Status and further work
Results from WP1 in the SAMBA-project
# Report

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Summary

This report summarizes the results of work package 1 (WP1) of the SAMBA-project. The main activities in WP1 were three workshops involving all partners in the project. The aim of these workshops was to get an overview of both the status and future needs concerning asset management in Statnett and of the research, methods, tools, systems and experiences within asset management of the industry and research partners.

The main results of WP1 are:

- An overview of status and future needs concerning asset management in Statnett.
- An overview (not complete) of data available in Statnett.
- An overview of what the industry and research partners can offer for asset management.
- A prioritization of the components the SAMBA-project will further focus on: transformers, circuit breakers, voltage transformers, overhead lines and cables.
- Recommendations for further work, including use case ideas to be investigated further in the SAMBA-project.

The status and future needs of Statnett concerning asset management are related to the maintenance of critical assets, high-level reinvestment decision-making and ICT. This report constitutes the starting point for the identification of use cases that are relevant for Statnett and will be further developed in WP2.

Chapter 6 of the report details some of the thoughts Statnett has for the future related to ICT and on different solutions for use case testing within the SAMBA-project. It is common understanding that data needed for smart asset management is not easily available, available at all or in a suitable format and time resolution. The description and testing of use cases in SAMBA will aid parts of the development of both the future asset management and the supporting ICT-solutions in Statnett.

Successful asset management is dependent on organization and management of people and processes. A culture of quality and continuous improvement can be created when those involved understand their roles and responsibilities and trust the data and the methodology used. To achieve acceptance for the analysis process and confidence in analysis methodology and tools used, the analysis process and background data must be open and accessible to all people involved.

The SAMBA-project will provide important parts to the puzzle that makes up the future asset management in Statnett. The project work continues with WP2, focused on the development of use cases that will be tested in WP5. WP3 and WP4 will work on data models and ICT-architecture to support asset management based on information from the use case descriptions and testing. WP6 will provide a feasibility study for a risk monitoring centre in Statnett. This feasibility study will investigate the different functions and tasks that can be included in such a centre and the potential benefits for Statnett.
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<tr>
<td>FASIT</td>
<td>Faults and interruptions in the power system (Feil og Avbrudd i Kraftsystemet)</td>
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<td>FOS</td>
<td>Regulations for system operation (Forskrift om systemansvar i kraftsystemet)</td>
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<tr>
<td>FOL</td>
<td>Regulations for quality of supply (Forskrift om leveringskvalitet)</td>
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<td>ICT</td>
<td>Information and communication technology</td>
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<td>NVE</td>
<td>The Norwegian Water Resources and Energy Directorate</td>
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<td>OLTC</td>
<td>On load tap changer</td>
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<td>SCADA</td>
<td>Supervisory control and data acquisition</td>
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<td>TSO</td>
<td>Transmission system operator</td>
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1 Introduction

1.1 About this report

This report summarizes the findings from work package 1 (WP1) of the SAMBA-project and gives direction for further work based on the user needs of Statnett, available research results and tools and systems available from industry partners.

First, some information about the SAMBA-project is given. Then, the R&D challenges and scientific method of the project is outlined. In Chapter 3, an overview of user needs is provided, while Chapter 4 presents status for asset management, fault analysis, information- and communication technology (ICT) and condition monitoring of components in Statnett. The mapping of the status for asset management in Statnett is essential to know where to start the work to improve asset management in Statnett. The overview of the ICT structure and available data will be the bases for the use cases to be described in WP2 and tested in WP5. Then, information about asset management research, solutions and systems from industry and research partners is provided. The SAMBA-project aim at being both realistic about what can be tested within the project and at the same time keeping future needs in mind. The future asset management of Statnett should not be limited by choices made today, for example by choices made for ICT-solutions. This report aims at both describing the new possibilities that are relatively easy to implement and those that have a longer time horizon. These new possibilities is summarized in Chapter 6. Chapter 7 relates asset management to organisation of processes within the company. Some remarks about way of work and recommendation for further work are given in Chapter 8 and 9.

1.2 Underlying idea of the SAMBA-project

Asset management in Statnett can be improved by utilizing new developments in ICT, such as big data technology, data fusion and business intelligence. The underlying idea of the project is to use these generic ICT-developments together with existing domain research results (such as models on ageing and lifetime of power system components) to establish a reference architecture for data collection, communication and handling. This can optimize maintenance and reinvestments through facilitating a more efficient analysis of incipient failures, ageing mechanisms and remaining lifetime of power system components.

Today, existing research results on ageing models and data from monitoring systems are not applied in a structured manner for asset management purposes. This is partly because ageing models and condition data are not fully integrated into current data analysis systems, and partly because data required to utilize models is not readily available. Optimal maintenance and reinvestment in the Norwegian transmission system have a large potential for savings as the need for reinvestments is increasing, because the current asset base of Statnett is ageing. In addition, a large number of assets in varying conditions will be transferred to Statnett from distribution system operators (DSOs). The challenge is to collect relevant data and make it available on an integrated platform for asset management purposes. The aim of such an asset management system is to utilize data and information for condition assessment of individual components and the whole fleet/grid. This will require that data from a variety of sources is made available for specific analyses enabling predictive, risk-informed maintenance and reinvestment decisions.

The industry partners GE Grid Solutions, ABB and IBM have know-how on component design and asset management systems that they can provide to the project. They will in the project learn about Statnett’s specific needs, and also about relevant research results from SINTEF Energy Research (SINTEF ER) relevant

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1 Asset base of Statnett is increasing due to the European Union’s Third Energy Package and corresponding changes in the Energy Act - making Statnett the sole owner of the transmission network.
for their products. The SAMBA-project will be an arena for open discussions in a pre-competitive environment.

The project will develop a system architecture for the future asset management system of Statnett. The project results include data models and analysis methods for big data driven asset management.

The underlying idea can be illustrated by one of the planned use cases, see Chapter 2 for information in use cases. There exist models for calculating life consumption for power transformers. The model requires data input such as water content in insulation, historical data on temperature stresses, and design information. However, historical temperature data is difficult to get today. Therefore, as an alternative to measured data, one has to use thermal models for transformers and knowledge of seasonal temperatures and historical loads to calculate life consumption. This can be improved when calibrated temperature data becomes available from the SCADA-system, together with other types of data from diagnostic and component databases. Then, this data could easily be used to automatize life estimation for individual transformers and the whole fleet. The approach could be further improved by using data from online water in oil sensors and other information from, e.g. scrapping of old units and external stresses like short circuit currents and overvoltages. This example illustrates the transition from indirect solely individual asset management to big data driven fleet asset management which the projects aims at facilitating.

1.3 Potential for value creation for Statnett in the project

There exists a non-utilized potential for added value in the management of Statnett’s fleets of components by activating more online, automatically collected data in condition modelling. In Figure 1 the increased value of increasing experience/complexity of analytics. The aim of SAMBA is to aid the Statnett’s journey from descriptive analytics towards prescriptive analytics:

1. Descriptive analytics: What happened? The analytics comes after an event and focus is on the event itself.
2. Diagnosis analytics: Why did it happen? The analytics comes after an event and focus is on the root causes of the event.
3. Predictive analytics: What will happen? The analytics comes prior to an event and focus is to find out what can happen.
4. Prescriptive analytics: How can we make it happen? The analytics comes prior to an event and focus is to find out what the best possible result is and how this result can be achieved.

The SAMBA-project will unleash this potential through close cooperation between Statnett, industry and research.
The main value creation from the SAMBA-project will be within Statnett. Improved and more efficient maintenance and reinvestment will yield large socio-economic benefits. Even if the transmission system is an ageing infrastructure, with an average age approaching 40 years, many of the assets still have a potential long remaining life if well maintained. Presently, Statnett has 142 transformer stations, 10500 km overhead lines and 1000 km HVDC cables. During the next years the cost of reinvestments and large maintenance operations will be of approximately 2 billions per year, illustrating the importance of correct reinvestments. In addition, the transmission network can become more robust as continuous monitoring might expose failures under development and thereby unwanted consequences of failures can be avoided. The SAMBA-project enables Statnett to transform into a data-driven organization for better predictions and analysis for asset management. The transmission network is a critical infrastructure for the modern society evermore dependent on a reliable electricity supply. Statnett can improve security of supply due to improved risk assessment and decision making regarding maintenance and reinvestments [1]. The restructuring of the asset management system and introduction of a new data handling structure for a TSO is a large and costly task. The experiences and lessons learned in the SAMBA project will reduce the risk exposure when building and procuring these systems.

1.4 About the SAMBA-project

SAMBA project is a 3-year research project funded by the Norwegian Research Council Energix program and will continue throughout 2018. Statnett, IBM, ABB, GE Grid Solutions and SINTEF ER are partners and contributors in the research project.

Main idea of the project:

- There is data in Statnett’s systems that can be retrieved and put together to provide better information about the condition, development of condition and residual life of components
- There are models and methods for condition and lifetime assessments, but today these are rarely used due to missing and incomplete data
  - Industry partners have systems that can be tested on data from Statnett
  - Research partners have methods and models that can be tested on data from Statnett
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The SAMBA-project will extract data, analyse the data and get results in terms of condition estimates, residual lifetimes, risks and optimal timing for maintenance and reinvestment. Large-scale utilization of information will require new ICT solutions in Statnett.

This project is important for Statnett due to aging of assets that increasing the need for reinvestments and by the many new capacity increasing projects. The overall aim of asset management is to be able to answer the questions below. The SAMBA-project aim at improving Statnetts ability to answer these questions:

- How is the condition of the components right now?
- How will the condition of the components develop in the future?
- Are we doing the right maintenance at the right time?
- When should we replace the components?

Project structure

The project consist of eight work packages (WPs). The progress plan and name of the WPs is shown in Figure 2.

![Figure 2: WPs in SAMBA and progress plan.](image)

The aim of this work package 1 is stated in the project description [2]:

"Describe state-of-the-art and user needs regarding asset management utilizing big data, as well as possibilities for using integrated systems for capture and adaptation of state information for analysis. Workshops with all project partners will be carried out in order to review state-of-the-art and previous research results on established methods as well as various vendor systems and what functionality these can cover separately and systematically implemented. The objective is to identify the gap between existing practice and the available methods and vendor systems and possible new applications given that the compilation of information from various data sources is available (big data)."

The project have decided to focus on the following components:

- Power transformer
- Overhead lines/cables
- Voltage transformers
- Circuit breakers
The SAMBA-project refers to both data available in Statnetts systems today and new data which will be available in the future. This includes both structured and unstructured data (i.e. documents). The project aims at using available data in the applications of methods and models for different asset management purposes and give advice on what new data to be collected in order to take into use more advanced methods and improve asset management decision making. The recommendations on new data to be collected will be the result of the use-cases to be developed in the project. The recommendations will also reflect the trade-offs regarding the value of new information versus the costs of acquisition and data storage.

The data already available might not be in a format, rate, location etc. that is desired/requested by the methods and decision support tools available; hence, the project will give advice on how this should be done in the future. Data needs and future growth areas that will be looked at in SAMBA:

- Collection of time series for analysis (historic data)
- Online analysis of data (real time)
- Combing multiple sources of data (internal and/or external)
- Exchange of data with external actors/sources
- New/additional sensors (more advances/intelligent – including analysis, aggregation, storage etc.)
- New ways to analyse data with the help of 'big data' techniques

All of the above-mentioned factors will change how asset management is performed at Statnett and affect the ICT-solutions chosen. Big data in Statnett might not be large compared to other industries, but the amount of data that will be made available and the analysis of data will have a large impact on asset management processes.

The hypothesis of the project is that the Big Data concept as an underlying technology can support Statnett’s need for complex analysis, advanced data processing and storage, and the future need for high volume, high variety and near real-time analysis. The project will test the parts of the Big Data concept that will be useful for Statnett’s future asset management.

This will include:
- Analysis to estimate and predict the current and future condition for a fleet of components based on data from operation, inspections, measurements and external data, such as meteorological data
- Analysis of historic data
- Predict failures based on measurements, past experience and meteorological forecasts

Future-oriented and adaptable ICT-solutions are crucial to support this development. In parallel with the SAMBA-project, the ICT-organization in Statnett is mapping the master data of the organization and this mapping is important input to the SAMBA-project.

Work package 1 and 2

Three workshops were held in WP1 to achieve the above-mentioned objective, with the following topics:

1. Presentations from Statnett and SINTEF ER:
   - Current practices related to condition monitoring and maintenance in Statnett today
   - Current practices and processes related to reinvestment decision-making in Statnett today
   - ICT related to asset management in Statnett today
   - Future needs of Statnett
   - Methods and models: transformer ageing, failure modelling and decision making
2. Presentations from the industrial partners about their systems and solutions
3. Presentations and discussions, based on questions sent out prior to the workshop, Appendix V1, one-on-one between Statnett and industry partners on the topics:
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- Components
- Fault analysis and asset management
- ICT

The project will continue with the development of use cases in WP2, using three main principles:

- Explore and exploit data already collected by Statnett today:
  - Activities that will yield "easily" available improvements for Statnett ('low hanging fruits') will be started as early as possible in the project to get as much benefit as possible out of the data available.
  - In addition, other relevant issues for Statnett will be described as use cases in WP2 and some selected use cases will be tested in WP5. The use cases to be tested will be selected based on their importance in the asset management context but also on the resources and data available. Some of the use cases will include models and methods for condition and lifetime assessments from research partners as well as software platforms that industry partners would like to share for testing. The use cases involving the industry partners will have to comply with the information security requirements of Statnett (especially if testing is to be done outside Statnett).

- New data sources or changes in current data collection schemes (sampling rates, storage, forms for inspection data...) might be needed to test use cases. Implementing changes in data collection can in some cases be easily done, as changing sampling rates, while other changes, as new grading schemes for inspection data, will include changes in processes and routines at Statnett, and will take more time. The testing of use cases requiring organizational changes will be limited, but the potential benefits for Statnett will still be illustrated. The recommendations from the project on new data or changes in data collection will still be valuable for Statnett.

- Test if the new possibilities introduced by the big data concept and underlying technology has benefits for the enterprise in terms of new types of analysis, new ways of collecting data, new ways of comparing data from different sources and how near-realtime analysis can be utilized. New approaches to asset management for Statnett as new data provides new possibilities, not just automation of manual tasks. Maintenance and reinvestment routines and decision-making processes will probably be affected by new data.
2 R & D challenges and scientific method

The complex research challenges in this project are specific to the transition towards the Smart grid. The European Smartlife-project concluded that management of ageing networks and the evolution towards smart grids require the optimization of network asset management and rely on in-depth knowledge of ageing mechanisms, a useful characterization of equipment performance and relevant asset management processes. This can only be done via widespread collaborative exchanges among utilities and R&D [3]. The SAMBA-project will use the Smart Grids Architecture Model (SGAM), see Figure 3, from CEN-CENELEC-ETSI Smart Grid Coordination Group to describe the projects central R&D challenges and scientific methods [4].

The project is concerned with transmission networks (domain\(^2\)) and asset management (enterprise zone\(^3\)) using data from all underlying zones (from sensors, relays, substations etc.). Hence, the data exchange between the zones will be a research task.

The SGAM framework consists of five interoperability layers representing business objectives and processes, functions, information exchange and models, communication protocols and components. Interoperability is an important issue and research challenge in smart grids [5]. This is also important in the SAMBA-project and integration of different data sources within the TSO (between zones) will be an important research task. This can also be useful in other activities handling the dataflow between the domains (not main activity in SAMBA-project, but data on i.e. asset condition will be more readily available for other actors, like regulator, as a consequence of the project).

The component layer covers the physical infrastructure; electrical components, sensors, networks, routers, computers and so on that form the basis for any form of communication and information gathering. Gaining an overview of this layer will be a starting point for the project. In the communication layer different protocols are used to send and receive data between components. However, just enabling better communication does not guarantee that useful information is exchanged.

The information layer describes the data models and information objects included in use cases in order for the information to be interpreted correctly when testing use cases. A datamodel using open standards (i.e. CIM) will be specified in the SAMBA-project. In an EU-report [5] it is stated that "an open and secure ICT infrastructure is at the core of the successful implementation of the Smart Grid. Addressing interoperability, data privacy and security are a priority requirement for making the ICT infrastructure truly open and secure and reducing transaction costs among Smart Grid users." Hence, the project is addressing important European research tasks. There are also significant gaps detected in standards and datamodels for asset management [6], [7]. Big data technology and business intelligence will be used in the testing of use cases. Big data technology will bring intelligence to asset management utilizing many different data sources in a coordinated manner.

In the function layer in Figure 3 functions and services are represented as use cases independent of the physical realisation in systems and components. The level ensures that the right information enters the right process and the right actor. This represent a large research challenge, as information must enter the asset management of Statnett, a high level process in any company.

\(^2\) Domain - complete electrical energy conversion chain
\(^3\) Zone - represent the hierarchical levels of power system management
Use case will be an important scientific method in the SAMBA-project. A use case is a description of the interaction between one or more actors, represented as a sequence of simple steps [9] and is a well-recognized tool used to describe what you want a system to do, but not how to do it. A use case will have focus on the actors (persons, systems, components, databases) involved and their interaction to bring about the wanted results. Use cases developed in the project will illustrate the connections between input data, ageing models and decision-making. Hence, an important research task will be to get an overview of the available data and decide what can be used as input into existing models to improve asset management.

This will probably reveal needs for more/different data and any shortcomings of the models, but development of new models is not included in the project, just improvements and adjustments. The inclusion of expert knowledge and possibilities for continuous learning are challenges that will also be a research task. The business layer represents the exchange of information in smart grid from a business perspective i.e. related to business models, processes and aims. The business layer in the SAMBA-project is Statnett’s business as the system operator of the Norwegian power system. Statnett is also responsible for a socio-economically efficient operation and development of the transmission network. The SAMBA-project will aid this by improving asset management in Statnett.

The scientific objectives are ambitious as the data sources are many and the formats used vary. The ability to gather all the data needed in a useful format constitutes a risk. Hence, the project will start with components with the most established ageing models and measuring schemes, like transformers and circuit breakers.
3 User needs overview

This chapter provides an overview of the main user needs for asset management, as shown in Figure 4. The use cases to be developed in WP2 will be build up to include some of or all the elements shown in the figure, including the specific ICT requirements. A well-designed and well-functioning ICT-architecture (illustrated by the light blue boxes) should be able to tie all the elements together and is a premise for the asset management platforms of the future. Data must be collected, exchanged, aggregated, presented, visualized and stored to fulfill the need of the users.

Figure 4: Elements in asset management.

The elements surrounding the ICT-architecture are shortly presented below, starting in the upper left corner.

Asset condition monitoring

Asset condition monitoring requires measurements and other types of data that can be recorded. The monitoring provides raw data for the assessment of the technical condition and the remaining life of components in the asset condition analysis. Some of the user needs related to asset condition monitoring were clearly stated in the first workshop of WP1; easy access to data from condition monitoring and integration of new data from new sensors to be installed on some types of components. In addition, unstructured data, in the form of i.e. inspection reports, should be combined and processed and made more accessible for analysis. For example, some sort of quantification (e.g. grades from 1-5) of the condition of the components onsite based on inspection data and expert judgment would improve the use of condition data in maintenance planning and management, and it will improve the quality of the analyses made for maintenance and reinvestment decision making.

Failure event monitoring

Failure event means component failure due to poor technical condition, the stresses on the component or a combination of the technical condition and the stresses. Failure event monitoring includes here both detection of component failures and events that have caused component failures or may have only weakened the technical condition of components. Such events are electrical and mechanical stresses due to
lightning strikes, short circuits, ice formation, conductor gallop, human mishandling, etc. Information about such events in the past is important for the analysis of the cause of failure after failure has occurred. It is also important to include such information when estimating the probability of failure. Upon component failure, information concerning the consequences, failure cause and current stresses should be stored. Consequences include repair time, repair costs, energy not supplied and costs of energy not supplied (CENS).

**Maintenance management**

Maintenance management includes maintenance planning, execution and reporting. Visual inspections and simple measurements of components' technical condition conducted manually are part of the maintenance. Reports from inspections and measurements can be both structured and unstructured information.

Reliability Centered Maintenance (RCM) analysis is used to decide how to maintain the assets. The RCM analysis needs updated information on the condition development and analysis of the effect of maintenance actions. The effect of maintenance can be measured with indicators such as i.e. number of and types of failures, share of corrective and preventive maintenance and share of costs for corrective and preventive maintenance. The indicators can be computed and displayed automatically.

**Asset condition analysis**

Different types of analyses can be made based on information related to the condition of components or groups of components. Health indexes can be computed based on weighing of different data to assess the current condition. In addition, degradation trends to predict the development of the condition can be made (typical development, deviations from a typical development, statistical analysis, etc.). For analysis purposes, data needs to be available as well as an analysis platform and analytic tools. The analysis themselves must be documented and stored properly. Additional data about the condition of components taken out of service, regardless of the reason for taking it out of service, is very important and should be also collected when available, stored and easily accessible for further processing.

**Failure event analysis**

Power system disturbance analyses and power quality measurements analyses are performed with an increasing amount of data. In addition, disturbance reports from external actors are collected, analysed and presented. All these analyses require a lot of data from both in-house measurements and external data. Further development is dependent on suitable data handling structure for big data. The data input to failure analysis today can also be input to condition assessments for improved planning of maintenance and reinvestments tomorrow. It is a user need to describe and implement routines for providing the improvement suggestions in the right form (adapted to the needs of the recipient) and to the right person in the organization.

**Risk analysis**

Risk at different levels (company, transformer station, individual components) and at different time scales (current risk (operational) and future risk scenarios (for decisions on maintenance and reinvestments) must be identified based on available information (probability and consequence) and the level of uncertainty shown. Risk analyses must be performed, updated, stored and made accessible together with other types of data in order to be able to justify the decisions made. Risk indicators must be enabled in order to check the validity of the estimates.

A further step compared to asset condition monitoring is to monitor risk by online updating of risk analyses based on information from condition monitoring. Operators in a future risk monitoring center will then have access to the current risk situation. When critical risk reach certain levels operational changes can be made in order to reduce the probability of failures and the corresponding risk. Operators can also get information
on how the planned operation of the grid and the expected stresses on the components due to operation and weather influence the future risk. Easy access to such risk information is important for the planning of the grid operation in advance of periods with reduced transmission capacity due to maintenance, increased probability of failures due to bad weather, and lightning activity, etc.

**Renewal cost-benefit analysis**

Such analysis requires, in addition to information from asset condition analysis and risk analyses, information on relevant renewal alternatives and the cost of these alternatives. More maintenance is often an alternative to renewal and thus in order to be able to compare different alternatives their benefits must be estimated and documented, as must the result from the analysis. It is important to measure if the estimated benefits are met, hence relevant indicators must be identified and followed up. This with the aim of learning and doing better analysis next time. Maintenance information should be used to update renewal analysis and vice versa. Easy access to maintenance cost-data and standardized cost databases common for all investment and reinvestment decisions should be enabled across Statnett’s departments.

**Failure model creation**

Failure models are the key module in the estimation of probability of failure and the related risk. A failure model includes elements that have major influence on the degradation of the technical condition and the relation between the technical condition and the probability of failure. It also includes the consequences of failures and the estimation of risk based on the probability and the consequences of failures. Consequences are in terms of costs, poor quality, personal injury, environmental damages, loss of reputation, etc. The degradation processes relate to given failure mechanisms. The physical design will often be decisive for whether a failure mechanism is significant for a given component. Various external and operational stresses influence how fast the technical condition deteriorates. Figure 12 in Chapter 0 shows a generic failure model with the mentioned elements. The creation of failure models are based on expert judgement and statistics regarding degradation and failures. Information from asset condition and failure event monitoring is the foundation for updating the failure models.

**History/statistic creation**

Historical data is information from asset condition monitoring/analysis, failure event monitoring/ analysis (including events that have caused major stresses), maintenance management (including work on components and visual inspections), circuit breaker switching operations, load and voltage measurements, etc. History and statistic creation is to organize and present historical data for different user needs. This includes creation of historical trends as well as estimates or forecasts of future trends based on historical data. Visualization in terms of dashboards etc. is important to make the information conveniently available. FASIT (failure statistics), based on data from failure event monitoring is an important example of useful statistics for asset management. Creation of statistics do include combining information from different kind of data sources, e.g. failure events and weather data for the periods before the failure events.

**Renewal plan creation (projects)**

Renewal plans comprise maintenance and reinvestment projects with different time horizons (short, mid and long term). A renewal project can include single components, group of components and even a whole station. Each project is a result of risk and cost-benefit analyses aiming to produce all relevant information for the decision process. Such information is e.g. future economic risk with/without the project, total costs, optimal timing, net present value (profitability) and sensitivity with regard to critical assumptions. The risk and cost-benefit analyses are performed for different renewal alternatives that give acceptable solutions to the renewal need. The renewal plan creation is to sort and prioritize renewal alternatives within the time horizons. Prioritization criteria may be budget restrictions, profitability, risk requirements, risk profile, etc. Application of fleet management methods and tools can be useful for the renewal plan creation.
Renewal strategy creation

Renewal strategies are both general and specific recommendations and decisions regarding maintenance and reinvestments related to e.g. given assets, technical condition, failure history and risk requirements. A given kind of switchgear of a given age (or technical condition) in a given environment shall e.g. have a maintenance program according to a specified strategy. The replacement time for the same kind of assets is e.g. when the degradation of the technical condition has reach a certain level. The renewal strategy may specify which kind of design/make that shall be selected when assets are replaced. The creation of renewal strategy for group of assets includes risk and cost-benefit analyses based on information from similar assets.

SCADA

The SCADA-system today provides operational information that is important for the asset management, e.g. circuit breaker switching operations, load and voltage measurements, protection relay signals, temperatures and alarms. This information have to be made easily accessible.

External data

Data from component vendors about failures, design weaknesses and failure statistics can be used in risk analysis and statistic creation. Fosweb is a system that Statnett uses to get failure and component data from owners of production units and transformers. Other external data relevant for i.e. failure event and risk analysis is meteorological data from MET Norway.

Exchange data

Data exchange between Statnett and distribution companies or TSOs of other countries increases the data foundation for asset management. Consultants, service providers and vendors may need data from Statnett when they perform condition assessments and analyses for Statnett. Security is an important issue related to data exchange between Statnett and external bodies.
4 Status for Statnett

4.1 What does Statnett do today?

Asset management

Asset Management in the Operation & Market division consists, as illustrated in Figure 5, of several processes i.e.: maintenance and renewal, outage optimization, investment planning and grid operation. All these processes provide and utilize an ever-increasing amount of data, which is not used today at its full potential. The data is both structured and unstructured, and stored in different systems. The challenge is the capacity of both the systems and the resources and capability (lack of methods) to use data in a structured manner. There is a lack of a holistic approach to predictive analyses and continuous improvement and many of the issues depicted in lower part of the figure below are not done or not done systematically at this moment in Statnett.

Figure 5: Asset management in Statnett.

The processes within asset management today in Statnett are:

- The process for updating the asset management plan (PFA), described in Figure 6.
  - The plan includes maintenance and reinvestment strategies for 10 years ahead and a macro analysis of reinvestment needs within a 40 years' time perspective
  - Updated every second year
  - The process includes dialogs with the regional asset managers and maintenance teams and the final plan/strategy is more or less manually assembled. These dialogs/coordination meetings are
being held for all substations and overhead-line departments. During the meetings, the available, relevant data is reviewed and the assets considered for renewal are analysed with respect to risk.

- A considerable amount of time in the process is dedicated to data collection and processing, development of methods for renewal analysis and strategy making.
- Renewal decisions are coordinated with other investment (capacity increase) decisions affecting for example the same substation.

![Figure 6: Process for the work with the Asset management plan.](image)

- The maintenance management process:
  - RCM-analysis is the basis for the maintenance plans
  - Planning and execution is well defined where important interfaces towards other processes, such as outage planning/optimization and projects, are covered
  - Maintenance performance is monitored through specific indicators
  - Maintenance information is today not used systematically to check if maintenance is efficient, changes are needed or to improve RCM
  - Maintenance information, including information about component failures, is not systematically used to estimate components’ condition, probability of failure or remaining lifetime.

- Renewals (reinvestments) are mostly time/age based, with corrections from experience and fault analysis, and are also coordinated with other activities:
  - Statnett has prepared strategies for every main component group; transformers, circuit breakers, disconnectors, compensation and control systems. These strategies specify recommended intervals for component replacement based on expected lifetime
  - The process regarding reinvestments is well defined, but have a potential for improvements for example by using data from performed maintenance, and reinvestment projects, in a structured way to improve the decision support

- D&M projects (5-year plan) – Smaller reinvestment and maintenance projects are done within an annual estimated budget. These projects are planned annually and are part of the 5-year plan process. The projects to be executed each year are prioritised based on condition assessment using operational experiences.
**Fault analysis**

The aim of fault analysis in Statnett is improved reliability in the Norwegian power system. Scope for fault analysis: Improvements in system operation, maintenance, reinvestment planning, technical standardization, procurement etc. Fault analysis was required by regulations since 1994 (FOS §22 since 2002).

Fault analysis department performs on behalf of asset manager / grid owner:

- Power system disturbance analysis
- Power quality measurements, reporting and analysis (FOL)

As system operator (TSO):

- Collect disturbance reports from / collaborate with other grid owners / power producers / industrial customers
- Present statistics and results from national fault analysis
- Functionality analysis for grid and power generation assets

The bow-tie model is the main principle for fault analysis see Figure 7.

*Figure 7: Bow-tie model.*

Disturbances produce (increasing amounts of) data and a typical challenge is acquisition and sorting of relevant data, analyse and then decision-making / adjust barriers. Today sorting and analysis of failures is largely performed manually. AutoDIG, see Figure 8 has been made to enable a better and more advanced fault analysis. AutoDIG performs automatic acquisition of relevant data after a power system disturbance as well as data processing and (partly) automatic analysis. Results are presented to analysts in an inter-active graphical user interface. The green boxes in the figure below are used in AutoDIG today, while the boxes with dotted lines are relevant future interfaces. AutoDIG is a part of the existing asset management system landscape in Statnett, see Figure 9, and one of several systems that are relevant in a SAMBA context.
Components

This chapter summarises the discussions during workshops regarding power systems components and the maintenance and reinvestment approaches that Statnett have today.

Transformers:

- The remaining life is estimated based on information regarding moisture in paper, furans, increase in fault gases, acid number, age (years in service) and the different parameters are weighted. This gives an idea about the remaining life, but it is not done systematically.
- Maintenance is decided on the basis of RCM and statistical data about failures
  - OLTC maintenance is done after 7-8 years or 30,000-90,000 operations, dependent on manufacturer.
  - Oil maintenance is condition based
  - No measurements on OLTC or bushings
- Statnett uses a mixture of manual and remote readings of measurements and sensors.

Voltage transformers:

- There are 1-2 items every 2-3 year in general, with change (increase/decrease) in secondary voltage. These voltage transformers require either replacement or closer follow up.
- Condition monitoring is done in the form of inspections and measurement of secondary voltage
- In addition to the manual measurement of secondary voltage, remote voltage measurements is also used to look for deviations (challenges breaker position and busbar configuration)
- Remaining life is estimated on the bases of service age (limit is 30 years) and number of operations – some differences due to different manufacturer and experience

Circuit breakers:

- Measurements or observations showing errors or unwanted events initiate further (maintenance and inspection) actions
- These components also have a time-based preventive maintenance in the form of condition monitoring (inspections) and changing of filters
- Remaining life is estimated on the bases of service age (limit is 40 years) and number of operations – some differences due to different manufacturer and experience
• Collecting data from disturbance recorders, fault clearance – automatically – in order to analyse failures

Powerlines and cables:

• Powerlines:
  o Maintenance mostly consists on inspections; reports are prepared when errors or non-conformities are found on the site. These are classified based on the level of severity, and placed in categories 0, 1, 2 or 3.

• Cables:
  o Collecting data from the cable systems
    ▪ Gas insulated and fluid filled sealing ends (terminations): Pressure data is monitored and logged. The purpose is to check the function of the termination. The data does not give information of the expected lifetime for the termination.
  o Oil samples from fluid filled cables and fluid filled terminations
    ▪ This is part of the status check and maintenance of fluid filled cable systems. The samples are taken manually by our maintenance personnel and checked by suppliers of chemical analysis. (i.e. this is not part of the data collecting work, but part of the maintenance of the cable system).
  o Temperature monitoring
    ▪ On the submarine cable system Ytre Oslofjord temperature is measured along the cable. This measurement amounts to a great collection of data. The data is used for checking the status of the cable in the seabed (submerged in soil) and that the cable is not overloaded.

**ICT**

Statnetts ICT-support for the above-mentioned areas has been developed over time, in form of different information systems, and often based on a peer need – approach. See Figure 9 for the asset management ICT-landscape.

*Figure 9: Asset management system landscape.*
The kernel of the asset database and asset management functionality is in the ERP-system IFS, but most of the analyses done in a series of additional tools which combined solve most current user needs. However, the analyses are fragmented and mostly have different logic for data collecting and storage. The current architecture is not a good basis for growth. The largest data storage is a traditional data warehouse with a BI-tool on top. Today Statnett has not realized any of the possibilities that are believed that big-data-concepts can provide. An exception from this is the GIS (map visualisation) tool.

The most important systems for asset management are IFS, SYSBAS and FOS. In addition, there are a number of fault analysis systems, which are also important for asset management. Those include AutoDIG and FASIT. Innsikt as a common analysis platform naturally plays an important role for Asset Management. His Web stores historical data.

Among other systems, it is important to mention TPV, TKP and BiCycle. TPV-T ("Total Planning Tool") database is practically a "mirror"/reflection of IFS, shows all our stations, with switchgear in all voltage levels and all components/equipment with technical data and age. Equivalent for overhead lines and cables. The tool generates "equipment replacement measures" based on age of the different type of components. TPV-P (project module) gives an overview of activities and is used to group activities together, manually.

4.2 Data collected today

The same data is not necessarily collected for all components of the same type. This could be due to age of component (newer components have more monitoring equipment) or that some components have been prioritized to have additional monitoring equipment installed, due to i.e. bad condition and/or high importance. Tables providing an overview of data collected today can be found in Appendix V3. These tables are not complete, but will be completed as a part of WP2 and WP3.
5 Industry and research partners

The three industry partners presented their systems and solutions for asset management in workshop 2 and the systems were discussed in more detail in workshop 3. A complete overview of the systems of the industry partners is out of scope for this report, but two of the industry partners have contributed to this report in the next sub-chapters. In addition, a brief overview of research done by SINTEF Energy Research related to asset management is presented.

5.1 IBM

5.1.1 Analytics implementation roadmap

For any organization, on any larger analytics implementation, the roadmap is vital to take care of the evolving the technology capabilities, dependencies, constraints and issues in a matured and feasible way. While business priority drives the necessary technical requirements in the organization, the individual technical block within it should follow its own organic life cycle. The roadmap should have:

- Foundation capabilities and allied framework processes should be defined first. Though not limited to, it should cover infrastructure, security, system management, data management, common integration tool and framework etc. As in analytics implementation, data is vital; the second priority goes for data. A right futuristic approach should be taken in choosing the tools and technologies that can support the growing volume, variety, velocity & veracity of data in the due course of time.
- Necessary technology capabilities milestones (Data, BI, Analytics, Visualization etc.) identified & plotted against the timeline. Individual capability should be further broken into sub-level categories to show the steady and matured capability growth
  - Data: Data Profiling > Data Modelling > Data Governance > Data Dictionary & MDM
  - Analytics: Descriptive > Predictive > Prescriptive > Cognitive
  - Visualization: Reports > Dashboard > Interactive > Self Service

Business Use cases should be plotted against the timeline in parallel to technology roadmap so that any dependencies can be taken care of further.

The Analytics Journey

IBM believe that utilities need to disruptively innovate, through analytics-driven operational excellence. The best starting points for this journey is an enterprise level analytics roadmap. Many utilities are already developing enterprise wide analytics roadmaps across a variety of business domains, and IBM helped small to larger utility companies to define and implement analytics solution for their various line of business. This journey will take the company to the highest level of analytics maturity level, where operation excellence is achieved completely, see Figure 1.

IBM analytics platform crosses the IoT and Analytics boundaries, which supports end-end solution from Descriptive analytics to Cognitive, the highest maturity level. The platform is capable of supporting veracity, volume, variety and velocity of the data.

An IBM analytics platform is outcome based analytics solution to achieve operational excellence, which is completely data driven analytics with the specialized models for different asset class.

For more details [10].
5.1.2 IBM Insights Foundation for Energy (IFE)

Energy and Utility companies need to disruptively innovate business processes through analytics driven operational excellence. Insights Foundation for Energy helps utilities deliver affordable, reliable and sustainable energy by:

- Providing actionable, enterprise-wide advanced analytic insights with pre-integrated applications.
- Increase the efficiency of operations and maintenance.
- Optimize network availability.

IBM Insights Foundation for Energy helps energy companies improve planning, construction, operations and maintenance. The solution helps advance predictive based, reliability centered maintenance.

- Extends the life of assets and/or defer maintenance by monitoring the health of assets in a risk assessed and safe way.
- Maintains reliability and availability by reducing the number of outages on the network required for maintenance.
- The solution is a planning tool for long term, strategic asset related capital allocation planning.

The solution is a single foundation for analytics across the energy enterprise. It is a strategic, extendable platform that unifies systems and business processes across the energy company. Open and extensible foundation: Insights Foundation for Energy enables an application ecosystem from IBM and Business Partners. Used by industry leaders such as National Grid and DTE Energy, Insights Foundation for Energy is available as both an On Premise solution as well as On Cloud (Softlayer footprint in Norway) / Software-as-a-Service (SaaS).

IFE is part of Watson IoT: The IBM Watson™ Internet of Things (IoT) Business Unit unites the Internet of Things with IBM Watson cognitive computing technologies to help our clients infuse a new kind of thinking into objects, systems and processes. These things are talking to other things, learning from other things – and talking to us. More information on Watson IoT can be found on [11].

The following sections describes the IFE applications currently available on the IFE platform. These applications leverage a set of IFE services and IFE building blocks. Such means allow either to customize these existing applications or to develop new applications. As an example, a connector has been made available in the last release of the IFE platform for integrating with The Weather Company, such that any IFE application can benefit of weather forecasting or weather history information to feed analytics models. Further information on available IFE services and building blocks can be found in [12] and [13].

Asset Health and Network Risk Application

Asset Health assessment uses a predictive decision tree to help you do an in-depth analysis of the many factors affecting an asset’s lifespan. This is based on the following functional features:

- Correlate and Visualize data from multiple data sources, such as: SCADA, AMI, GIS, EAM, Inspection Logs, Work Orders,
- Models for Substation and Distribution Transformers, Poles, Overhead and Underground cables, as well as other types of assets planned for near future such as Voltage Regulators, Disconnect Switch, Fuse, Breakers, Reclosers, Sectionalizers, Circuit Switchers
- Blend models from 3rd Party/Custom Analytics
- Review evidence to support findings and Rate Case proposal
- Advanced Analytics for root cause analysis
- Review Asset Master and Work Order history
- Optimized Treatment Recommendations
- Cluster Analysis and Work Prioritization
• Feed Asset Investment Planning

**Network Risk**

Assessment provides interface to network risk assessment result, including current and predicted asset failure probability, consequence and risk. This service is supported by backend GRID engine and composite failure probability model, the model analyses the failure probability and risk in the context of grid connectivity, considers the cascading effect of all downstream / upstream / circuit level assets in the network.

**Situational Awareness**

Situational Awareness provides a geospatial view of assets. Situational awareness seeks to identify asset anomalies and alert operators to act before cascading failures lead to massive outages or dangerous situations.

For this purpose, it incorporates Business Process/System integration to other grid application using Standard Operating Procedure workflow engine, and can also incorporate third party/custom analytics from operations, and provide Work Order Integration.

**Network Connectivity Analytics Service**

This application leverages GIS, Voltage and AMI Data (Meter, Feeder and Transformer Load) to infer the correct Connectivity Model between distribution grid equipment’s in scope. Connectivity Errors are displayed with Confidence Interval, whereas traceability is provided for root cause analysis investigations. Results can be applied to client’s GIS manually or thru automation.

The benefits of having an accurate connectivity model are manifold: Accurate Outage Reporting (compliance), Improved Fault Detection, Isolation and Restoration, Balanced Feeders (efficient operations), Accurate Power Flow Analysis, Accurate Load Balancing, Energy Loss/Theft Detection.

**Predictive Maintenance**

This application leverages predictive models to identify pending asset degradation or failure. It analyses maintenance records to identify top failure modes, provide real-time asset health assessment with predicted time to failure. The resulting decision support insights are recommendations for repair procedures based upon current asset health, and recommendations for optimum maintenance schedule. The application can furthermore initiate or update work orders with asset repair recommendations.

5.2 ABB

Statnett’s SAMBA program fits very well with ABB’s strategy for enabling the digitalization of the power grid via ABB Ability™ [14].

Many pieces of this strategy are already available and in use at customers like Statnett. The SAMBA program, like ABB Ability, focuses on the top two levels of the strategy, Remote Monitoring and Control and Enterprise Software Solutions, but is clearly supported by all four levels, see Figure 10.
Digital grid vision

ABB Ability™ enables the digitalization of power grid and opens new business opportunities in the new energy landscape

The primary solution from ABB in support of the SAMBA project is at the top middle of the strategy image above, ABB Asset Health Center. As Figure 11 below highlights, most of the documented requirements from the SAMBA project are (or soon will be) supported within the ABB Asset Health Center solution. The SDM 600 as well as ABB’s transformer service also support the SAMBA project and are discussed below.

ABB is already an established provider for Network Management, and a vendor for Maintenance Management solutions for the utilities industry. Information about these solutions is not included here, but certainly available upon request.
**ABB Asset Health Center**

Asset Health Center combines decades of subject matter expertise in transformer, breaker and control systems manufacturing and maintenance, with historical and real-time data analysis. It is an ICT solution that collects, aggregates and stores both operational data (from sensors, SCADA, IED’s) and IT data (from maintenance, inspections, asset repositories). It then uses first principles and machine learning models to analyze that data. It generates condition information, asset risk levels, predictions of future asset health and recommended actions which should be taken. These algorithms incorporate ABB’s, partners’ and customers’ knowledge about asset failure modes, as well as leveraging machine learning to identify new correlations not previously identified. It provides interfaces for presentation and visualization as well as direct interfaces into Maintenance Management systems (such as IFS). Statnett has the ability to consolidate the wealth of data on system loads, markets, inspections and equipment sensors into meaningful insights on the health of their critical assets.

Asset Health Center helps customers plan asset renewal by both prioritizing asset replacements and in the near future will support the decision process of analyzing various scenarios to find the optimal solution to reduce overall risk to the grid, while finding the right level of investment.

Asset Health Center also supports the process of handling issues that have been identified. Too often the focus of such solutions is only on identifying issues, without the process of documenting what is being done to solve those issues. Seeing a problematic transformer on a dashboard is only the first step. Asset Health Center, by integrating directly with the Maintenance Management system, helps users to act on the insights that the solution provides. More information can be found in [15].

**SDM600**

ABB SDM600 talks to relays to collect and collate fault records data. The gathered comtrade files are recorded into short reports for later analysis, while the SDM600 dashboard presents historical reports so Statnett can see what happened and when. Using IEC 61850 interfaces the SDM600 software also keeps a watchful eye on protection relays so customers can ensure they are all running the latest software and with the right configuration. Finally, with centralized security logging and central account management SDM600 assists with identifying cybersecurity risks.

ABB SDM600 and ABB Asset Health Center integration is currently in development, see [16] for more information.

**ABB Transformer Service**

ABB provides services throughout the transformer life cycle, from commissioning to recycling, for all brands and kinds of transformers. ABB’s archives contain technical information for more than 30 legacy brands. ABB offers a direct support line with Transformer Specialists with an agreed upon response time. Customers can get quick and expert feedback on the interpretations given by the Asset Health Center.

Additionally, an optional remote connection could be established to enable ABB experts to access the customer’s Asset Health Center and guide them through maintenance recommendations and procedures. More information in [17].

ABB’s Asset Health Center works with a large number of competitor’s monitoring devices. However, ABB also offer ABB’s monitoring devices which interface with Asset Health.
5.3 SINTEF Energy Research

SINTEF Energy Research (SINTEF ER) has worked with development of methods for deterioration [18] and failure modelling and residual lifetime estimation for use in technical economic analysis [19] and risk based decision-making. The failure model [20], as shown in Figure 12, illustrates the data and the connections (impact of design on failure of a component) needed for estimation of risk. This model is generic and can be used for all types of components. Results from the failure model can be a health index (red box) or risk (pink box).

![Figure 12: Failure model.](image)

SINTEF ER has also worked with implementation of the mentioned methods and analysis for risk-based decision-making within the energy sector related to hydro power [21], distribution networks [22], [23], [24], including multi-criteria decision making [25], and wind energy. The testing of cases related to the entire failure model or parts of it for companies in the energy sector has also provided knowledge about the availability and quality of data in companies in the energy sector and organizational issues related to asset management [26].

SINTEF ER has worked with the use case methodology from smart grid projects [27]. The value of describing and testing of use cases in the distribution network is documented here [28].

SINTEF ER has experience on asset management related activities on many of the main components and this is summarized below. A survey of diagnostics techniques and evaluation is also made [29] and a methodology to establish life curves based on condition monitoring data and expert judgements [30].

Transformers

Models for life estimation of transformer windings and effect of operating temperatures and contamination of oil and cellulose are developed. Also recommendations for ageing markers are suggested [31] and [32]. These models, combined with thermal models and service data of temperature and loads will allow for life estimation of windings. On the diagnostic side, one has experience with multivariate analysis of ageing (general oil tests - GOT) and failure markers (dissolved gas analysis - DGA) for fleet analysis, provided diagnostic data is available in a digitized format. In an alliance with the "User Group for Industrial and Power
transformers” SINTEF ER has developed an web based registration in order to build up a national database for transformer failures [33]. This database will provide information about the transformers internal life, which FASIT does not supply. This user group will also with help of the Norwegian utilities, start building a database over conditions of winding insulation from scrapped transformers. Finally, SINTEF ER are together with Energy Norway designing a tool for asset management of fleets analyzing health indexes, remaining life and need for maintenance [34].

**Circuit breaker**

SINTEF ER has experience with acoustic failure detection on circuit breakers. Statnett has test equipment for this.

**Overhead lines**

SINTEF ER has worked on the following topics relating to overhead lines:

- Mapping of atmospheric corrosive environment and associated salt deposition severity [35], [36]
- Failure analysis, testing, condition and life assessment of new and old lines [37]
- Dead end clamps, guy anchors and line splices [38], [39]
- Conductor joints and suspension fittings [40]
- Insulators cross arms, anchor rods, and earthing and surge arrester systems with regard to corrosion, mechanical and electrical degradation.

**Cables**

**Simulations and calculations**

SINTEF ER has experience with simulations and calculations for all electrical, mechanical and thermal aspects of a cable system. Simulations of electrical values can be confirmed by laboratory or site measurements [41].

SINTEF ER has experience with finite-element analysis of electro-thermal problems for calculating currents and temperatures in cable systems, including direct electrical heating (DEH) of oil/gas pipes. Monitoring of electrical and thermal properties of cables and the surrounding environment can be performed for scaled laboratory model and full-scale systems. Remote monitoring of thermal properties from cables systems in service can also be done.

**Condition assessment/monitoring**

SINTEF ER has long experience with condition assessment of medium and high voltage cables and accessories [42], [43], [44], [45], [46], [47] and [48]. Main research activities involve developing methods, analysis tools and robust criteria for condition assessment. SINTEF Energy Lab contain facilities for testing high voltage cables and accessories up to 800 kV AC, 1200 kV DC and 2.4 MV impulse (120 kJ).

Partial discharge measurements, dielectric loss and spectroscopy are common assessment methods applied both in SINTEF’s laboratories and for field use. E.g., a simple method for assessment of extruded distribution cables have been developed [49], the effect of testing voltage frequency are investigated [50] and guidelines for condition assessment XLPE cable systems [51] and mass impregnated [52] have been developed in close collaboration with Norwegian grid owners and industry.

A method for direct measurements of relative humidity/calibrated water vapour content and free water in HV oil-filled terminations has been developed [53], [54] and [55].
Fault analysis

SINTEF ER has laboratory facilities for performing fault analysis for cables and accessories, such as PD-measurements, HV tests, resistance measurements, dissections, optical and electron microscopy and material characterization (DSC, FT-IR, etc.).

Mass impregnated cables

SINTEF ER has done studies on void formations, radial mass transport, electric field/temperature gradients in mass impregnated non-draining HVDC cables. Laboratory work has been performed in connection with this [56].
6 New possibilities

6.1 Asset management

The aim for Statnett is to evolve towards smarter asset management through up-to-date methods/models and innovative technology in compliance with PAS 55/ISO 55000 standard. Statnett shall be better equipped to predict the condition of critical components and to determine optimal time for maintenance and replacement/renewal, and will have better control on risk and reliability. This would be continuous improvement where data flows seamlessly to wherever it is needed and data quality and aggregation level is in accordance with the different needs in the company.

For instance, in the future, the estimation of condition will be based on information from inspections, sensors, operation data, expert judgement, failure analysis, post-mortem analysis of similar components and national/international failure statistics. This data is easily available on an appropriate platform for analysis and some basic analysis is automated. The condition estimates are recalculated whenever new information is available and are subsequently used to plan maintenance and reinvestments, and the risk map is continuously updated.

Statnett wants to investigate what the cross-cutting topics of real-time stream analytics, automation, machine learning, industrial internet of things, forecasting and integration and data management, see Figure 13, can offer for asset management. Cross-cutting topics will have a strong impact on all areas of a company and therefore must receive special attention. For Statnett cross-cutting topics will typically impact all layers of Figure 3 and must be in place to assure interoperability, as defined in appendix V2. Machine learning and forecasting is expected to be included in the use case testing of WP5 in the SAMBA-project, while recommendations within certain areas of real time stream analytics, automation, industrial IoT and integration and data management is expected to be provided as part of WP3, WP4 and WP6.

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Figure 13: Cross-cutting topics.
Maintenance

- A predictive and prescriptive approach where tasks are automatically pushed to the service provider
- Maintenance information is systematically (and automatically) used to improve the maintenance program and to measure reliability and efficiency
- Analysis of cost related to different types of maintenance (corrective, preventive, predictive, prescriptive) for different assets as indicators

Renewal/reinvestment

The process regarding renewal (reinvestments) is well defined, but have potential for improvements:

- Residual lifetime estimation based on the condition and estimations for future condition development
- Better decision basis/support for residual lifetime- and risk evaluation for single components and groups of components (fleet management)

Fault analysis

- Disturbances produce (increasing amounts of) data and this need to be handled.
- Typical challenge: Acquisition and sorting of relevant data
  - Aim: Improve ability to analyse for better decision making and Statnett can adjust barriers both for causes and consequences of failures
- Future: real-time assessment of asset condition

Mutual interests for fault analysis and SAMBA:

- Data sources and acquisition
- Extracting and analysing data
- Models and competence for exact decision making
- Further development is dependent on suitable data handling structures → big data platform
- Real-time condition assessments as an everyday activity in asset management
- Pilot R&D (circuit breaker wear assessment etc.)

The data input to fault analysis today can be input to condition assessments for improved planning of maintenance and reinvestments tomorrow.

6.2 Components

Generally, for all components in the transmission network it is expected that the future will bring more sensors as an integrated part of the components. This will increase the amount of data that can be available for analysis and many choices will have to be made i.e on both storage (locally, centrally, aggregation) and analysis (locally/distributed or centrally).

Transformers:

- Easy access to all data about the transformers (i.e. results from oil/DGA analysis)
- Easy access to all data from sensors and measurements on transformers (i.e. remote reading of switching of tap changer which is done manually today)
- Measurements of PD (additional measurements)
- New tool to analyse individual and group of transformers

Circuit breakers:

- Plan to replace 456 CBs in the next 5 years – is this wise? Possible to have input from SAMBA on replacement strategy.
• Does not have any routines for checking the condition of replaced items and this is needed in order to evaluate if the condition assessments and replacement strategies are good.
• No instructions today to operate breakers that are not operated – should there be? This might reduce the probability of failure.
• New sensors might provide valuable information.

Voltage transformers:
• Voltage transformers – changes in secondary voltage – replace or follow up – too conservative estimate of lifetime today? Online measurements provide more correct indication on when to replace?
• Does not have any routines for checking the condition of replaced items and this is needed in order to evaluate if the condition assessments and replacement strategies are good.

Lines and cables
• Can use data for better prediction of maintenance:
  o When to remove ice from line
  o Replacement of equipment due to vibration?
• Future measurement goals:
  o Vibration / load sensors at critical spans / areas. Able to transmit data at regular basis.
  o Ice build-up, calculated from data or direct measurements
  o Hand-held NDT equipment (X-ray, …) to evaluate lines – do not know the condition today HES implications.
• Use of data from failure analysis:
  o Electrical faults due to galloping? If so, feedback to control centre is desired.
  o When to replace?
• Corrosion: just visual inspection today – important ageing mechanism, clam corrosion (X-ray?)

6.3 ICT

Statnett needs to build an ICT platform and architecture to support both present and future need.

The goal of the ICT architecture is to be robust enough to meet the needs of the business side in Statnett. So far, the project has identified the following areas where Statnett will build a target architecture:
• Data collection
  o Common way to collect data from different sources to avoid performance issues on critical sources and unnecessary complexity
• Data storage
  o A way of making analysis data available across ICT tools, business areas and physical data storage
  o Based on a technology that will not be a limitation in volume and velocity
  o Based om a common information model
• Functionality
  o Functionality through traditional analysis tools combined with new tools to handle high volume and variety
• Presentation and visualization
  o Tools to fill any need for presentation of analysis results, for example maps to show geographical information

The parts of analytics where new possibilities is presenting itself is predictive and prescriptive analysis. Statnett also need to explore the possibilities for near real-time data collection and analysis in the context of both operational and monitoring needs.
Analytics is an important area in the enterprise, but the type of technology and architecture needed for predictive and prescriptive analysis must be reusable for other areas. Statnett needs to build an architecture to serve the total need of the business. The big data concept needs to be explored to see how it can help the enterprise meet the needed target architecture.
7 Implementation of processes for systematic renewal analyses

Successful asset management is dependent on organization and management of people and processes. This subject was discussed during WP1 and will be worked on further in the SAMBA-project as the use cases will influence, when implemented, processes within Statnett. These changes in processes is crucial for a lasting change and improvement of asset management. The SAMBA-project will provide recommendation for implementation of such processes.

Important processes that must be implemented if a company is to make decisions about maintenance and reinvestments based on systematic assessment of technical condition and analysis of risk and profitability is shown in Figure 14. The figure and the recommendations in this chapter are according to a report prepared for Energy Norway [26].

The processes include the following three primary and four secondary (support) processes:

**Primary processes**
- Renewal needs (identification of the need for renewal analysis)
- Project analyses (analyses of asset’s condition and remaining life, probability and consequences of failure, risk, profitability of alternative maintenance and reinvestment solutions)
- Decision support (presentation of results from the analyses and preparation of recommendations for the decision-making)

**Secondary processes**
- Data and tools
- ICT solution
- Management
- Competence

The following bullets describe the main recommendations in the report from Energy Norway (3) concerning the implementation of processes for systematic renewal analyses. These constitute a recommended minimum.

- The company’s management must own the processes for renewal analyses. The management must ensure that the defined tasks are performed with the required quality and efficiency.
Status and further work - Results from WP1 in the SAMBA-project

- There must be a formal person in charge (leader) of the processes for renewal analyses that reports to the company's management. The leader may have other responsibilities within the company.
- Processes, tasks and roles must be specified in the company’s strategy for renewal analysis.
- One person must have the overall responsibility for the assessment of technical condition of an asset group, for example transformers, cables, overhead lines, etc. These are responsible for approving state assessment performed by others.
- Annual assessment of needs for renewal analysis based on the company's long-term renewal plan and available (updated) assessments of the technical condition and remaining life of assets.
- Need for methods, tools and support concerning renewal analysis must be assessed and then made available.
- A minimum of two people must have sufficient expertise on present value analysis and calculation of the present value of failure costs based on probability of failure and consequences of failure. They must master the appropriate tool for such calculations.
- Project analyses shall be performed and documented according to a procedure. The procedure must be prepared.
- Information about assumptions and results from completed project analysis shall be archived electronically and be available to anyone involved. What should be archived are described in a procedure and the procedure must be prepared.
- Systematic quality assurance of completed project analyses.
- Systematic quality assurance of processes, roles, tools, project analysis procedures and competence, for example in connection with an annual review and evaluation.

Results from the technical-economic analysis of alternative maintenance and reinvestment solutions detailing uncertainty in assumptions and the consequences this has for the options is a very useful basis for being able to make good decisions. Systematic analysis and related documentation according to a given template depending on the issue allows for reuse and continuous improvement. Analyses also provide learning and skill with regard to the links between technical condition, state development (degradation), risk and the utility values (incl. profitability) of risk reduction measures as preventive maintenance and reinvestment.

Good processes for systematic renewal analyses is all about relationships. Those carrying out project analysis is dependent on good relations with those who carry out condition monitoring, assessment of technical condition, controllers, decision makers and management to achieve acceptance for the analysis process and confidence in analysis methodology and tools used. To achieve this, the analysis process must be open and clearly visible. A culture of quality and continuous improvement can be created when those involved trust each other and the methodology used.

An analogous figure to Figure 14 can also be made for operations and risk monitoring of the network in real-time/short term. Such a figure could also include the robotization of decisions, implying that certain decisions can be made without human involvement. Operation of the transmission network is included in the SAMBA-project, particularly related to failure analysis (see Figure 8) and the planned risk monitoring center. The risk monitoring centre is included into SAMBA as a separate WP, WP6. The task of WP6 is to perform a feasibility study to describe and evaluate:

- Application of real-time monitoring of technical condition and associated technical and economical risks in a dedicated environment (center) for asset management
- Examine what such innovative monitoring can provide asset management in Statnett
- Information needs, analysis, decision support, competence, roles and resource requirements.
8 Way of working

The SAMBA-project has been planned [2] as a traditional research project, which generally goes as follows:

1. Problem definition and description
2. Breakdown of the problem (providing ideas for use cases)
3. Description and development of use cases
4. Testing of use cases
5. Results of testing is summed up and conclusions are made

This differs from the approach of the industrial partners which all have a more agile approach [57], in the sense that in close cooperation with clients they develop the systems together and adjust it to specific need of the clients. Little time is used on specifications, as an important point is to look at the data available and make adjustments dependent on client's needs. Hence, the industrial partners are eager to start looking at the data, while the SAMBA-project makes it a priority to describe and prioritize prior to testing. Finding a way to work together in the SAMBA-project, given the differences in approach will be important for the project. One option is to both describe use cases and do some testing in parallel.

The industry partners is also eager to illustrate the utility value in practice through big data analysis. In the SAMBA-project both illustration (qualitative) or description (quantitative) of the utility value in the use cases compared with the situation today is important.

There are several possible testing environments for use cases:

- Statnett data on partner's platform. In collaboration with industry partner test how Statnett data can be utilized in new ways by the use of partner technology.
- Big data technology on an onsite platform to test what big data can provide in terms of analytics tools, storage and performance on high volume.
- Big data tools as cloud service. Test what big data can provide in terms of analytics tools, storage and performance on high volume.
- Use existing onsite tools to test new algorithms and new use of existing data.

Any security issues related to testing must be described and discussed with the relevant personnel/departments within Statnett.
9 Recommendations for further work

Ideas for use cases came up during WP1 and these are listed up below. These use case ideas will have to be discussed with the relevant domain experts in Statnett in order to prioritize them. In addition, the project partners must generate more ideas for use cases.

Some use case ideas on component level: (not a complete list and no prioritizing made)

- Multivariate analysis of oil-and gas data
- Visualisation of trends of parameters in the oil-and gas data
- Paper ageing of transformer paper
- Counting the number and sizes of lightening and short circuits that the transformer is exposed to
- Maintenance history: correlation between preventive maintenance and failure rate
- Image recognition to analyse pictures from helicopter inspections of overhead lines
- Correlation of weather information and typical failure situations
  - Prediction of overhead line failure based on historical data on weather and failures
- Health index for transformers
- Icing forecast for powerlines

Some use case ideas on decision level: (not a complete list and no prioritizing made)

- Decision-making process for reinvestment
- Operational risk-based decision-making (i.e. overloading of components)
- Analysis of cost related to different types of maintenance (corrective, preventive..) for different assets
- Estimation of residual life, probability of failure and risk for assets based on technical condition and other relevant information

In WP2 use cases will be identified and described. In this work, it is important to include both use cases related to component and higher-level use cases, see Figure 3. The use cases on component level will often be input to higher-level use cases, i.e. input to reinvestment decisions. A use case on component level can be a description of the gathering and processing of data from one type of measurements. One example of possible use case on higher level is a description of which and how data from i.e. different measurement and inspections of components should be use to estimate the optimal time for reinvestment of the components. These estimates, combined with other relevant information, can be used further for instance in analysis performed to prioritizing reinvestments. The testing of use cases, in WP5, will be challenging for high-level use cases, but this is an important part of the SAMBA-project, hence effort must be put into identifying use cases or parts of use cases that can be tested. Both the making and testing of use cases must be done in close partnership between the technical and the ICT departments of Statnett. This is an important success criterion for the SAMBA-project to make sure that the results from SAMBA will make a lasting positive impact on the asset management of Statnett.

Three activities, closely related to the theme of SAMBA, had already started in Statnett when SAMBA was initiated and these activities have been included in the SAMBA-project. These activities are described in Appendix V4.

Some general recommendation where stated during WP1 and these are listed below:

- Establish better/faster access to data
- Perform systematic cost-benefit analysis of projects
- Employ new methods for analysis (machine learning...)
- Store more information with higher resolution compared to today
  - Install new sensors/measurements (overhead lines in particular)
- Increase event registration (not limited to failures), like information about lightening, short circuits, galloping, earth faults and so on. Such information is important for residual lifetime estimation, even though it did not cause a failure of the components
- Store more data than is needed today as the future might bring new needs
  - Get access to/employ data from external sources (lightening, weather etc.)
  - Dissect components taken out of service to learn more about the degradation process and investigate whether or not the condition was correctly estimated
  - Perform systematic data cleaning/quality checks
  - Perform systematic calibration of measurement equipment
  - Investigate the possibilities to perform analysis externally (if found beneficially) – by external consultants
10 Literature references

1. Governing policy for asset management in Statnett


4. Final report of the CEN/CENELEC/ETSI Joint Working Group on Standards for Smart Grids
   http://www.cen.eu/cen/Sectors/Sectors/UtilitiesAndEnergy/SmartGrids/Pages/default.aspx


7. State of the art in Asset Management of HV Transmission Grids


9. Use case collection, management, repository, analysis and harmonization CEN/CENELEC/ETSI Smart Grid Coordination Group / Mandate M/490 Draft 0.5.

10. IBM Agile https://jazz.net/agile/?cm_mc_uid=70251543628814637459515&cm_mc_sid_50200000


13. IFE Knowledge Center


58. ISO 55000.
60. IEC, IEC61850. 2010.
61. Mandate M/490 “Standardization Mandate to European Standardisation Organisations (ESOs) to support European Smart Grid deployment” European Commission Directorate-General for Energy. 2011.
V1 Questions asked to industry partner prior to WS3

V1.1 Components

All the questions below should be answered, if possible, for transformers, substations (circuit breakers, voltage transformers...), powerlines and cables. Not all the questions might be relevant for all of the industry partners.

- Which degradation – and failure mechanisms are the most important, in a Nordic perspective, for the different components? What is the most important to keep track of, given the climatic conditions?
- What data is needed to estimate the condition and remaining life of the components?
  - What is the minimum of amount of data needed?
  - Operation data: control and protection systems...
  - Monitoring data: sensors...
  - Other data: weather, information from tests (at factory, on-site...)
- What level of quality, sampling rates and databus/communication is necessary for the different data?
- Which sensors are relevant for the different components? What type of data is registered and transmitted from these sensors?
- How can data quality be secured?

V1.2 Fault analysis and asset management

- Analysis of the technical state of components
  - What kind of algorithms does the vendor systems have for the estimation of the technical state (condition) of components?
  - What kind of functionality/algorithms does the vendor systems have for combining information about the technical state with sources of information such as:
    - SCADA/operation control system
    - Measurements of temperature, moisture, motion sensors, etc.
    - Component data in network information systems (NIS)
    - Location data in geographic information systems (GIS)
    - Weather data (temperature, wind)
    - Load history
    - The number of switching operation with/without short-circuit current
    - Maintenance history for the current component
    - Fault history/-statistics for corresponding components in similar/different environment
  - Does the vendor systems have functionality for analysing the technical state continuously (continuous condition analysis)?
  - To what extent is machine-learning algorithms used?

- Fault analysis and fault consequences
  - Which user flexibility does the vendor systems have for combining information from different data sources (fault analysis requires information from different data sources depending on the type of fault)?
  - Does the vendor systems have functionality for estimation of the consequences of faults (outage time, energy not supplied, costs)?
  - Establishing and updating of the experience/knowledge base
    - How can fault analysis improve the experience/knowledge base for asset management?
    - Does the vendor systems have functionality that (continuous) update the experience/knowledge base (degradation times, lifetimes, failure rates, failure causes, consequences of failure, etc.)?
• Decision support regarding maintenance and reinvestments
  o Does the vendor systems have functionality for the estimation of:
    ▪ Remaining life (time to failure)
    ▪ Annual probability of failure
    ▪ Economic risk (expected future costs)
    ▪ Optimal timing of maintenance and reinvestments
  o What is included in the cost-benefit analysis, and what types of maintenance and reinvestments measures/alternatives/actions can be analysed?
  o How are the results of the analysis organized in terms of decisions, i.e. presented for the decision maker?
  o What kind of decision logic does the vendor systems apply?
  o Does the vendor systems provide input data for Reliability Centered Maintenance analysis (RCM)?
  o Does the vendor systems have functionality to adjust/modify maintenance programs/plans based on information about the current condition of the component as well as about similar components?
  o Does the vendor systems have functionality for evaluating the effectiveness of performed maintenance and reinvestments (reduced cost, improved safety, reduced failure rates, reduced outage times etc.)?

V1.3 ICT

Your solution:

Data collection from source systems

• Use of standards for integration
  o Technology standards/protocols
  o Data models (IEC61968-4 Edition 2?)
• Collection methods
  o ETL/ELT- what APIs and technologies are used
• Data keywords for discussion
  o Real-time
  o Volume
  o Velocity
  o Variety
• Geographical location

Openness, component based

• Access to data (for analysis purposes) - what APIs and technologies are available
• Access to data (streaming) - what APIs and technologies are available
• Modularity, select parts of solution
• The technology stack – what technologies on different levels? (open source, proprietary)

Architecture

• Redundancy / reliability
• Scalability
  o Example installation (size)
  o How easy to scale?
• Performance - benchmarking results?
• Expected planned downtime (maintenance)
• What security measures taken in your solution?
• Security - AAA - requirements to the infrastructure on site
• Software stack (Big Data - which components)
• Any additional components - administration etc

**HW**

• Minimum/typical setup requirements (typical CPU Power, Memory, Storage, OS, IO performance, Number of nodes, Physical (rack/ space/power))

**Cloud**

• Included/not included in the solution
  o Geographic Location?
• Compatibility with AWS/Azure/Google
• Security support (what support is built in in platform)
  o Encryption
  o Tokenization
• Support for connectivity/Gateways

**Resources**

• Courses/training?
• Maintenance of system? External resource need?

**Your experience:**

• Big Data
  o Technology
  o Predictive, prescriptive analysis
• Analysis
  o Data aggregation
  o Data analysis across several data models (sources)
• Real-time analysis, monitoring
V2 Definitions and standards

V2.1 Definitions

Asset management is the coordinated activity of an organization to realize value from assets [58].

Big Data refers to the inability of traditional data architectures to efficiently handle the new datasets. Characteristics of Big Data that force new architectures are:

- Volume (i.e., the size of the dataset);
- Variety (i.e., data from multiple repositories, domains, or types);
- Velocity (i.e., rate of data flow); and
- Variability (i.e., the change in other characteristics like flow rate, format or composition).

These characteristics of volume, variety, velocity, and/or variability (4 Vs) require a scalable architecture for efficient storage, manipulation, and analysis. Other terms are also used, for instance veracity (i.e., accuracy of data), value (i.e. value of the analytics to the organization), volatility (i.e. the tendency of data structures to change over time) and validity (i.e. appropriateness of the data to the intended use).

Data science is the extraction of actionable knowledge directly from data through a process of discovery, or hypothesis formulation and hypothesis testing. Knowledge needed in data science is illustrated below; this can be one person, or more likely a team of several persons. Data science is an interdisciplinary field and aim at getting value out of the data.

![Figure V2-1: Skills needed in data science.](image)

Data life cycle is the set of processes in an application that transform raw data into actionable knowledge and consists of the following four stages:

1. Collection: This stage gathers and stores data in its original form (i.e., raw data.).
2. Preparation: This stage involves the collection of processes that convert raw data into cleansed, organized information.
3. Analysis: This stage involves the techniques that produce synthesized knowledge from organized information.
4. Action: This stage involves processes that use the synthesized knowledge to generate value for the enterprise.

In the traditional data warehouse, the data handling process followed the order above (i.e., collection, preparation, storage, and analysis.) The relational model was designed in a way that optimized the intended
analytics. The different Big Data characteristics have influenced changes in the ordering of the data handling processes. Examples of these changes are as follows:

- Data warehouse: Persistent storage occurs after data preparation.
- Big Data volume system: Data is stored immediately in raw form before preparation; preparation occurs on read, and is referred to as ‘schema on read.’
- Big Data velocity application: The collection, preparation, and analytics (alerting) occur on the fly, and possibly includes some summarization or aggregation prior to storage [59].

**Interoperability** is the ability of two or more devices from the same vendor, or different vendors, to exchange information and use that information for correct cooperation [60].

**Smart Grid** is an electricity network that can cost efficiently integrate the behavior and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety [61].

**V2.2 Standards**

**ISO55000/BS PAS 55**

The most important standard for asset management is the ISO55000/BS PAS 55. The standard specify what is needed to optimize management of assets. It is based on the Plan-Do-Check-Act (PDCA) framework, which is also called continuous improvement.

**IEC Common Information Model (CIM) (IEC 61970, IEC 61968, IEC 62325)**

International Electro technical Commission (IEC) Common Information Model (CIM) aim at making a common information model for the entire value chain within power engineering, including power system analysis, asset management and energy market. Both the European standardization group CENELEC and the Norwegian standardization group (Norsk Elektroteknisk Komite (NEK)) has adapted IEC CIM. It is therefore a valid standard for Norway. The standard consists of three standardization groups, IEC 61970, IEC 61968 and IEC 62325.

**NIST Big Data Interoperability Framework**

To advance progress in Big Data, the NIST Big Data Public Working Group (NBD-PWG) is working to develop consensus on important, fundamental concepts related to Big Data. The results are reported in the NIST Big Data Interoperability Framework series of volumes. This framework consists of the following documents [62]:

- Big Data Definitions
- Big Data Taxonomies
- Big Data Use Cases and Requirements
- Big Data Security and Privacy
- Big Data Architecture White Paper Survey
- Big Data Reference Architecture
- Big Data Standards Roadmap

**Smart Grids Architecture Model (SGAM)**

Smart Grids Architecture Model (SGAM) is made by the CEN-CENELEC-ETSI Smart Grid Coordination Group. In essence, the purpose of a Reference Architecture is to allow for a separation of a complex system (which a smart grid definitely is) into entities that can be isolated from each other according to some principles, thus making possible the description of the whole system in terms of the separate entities and their relationships [4].
### V3 Data collected today

**Table V3-1: Transformer data.**

<table>
<thead>
<tr>
<th>Transformer data</th>
<th>Sampling rate</th>
<th>Collection system</th>
<th>Storage system</th>
<th>Storage information</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nameplate data</strong></td>
<td>Once – when transformer is new</td>
<td></td>
<td></td>
<td>Stored for the entire lifetime of the transformer</td>
<td></td>
</tr>
<tr>
<td><strong>Load</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Current</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Voltage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Temperature (top oil and winding temperature)</strong></td>
<td>Many different instruments used.</td>
<td></td>
<td></td>
<td>Calibration routines?</td>
<td></td>
</tr>
<tr>
<td><strong>Hydran and Transfix</strong></td>
<td>Continuously</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Transport X</strong></td>
<td>Portable instrument – installed when needed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gas- and general samples (DGA and SOT)</strong></td>
<td>Once a year Oil is manually tapped from transformer and sent to lab. Pdf with test results are sent to Statnett</td>
<td></td>
<td></td>
<td>Database is under production. Stored as pdf for the entire lifetime of the transformer.</td>
<td></td>
</tr>
<tr>
<td><strong>Degree of polymerization (DP)</strong></td>
<td>Rarely – from baskets during lifetime or when decommissioned</td>
<td>Manually, paper sample collected and sent to lab.</td>
<td></td>
<td>Stored as pdf. Reported to the national database for</td>
<td></td>
</tr>
</tbody>
</table>
### Transformer data

<table>
<thead>
<tr>
<th>Transformer data</th>
<th>Sampling rate</th>
<th>Collection system</th>
<th>Storage system</th>
<th>Storage information</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of switching of OLTC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure relay OLTC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas relay Buchholzrelay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overpressure tank (Qualitrol pressure relief valve for the tank)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Megging of the core</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lightning detection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>History of service (maintenance actions, repairs..)</td>
<td>Whenever service is performed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fault information</td>
<td>Whenever fault</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table V3-2: Circuit breaker data.*

<table>
<thead>
<tr>
<th>Circuit breaker data</th>
<th>Sampling rate</th>
<th>Collection system</th>
<th>Storage system</th>
<th>Storage information</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nameplate data</td>
<td>Once – when new</td>
<td>IFS</td>
<td>Stored for the entire lifetime</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of operations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspection data</td>
<td>Manually every 3.months</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Status and further work - Results from WP1 in the SAMBA-project

<table>
<thead>
<tr>
<th>Circuit breaker data</th>
<th>Sampling rate</th>
<th>Collection system</th>
<th>Storage system</th>
<th>Storage information</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermography</strong></td>
<td>Manually every second year</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Condition monitoring</strong></td>
<td>Manually every fifth year</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Collecting data from disturbance recorders, fault clearance (new approach)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table V3-3: Voltage transformer data.

<table>
<thead>
<tr>
<th>Voltage transformer data</th>
<th>Sampling rate</th>
<th>Collection system</th>
<th>Storage system</th>
<th>Storage information</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nameplate data</strong></td>
<td>Once – when new</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Secondary voltage</strong></td>
<td>Every third month – continuously in the future</td>
<td>Manually now, automatic in the future</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Inspection data</strong></td>
<td>Every sixth month</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table V3-4: Overhead line data.

<table>
<thead>
<tr>
<th>Overhead line data</th>
<th>Sampling rate</th>
<th>Collection system</th>
<th>Storage system</th>
<th>Storage information</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nameplate data</strong></td>
<td>Once – when new</td>
<td></td>
<td></td>
<td>Stored for the entire lifetime</td>
<td></td>
</tr>
<tr>
<td><strong>Ground inspection data</strong></td>
<td>Every fifth year</td>
<td>Manually</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Heli-inspection</strong></td>
<td>4 out of 5 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Status and further work - Results from WP1 in the SAMBA-project

<table>
<thead>
<tr>
<th>Overhead line data</th>
<th>Sampling rate</th>
<th>Collection system</th>
<th>Storage system</th>
<th>Storage information</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower control / Line inspection</td>
<td>Manually</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspection of upper part of the tower including fittings and conductor &quot;Toppkontroll&quot;</td>
<td>Every tenth year</td>
<td>Manually</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundation inspection</td>
<td>Every tenth year</td>
<td>Manually</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermography by helicopter</td>
<td>Yearly/every 10 year</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspection after bad weather</td>
<td>Whenever bad weather</td>
<td>Manually/helicopter</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table V3-5: Cable data.

<table>
<thead>
<tr>
<th>Cable data</th>
<th>Sampling rate</th>
<th>Collection system</th>
<th>Storage system</th>
<th>Storage information</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nameplate data</td>
<td>Once – when new</td>
<td></td>
<td></td>
<td>Stored for the entire lifetime</td>
<td></td>
</tr>
<tr>
<td>Oil samples from fluid filled cables and fluid filled terminations</td>
<td>Manually samples taken and sent to lab for analysis. Pdf with test results are sent to Statnett</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature monitoring (submarine cable system, Ytre Oslofjord)</td>
<td>Continuously</td>
<td>Automatic</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table V3-6: Asset management data.

<table>
<thead>
<tr>
<th>Asset management data</th>
<th>Sampling rate</th>
<th>Collection system</th>
<th>Storage system</th>
<th>Storage information</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nettutviklings-plan (NUP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PPP (Project Portfolio Plan)</td>
<td>Every Year</td>
<td></td>
<td>Clarity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D&amp;M’s 5-year plan</td>
<td>Every year</td>
<td></td>
<td>TPV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk assessments</td>
<td>Every second</td>
<td></td>
<td>IFS dokadm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plan for anleggsforvaltning (PFA)</td>
<td>Every second</td>
<td></td>
<td>IFS dokadm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year plan/budget</td>
<td>Every year</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Planning Tool (TPV-T ) and Total Planning Tool Project (TPV-P) are tools used to keep track of future actions and projects. The results from these tools are given in PFA, 5-year plans and yearly plans/budgets. TPV is a mirror of IFS and are hence updated regularly with new information entered into IFS. The actual planning of actions and projects are performed manually, there are no actions or projects that are automatically generated.

Table V3-7: Fault analysis data.

<table>
<thead>
<tr>
<th>Fault analysis data</th>
<th>Sampling rate</th>
<th>Collection system</th>
<th>Storage system</th>
<th>Storage information</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital fault recorders</td>
<td>2 / 4 kHz sample rate</td>
<td></td>
<td></td>
<td></td>
<td>Accuracy in ms domain</td>
</tr>
<tr>
<td>Waveforms (I/U), digital markers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>95-99% coverage for 300-420 kV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMU I,U,f,P,Q</td>
<td>50 Hz sample rate, continuous, part processed</td>
<td></td>
<td></td>
<td></td>
<td>High accuracy (microsec.) combined with real-time streaming</td>
</tr>
<tr>
<td>~ 30 units in Statnett 2016 and increasing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fault analysis data</td>
<td>Sampling rate</td>
<td>Collection system</td>
<td>Storage system</td>
<td>Storage information</td>
<td>Quality</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>-----------------------</td>
<td>-------------------</td>
<td>----------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>Oscillation recorders</td>
<td>20 Hz sample rate</td>
<td></td>
<td></td>
<td>Starts recording by pick-up, oscillations etc.</td>
<td>Accuracy ms domain</td>
</tr>
<tr>
<td>f, P, Q, analogue signals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>~ 20-30% (?) coverage for 132-420 kV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meteorological data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid model/GIS map</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCADA system</td>
<td>Typically 3 or 10 seconds - average values / continuous measurements</td>
<td></td>
<td></td>
<td>Messages from control system – accuracy from 2 ms to seconds</td>
<td></td>
</tr>
<tr>
<td>I, U, f, P, Q, alarms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% coverage for 132-420 kV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asset database (IFS?)</td>
<td></td>
<td></td>
<td></td>
<td>High accuracy (micosec.)</td>
<td></td>
</tr>
<tr>
<td>Power quality measurements</td>
<td>Up to 50 kHz sample rate, continuous</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waveforms (I/U)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-30 units in Statnett 2016 and increasing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
V4 Description of already initiated work in SAMBA

V4.1 Wear on circuit breakers

The arcing time (combined with the short circuit current) is the most important parameter for calculating electrical wear.

Principle: \[ EW = \int_{t_0}^{t_a} i^2(t) \, dt \]

- **EW** = Electrical wear
- **t_a** = arcing time
- **i** = short circuit current

Example of estimated wear on circuit breakers:

Keywords for further pilot development in SAMBA:

- Impact of on-site condition control
  - Change in estimated condition of asset?
- Wear due to normal breaker operations
  - Number available as SCADA messages
  - DFR-records available for some breakers
  - Are we able to measure arcing time?
- Method and algorithm for wear and aging
  - Verification and further development

V4.2 Use of data from HIS to calculate voltage differences on busbars

The aim of this activity is to be able to monitor the condition of capacitive voltage transformers using data already recorded at Statnett. The method should detect condition deteriorate at such an early state that replacements can be planned and executed prior to a failure. If this works, it can be an automation of what is today a manual maintenance task. Statnett already records the necessary data in HIS. The activity will check if the data quality is good enough for the described purpose. A prototype will be ready by Q2 2017 and tests will be performed on two stations during 2017.

V4.3 Oil-and gas analyses

An external lab performs oil- and gas analyses of transformer oil from Statnett. Results from oil- and gas analyses has most often been returned to Statnett in the form of pdfs, one pdf per transformer per analysis. In these reports recommendations for actions is sometimes provided if the measured parameters are outside the limit values in standards from IEC or IEEE. The historical data from the pdfs is now being
transferred to IFS to make it easier to analyse and trend the development for oil- and gas parameters. This data will be available for the SAMBA-project. As shown in the figure below test results from the lab will in the future be inserted into FosWeb directly from the lab. An interface with IFS is not created yet, but by March 2017 it should be possible to perform trend analyses in the system called anlegsguiden.

Figure V4-1: Oil- and gas analyses.