämällä Smart Sensorin tuottamia tietoja ennakoivien huoltojen ja korjausten ajastamisessa. Ilmi tuli myös, että Smart Sensoreiden tuottamaa dataa voi käyttää myös kappaletavateollisuudessa käytössä olevissa moottoreissa, jotka eivät ole jatkuvassa käytössä. Näin on siis prosessiteollisuudessa jatkuvassa käytössä olevien moottorien lisäksi, jossa sensorien tuottaman datan hyöty on vahvistettu jo aikaisemmin.

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**AVAINSANAT:** Älykäs anturi, Sähkömoottori, Ehkäisevä huolto

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**University of Vaasa**

Tekniikan ja innovaatiojohtamisen akateeminen yksikkö

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**ABSTRACT:**

The topic of this master's thesis was the utilizing of the value of smart sensor data in motor manufacturing at an electric motor factory in Vaasa. The target company has developed and manufactured smart sensors to customers for years and is now implementing them in its own production. In the thesis's the possibilities of utilization of the data of smart sensor utilization in the Vaasa factory has been studied through a specified case study. The motors included in the pilot were selected by their usage in the process. The target was to identify improvement potentials for smart sensors in discrete industries and to create a plan for sensor data usage and further development. With the increased value of the efficient data usage, the target is to reduce unplanned stoppages, improve safety, and minimize the penalties and other costs paid because of delayed motors. An additional target was to improve the service and spare part activities with better utilization of data from the sensors as well as define the suitability of current motors in use to their current intended use. The concrete target of this thesis was to create reporting tools to the target company.

First, a literature study was carried out for the basics in sensors, smart sensors, and electric motors. Special focus was on the target company's smart motor sensors and their competitors on the market. With the information available the products were compared to each other. Conclusion were made on the basis of the pilot installation on the target factory's premises on the value of the smart sensors on discrete production. Through the case study the additional value created to the target company of the smart sensor data was analyzed. A roadmap was created for the smart sensor data for further analyses, storing data and user experience.

The outcome of this thesis was several Power BI templates, a fleet report and several recommendations for further development. Through a comparison it was noted that the ABB Ability Smart Sensor TM as a product is slightly more advanced than the smart sensors of the competitors. It was observed that only measuring the data does not bring value to the company, but the data has to be transformed into understandable and visual information and only after that it can bring real value to the company. In the case study it was also noted that actions based on the data created by the sensors can be performed in order to reduce unplanned outages in the motor manufacturing with the predictive data for timing of services and repairs. It was also observed that the data and information provided by the smart sensors can also be utilized in discrete manufacturing on motors that are not continuously used. This is additionally to the knowledge compared to the motors used in process industries where the value of the sensor data was already confirmed in earlier studies.

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**KEYWORDS:** Smart Sensor, Electric Motor, Preventive maintenance

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## Symbols and abbreviations

A/D	Analog to digital
AC	Alternating Current
AI	Artificial intelligence
B	Magnetic field
BI	Business Intelligence
D-end	Drive end of a motor
F	Force
FAT	Factory acceptance test
FFT	Fast Fourier transform
HVAC	Heating, Ventilation, and Air Conditioning
I	Current
IEC	International Electrotechnical Commission
IEEE	The Institute of Electrical and Electronic Engineers
IoT	Internet of Things
IT	Information Technology
KPI	Key Performance Indicator
kVA	Kilovolt Ampere
kVAr	Kilovolt Ampere Reactive
kW	Kilowatt
kWh	Kilowatt hour
l	Length of conductor
LCA	Lifecycle Analyses
LCC	Lifecycle Cost
LV	Low Voltage
N-end	Non-drive end of a motor
OEM	Original equipment manufacturer
R&D	Research and Development
SQL	Structured Query Language
WiFi	Wireless Communication
WLAN	Wireless Local Area Network

## 1 Introduction

To manage change, or correct any process, machine, or behavior an organization or a person needs data. Reliable data is acquired only by measuring an input or an output. In the best case the measurement should be made in real time as the phenomena is happening. Sensors, and especially smart sensors, are designed to measure the phenomena in real time with the possibility to relay the data onward, if needed. Smart sensors operating wirelessly are using different communication protocols such as Bluetooth, LoRa, or Wan from a sensor to a gateway, and a gateway can then communicate over 4G, 5G or Wi-Fi the data to a database on a server. The data sent to the database is then analyzed by a specific software that monitors and displays the parameters of the data. Further, a specific application can be used to display the data in a specific format.

In this master's thesis the sensor data and the value of the sensor and the data are studied. The scope of the thesis is limited to Smart Motor sensors and electric motors in the ABB Vaasa environment. An electric motor is an electrical machine that converts electrical energy into mechanical energy. Electric motors operate through interaction between the motor's magnetic field and the electric current in a wire winding to generate force in the form of torque applied on the motor's shaft. Like generators, electric motors consist of a stator and a rotor and the three ingredients: electric current, magnetic fields, and something rotating. A basic rule of thumb is that in an AC motor, as in an AC generator used for industrial power production, the magnet is on the rotor and the current flows in the stator (Moyer, 2010). Nearly all motors exploit the force which is exerted on a current-carrying conductor placed in a magnetic field. The great majority of electric motors have a shaft which rotates (Hughes, 2019). The value of sensor measuring comes from preventive information on the motor's condition. The failures in a motor can be categorized into mechanical failures, electrical failures and failures related to the aging of the motor.

Sensors designed specifically to monitor electrical motors are called Smart Motor Sensors. They are currently used to monitor the health of motor systems, whether measuring the vibration of a motor, or the temperature of bearings in a mounted bearing assembly, although the extent to which this technology has been adopted is thought to be very limited (Lloyd, 2019). Smart Motors Sensors are normally one device with wireless digital communication, battery powered and with some built-in intelligence. A Smart Sensor converts traditional motors, pumps, and general machinery into smart, wirelessly connected devices. It measures key parameters from the surface of the equipment, which can be used to gain meaningful information on its condition and performance, enabling users to identify inefficiencies within their system and to reduce risks related to operation and maintenance. Maintenance can be planned according to actual needs rather than based on generic schedules. This extends the lifetime of equipment cuts maintenance costs and reduces or prevents unplanned downtime. (ABB, 2021).

The case study in this master's thesis is done in co-operation and with economical support from ABB Low Voltage Motor factory located in Vaasa, Finland. In this factory several motors and sets of motors are used in the manufacturing process of electrical motors. The predictability and condition of these motors is a crucial element of productivity and profitability of the factory, which can be secured by managing and minimizing the risk of the motors, eliminating inefficiencies in the motors, optimizing future investments and improved user experience. These are the targets that ABB's own Smart Motor Sensor, ABB Ability Smart Sensor TM is a measuring device for collection, database for storing and sorting, software for analyzing, and user-friendly application for presentation tries to secure.

The targeted outcome of this thesis is to create visibility to the data by creating new report templates and overall report to show the status of all the motors in which a Smart Sensor is installed. Further more it is understood that not all final reports can be created for this master's thesis and thus further recommendations to the target factory is expected.

The method used in this master's thesis, is a case study for a selected set of motors in the process to which ABB Ability Smart Sensors TM are and will be installed. The target of the thesis is to verify that the sensors add value to the process, have a payback as an investment, and that correct data is measured, and correct decisions based on the data are taken. Also, the future usage of the measurements and presentation formats of the data are to be considered.

## 2 Theory and background

### 2.1 Electric motors

#### 2.1.1 History of Electric Motors

The history of electric motors can be traced back to the early 19<sup>th</sup> century. With the Alessandro Volta's invention of the battery in the year 1800, the generation of a magnetic field from electric current by Hans Christian Oersted in 1820 and the discovery of electromagnet by William Sturgeon in 1825 the foundation for building electric motors was laid. At that time, it was still open whether electric motors should be rotating or reciprocating machines, i.e. simulate a plunger rod of a steam engine. Often the inventors knew nothing about each other and developed similar solutions independently. National histories are shaped accordingly until the present day. The first rotating device driven by electromagnetism was built by the Englishman Peter Barlow in 1822; this is the so-called Barlow's Wheel. (Dobbelbauer, 2014)

Prussian Moritz Jacobi created the first real rotating electric motor in May 1834 that actually developed a remarkable mechanical output power. The second version of the motor in 1838 was already so powerful that it could run a boat. He was years ahead of his competition in developing electric motors. However, all the early developments by Jacobi and others eventually did not lead to the electric motors we know today. (Dobbelbauer, 2014)

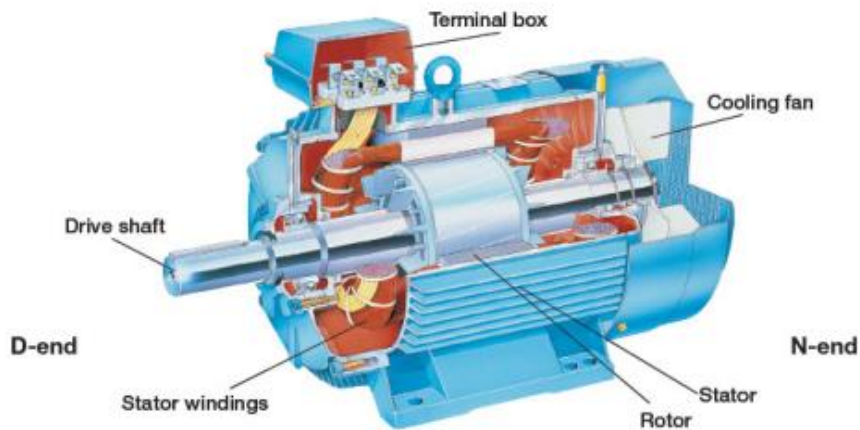
The years 1885 until 1889 saw the invention of the three-phase electric power system, which is the basis for modern electrical power transmission and advanced electric motors. A single inventor for the three-phase power system cannot be named. The highly successful three-phase cage induction motor was built first by Michael Dolivo-Dobrowolsky in 1889. Today, this is the most frequently produced machine in the power

range of 1 kW and above. (Dobbelbauer, 2014) Today's electric motors are based on the inventions of the late 1800's inventors, only the materials and production technologies have changed.

### **2.1.2 Electric motors**

Electric motors convert electrical energy, supplied from an alternating current or direct current source to mechanical energy at a rotating shaft. All electric motors have certain basic features in common. Each has a stationary member, the stator, and a rotating member, the rotor, separated by an airgap. The stator and rotor each have a magnetic core. The core carries copper or aluminum windings in slots or on salient poles. The windings are insulated. The principles of operation to all electric motors can be described as follows: The windings carry currents which may be caused to flow by direct conduction or electromagnetic induction. The currents produce magnetomotive force (m.m.f), more commonly known as Ohm's law for magnetic circuits, waves of magnitude varying approximately sinusoidally around the airgap circumferentially. (Brown, 1988)

The moving part in an electric motor is the rotor, which turns the shaft to deliver mechanical power. Magnetic field of the stator exerts force to turn the shaft, there must be an airgap between the rotor and stator. The stator consists of conductor windings. The rotor is supported by bearings and the bearings are supported by the motor housing. At the N-end (Non drive) of the motor there is normally a cooling fan to cooldown the motor. The shaft comes out from the D (Drive end) to provide the mechanical power. A terminal box is for connecting the motor to the electric grid. All of these parts can be seen in Figure 1.



**Figure 1.** Construction figure of an electric motor (WatElectric, 2021).

The function of a motor is to produce force. This is done by current-carrying wire placed in a magnetic field. The force  $F$  on a wire of length  $l$ , carrying a current  $I$  is exposed to a uniform magnetic flux density  $B$  through its length is given by the simple expression

$$F = B \times l \times I$$

**Formula 1.** Calculation of force.

More force can be obtained by obtaining the highest possible flux density. This is achieved by designing a good magnetic circuit. Secondly, as many conductors as possible must be packed in the space where magnetic fields exist, and each conductor must carry as much current as it can without heating up to a dangerous temperature. (Hughes, 2019)

A feature of an electric motor is torque production. The tangential electromagnetic force on all positive conductors will be downwards while the force on the negative ones will be upwards: a torque will be therefore exerted on the rotor, which will be caused to rotate. As in most engineering design, guidelines emerge as to what can be achieved in relation to particular sizes and types of machines, and motor designers usually work in terms of two parameters, the specific magnetic loading, and the specific electric loading. Together with the volume of the rotor, they define the torque that can be produced and are, therefore, of fundamental importance. (Hughes, 2019)

All electric motors are governed by the laws of electromagnetisms and are subject to essentially the same constraints by the materials (copper or aluminum for the electric circuit, magnetic steel, and insulation) from which they are made. The cooling arrangement of a motor is the single most important factor in determining the permissible output from any given motor. Any motor will give out more power if its electric circuit is worked harder (i.e. if the current is allowed to increase). The limiting factor is normally the allowable temperature rise of the windings, which depends on the class of insulation. (Hughes, 2019)

In all polyphase alternating current machines, the stator wave is developed by alternating currents of supply frequency. It rotates at synchronous speed relative to stator. In a synchronous motor the rotor rotates at exactly synchronous speed, therefore no voltage is induced in the rotor windings. The rotor wave is developed usually by direct current fed to the rotor windings through sliprings. It is therefore stationary relative to motor. In addition to the contribution to magnetizing flux, the stator currents produce leakage flux, which links with the stator windings only, and the rotor currents produce leakage flux with the rotor windings only. (Brown, 1988)

The stator of a polyphase induction motor is wound with a polyphase winding, now almost invariably a three-phase winding. The rotor may be wound with a similar winding, but a different number of turns. Alternatively, the rotor may have a cage winding consisting of bars through the rotor slots, joint together at each end by endrings. (Brown, 1988)

The efficiency of an induction motor is best expressed in the form:

$$\eta = 1 - \left( \frac{\text{Losses}}{\text{Input}} \right)$$

**Formula 2.** Efficiency of an induction motor.

Losses / input can also be called inefficiency. The losses consist of stator and rotor copper losses due to both load and magnetizing currents. In addition, losses can consist of stator

core losses, rotor core losses, extra stator copper losses, mechanical losses due to friction and windage and so-called stray losses, being all the losses additional to the before mentioned. As an example, in an induction motor a full load efficiency 0.88, the deficiency of 0,12 would be comprised approximately as follows: stator copper loss 0.04, rotor copper loss 0.02, core losses 0.04, mechanical losses 0.01 and stray losses 0.01. The core losses and mechanical losses taken together as rotational losses remain approximately constant; the other losses are load-dependent. The efficiencies of wound rotor motors are lower than those of corresponding cage rotor motors. (Brown, 1988)

### **2.1.3 Usage of electric motors**

Electric motors are used in a wide range of industrial applications, but also in many types of applications in the commercial, residential, agricultural and transportation sectors. Typically, electric motors are a component in a motor system, responsible for converting electrical power into mechanical power. Consumption of a motor system corresponds to electricity consumption of its motors plus a small additional quantity to power system controls. (Waide, 2011).

As stated, electric motors are found in the residential, commercial, agricultural, transportation and industrial sectors:

- In the residential sector, motors are used for compression, ventilation, pumping, cooking appliances laundry, cleaning, IT, and garden appliances. Some less widespread residential applications such as automatic gates and shutters also use motors.
- In the commercial building sector, motors are used for heating, ventilating and air conditioning, pumping, IT, escalators, elevators, hoists, laundry, cleaning, and cooking.
- In the agricultural sector, motors are used for pumping and conveyance activities
- In transportation, motors are used for motive power for electric trains, trucks, cars and motorbikes and related cooling, ventilation and auxiliary devices, fluid

pumping in vehicles shipping and planes, HVAC applications, servo-mechanisms in aviation and several other applications.

- Yet it is in industry that electric motors dominate and account for the largest amount of total electricity consumption. In industrial applications, motors are used for pumping, fans, air and liquid compression, conveyance, and other forms of mechanical handling and processing. Electric motor-driven systems are by far the most important type of electric load in industry. In the European Union, for example, they are estimated to account for about 70% of all industrial electricity consumption. (Waide, 2011).

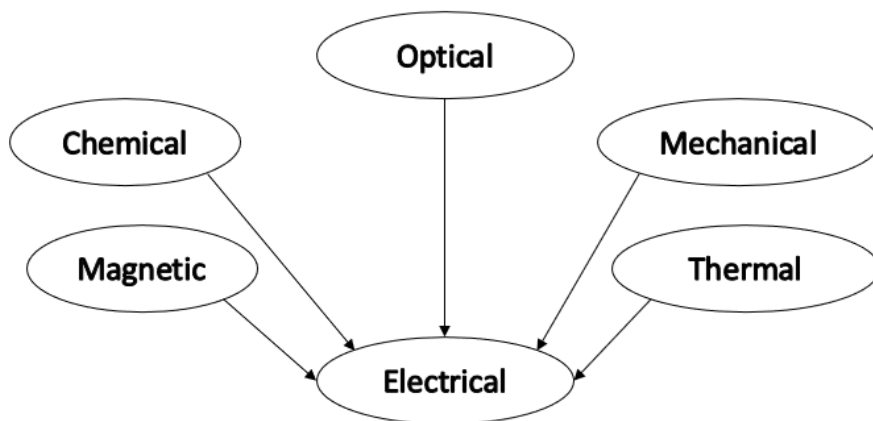
Electric motors and the systems they drive are the single largest electrical end-use, consuming more than twice as much as lighting, the next largest end-use. It is estimated that electric motor driver systems account for between 43% and 46% of all global electricity consumption. The largest proportion of motor electricity consumption is attributable to mid-size motors with output power of 0.75 kW to 375 kW. Such stand-alone motors are produced in large volumes, according to standardised input power and size specifications, with varying channels to market and integration into electromechanical systems. (Waide, 2011).

## **2.2 Sensors**

### **2.2.1 Defining a sensor**

With sensors we are now learning to artificially expand our senses. Sensorization together with mechanization and informatization will bring about the third industrial revolution of full automation or robotization. Usually, traditional integrated sensor can be divided into three parts which are, sensing element (e.g. resistors, capacitor, transistor, piezoelectric materials, and photodiode), signal conditioning and processing (e.g. amplifications, linearization, compensation, and filtering), and a sensor interface (e.g the wires, plugs and sockets to communicate with other electronic components). (Son, 2009).

Sensors transform signals from different energy domains to the electrical domain. Signals can be defined into six domains, which can be seen in Figure 2. Optical sensors are able to translate these signals into electrical signals, which are depicted in the lowest domain. An example is an image sensor that translates a picture into an electrical signal. The second domain is the mechanical signal domain. A good example of this is an accelerometer, which is able to translate mechanical acceleration into an electrical signal. The third domain is the thermal domain, which translates temperatures to electrical signals. The fourth one is the electrical domain, which translates electrical signals into other electrical signals. The fifth one is the magnetic domain, which converts magnetic signals into electrical signals. The final one is the chemical domain, that translates these signals into electrical ones. (Huijsing, 2008).



**Figure 2.** Different energy domains.

Sensors can be further divided into passive, self-generating and active, modulating types. Passive sensors such as electrodynamic microphone obtain their output energy from unput signal. Active sensors, on the other hand, such as condenser microphone, obtain it from an internal power source. Active sensors can achieve a large power gain between the input and output signals. Furthermore, sensors can be divided into two classes,

which are open systems, in which there is no feedback and closed-loop systems with feedback. (Huijsing, 2008).

A multitude of materials can be chosen for sensors. Semiconductors are becoming increasingly popular as a sensor material because of their stable crystalline structure and because its standardization in mass fabrication is being improved and because of their low price. Other materials used in sensors are:

- Thin film
- Thick film
- Opto-electronic
- Ceramic
- Foil.

For each sensor domain there are thousands of possible parameters to be measured. For this reason, there are thousands of different sensors on the market. Another factor is the many output signal types for sensors. The smart sensor is the solution for standardization and compacting of the sensor.

### **2.2.2 Smart Sensor**

The Institute of Electrical and Electronic Engineers (IEEE) committee has consolidated terminology that applies to microelectronic sensors. The IEEE 1451.2 specification defines that a smart sensor as a sensor that “provides functions beyond those necessary for generating correct representation of a sensed or controlled quantity. This function typically simplifies the integration of the transducer into applications in a networked environment”. This definition provides starting point for the minimum content of a smart sensor and focuses on industrial measurements. (Frank, 2013).

A smart sensor node consists of three basic elements, a physical transducer, a processor/memory core and a network interface. The physical transducer senses the physical quantity and converts it to an electrical signal. The signal is fed to an A/D converter to

produce a digital value for use by the processor. The processor, which is normally a microcontroller, performs signal processing on the data and sends the resulting data to the network. Thus the processor in a smart sensor network may be thought of as a distributed parallel computer. Traditional sensor systems have only one central data processing resource. By processing data locally at the node, only the desired data is sent out to the network. (Hamrita, 2005). From the architecture perspective, most definitions of a smart sensor include the basic architectural elements. These are the following seven major elements:

- Sensor, a device converting energy from one domain into another.
- Signal conditioning, circuitry that prepares the electrical signal conversion to the digital domain.
- Analog-to-digital conversion, a device that converts the analog input signal into a digital code that represents the magnitude of the analog signal.
- Application algorithms, Application-level software, or hardware whose functions include converting the data to user-specified units, signal processing, data analysis and reduction, watching for alarm conditions, or other operations appropriately performed closely to the point of measurement. These algorithms provide the “smartness” in smart sensors.
- Data storage, digital data storage for sensor identification and configuration information, calibration data, user display preferences, the time-stamped logged data and anything else that is valuable to store within the sensor.
- User interface, a standardized presentation of corrected data to the end user in the user’s language and terminology, and in the application-specific units.
- Communication, an interface to a communication medium for remote access to the sensor for setup, calibration, diagnostics, data capture and general status monitoring. (Zhang, 2004).

From functionalities perspective, based on the study of Yong Chang, Yikann Gu, Vlatko Vlatkovic and Xiaojuan Wang the authors comply an attribute list highlighting capability of smart sensors as follows:

- Two-way digital communications, this is the number one parameter. Only when communication is supported, can other important functions be realized. One of the key function is remote configuration and calibration.
- Self-identification, the smart sensor must know what it is and how it works, and it should communicate the information with other components via a network. When sensors can identify themselves and their capabilities to a system. plug-and-play will become feasible.
- Self-diagnosis, with self-diagnosis capability, the smart sensor can indicate if it is malfunctioning, or if something is about to go wrong.
- More powerful data processing, providing powerful measuring and computing capabilities may equip sensors with advanced algorithms to translate input raw data into information and then knowledge. (Zhang, 2004).

With technology development many more advantages of the smart sensor are also possible, such as:

- Easy/faster installation and maintenance, system setup will be more automated and will incur less opportunity for errors.
- Increased diagnosis and advanced functionalities, smart sensors are able to immediately identify and report any malfunction of a system or plant equipment. With the ability to amplify and digitize signals, unexpected downtime is thus minimized, and the overall system reliability is improved. (Zhang, 2004).

### **2.2.3 ABB Ability Smart Sensor TM**

ABB introduced ABB Ability Smart Sensor TM to the market in 2016. The first version (see Figure 3.) could be used to measure and monitor temperature and vibration across a range of general machinery applications, from fans to mechanical skids. It can measure

temperatures from -40 degrees to +85 degrees Celsius, with a resolution of 0.05 degrees. It also measures vibration in the amplitude range of 0.04 to 700 mm/s, but not the direction of the vibration. It communicates with Bluetooth 4.0 and has a battery lifetime of approximately five years. The first-generation sensor package weights 0.26 kg and is mounted to the motor frame. Even if this sensor has already been for six years in the market, it is still available to the customers.



**Figure 3.** First generation ABB Ability Smart Motor Sensor TM. (ABB Inside, 2021).

In the year 2020 ABB introduced ABB Ability Smart Sensor TM for hazardous areas, which is the same as the second-generation sensor (see Figure 4.). With the improved measurement capability, it measures vibration by measuring low frequency acceleration to x,y,z direction, with the amplitude range of 0.03 to 157 m/s<sup>2</sup> and high frequency acceleration to z direction with the amplitude range 0.1 to 490 m/s<sup>2</sup>. Generation 2 smart sensor also measures magnetic field to x,y,z direction with amplitude range 1 to 1600  $\mu$ T as well as ultrasonic sound measurement with the amplitude range 0.6 mN/m<sup>2</sup> to 20 N/m<sup>2</sup>. The temperature measurement of generation 2 sensor is the same as in the generation 1 sensor, with the measurement range of -40 degrees to +85 degrees Celsius. With all these measurements the generation 2 smart sensor can monitor the following motor operating parameters:

- Radial vibration (velocity rms)
- Tangential vibration (velocity rms)
- Axial vibration (velocity rms)
- Speed (rpm)
- Operating hours
- Number of starts
- Supply frequency (Hz)
- Output power (hp/kW)
- Regreasing count-down.

With these motor operating parameters, the following health parameters can be monitored:

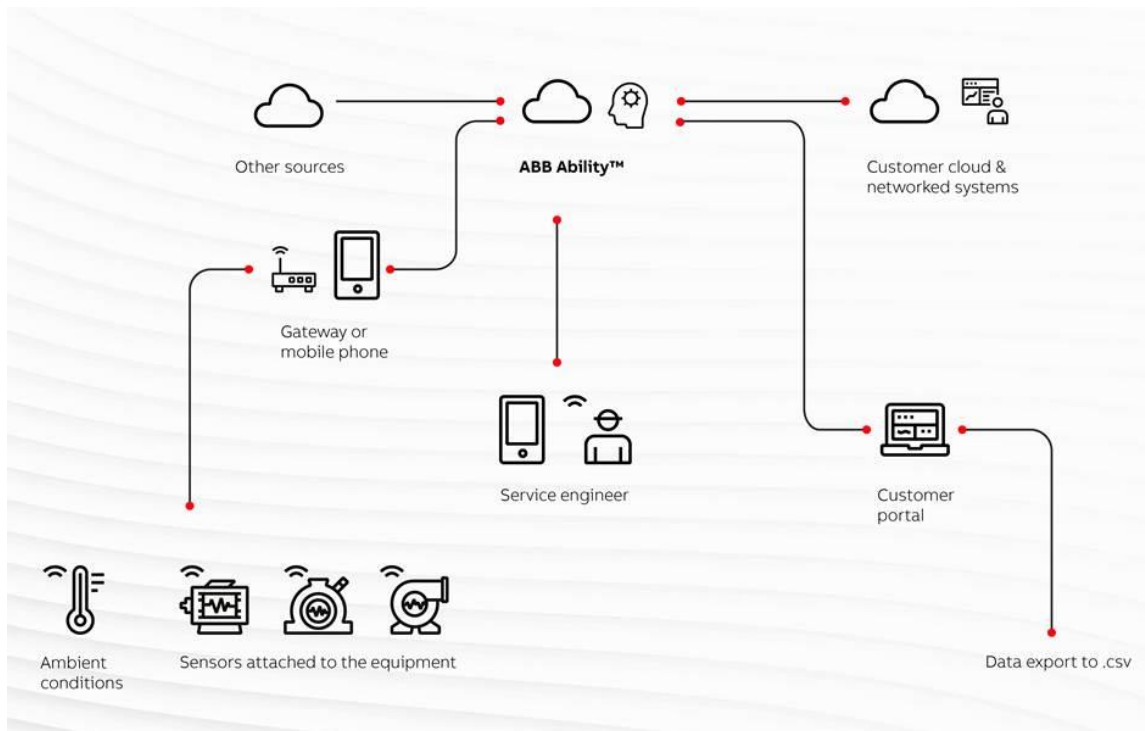
- Overall condition
- Overall vibration (velocity rms)
- Bearing condition
- Skin temperature (degrees).



**Figure 4.** Second generation ABB Ability Smart Motor Sensor TM. (ABB Inside, 2021).

The ABB Ability Smart Sensor TM, generation 2 is available in two variants namely as, high performance sensor and standard performance sensor. In terms of measurements the difference between the two is that the standard performance sensor does not measure the high frequency acceleration (z direction). The high-performance sensor provides lifetime of the sensor up to 15 years. The standard conditions of operations are sensor measurement interval of 1-hour, raw data collection once per day, non-condensing environment, and measured asset skin temperature +15 to 50 degrees Celsius. The battery type used is non-replaceable C-type battery. Compared to the standard performance sensors lifetime of up to five years, with AA-type non-replaceable battery. Both variants of the generation 2 sensor communicate with Low Energy Bluetooth 5.0. The high-performance variant weights 185 g and the standard performance variant 130g respectively. Both sensors' variants are installed to the equipment's frame with a clamping bracket and a screw or a with adhesive putty.

Data is collected from the sensors attached to the motors, pumps, and generators through Bluetooth protocol to a gateway. The gateway ABB recommends is Cassia X1000 Bluetooth gateway, which is suitable for explosive environments. The gateway is connected to a database, which can be read through different ways. These are application, web portal or the user's own system. The application and the web portal utilize the ABB Ability Smart Sensor TM algorithms to analyze the data and convert it into meaningful information, presented on both user interfaces. The application is an interface to the equipment's status for technicians on the factory floor. A traffic light display gives an easy overview of the condition of all the monitored equipment. The second way to connect to the data is through a web portal, where the complete powertrain dashboard is available for operators to view condition and performance trends, access historical data, manage user access rights and set alerts and alarm. The third option to connect to the database is the user's own system, in which the smart sensor data can be accessed via the smart sensor cloud interface. This information flow can be viewed in Figure 5.



**Figure 5.** Dataflow of sensor data. (ABB Inside, 2021)

## 2.2.4 Other manufacturers in the field

Besides ABB there are several smart motor sensor suppliers. In this thesis, three other sensors, namely those of Siemens, WEG, and Analog Devices, were selected for a closer study. Siemens and WEG are also motor manufacturers as is ABB. Analog Devices is an electronics manufacturer specializing in sensors.

The Siemens smart motor sensor is called SIMOTICS CONNECT 400. It is a plug-and-play connectivity module for measuring and preprocessing the motor-specific condition data that's analyzed in the MindSphere application. MindSphere application is the Siemens platform for IoT connected devices. (Siemens, 2021.)

The measured parameters of SIMOTICS CONNECT 400 are:

- Temperature (Range: -40 – +85 Celcius)
- Radial/tangential/axial vibration (Range: 0.02 to 180 mm/s and 10 Hz to 1.6 kHz)

- Electrical stator frequency
- Slip frequency.

And calculated parameters are:

- Motor state (on/off)
- Rotation speed
- Torque
- Electrical power
- Energy consumption
- Number of starts
- Hours of operation.

Based on these the SIMOTICS CONNECT 400 also provides suggestions for maintenance requirements, such as relubrication interval. The sensor is externally mounted on the motor's cooling fins with a mounting bracket (glued). The operating lifetime of the sensor without changing the battery is up to two years. If the connection to MindSphere is interrupted, it can store data for a minimum of 48 hours. The sensor communicates with Bluetooth or WLAN. Measurement interval is configurable between one minute and one hour. The sensor package weights 0.25 Kg. (Siemens, 2021.)

WEG's smart motor sensor is called WEG Motor Scan. The sensor is fixed by a screw on the motor fin and there is no electrical connection between the motor and the sensor. The data collected by the sensor is further analyzed in WEG's own sensor application called WEG Motor Fleet Management. (WEG, 2021)

The measured parameters of WEG Motor Scan are:

- 3-Axis vibration (mm/s)
- Vibration spectrum

- Surface temperature (°C)
- Running hours (h)
- Energy consumption (kWh)
- Load (%)
- Speed (rpm)
- Frequency (Hz)
- Unbalancing
- Misalignment.

The WEG Motor Scan sensor is able to connect all the devices at the plant together, Synchronize data through WEG IoT Platform, name and monitor as many motors as you need, analyze data sent to the cloud, and get diagnostics of the motors. The battery life is estimated to be over three years. The sensor is connected to the application with bluetooth. (WEG, 2021).

Analog Devices' smart motor sensor is called ADI OtoSense Smart Motor Sensor, which is an AI-based, full turnkey hardware and software solution for condition-based monitoring. It is connected to the frame by screwing the sensor on to the fins. Once the device is installed it starts sending data to OtoSense AI, which requires a process of learning about the motor's operation to be able to predict its faults. This process' duration varies, depending on the motor's operating conditions, but it usually takes approximately four weeks (Otosense, 2021). After that it can detect nine mechanical and electrical faults, which are:

- Asymmetry in motor currents
- Gravity center displacement
- Motor/load misaligned
- Stator resistance variation
- Stator/rotor concentricity issue
- Motor cooling system problem

- Rotor resistance variation
- Failures/defects in bearing
- Fixing system problems.

The data can be monitored through the ADI Otosense application's web-based interface. Because of this the sensor needs to be connected to the internet. The hardware is designed and manufactured by Analog Devices' and the software is designed by Otosense, a company specializing in sensors. Otosense is specializing in sound recognition technology, which its manufacturer claims is the key measurement for motor monitoring. (Analog Devices, 2021). Another smart motor sensor manufacturer that is using Analog Devices' sensors and Otosense's software and artificial intelligence is RMS, Reflexes Motor Sensor, but they are not a global competitor in smart motor sensor, as they are focused on North and South American markets (Reflexes,2021).

From the above it can be concluded that these sensors measure the same relevant attributes, only the ranges of the different measurements vary from one to another. The mounting of the sensor varies; it can be either glued or screwed to the cooling fins of a motor. The transmission of the data to the database is either by WLAN or Bluetooth, however the motor manufacturers prefer Bluetooth transmission to a hub and from there with WLAN, due to quantities of motors with sensors at one plant is larger than one. Analog Devices utilized AI-based technology in the sensors data analyzing, and thus the implementation time of their system is over four weeks. Because the others are motor manufacturers as well, they know the limits and ranges of the motors and can use preset values for alert limits for maintenance persons to act on.

### **2.2.5 Relevant other smart motor sensor usage cases**

Several smart motor sensor manufacturers published success stories can be found. In this chapter a closer look is taken into some of these cases. It has to be noted that the cases presented are from sales promotional material.

At a pharmaceutical factory smart motor sensor device was installed on a three-phase asynchronous motor driving an air conditioning turbine. The factory experienced a power outage which caused the motor to stop for a few hours. After the motor was restarted, the vibration levels increased. This increase in vibration was likely due to a failure in the motor bearing cage. After this an alert was generated and sent to the application and email, along with the recommendation to check the bearings and lubrication conditions. In this case the customer decided to continue running the motor for five more days, the vibrations remained high, but stable. Then the customer decided to perform a test by stopping the motor and restarting it. This led to vibration levels dropping. The severity level of the fault indicated that failure was not imminent, allowing the manufacturer to wait until the next maintenance period to replace the bearings. (Bearing News, 2021).

At an oil refinery the main cooker bearings were experiencing issues due to overheating. A part of the problem was connected to cooker alignment, which led to the overheating and subsequent failure of these bearings. Smart motor sensors were installed to monitor the issue. The system featured bearing sensors, motor sensors and a gateway. This gave the company and the maintenance team the ability to remotely monitor the motors and help prevent failures. As the site access is strictly limited and traditional condition monitoring activities are not able to be conducted at particular times, the data from the sensors saves time and money to refinery. (ABB Limited, 2020).

Smart Sensors were installed on motors in the 'mash preparation' process, a continuous function critical to the overall distillery operations at a vodka distillery. Right after the sensors were fitted to the motor housings, an abnormal vibration curve was detected on an agitator motor, indicating possible bearing failure. A more in-depth analysis confirmed that there was indeed a faulty bearing. Detecting the defective bearing before it failed allowed the distillery to fix the problem during a planned shutdown, avoiding lost productivity caused by unexpected downtime. A second possible problem the sensors picked up was significant vibration in one of the pumps, also on the mash preparation

line. At first, engineers thought it might also be a bearing issue, but it turned out to be a valve that had shifted accidentally resulting in pump cavitation. (ABB Limited, 2021).

At a pulp mill, a pulp dryer features 140 motors controlling fans that are used to dry the wet timber before it enters the dryer. There are two banks each containing 70 fans and their associated motors. Initially, half of the installed base of motors were fitted with Smart Sensors. The banks of fans are stacked in such a way that an aerial platform lift was needed to give engineers access so they could manually take vibration measurements. This monthly requirement incurred costs for the platform, the qualified engineer, and the vibration analysis equipment. Due to the installation of the smart sensors and remote monitoring the pulp mill can now closely track the performance of individual motors, remotely, thereby avoiding cost of the manual approach. Because of the saved time the company can allocate resources to different more value adding tasks and maintenance can now be planned according to current needs rather than based on general schedules. Also, with less time spent around running motors safety improved, according to ABB's Service Manager Erik Bohman: "One of the advantages of Smart Sensors is that the motors can be measured without risk when, for example, they are near rotating parts or where lifts and scaffolding are needed to access manually." (ABB Limited, 2020).

### **2.3 Condition monitoring and fault diagnosis of electric motors**

As any unplanned stoppage at a factory is costly and the companies try to limit or even exclude such situations related to any operation of their factory, but especially related to electric motors. The motors carry out many important tasks for any factory or process. For this reason, the condition of the electric motor is important information to the process owners of the factories. Smart motor sensor is a method to monitor any fault or condition change in a motor. Major faults in electrical machines can broadly be classified as:

- Stator faults resulting in the opening or shorting of one or more of a stator phase winding
- Abnormal connection of the stator windings
- Broken rotor bar or cracked rotor end-rings
- Static and/or dynamic air-gap irregularities
- Bent shaft, which can result in a rub between the rotor and stator, causing serious damage to stator core and windings
- Shorted rotor field winding
- Bearing and gearbox failures (Nandi, 2005).

Of the above types of faults bearing, the stator or armature faults, broken rotor bar and end-ring faults and the the eccentricity-related faults are the most prevalent ones. These faults produce one or more of the symptoms:

- Unbalanced air-gap voltages and line currents
- Increased torque pulsations
- Decreased average torque
- Increased losses and reduction in efficiency
- Excessive heating (Nandi, 2005).

To detect such fault related signals, several different methods can be used. These methods include the following ones:

- Electromagnetic field monitoring, search coils, coils wound around motor shafts
- Temperature measurements
- Infrared recognition
- Radio-frequency emissions monitoring
- Noise and vibration monitoring
- Chemical analysis
- Acoustic noise measurements

- Motor-current signature analysis
- Model, artificial intelligence, and neural-network-based techniques (Nandi, 2005).

Almost 40 % - 50 % of all motor failures are bearing related. Bearing faults are either rotor asymmetry faults or bearing race related, either ball effect or train effect. These faults can be detected by the vibration frequencies and the changes of those. Second most frequent failure reason for motors is an insulation failure. Almost 30 % - 40 % of motor failures fall into this category. Such insulation faults on larger motors can be detected with Partial-Discharge methods. Rotor failures account for around 5 % - 10 % of total induction motor failures. The other common failure causes are much more rare, and account for the remaining faults. (Nandi, 2005).

### **2.3.1 From preventive maintenance to predictive maintenance**

The manufacturing sector is facing a number of challenges, but they all point to one direction – improving the bottom-line performance. Asset management is key to achieving this. Traditionally assets are large and costly, with long service lives. To achieve high operational efficiency and availability means ensuring that all assets are performing at peak performance with high availability and the lowest possible maintenance costs. (Maritime, 2021).

The strategies adopted by companies to manage their assets have evolved over the years but never has the pace of change been so dramatic and profound. Fueled by the proliferation of accurate low-cost sensors, improved high-speed communications, powerful computing including cloud and edge, machine learning and advanced analytics, operating companies are provided assets with some compelling options. When backed up by extensive domain expertise that allows the strategy to be customized to match all the operating requirements perfectly, the pathway to more significant asset optimization and increased operational efficiency can be plotted with confidence. (Maritime, 2021).

Many maintenance strategies have been well documented to appropriately manage assets. The traditional scenario includes routine planned maintenance that is typically carried out at the intervals suggested by, among other things, the Original Equipment Manufacturer (OEM). When managed correctly, preventative maintenance has been scheduled by time or some performance parameter, but if not implemented successfully, it turns into a reactive failure and a fixed scenario that can be disruptive. (Maritime, 2021).

Despite the wealth of opportunities, many companies in the process industry and energy sectors are still using reactive and preventative maintenance regimes across their asset base. The optimal way forward is for companies to evaluate where they are in the Asset Performance Management journey and then choose the right types of strategies for each asset or equipment type, based on the operating scenario of each plant, the role of each piece of equipment, how it might fail and how critical it is to the overall process performance or plant availability. The key is to deploy predictive maintenance on assets where it makes sense. (Maritime, 2021).

A six-step predictive maintenance strategy has been developed and the steps are:

- Step 1
  - Gain visibility of the data
- Step 2
  - Understand the gaps and remediate with added sensing
- Step 3
  - Analyze and understand key trends towards faults
- Step 4
  - Leverage trends to predict faults before they happen and optimize maintenance strategy
- Step 5
  - Learn and adjust operations
- Step 6
  - Establishing a reliability culture. (Maritime, 2021).

In the first step the important issue is to understand where the company is with its processes and equipment. Typically, a company needs to understand what their current performance of their assets is. This involves taking existing data and visualizing that information to support decision making. It is important to capture the data that hasn't been previously used and integrate it into the system where it can be manipulated and analyzed.

Once the visibility to existing data has been established the second step is to close the gaps where information could be lacking from the critical assets at the plant. Here additional data points could be added to gain a deeper understanding of asset conditions. There is a vast array of sensors that can be deployed on electrical equipment, rotating equipment, and other plant assets that can then be part of a condition-based maintenance regime. This could be in the form of an engineered system tied to a control system or a completely independent system that allows informed decisions based on the condition of the assets. Condition and remote monitoring solutions are vital tools especially when assets are in remote and inhospitable locations.

Step three is to analyze and understand key trends that lead to faults. Different software solutions gather and present real-time condition data from disparate systems into one dashboard so that users can save time to action by having equipment health data and operational insights available all in one place. This is a crucial step on the transition to a predictive maintenance strategy. Such software gives an instant and secure access to the equipment data they need to make decisions that help optimize operations and reduce maintenance and operating costs.

On the fourth step the trends of the information are used to predict the faults before they happen and as such optimize maintenance strategy. By using the plant specific data with the OEM's model-based data, a trend to predict can be created.

The fifth step is to learn and adjust operations from the new information provided by the sensors. Predictive analytics and asset performance solutions have the overall capability to monitor, analyze, plan, and act for optimized managements strategies.

The final step is to establish a reliability culture within the company. In order to attain the highest performance standards for reliability, companies must not neglect the vital role of people, no matter how advanced the technology deployed is. A site needs to develop a reliability-centered culture where everybody recognizes their personal responsibility just as the importance of safety is widely recognized. People in all roles and at all levels work to improve the processes, systems and working relationships they depend on. High levels of equipment reliability is expected to result in improved safety, environmental and production benefits. Reliability excellence is a journey, not a destination. (Maritime, 2021).

### 3 Research plan

First, the research problem was defined together with ABB LV Motors factory and the scope was limited to the motor production at the Vaasa plant. The factory was implementing Smart Motor sensors to the motors used in their production. It was agreed that a case study method would be the best option for the study.

The second step is acquiring background information to the topic by studying literature on the topics on motors, sensors and condition monitoring and fault diagnosis of electric motors. After getting familiar with the literature a more detailed study on manufacturers of smart motor sensors was done by going through available material. A factory tour was organized to get a more detailed and specific view of the actual case. The visit raised the topic of predictive maintenance by using sensor data to the factory's advantage as a topic to be covered by the study.

The third step is to create a plan for implementing the case study and in this thesis the case study is divided into three steps:

- Identifying the motors in the scope
- identifying the tools used
- Defining the need of additional tools.

This step will be carried out by using the tools that the target company already has in its daily use.

The fourth step is the actual implementation of the plan. The plan will be implemented as such and after that it will be studied if any recommendations for further actions will arise.

The fifth and final step will be recognizing the value of the study to the target company by gathering all the findings and making an analysis and conclusions. These conclusions will then be presented to the target company for any further actions.

## **4 Current situation of smart sensor usage and information utilization at the low voltage motor factory**

The low voltage motor factory in Vaasa is one of the five IEC low voltage motor factories of ABB. ABB group worldwide has 105 000 employees and 26 billion USD in revenue. The business areas of ABB are Electrification, Motion, Process Automation, and Robotics & Discrete Automation. The IEC LV Motors division, in which the Vaasa LV Motor factory belongs, belong to the Motion business area. At the Vaasa factory 600 professionals produce 75 000 motors annually. All are engineered or configured to order to meet the customer's specifications in different segments and applications. The frame sizes of motors are IEC 71 (71 mm axis height) to IEC 500 (500 mm axis height) with the power rating up to 2000 kW. The product portfolio includes cast iron and aluminum process performance motors, motors for explosive atmospheres, water cooled motors and application specific motors, such as synchronous reluctance motors, permanent magnet motors and high-speed motors.

### **4.1 Utilization of data for preventive/predictive maintenance at the factory**

Prior to introduction of generation 1 ABB Ability Smart Motor sensor TM, the data gathering from the motors was based on oil sampling during scheduled production breaks. Analyses were made based on the oil samples to determine the specific properties and characteristics of the oil. From these possible wear or contamination in the motor can be detected, as well as any outside contaminants that may have entered the motor can be detected. In addition, during the scheduled maintenance breaks, the bearings were regularly changed to some motors. As the preventive maintenance activities were limited motors still faulted during production and the production line had to be stopped and motor changed or repaired before the production line could be restarted.

After the introduction of generation 1 ABB Ability Smart Motor sensor TM, some sensors were attached to the motors at the LV motor factory in Vaasa. The data gathered was unreliable and irregular and, thus, the oil samplings continued to provide data from preventive maintenance. Also, many of the motors monitored with generation 1 were special motors and the generation 1 sensors were not designed for such. The generation 1 motor sensor was more like a pilot product for a new improved generation 2 motor sensor introduced in 2020, that were built on the foundation of the working features of generation 1.

Generation 2 smart sensor, which were installed at the LV factory during the year 2021, provide correct data to the web portal. Access to the web portal is limited to a few employees, or the complexity of the portal is hindering the new methods to be used or the user interface is considered to be too complicated for the data to turn it into usable information. Due to this, the preventive maintenance activities remain the same as earlier and no new actions are taken due to the data.

## **4.2 Opportunities created by the sensor data**

Several different opportunities are identified at the Vaasa LV motor factory after the implementation of the smart motor sensors. There are improved occupational safety, reduced energy consumption, increased reliability of research and development projects, improved preventive maintenance actions, reduced downtime of the factory, decreased number of spare parts, increased awareness of the employees at the factory and higher sales potential of motors and smart sensors with the displaying of the smart sensor implementation.

Occupational safety is improved by the reduced need to check on each individual motor during the maintenance break. The motors in the study are mostly located at hazardous locations and so an unnecessary exposure to the risk of getting injured while maintaining the motors is reduced. With the information from the smart sensors the maintenance persons would know which motors to focus on during the scheduled maintenance break

and hence, there is a lower workload, which again leads to lower risk of harming the person.

With the information from the smart sensors, the motors that are unnecessary running when not needed, can be identified. The reduced usage of power leads to lower energy cost and reduced carbon dioxide footprint, which then again improved company image. Reducing the unnecessary running of motors also increases the lifetime of the motors and reduces the maintenance costs.

ABB is a motor manufacturer, developer and an innovator, and the Vaasa LV factory is a crucial research center in the global motor business. The available setup of the sensor data gathering environment provides the R&D team online information of the radial, tangential, and axial vibration of the motors currently under prototyping testing. Also, the information from the already running sensors installed is available for R&D to be used in future product development. R&D can also benefit from the historical data stored in the cloud database and this information can be used in verifying the next generation motors.

Changing the maintenance and service culture from reactive to preventive, with the information from the smart sensors will save maintenance resources and thus costs. This can be achieved by focusing the resources efficiently on motors that indicate an alert or an alarm in their condition. Also, the skills needed by the maintenance crew can be less critical and still enough to perform corrective actions.

With the online information from the smart sensors and improved preventive maintenance activities the risk of unplanned downtime of a machine or the factory can be reduced. This will lead to a higher and more reliable capacity of the factory and increased revenue volume from the sales. Also, avoiding penalties from any delays has a financial impact on the factory.

With the increased knowledge from the data acquired from the smart sensors, the critical and higher risk motors can be identified. The criticality could be, for example, due to increased vibration or increased temperature of a motor. Having spare motors and spare parts only for the most critical motors instead of having them for the whole fleet of motors saves costs, space for storing, and administration work for carrying inventory and procuring of spare parts for the LV motors factory.

With visible, transparent, understandable information of the condition of the motors to the employees of the factory can provide several positive outcomes. The employees working on a machine or a production line of a specific motor with a sensor installed will receive daily feedback of the condition of the motor's he is working with, which will potentially increase his/her trust into the machine and thus increase motivation towards his/her work. From the data one could also realize that the operating modes and methods during different shifts differ from each other, and one method is more efficient than another. The information shared would also give confidence to the management of the factory that the critical machines are maintained and serviced correctly and on time.

The visiting customers and potential customers coming to the factory for a Factory Acceptance Test (FAT) or other reasons are potential customers who could purchase new motors and smart motor sensors from ABB. The visible displays at the factory can initiate an interest to the pilot smart sensor implementation at ABB's own factory and resulting in wanting the same kind of environment at the customers' own factories.

## 5 Introduction to case study

### 5.1 Motors in the pilot study

The case study includes 43 electric motors and generators which are located either in hazardous areas or in hard-to-reach places. The motors are grouped to five asset groups, depending on their function in the manufacturing process. The asset groups are Punching and Notching, Frame Presses, Rotor-Casting, Stator-Core and Test Lab. In Tables 1.-5. the different types of motors per asset group can be found. In all the 43 motors and generators, a generation 2 ABB Ability High Performance Smart Sensors are installed. 16 of these sensors are set to measure once an hour and 27 operate at 15-minute intervals.

**Table 1.** Asset group Punching and Notching.

Asset ID	Asset type	Speed(rpm)	Speed Control	Voltage	Current	Power	Line Frequency	DE Bearing	NDE Bearing	Real Shaft Height	Motor Type
38526	Motor	1480	Fixed Speed	400 V	81.30 A	45.00 kW	50.0 Hz	6313	6212	225	Induction
37608	Motor	2000	Variable Speed	400 V	211 A	114.40 kW	67.7 Hz	6312	6309	-	Induction
38457	Motor	430	Fixed Speed	400 V	15.20 A	7.50 kW	50.0 Hz	6316	6316	-	Induction
38522	Motor	1400	Fixed Speed	400 V	15.00 A	7.50 kW	50.0 Hz	6316	6316	-	Induction
38532	Motor	1455	Variable Speed	400 V	15.20 A	7.50 kW	50.0 Hz	6313	6313	-	Induction
38538	Motor	1470	Variable Speed	400 V	10.00 A	7.50 kW	50.0 Hz	6308	6308	132	Induction
38536	Motor	1470	Fixed Speed	400 V	28.50 A	15.00 kW	50.0 Hz	6209	6309	132	Induction
37638	Motor	2000	Variable Speed	400 V	211.00 A	117.40 kW	67.7 Hz	6312	6309	160	Induction
38502	Motor	1430	Fixed Speed	400 V	15.20 A	7.50 kW	50.0 Hz	6316	6316	132	Induction
38525	Motor	1485	Variable Speed	400 V	134.00 A	75.00 kW	50.0 Hz	6317	6317	-	Induction
38529	Motor	1484	Fixed Speed	400 V	135.00 A	75.00 kW	50.0 Hz	6316	6316	280	Induction
38540	Motor	2950	Fixed Speed	400 V	65.00 A	37.00 kW	50.0 Hz	6312	6311	200	Induction

The power rating of the motors in Punching and Notching vary from a small 7.5 kW motor to a medium size 117 kW motor, which is for press usage in a hydraulic press. The asset group includes both variable speed controlled and fixed speed motors.

**Table 2.** Asset group Frame Presses.

Asset ID	Asset type	Speed(rpm)	Speed Control	Voltage	Current	Power	Line Frequency	DE Bearing	NDE Bearing	Real Shaft Height	Motor Type
38579	Motor	1475	Variable Speed	400 V	56.00 A	30.00 kW	50.0 Hz	6312	6310	200	Induction

In the Frame Presses asset group, where the stator is pressed into the frame there is only one small motor.

**Table 3. Asset group Rotor-Casting.**

Asset ID	Asset type	Speed(rpm)	Speed Control	Voltage	Current	Power	Line Frequency	DE Bearing	NDE Bearing	Real Shaft Height	Motor Type
37826	Motor	1480	Fixed Speed	400 V	84.00 A	45.00 kW	50.0 Hz	6212	6313	225	Induction
37827	Motor	1470	Fixed Speed	400 V	35.00 A	18.50 kW	50.0 Hz	6310	6209	180	Induction
37828	Motor	1480	Fixed Speed	400 V	68.00 A	37.00 kW	50.0 Hz	6313	6212	225	Induction
37850	Motor	1465	Fixed Speed	400 V	30.00 A	15.00 kW	50.0 Hz	6309	6209	180	Induction

Asset group Rotor-Casting has four small, fixed speed motors that are used for rotating pumps.

**Table 4. Asset group Stator-Core.**

Asset ID	Asset type	Speed(rpm)	Speed Control	Voltage	Current	Power	Line Frequency	DE Bearing	NDE Bearing	Real Shaft Height	Motor Type
38581	Motor	970	Fixed Speed	400 V	15.40 A	7.50 kW	50.0 Hz	6209	6209	-	Induction
38666	Motor	970	Fixed Speed	400 V	33.00 A	15.00 kW	50.0 Hz	6313	6313	180	Induction

Motors in the asset group Stator-Core are small, fixed speed motors, which are running a small conveyer line.

**Table 5. Asset group Test Lab.**

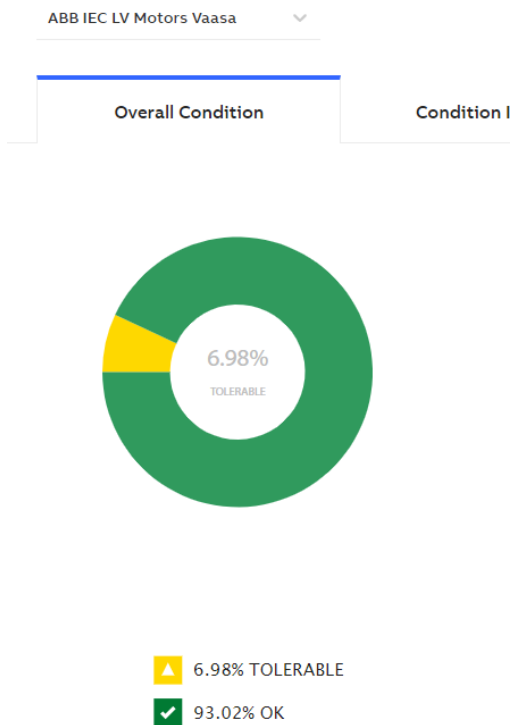
Asset ID	Asset type	Speed(rpm)	Speed Control	Voltage	Current	Power	Line Frequency	DE Bearing	NDE Bearing	Real Shaft Height	Motor Type
37954	Generator	1500	Fixed Speed	400 V	192.00 A	100.00 kW	50.0 Hz	6310	6209	-	Induction
37670	Motor	1490	Fixed Speed	690 V	414.00 A	400.00 kW	50.0 Hz	6322	6316	350	Induction
37667	Motor	1490	Fixed Speed	690 V	414.00 A	400.00 kW	50.0 Hz	6219M	6316	350	Induction
38724	Generator	1500	Variable Speed	400 V	1312.00 A	500.00 kW	50.0 Hz	6322	6319	-	Induction
38722	Generator	1500	Fixed Speed	400 V	682.00 A	300.00 kW	50.0 Hz	6320	6320	-	Induction
37708	Generator	1000	Fixed Speed	415 V	131.00 A	100.00 kW	50.0 Hz	6320	6320	-	Synchronous
37757	Motor	1500	Fixed Speed	230 V	432.00 A	100.00 kW	50.0 Hz	6214	6214	-	Synchronous
37953	Motor	1475	Fixed Speed	400 V	40.90 A	22.00 kW	50.0 Hz	6310	6209	160	Induction
37702	Generator	1500	Fixed Speed	400 V	3623.00 A	250.00 kW	50.0 Hz	6334	6334	560	Synchronous
37704	Motor	1491	Fixed Speed	400 V	1160.00 A	650.00 kW	50.0 Hz	6319	6319	400	Induction
37696	Motor	1490	Fixed Speed	400 V	1263.00 A	710.00 kW	50.0 Hz	6324	6319	400	Induction
37957	Motor	1500	Variable Speed	690 V	1943.00 A	2000.00 kW	50.0 Hz	6330	6324	500	Induction
38721	Generator	1500	Fixed Speed	415 V	2200.00 A	1000.00 kW	50.0 Hz	6334	6334	-	Induction
37658	Motor	1490	Fixed Speed	690 V	414.00 A	400.00 kW	50.0 Hz	6322	6316	-	Induction
37669	Motor	1490	Fixed Speed	690 V	414.00 A	400.00 kW	50.0 Hz	6219M	6219M	355	Induction
38728	Motor	1500	Variable Speed	415 V	725.00 A	300.00 kW	50.0 Hz	6320	6320	-	Induction
38727	Motor	1500	Fixed Speed	380 V	530.00 A	300.00 kW	50.0 Hz	6322	6319	-	Induction
37756	Generator	1000	Fixed Speed	230 V	415.00 A	90.00 kW	50.0 Hz	6318	6318	-	Induction
37710	Motor	1000	Fixed Speed	380 V	206.00 A	100.00 kW	50.0 Hz	6320	6320	-	Synchronous
37952	Motor	1482	Fixed Speed	400 V	83.00 A	45.00 kW	50.0 Hz	6313	6211	225	Induction
37705	Motor	1491	Fixed Speed	400 V	1160.00 A	650.00 kW	50.0 Hz	6319	6319	400	Induction
37703	Motor	1490	Fixed Speed	400 V	1265.00 A	710.00 kW	50.0 Hz	6324	6319	-	Induction
37962	Motor	3600	Variable Speed	690 V	2620.00 A	2500.00 kW	60.0 Hz	6313	6313	560	Synchronous
37956	Generator	1000	Fixed Speed	690 V	2892.00 A	1730.00 kW	50.0 Hz	6313	6313	-	Induction

In the asset group Test Lab, all the motors and generators of the factory test laboratory are included. The power ratings of the eight generators vary between 100 kW and 1730 kW, and they feed the power to the test objects.

## 5.2 LV Motors Smart Sensor data in the smart sensor tool

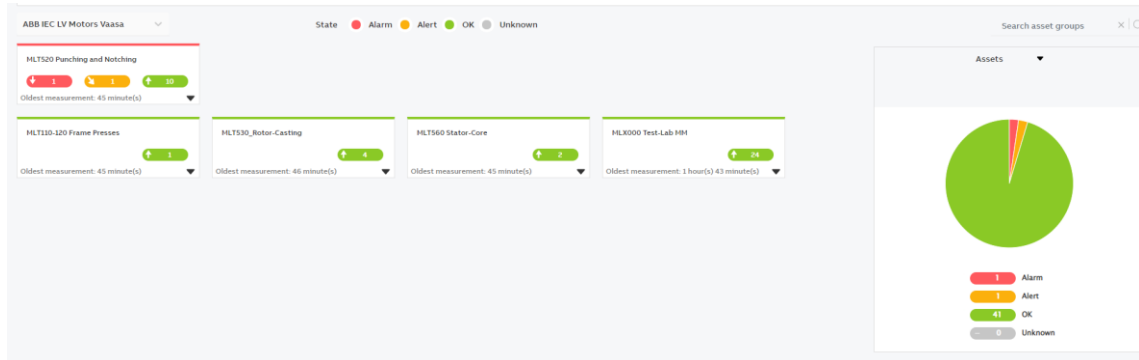
Currently the smart sensor data of the 43 motors is collected into the default smart sensor tool. The tool divides the information into four sections that are condition monitoring, symptom monitoring, asset details and organization management. The tool is designed for multi-site asset management as the user can select between the sites and he has access to sites all over the world. In this study only the ABB IEC LV Motors Vaasa factory will be taken in consideration.

The condition monitoring section includes an overall condition of the motors over a period of time, which can be either daily, weekly, monthly, or yearly. It also calculates an index of the measured events and gives a traffic light type of a view of the overall situation of all the motors in the selected plant, as shown in Figure 6. This section also provides an individual condition index of the state of each motor. The different stages are unknown data (question mark), condition ok (green), condition alerting (yellow), and condition alarming (red).



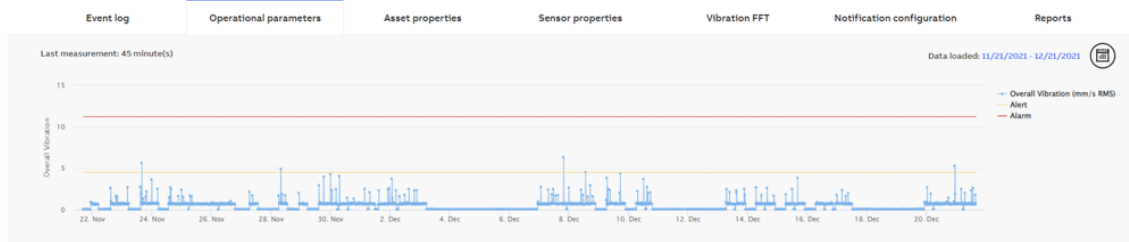
**Figure 6.** Overall condition of motors.

The symptom monitoring section gives an insight view of each of the 43 motors in detail, also showing the state of the motor with the same four signs. The view is divided first to asset groups and under the asset groups are the asset names, which are the motors. It also gives an overall Pie-view of the assets as shown in Figure 7.



**Figure 7.** Symptom monitoring.

The asset details section focuses on individual motors. The sector is further divided to seven different tabs including event log, operational parameters, asset properties, sensor properties, vibration FFT, notification configuration, and reports. The event log divides the measurement events into alarms, alerts, maintenance, and diagnostic categories. It also stores the events to open and closed events. The operational parameters tab provides health parameters and operational parameters. Health parameters are overall vibration, bearing condition, and temperature of each asset and operational parameters provide the actual data of the measurement such as acceleration, true temperature, and vibration to different directions. Drilling down to any of the parameters a diagram over a time period can be viewed. In Figure 8. an overall vibration diagram of a specific motor is presented as an example.



**Figure 8.** Example diagram of an asset's health parameter.

In the asset properties tab and the sensor properties tab each asset and each sensor is identified respectively. For the assets the asset details and its nominal details are visible and for the sensor properties sensor details and sensor features are shown. The sensor properties tab also shows the gateway and connection details of each sensor to the tool.

The vibration FFT tab, is not in use without a special raw data collection. This tab would give a vibration analysis with the use of Fast Fourier Transform Spectrum. The notification configuration tab gives the user the possibility to set up his preferred notification methods and the information he wants a notification from. The final tab, reports, reports generated by eligible users can viewed by all users that have access to the tool and site.

In the organization management section assets and asset groups can be created and managed, user and user accesses can be administrated. Also, overall settings for the events and firmware can be maintained and changed. Sharing of the information to trusted organizations is also managed under this section. The trusted organizations are either ABB units or business partners of ABB.

### 5.3 Research problem definition

As motor sensor data and information is available the utilization of the data becomes the main target of the smart sensor implementation at the LV motor factory. The first issue is that the data is visible only to a limited number of people in the organization, some of whom do not use the web portal actively.

With a short questionnaire to the current users of the web portal and interviews of the users this research problem can be further narrowed to:

- How to share the information to more employees.
- How to actively push the data from the web portal to the users instead of the current pull method used.
- How to make the user interface more understandable.

When providing a result for this problem the objective is to take into consideration the current users of the web portal, the service and maintenance team of the factory, other employees working at the factory, management, and possible visitors at the factory. As individual web portals are not a common practice at ABB and the local factory, the solution to the problem have to be found in the applications already in daily use in Vaasa LV Motors factory.

The second problem that can be solved is the dimensioning of the current motors in the case study correct, by measuring the online real duty point and the nominal duty point of the motors the efficiency can be re-evaluated. The sensors measure data in real time and the data can be utilized for the first time to calculate the correct efficiencies and not only the nominal values.

With the information from the data the cost saving potential for replacing the current motors with new higher efficiency motors can be calculated as well as dimensioning the motor size correctly. A payback for each motor on the energy savings is one of the outputs of the case study.

#### **5.4 Tools to solve the problems**

The application to be selected had to fulfill at least the following criteria. It has to be able to easily visualize data via interactive dashboards and reports, it has to also be possible

to connect to data stored in variety of sources, such as Microsoft excel, SQL, and other databases. The applications also have to be able to slice, filter and drill down for deeper insights and be able to share information with colleagues and larger audience, ensuring that they have the information they need for critical business decisions.

ABB has been working in Microsoft environment for more than 30 years. Around 2010 Microsoft announced Power Pivot for Microsoft Excel, which allowed users the idea of self-service business intelligence. In 2014 Microsoft introduced Power BI, which is an evolution of the add-ins previously available in Excel; Power Pivot, Power Query, and Power View. Users can use Power BI with or without Excel and they are no longer dependent on the version of Microsoft Office installed at their company. It allows a mobile experience, which could be used by the factory workers. It also allows a seamless experience in loading data from many different cloud sources and databases and building the infrastructure needed for ever growing framework of reports. (Ferrari, 2016).

Microsoft Power BI can meet some of the research problems identified and the needs of the Vaasa LV Motors factory. This is why Power BI was selected as the visualization application to fulfill the value creation need for general public and the service team. As the Power BI cannot calculate the values for temperature rise, utilization power, efficiency, reactive power, utilization time and life cycle costs, an outside Excel calculation has to be performed. The Excel input would be drawn directly from the ABB Smart Sensor portal, with some editing performed by the user.

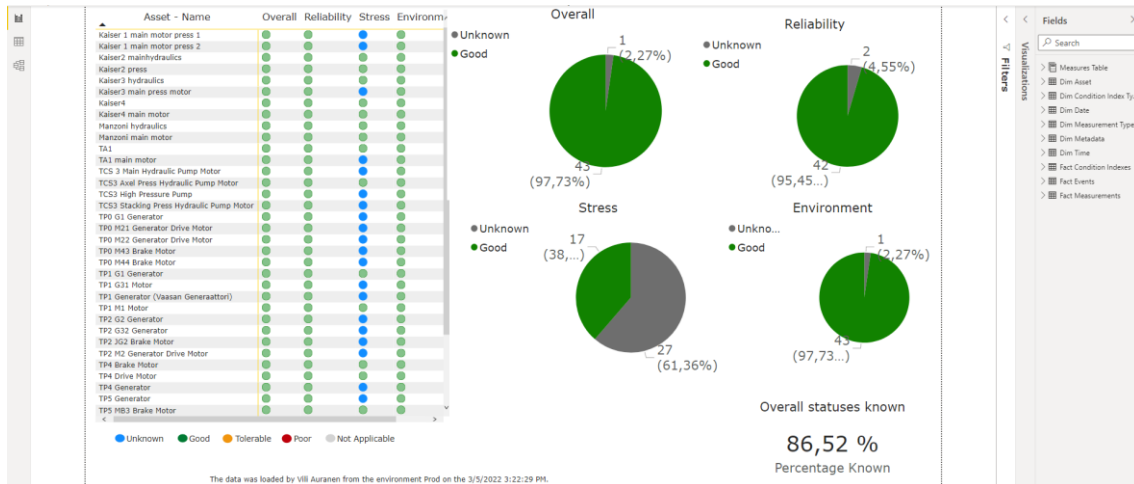
## **6 Case study**

In the case study the utilization of smart sensor data and the possibilities of utilization were studied. First it was verified that the smart sensors were installed into the pilot motors and that the gateways were receiving data, which can be then further transferred to the smart sensor portal. The verification confirmed that all of the above were functioning correctly. The utilization of the data is further divided into three sub-categories as defined in the research problem. These three categories are visualization of data to employees and customers, visualization of the data to the maintenance and service team, and energy efficiency and investment payback.

### **6.1 Visualizing the data into information**

The info-TV system at the Vaasa LV Motor factory provides information to employees and visitors of the factory. The information shared is managed by the assistant at the factory and the information itself is provided by different teams at the factory. Information provided by the sensors could be one of the information sets shared on the info-TV. The information should be detailed enough so that the employees could have a good understanding of the status of the motors, yet general enough so that the random visitors could also have view of the status.

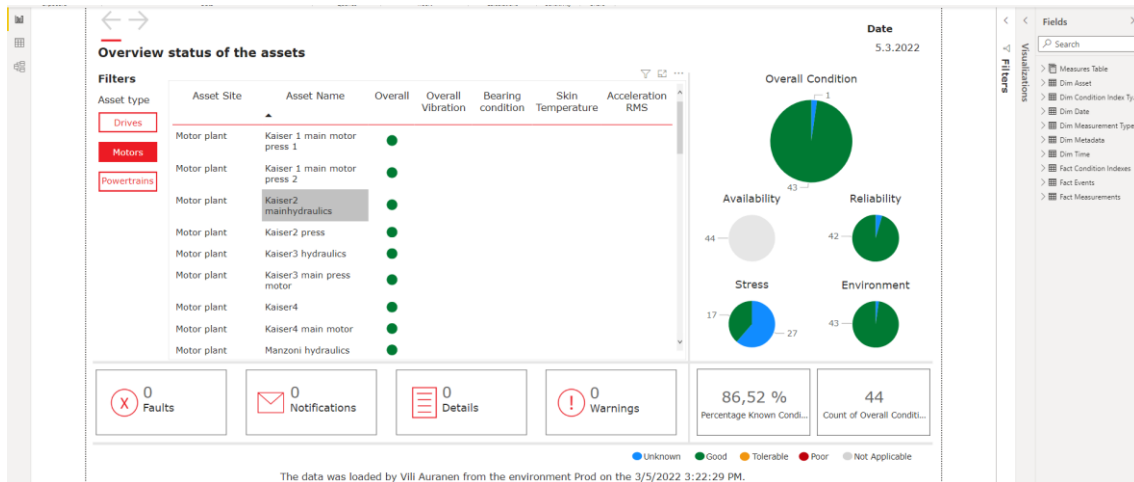
The Power BI format of the data was found to be the most suitable format for the presentation in the info-TV's, it can process and present a lot of information at the same time and visualize the data in an understandable format. Below in Figures 9, 10, and 11 examples of the info-tv views can be seen.



**Figure 9.** Overall view of the motor indexes.

In Figure 9. the status of motor indexes can be seen. Each asset is separately shown on the list and four separate indexes are shown with a traffic light for each motor. The traffic light colors are green for good, orange for tolerable, red for poor, and if the information is unknown the color is blue, and for not applicable information the color is grey. On the right-hand side four different pie charts are shown with the same color scheme showing the quantity and portion of the different conditions by motor.

As the indexes are shown by asset, the information is valuable enough for the employees as they know the general location of each asset in the factory and can, therefore, see the condition of the asset they are working with. For the random visitors the indexes show the view that measurements are taken from the motors and the host of the visitor, or a salesman, can easily explain to the visitor that there are sensors installed in the motors and that online measurements are taken and with this visualization such information is available and could be implemented to the customer's motors as well. With this an interest can be raised for ABB sensors, ABB motors, ABB service, and ABB provided consulting and a possibility for a new sale may be achieved.

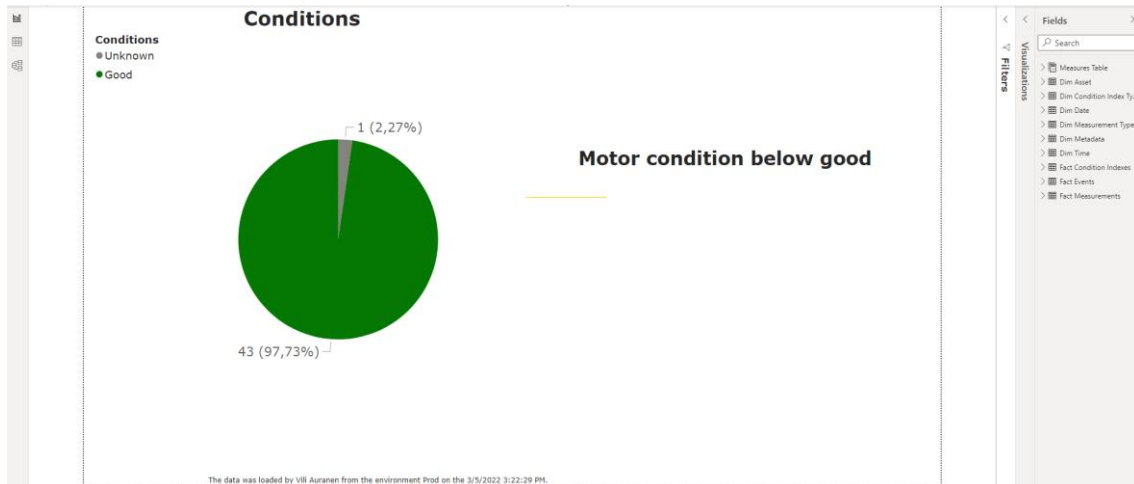


**Figure 10.** Overview status of the asset measurements.

The overall status of measurements of individual motors is shown in Figure 10. With the connection between the portal and Power BI such masses of data cannot be currently transferred, so Figure 10. needs further development, but as such should be one of the figures to be shown.

The Figure 10. shows all the assets by name, the overall condition index, and the real measurements of all measurements measured by the sensor. The measurement results could be shown as traffic lights alarming or alerting of the condition. It would also show the number of faulty motors, notifications provided by the sensor, other details on the sensors, and warnings from the motors.

The difference between Figure 9. and Figure 10. is that Figure 9. is based on indexes calculated by the portal and Figure 10 is showing the real measurements and the traffic lights are calculated in the Power BI environment. On the right side of Figure 10. the same pie charts are visible as in Figure 9.



**Figure 11.** Condition of the motors needing action.

A view visible on the info-TV's is shown in Figure 11. of the motors needing actions from the service and maintenance team. The figure shows the individual motors of which index shows a condition below good. This index status should alarm the maintenance team to act. The first action of the maintenance team would be to see the alarm information from the portal and then act accordingly. The reason why such a view is included in the info-TV, is that the employees of the factory would have visibility to the fact that the maintenance and service team do take care of the motors.

The three figures (9., 10. and 11.) are included in the info-TV to provide the factory employees the feeling that latest sensor's technology is used at their factory and that the factory is being modernized. For the visitors to the factory the info-TV views should increase interest towards ABB products, such as sensors motors, and services. The hosts at the factory should be taught to explain the info-TV views to the visitors.

## 6.2 Providing information to the service team

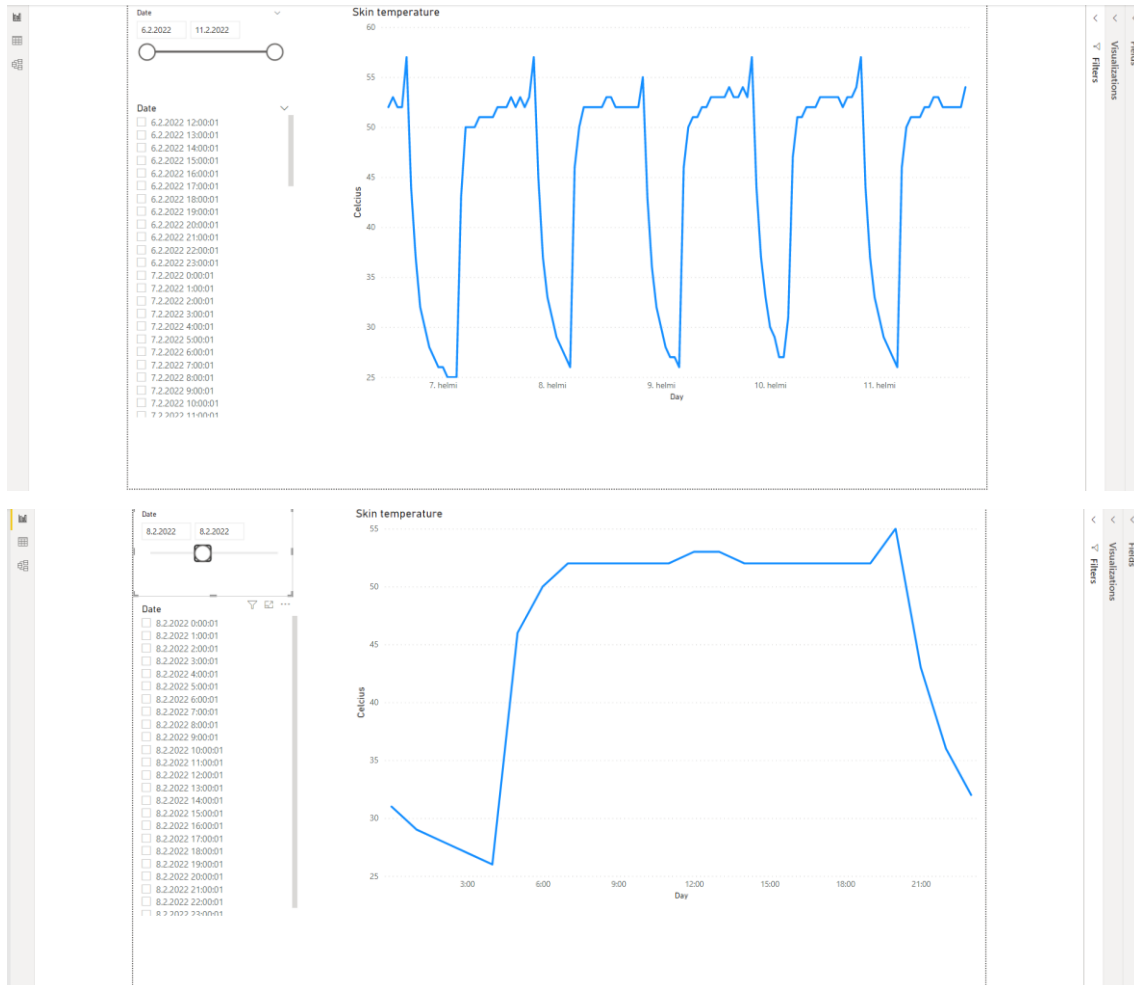
The data in the portal is the main source of information to the maintenance and service team. It is also used for a deeper dive into an individual motor. For visualization, seeing trends, averages, variations and for faster data handling Power BI views are created for the maintenance and service team, production, and the R&D team.



**Figure 12.** Bearing condition indicator.

In this Power BI view (Figure 12.) the service engineer can view the bearing condition of any motor selected individually. The engineer can see the alert level with the yellow line in the picture and the alarm level with the red line. The engineer can select the dates he wants to view and if he wants to focus on conditions of certain level of bearings this can also be selected.

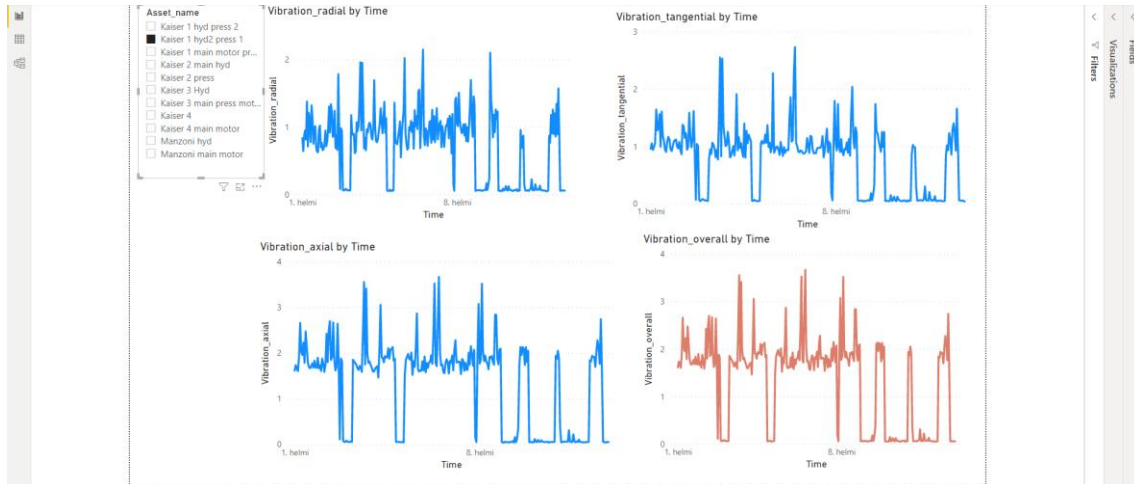
The bearing condition indicator would also be interesting to the R&D team of the factory, as a new sensor could be installed in any motor during the development phase and be viewed during the testings. In addition the production management of the factory can have a better understanding of the motors under his/her supervision in the process.



**Figure 13.** Skin temperature of a motor over a time period.

In Figure 13. the skin temperature of a selected motor over a time period can be viewed. The engineer can select the duration of the view from one day to several months. He can also select the same time of the day on several days and compare the temperature of the motor over a long time period. He/she can calculate the trends and averages of a selected period of time. With this information the engineer can predict if the motor has something wrong with it, which might make it break in the near future.

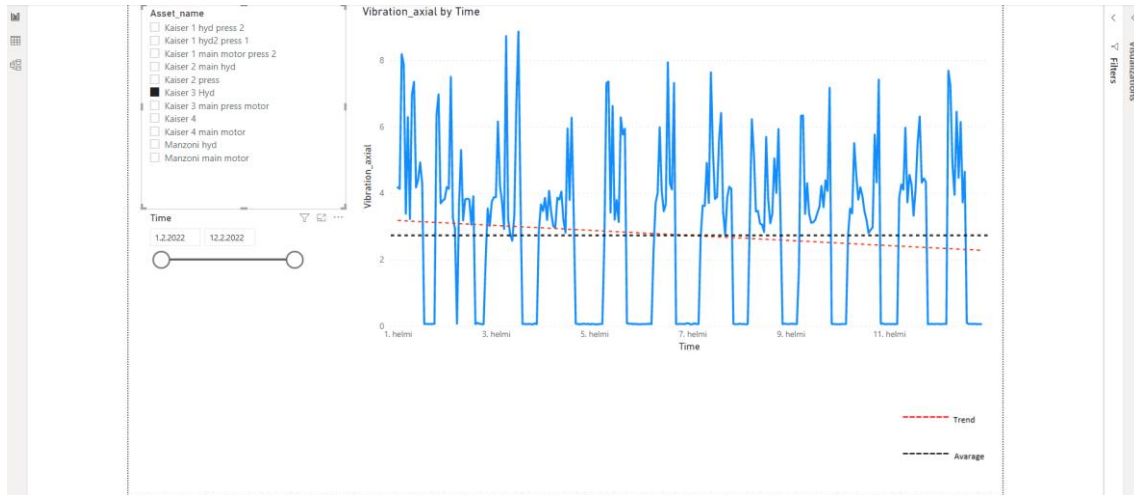
From this view the engineer can see if the motor is overheating under a certain load or if the motor is running cold most of the time. Both of these conditions are not good for the efficiency of the motor.



**Figure 14.** Four quadrants with vibration information of a motor.

As the ABB Smart Motor sensor Gen 2 TM has the ability to measure vibration three dimensionally, all these three and overall vibration are visualized, in Figure 14. Clockwise from the bottom left quarter axial vibration, radial vibration, tangential vibration, and overall vibration over the same time period of a selected individual motor can be seen.

The service engineer can with this information determine if the vibration is normal and if it is not normal then what kind of an issue the motor might have. Such causes might be failed bearings, loose foundations, mechanical Imbalance, an electronic imbalance, faulty gears, wear, and tear of an old motor. With the direction of the vibration an experienced engineer can estimate where to look first.



**Figure 15.** Vibration trend and average.

For each of the vibrations a trend and an average chart can be created. In Figure 15, the axial vibration of a motor over time is visualized. The average vibration over the respected period is calculated and also the trend over the same period of time is calculated. The trend and average lines visualize the long-time development of a motor's health. The information of the trends is more reliable on the motors that are utilized constantly on the same load level, such as pump and fan motors.

The Power BI charts are mostly for visualization of the information, more precise information should be viewed from the portal directly. An engineer can also download all the numerical information from the portal to Microsoft Excel, where it can be utilized for its full value.

### **6.3 Selecting efficient motors and investment payback**

The data from the smart sensors can be utilized in many different ways, it does not require the usage of the portal, nor any visualization tools. As an example the selecting of efficient motors for the right load, or investment payback calculation of replacing the current motors are ways to utilize the data. The portal saves the data from the day of installation of the sensor to the database. The data can be extracted in any time period

selected. The efficiency calculations of all the motors create a fleet report of the motors selected.

The fleet report shows the KPI's (Key Performance Indicator) for selected objects. The objects for this study are temperature, motor dimensioning, efficiency of the motor, reactive energy consumed and life cost analyses. Each of the measurement results are shown in a traffic light configuration.

To prepare the fleet report each motor and its data has to be individually studied. The basic data can be found in the portal and as the fleet report is made on Microsoft Excel the respective motor basic data is keyed into the worksheet. From the basic data the calculated efficiency of the motor can be determined and this efficiency-% can be compared to the general energy classification standards of electric motors. The skin temperature and output power data of the selected time period is downloaded from the portal to the excel worksheet. The worksheet calculates the utilization percentage out of the data and calculates the annual operational hours of the respective motor. By the utilizing the data, the short-term peak power and average active power in Kilowatts is calculated. With the average active power the percentage of the nominal power of the motor can be calculated and as such the over-/under sizing of the motor can be viewed.

All induction motors have generic behavior, if the motors are of same size, power, and same pole number. The efficiency and power factor of the motor at average power can be calculated. Knowing the power factor and efficiency the apparent power (kVA) and reactive power (kVAr) can be calculated. Furthermore with the annual operating time, average active power, and efficiency at average power the annual generated losses in kWh can be calculated and knowing the energy cost per kWh the cost of the losses generated by individual motor in euros can be calculated.

From the worksheet the thermal and electrical KPI's and lifecycle analyses (LCA) and lifecycle cost (LCC) of each motor can be created. Combining each motor's KPI's a fleet report can be created, seen in Figure 16.

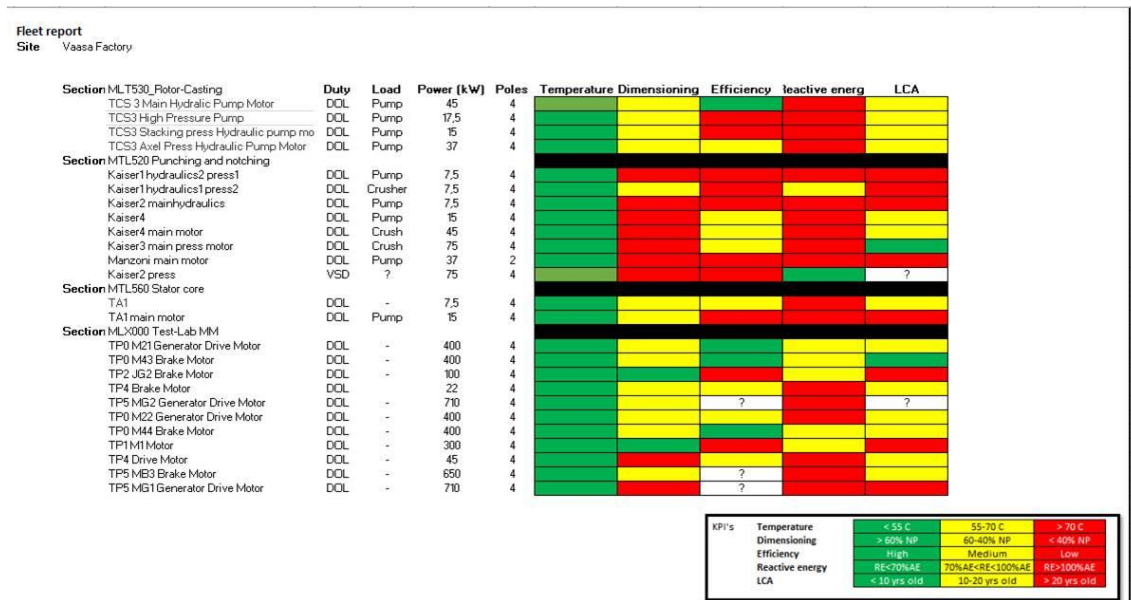


Figure 16. Fleet report example.

The fleet report is a snapshot of the status of the motors at the time of the study. From the fleet report the management of the factory and the maintenance and service teams can see if the temperatures of the motors are on acceptable level if the dimensioning of the motor at the time of investment was correct for the current job. The percentage of reactive energy compared to apparent energy can also be seen on the report. The development on the energy market will show if the consumers have to pay for the consumed reactive energy in a similar way than apparent energy in the future. The life cycle analysis on the fleet report shows the age of the respective motor. The estimated commercial lifetime of an electric motor is around 20 years.

Based on the fleet report a specialist can decide what long-term activities are to be taken on individual motors and the whole fleet in general, when to invest to new motors, which motors to change. Also the cost savings based on the dimensioning and efficiency can be bases for future activities.

## 6.4 Next steps and recommendations

The recommendations in this chapter are based on the case study at the ABB IEC LV Motor factory in order to improve the utilization of the data from the smart sensors. The quality of the base data of the selected motors should be revisited as any error or lack of information in the motor base data, will lead to incorrect conclusions when analyzing the data and hinders the implementation of the future plugin-extensions. It is recommended that during the next maintenance break all motors and the master data of the motors in the web portal are verified and compared.

In the web portal, where one can add, and modify the alarm and alert levels for vibration and temperature measurements, a log should be implemented by the ABB portal management team in order to keep track, who, why, and when changes have been made. Currently it is hard to know if the levels set are correct for the respective motor. For better utilization of Power BI and other similar visualization tools the link between the web portal and the tools should be improved. The ABB development team should make sure that the indexes and measurements from web portal are transferred to the respective tools consistently and in full every time the transfer is executed.

For visualization of the data on the info-TVs at the factory the respective Power BI views should be approved for info-TV usage and the responsibilities of uploading the data and the views to info-TVs should be agreed. Also, the respective training to the responsible persons should be conducted.

The implementation of the Power BI views for the maintenance and service teams should be organized. The implementation would include training on the web portal and Power BI and understanding the data available and how to read and utilize the data for the maximum value. This would turn the data to information. Fine tuning of the alert and alarm settings for vibration and temperature in the web portal should be done for the respective motors over a period of time. In order to have the alert and alarm levels

working in Power BI, it is crucial that correct measurement data is transferred constantly from the web portal to Power BI.

To easily prepare the fleet report, which provides an overview of the following motor status: motor temperature, motor dimensioning, motor efficiency, reactive energy consumed, motor life cycle analyses, and annual cost savings of the losses, the report generation should be automated. The automation could be done directly in the web portal or as data transfer to some other tool, such as Microsoft Excel. Based on the future decisions the development of the automatic transfer could be done by either web portal development team or by the motor service team.

A new R&D motor plant should be created in the web portal. The sensors to be used by the R&D of new motors should be included in this new plant. The sensors of this plant would be used for the motors currently under development by the R&D team. Sensors would not be permanently installed to any motor, but the sensors would be changed from one prototype motor to another. With these sensors instant online information of the measurements would be uploaded to the portal and would be visible to the R&D team instantly during the testing of the prototype motor.

The final recommendation is that a sensor is installed in each and every special motor manufactured in Vaasa motor factory. This would extend the service portfolio of ABB service teams around the world, with instant capability of selling fleet reports, online analysis, reports and similar to any customer of ABB. This would tighten the relationship of the end customer and ABB, since the sensor data guarantees the future collaboration between the parties.

## 7 Conclusion

This Master's thesis identified a number of reports for the motor factory to utilize in their communication to their employees and visitors at the factory. It also visualized more specific report templates to the service team of the factory to use in their daily operations. Also a fleet report was prepared to assist in selecting more efficient motors to be used at the factory.

Sensors and especially smart sensors are a crucial element of today's and the future's IOT environment. Smart motor sensors are specifically designed for motor applications, and they measure information about their status and tries to elaborate on their future condition. There are several smart motor sensor suppliers whose products are similar to the one focused in this thesis. It was found that the ABB Ability Smart Sensor TM is slightly ahead of its competitors, especially in measuring more parameters than others. This is mainly due to the fact that ABB is also a motor manufacturer and can use the field expertise and feedback to its advantage.

It was also confirmed that just by measuring the parameters, and thus providing data, is not adding value to any organization. Only when the data is turned to visible and understandable information it can be used for creating value to the organization and only the one who utilizes the information can create value. Probably this is also the most important finding of the study, as - even if data is measured and exists- if it is not utilized it does not add value to the organization.

In the case study that was performed for the thesis it was noted that the downtimes can be reduced by the usage of the smart motor sensor data for preventive maintenance as the actions during service breaks can be focused on the motors indicating a higher risk of failing. These actions would lead also to improved on-time delivery, higher output, and improved profitability of the factory.

The smart sensor data also helps the factory to eliminate inefficiencies, such as energy saving, reduced working hours, efficient use of resources and managing the lack of competencies of individuals. With the data accurately engineered plants require less redundancies and fewer spare parts and run longer, which all lead to optimized investments. The improved user experience offers employees a more satisfying way to operate. Flexible configurable functionality leads into easy-to-use interface and an easy way of sharing knowledge. This leads to better decisions within the organization.

The study showed that smart motor sensors and data from the sensors can also be used in motors used in discrete industries where motors are running only sporadically instead of continuously as normally in process industries. Nevertheless, the longer the measurement window is, the more accurate the data is. Also, the usage of the data should be further optimized since data is useless without proper analyses and usage.

In general the research objectives were fulfilled well. One of the targets was to provide visible and understandable information to the employees as well as to the service and maintenance teams. The level of detail of the information to the target groups varies, but the detail level can be reached by using the web portal or other visualization tools. The second objective of dimensioning of the current motors was also solved by using the fleet report, which provides the information to the decision makers from the online measurements measured by the smart motor sensors.

The full value of the thesis to the principal company can only be realized if the recommended actions and next steps are implemented. By fine tuning the tools and implementing the visualization the real value in euros and the saved carbon dioxide emissions can be reduced and the safety of the employees improved. The value to the principal company is purely from the practical purposes of the study as the theoretical framework is already fully known to the principal company.

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