Welcome to

Statnett's R&D Conference 2019

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Smart Grid Session

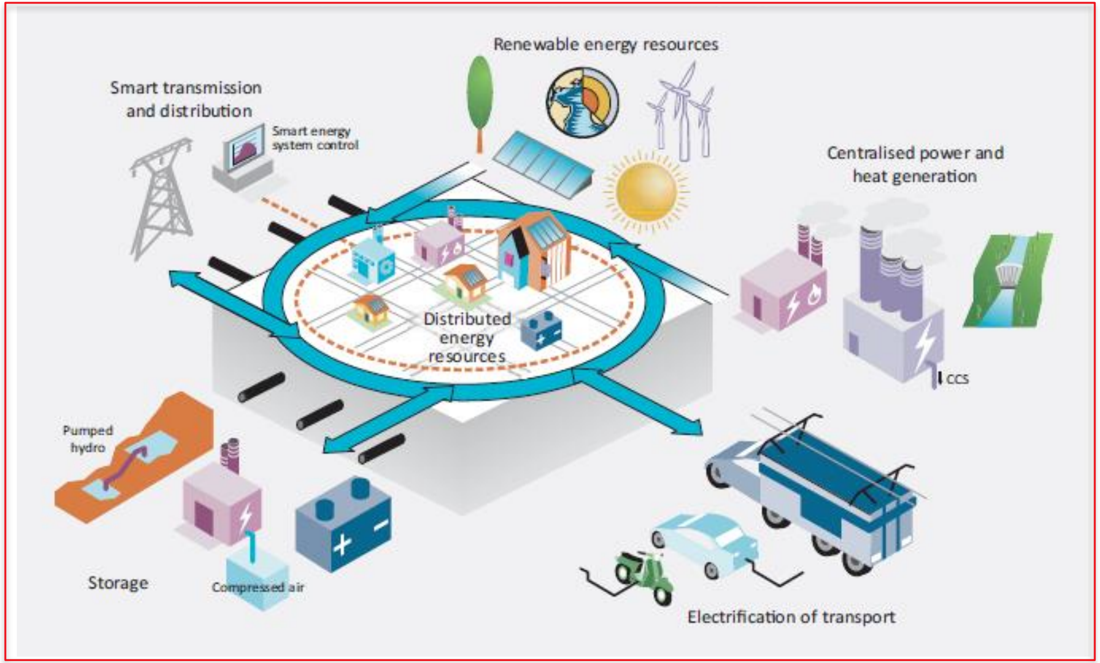
Introduction to Smart Grid	Jørn Egil Johnsen	Statnett
How can big data help us with smarter asset management?	Arne Smisethjell	Statnett
Can PMU data help with system operation?	Anders Holten Skånlund	Statnett
IMPALA – Imbalance Predictions with Machine Learning – a Key to Automation	Eivind Lindeberg	Statnett
Is large scale demand side response a myth or can it be reality?	Knut Styve Hornnes	Statnett
Drones, just fun fact or an asset management tool?	Thomas Negård, Rolf Broch	Statnett

Smart Grid Program

Introduction

Jørn Egil Johnsen, program manager
@Ullevål Business Center, 03.04.2019

Next generation power system
- SAFE, SMART & DIVERSED



Source: IEA – ETP 2014 (IEA scenario 2050)

ICT plays an important role in the (next generation) power system

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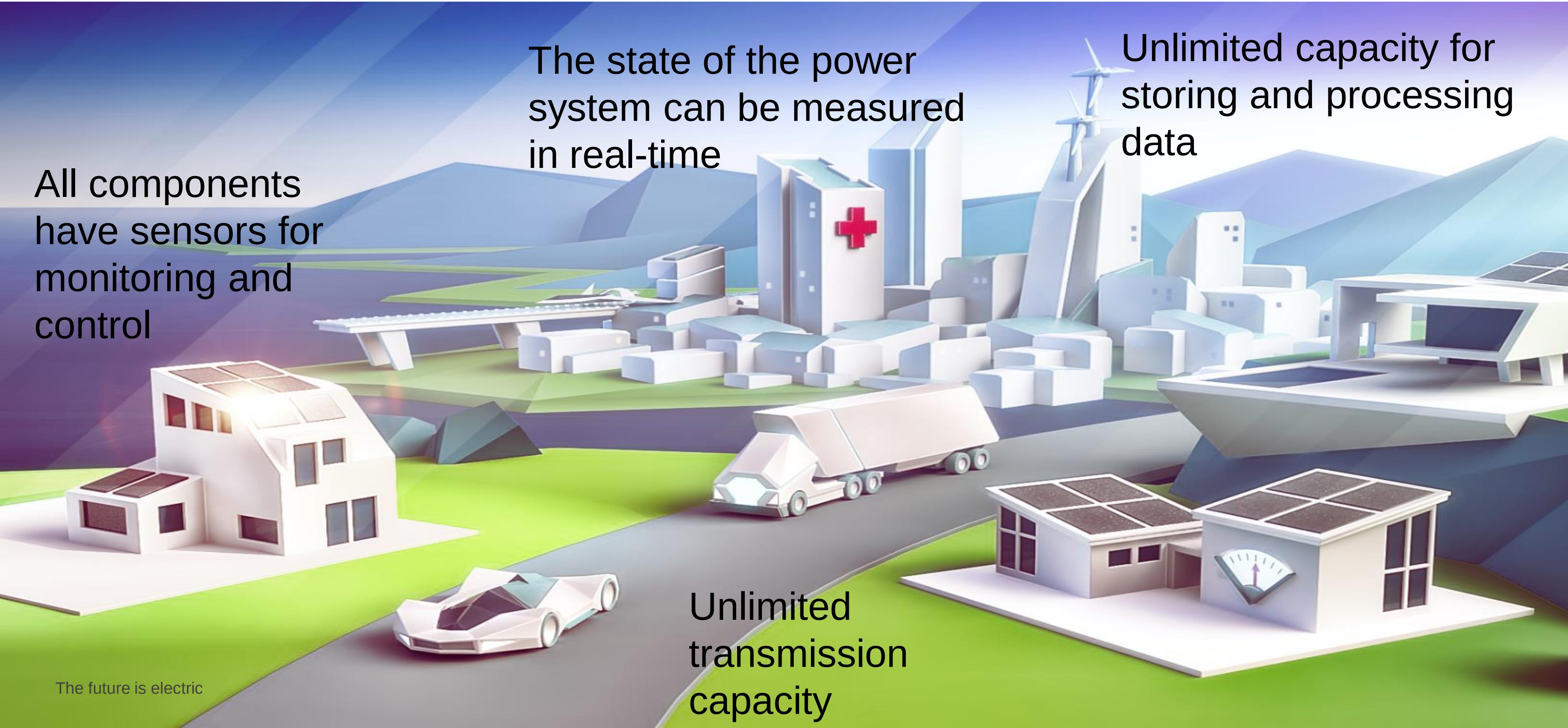


The state of the power system can be measured in real-time

Unlimited capacity for storing and processing data

All components have sensors for monitoring and control

Unlimited transmission capacity

Increased complexity requires real-time decisions

Real time
- Measurement and control
- System operation and asset management
- New operator environment

Machine learning and Big data
- Real-time analysis and decision models
- New Architectures (Fog, cloud +++)
- New skills (data scientists)

Automatization
- Robots and control engines
- Artificial Intelligence (AI)
- Control systems for automation

Framework for the Smart Grid program

- How to handle increased complexity
- Good knowledge and complete control is required.
  - The power systems condition in real-time.
  - Automatic solutions
  - Control systems that optimize operation.

Digitized asset management

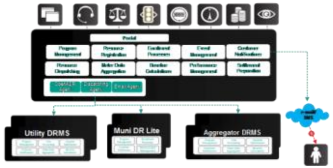
Integrated platforms

Real-time analysis

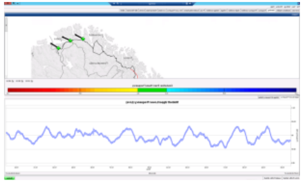
Exploitation of flexibility

How do we achieve better insight and control

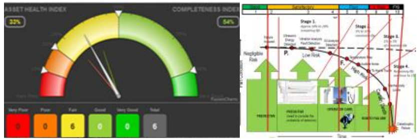
Dashboards



Large scale demand side response

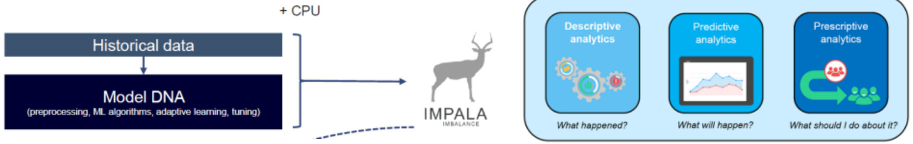


Applications for better monitoring and increased control



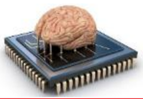
Smarter asset management with big data

Decision support and automation



Models of the power system, and machine learning, provide real-time decision support.

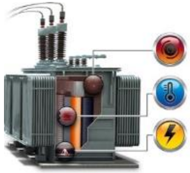
Machine Learning and Big Data



No limitations within ICT.

Control

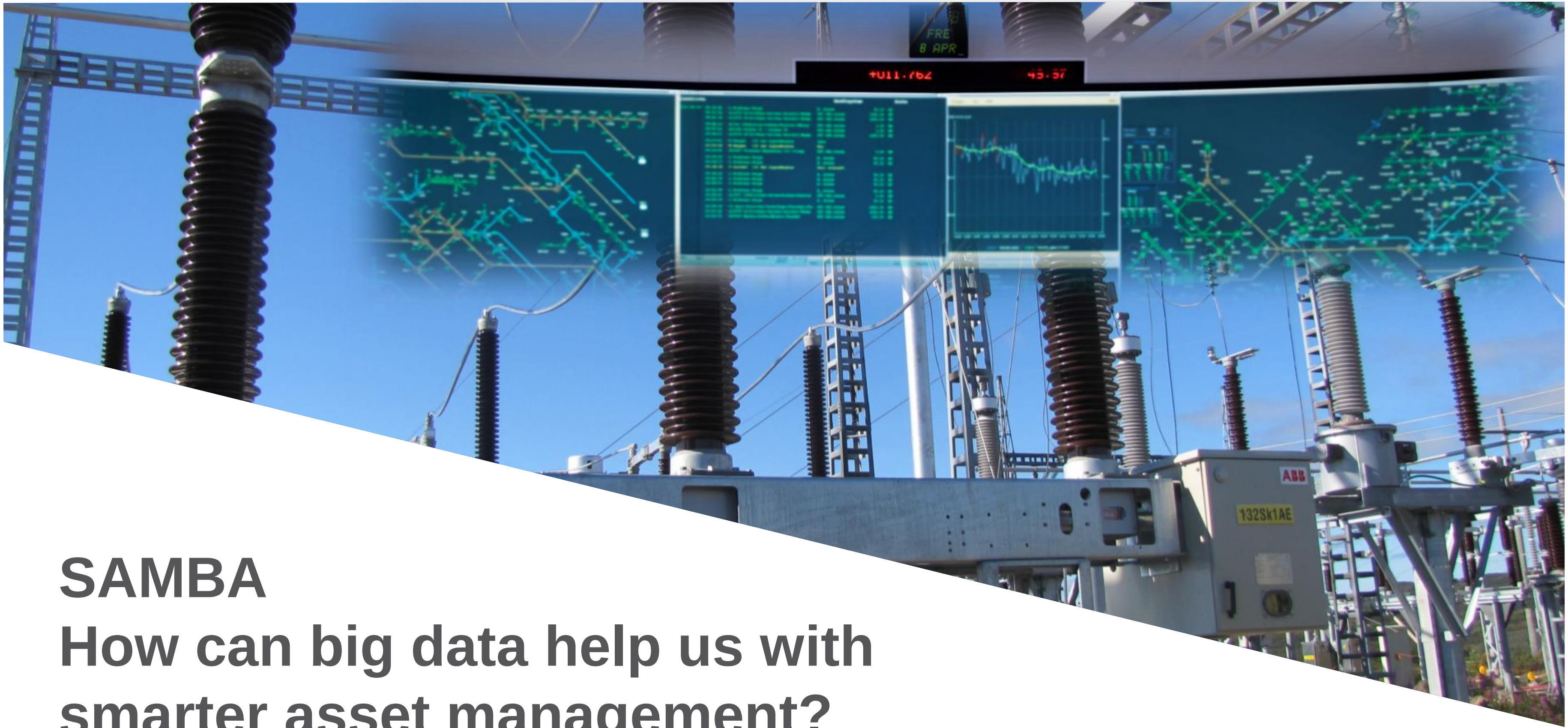
Surveillance



Sensors do the measurements and control all parameters.

Thank you for your attention

- Contact: jorn.johnsen@statnett.no



SAMBA
How can big data help us with smarter asset management?

Presentation Statnett R&D Conference 3rd. April 2019, Meet Ullevaal, Oslo

Arne Smisethjell, Project Manager SAMBA

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What is the SAMBA project?

- The SAMBA project has been a **<u>3 year R&D project</u>** financially supported by the Norwegian Research Councils Energix program and completed in March 2019.

With funding from
The Research Council of Norway

- The partners in this project have been:

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The challenges for Asset Management in Statnett

- Aging and increased volume of assets
- Statnett must optimize maintenance and investments
- Statnett has a lot of data about its components, but can utilize these in a better way

Some key figures from the SAMBA project:

- Total NOK ~26 mill
- 19 use case
- 53 presentations of the project
- 3 summer Students from NTNU
- ~18 researchers from Sintef
- ~70 Statnett employees

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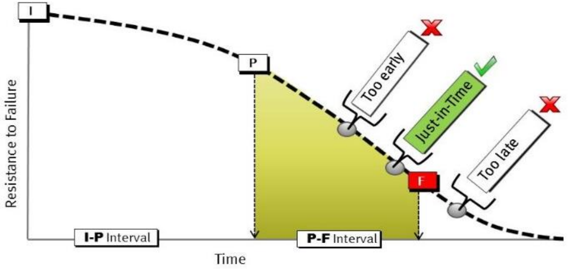
Why SAMBA project?

- Predict **now condition** for critical components
- Predict the development **over time** for critical components
- The basis for predictive maintenance
- Optimize the right time for critical component replacement
- Simplify and automated decision processes



Asset condition transformer

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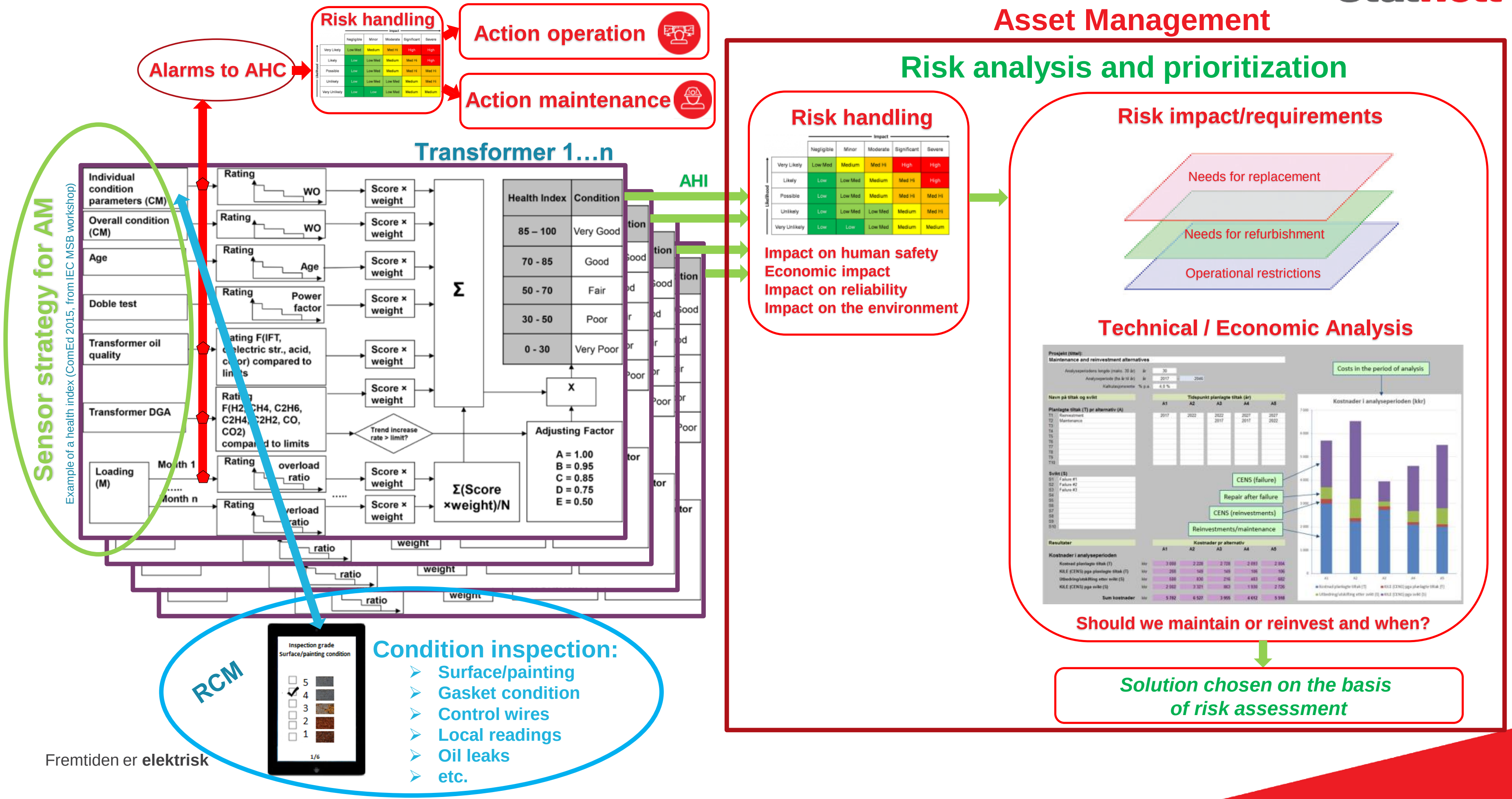

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Innovations

Statnett use case identification	Circuit breaker failure model	Risk monitoring function	Voltage transformer failure prediction
Multivariate analysis of transformer gasses	Overview of historical data availability	Cable and transformer temperature prediction	Asset reinvestment analysis testing
Reactor breaker reignition identification	Health index transformers	Line connector condition assessments	ICT asset management architecture investigation

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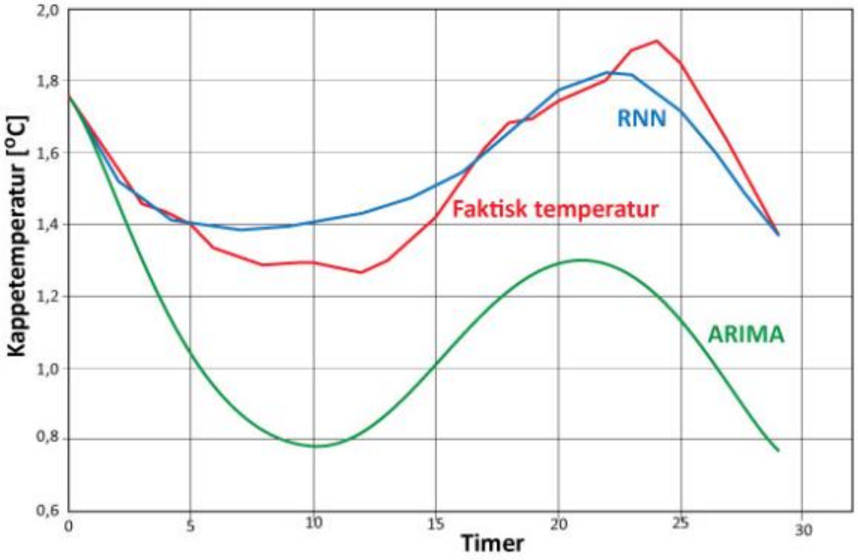
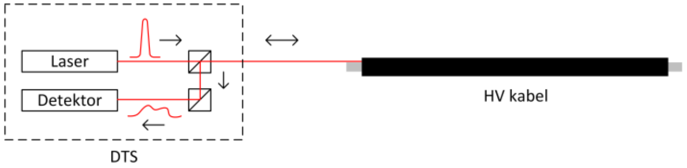
Innovation

Cable temperature prediction

- Tested on Statnett data
- Possible to predict temperature in cable
- Goal: Used in operation and detection of abnormal conditions





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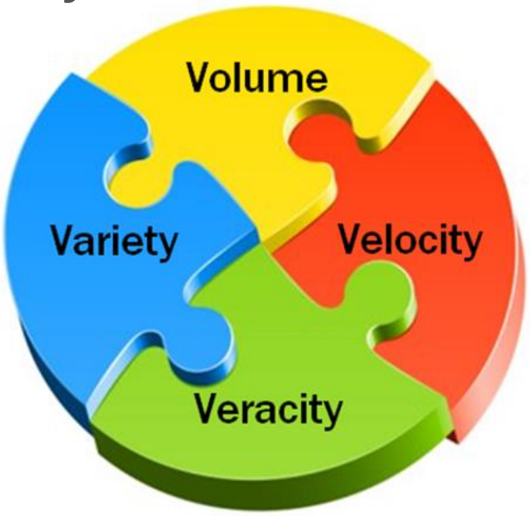
Recommendations

Improve data quality and availability

- Data Volume
- Data Velocity
- Data Variation
- Data Veracity



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What is the benefit of the SAMBA project?

Statnett has achieved:

- An ICT architecture suitable for asset management
- Demonstrate the need for sensors, measurements and data quality
- Expertise for condition monitoring models for power components
- Basis for development of Asset Health

Effective

Smart

Safe

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Potential savings for Statnett

- Saving ~ 30 - 40% by going from preventative to predictive maintenance

- Annual savings by postpone the replacement of a transformer is approx. NOK ~ 0.5 million

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Tank you for your attention!

Can PMU data help with system operation?

Presentation Statnett R&D Conference 3rd. April 2019, Meet Ullevaal, Oslo

Anders Skånlund, Project Manager SPANDEx and NEWEPS

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System operation will have to change…

RETAIL → ← **WHOLESALE**

Smarter homes

- Hourly meters
- Flexible demand
- Battery/storage
- Own generation

Smarter communities / cities

- Share resources
- Local generation
- Exploit local opportunities in storage, heating, cooling, geothermal, transport etc.

Smarter markets & grids

- Overall system optimization
- Integrate across borders
- Integrate distribution and transmission

New generation mix

- Volatile renewables replace plannable thermal
- Digital solutions improve forecasts and optimization

… because the system change

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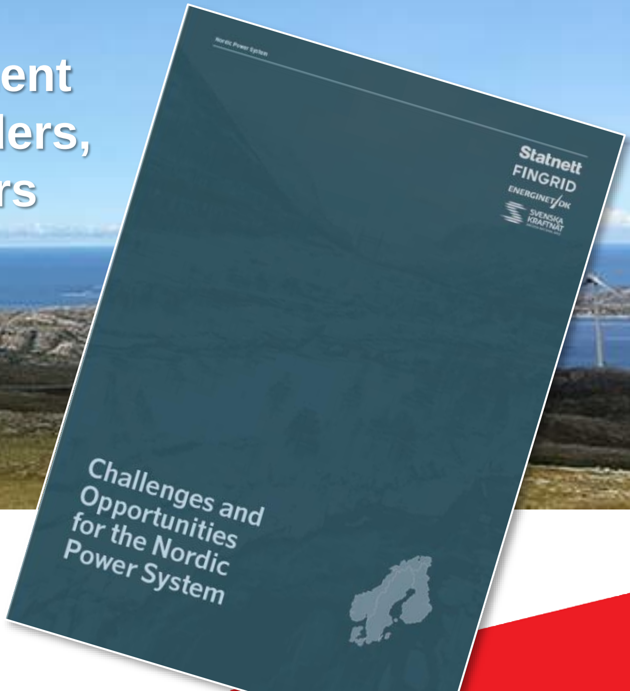
Challenges and opportunities

- ✓ More renewable generation
- ✓ More demand response
- ✓ More electrification
- ✓ Fast technological development
- ✓ More integration across borders, grid levels and energy carriers



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What is a Phasor Measurement Unit (PMU)?

A device that makes it possible to monitor frequency, current, voltage and phasors

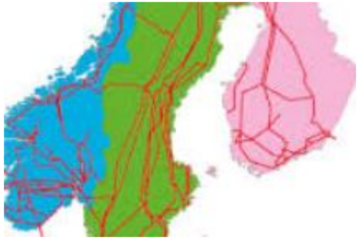
Some parameters are measured directly and others are calculated

A PMU can be a separate instrument or integrated into other instruments

When we say "PMU" we often mean "PMU-data" and not a physical box

Digital transformation in 4 dimentions

WIDE AREA



REALTIME

TIMRESOLUTION

1 vs. 500

(observasjoner per 10 sek)

SYNCHRONIZED

→ *New knowledge of the state of the grid*
→ *Solve traditional challenges smarter*
→ *May lead to new ways of operating the grid – significant possibilities for innovation and creativity*

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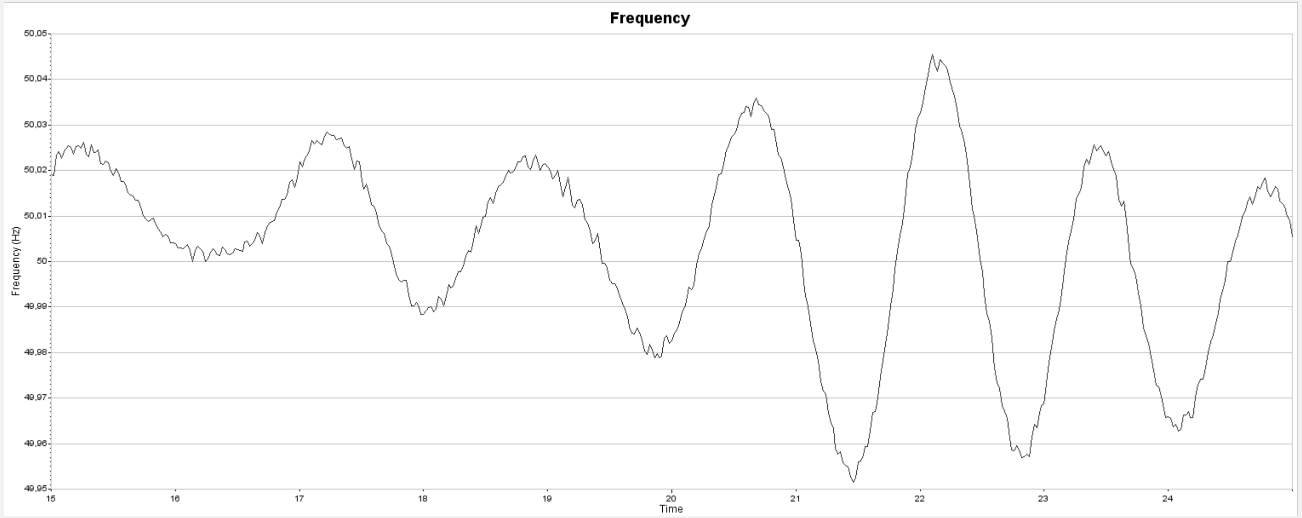
Being able to identifying frequency oscillations



10 seconds of frequency oscillations – current SCADA system would show one arbitrary value

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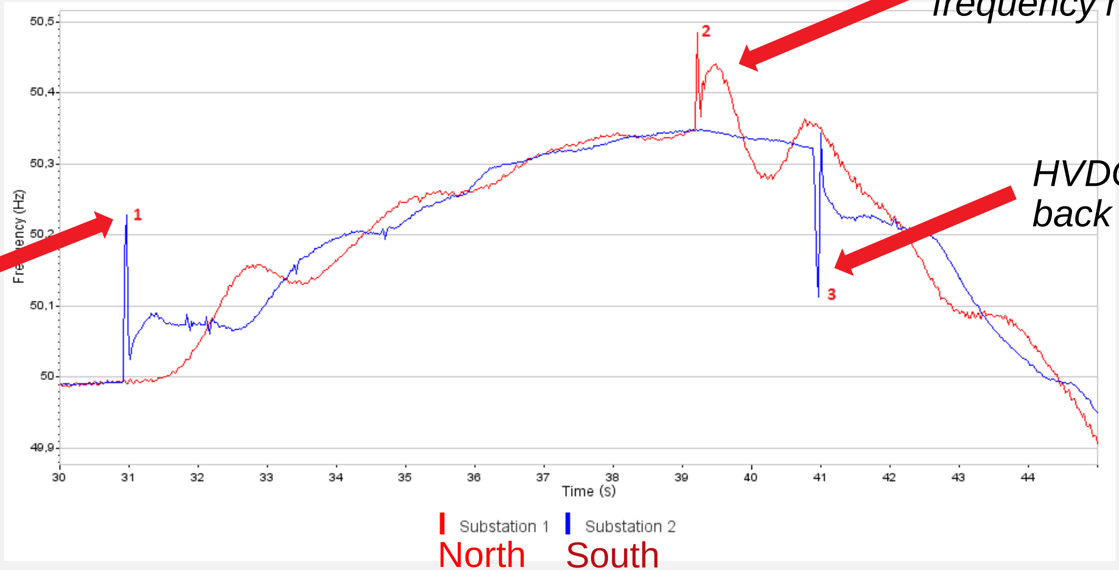
Being able to see a bigger picture

Load trips due to high frequency north in Norway

HVDC ramps back to full export

Trip of HVDC south in Norway



North South

10 seconds of frequency variations – current SCADA system is neither showing nor connecting the dots

USE CASES

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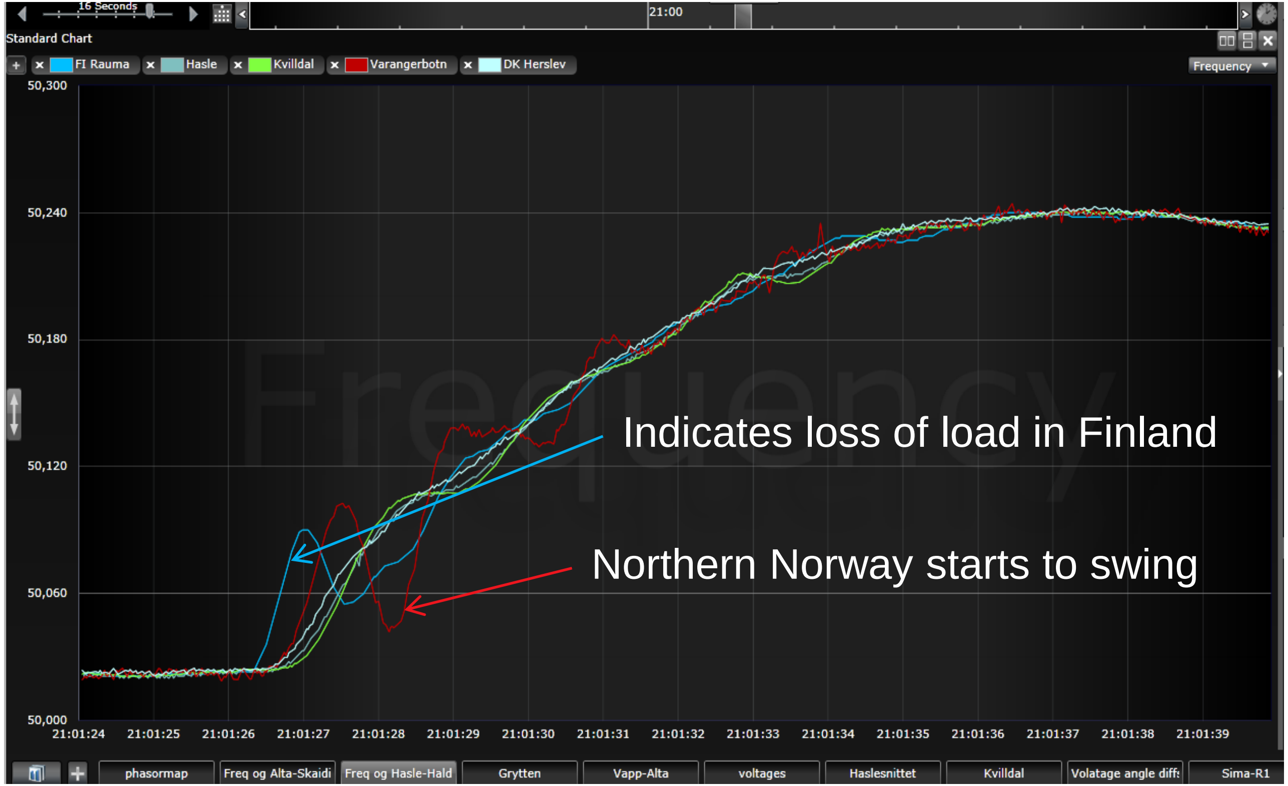
Getting new information about disturbances

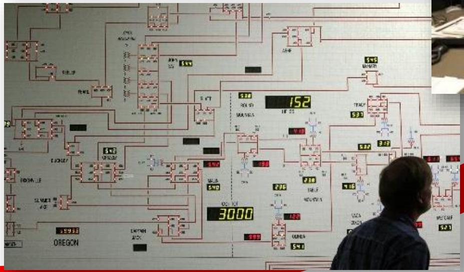


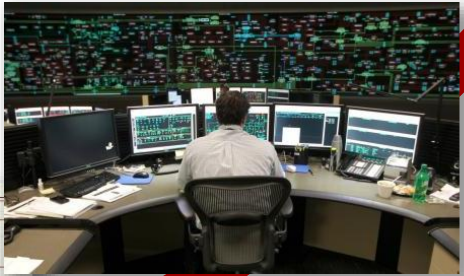
About 10 seconds of disturbances not seen in current SCADA system

PMUs to facilitate a digital transformation

Digital Transformation

- *Novel use of digital technology to solve traditional problems.*
- *Enable new types of innovation and creativity, rather than simply enhance and support traditional methods*





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A wide range of use cases, eg.

Monitoring and visualization

- Detect fast changes in voltage, current, phase angles and power flow
- Detect power oscillations and their origin and cause
- Calculate voltage stability limits
- Monitor system imbalances and the use of system services
- Improve state estimators
- Islanding management

Analysis of incidents

- What happened?
- Causes and effects
- Generation and system modeling and validation

Protection and control

- System protection
- Coordinated Voltage control
- Measures to stop oscillations (wide area power oscillation dampers)

…more opportunities to be developed

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Business Case for the use of PMU-data

Wide Area Monitoring, Protection and Control System (WAMPACS)

WAMS

Synchronized data provide more insight into system dynamic …

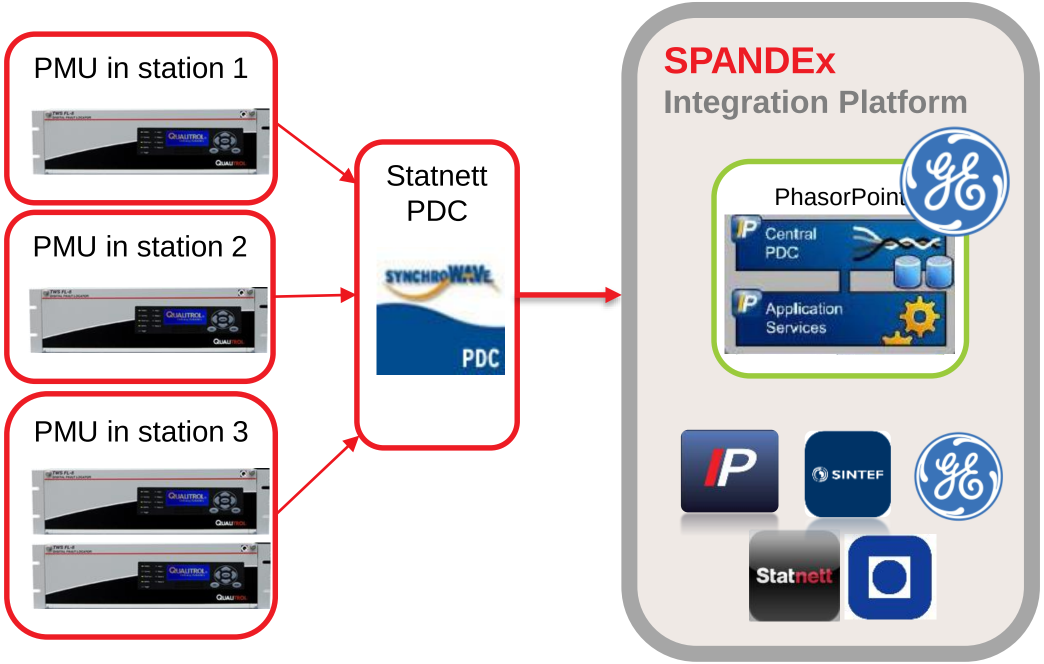
WAPS

… and can improve automatic response measures like system protection …

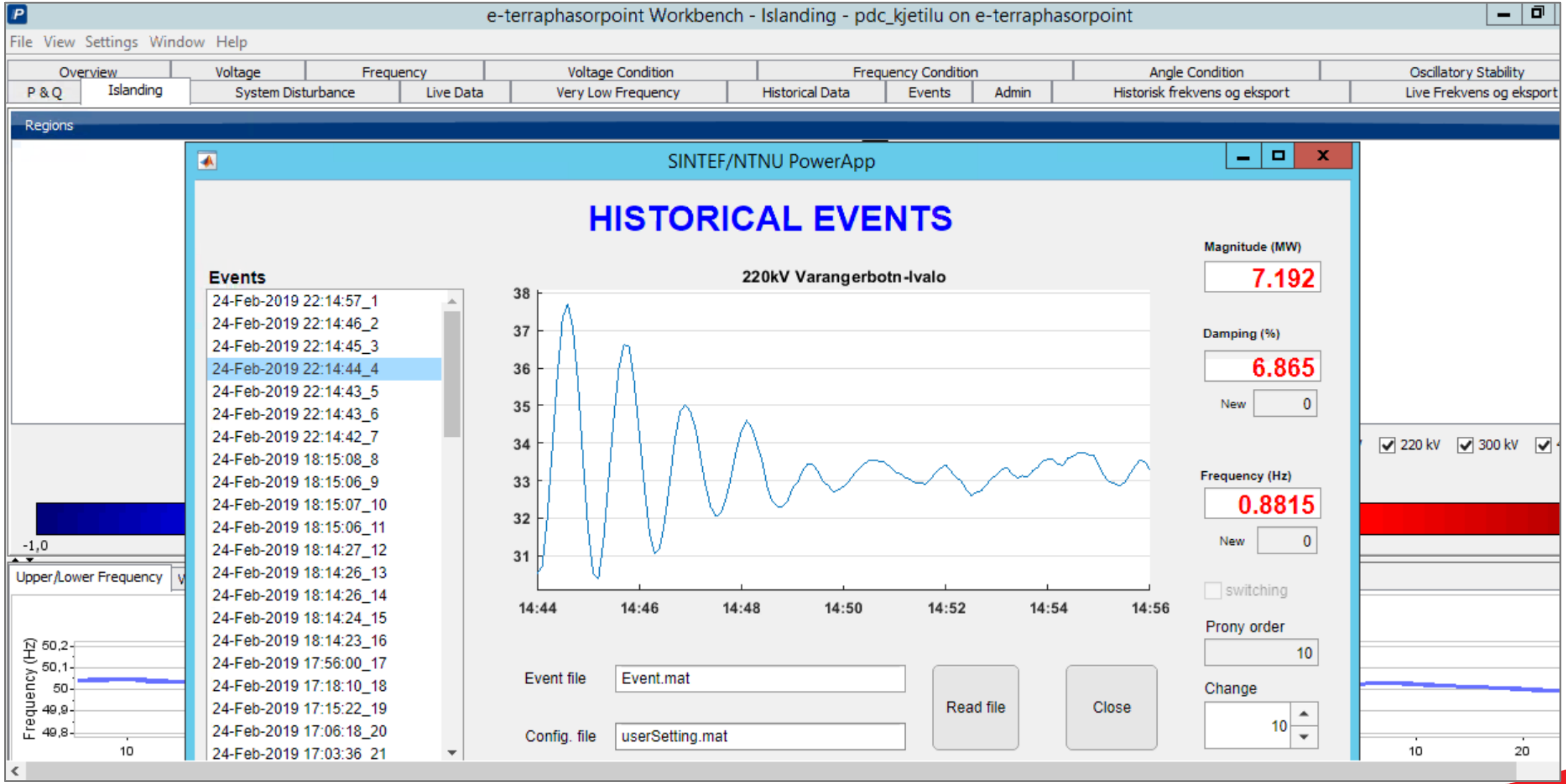
WACS

…control/regulation based on a complete set of synchronized measured and calculated state estimates

SPANDEx: Platform for operators to see grid dynamics



SPANDEx: Application used to illustrate dampening effect



Some findings…

- Include operators from idea to implementation and use
- Implementing new information system like WAMS is an iterative process
- Initially, researchers/developers and operators have different understandings of needs, possibilities and benefits and best solutions are developed during discussion and training
- Need to implement applications into the SCADA-system in order to get real experience

Going Nordic! The NORDGRID initiative

Nordic challenges

A Nordic platform for R&D

FINGRID
ENERGINET
LANDSNET
Nordic Energy Research
SVENSKA KRAFTNÄT
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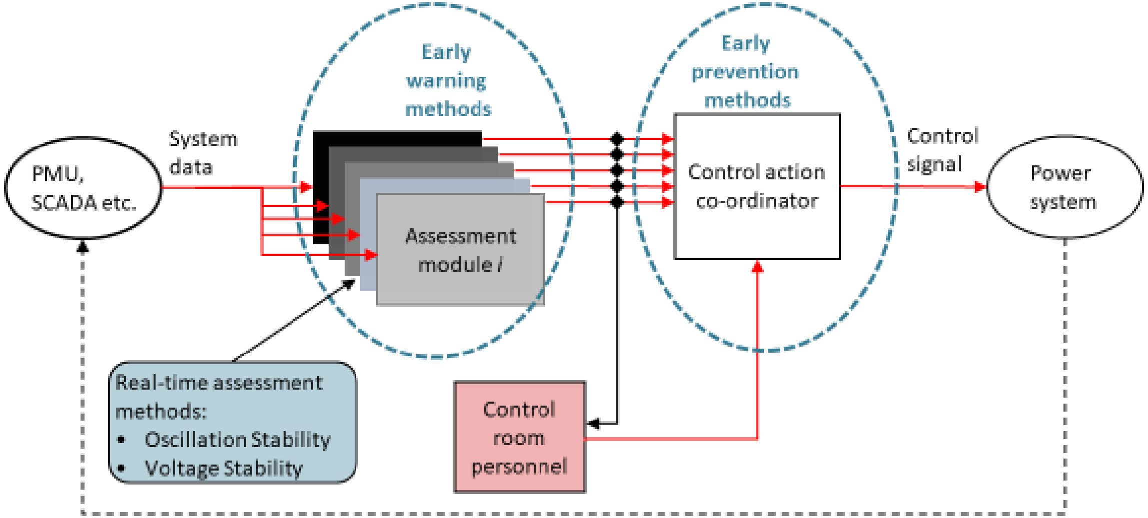
- A cooperation between Nordic Energy Research and the Nordic TSOs
- Nordic ministers allocating 500 MNOK to joint Nordic R&D (incl. energy)

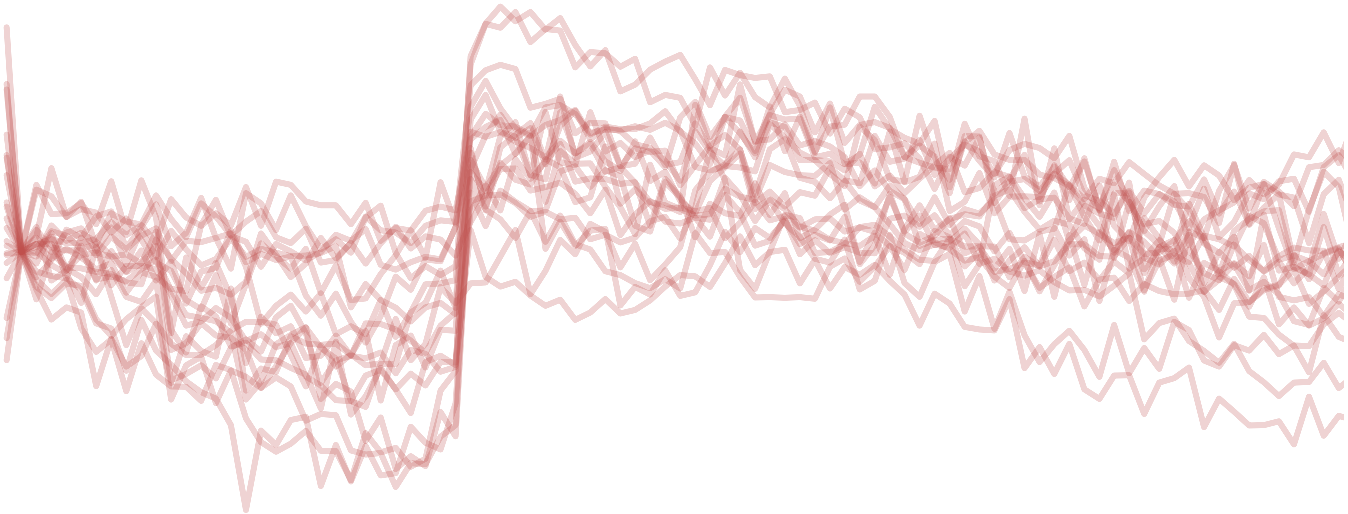
NEWEPS – a Nordic opportunity

- Improve the ability to monitor and control the power system in real-time
- Automatic response to dynamic changes in an integrated and renewable Nordic power system.



International Energy Agency · SVENSKA KRAFTNÄT · ENERGINET · FINGRID · LANDSNET · Statnett · Nordic Energy Research Nordic Council of Ministers

Thank you for your attention



IMPALA

Imbalance predictions with Machine Learning – a key to automation

Eivind Lindeberg

Statnett R&D Conference.
Ullevål, April 3 2019

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Outline

- Balancing the power system – and why it's getting harder
- Predicting imbalances with machine learning
- Prediction – a key to automation

Balancing is a Statnett task

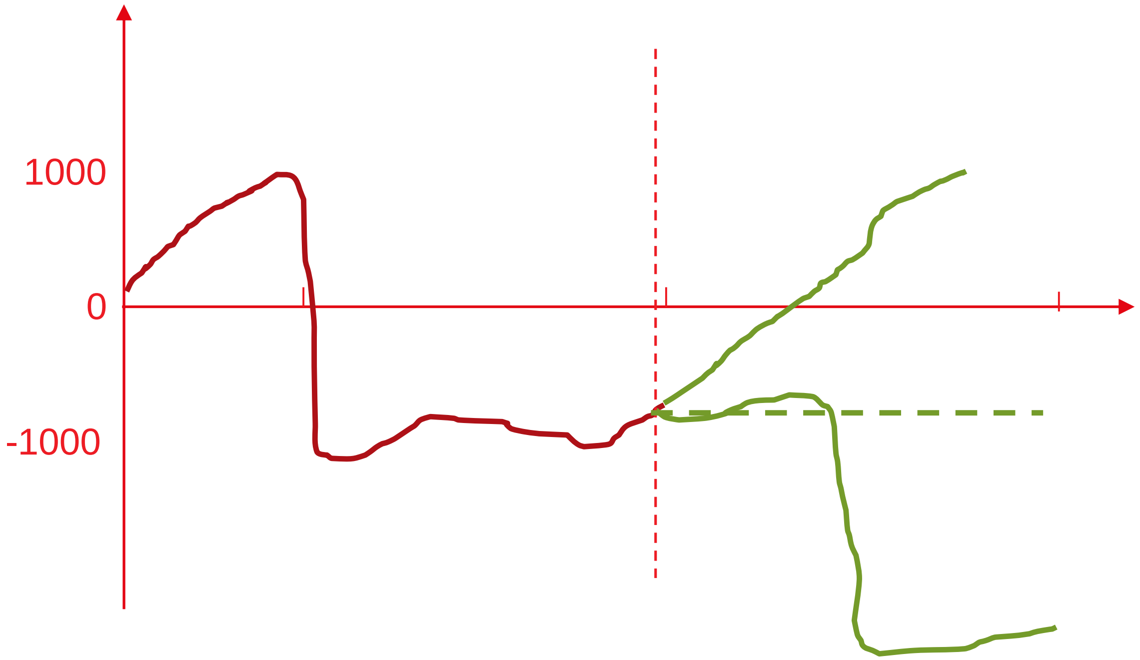
Hourly market balance vs. momentary system balance

Wind and sun – no schedule

Consumption changes are unplanned

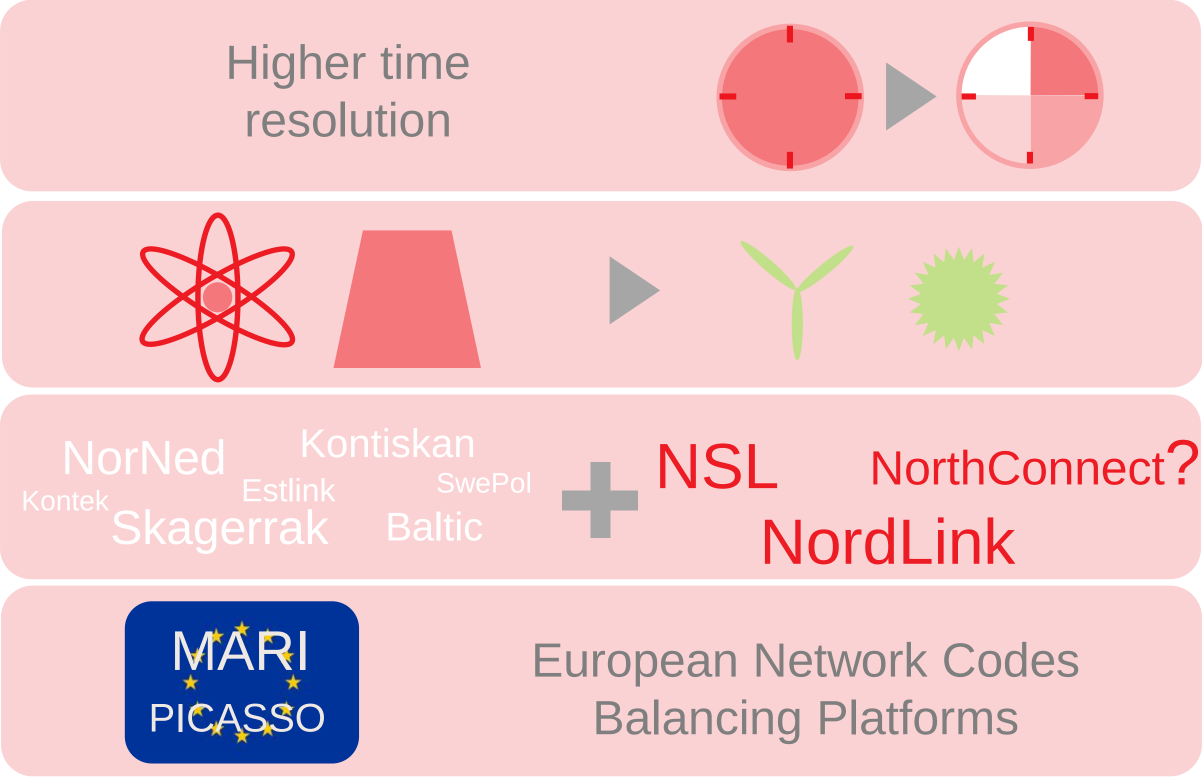
Taking actions for the unknown

Manual reserves are activated to solve the **imbalance** in 10-60 minutes

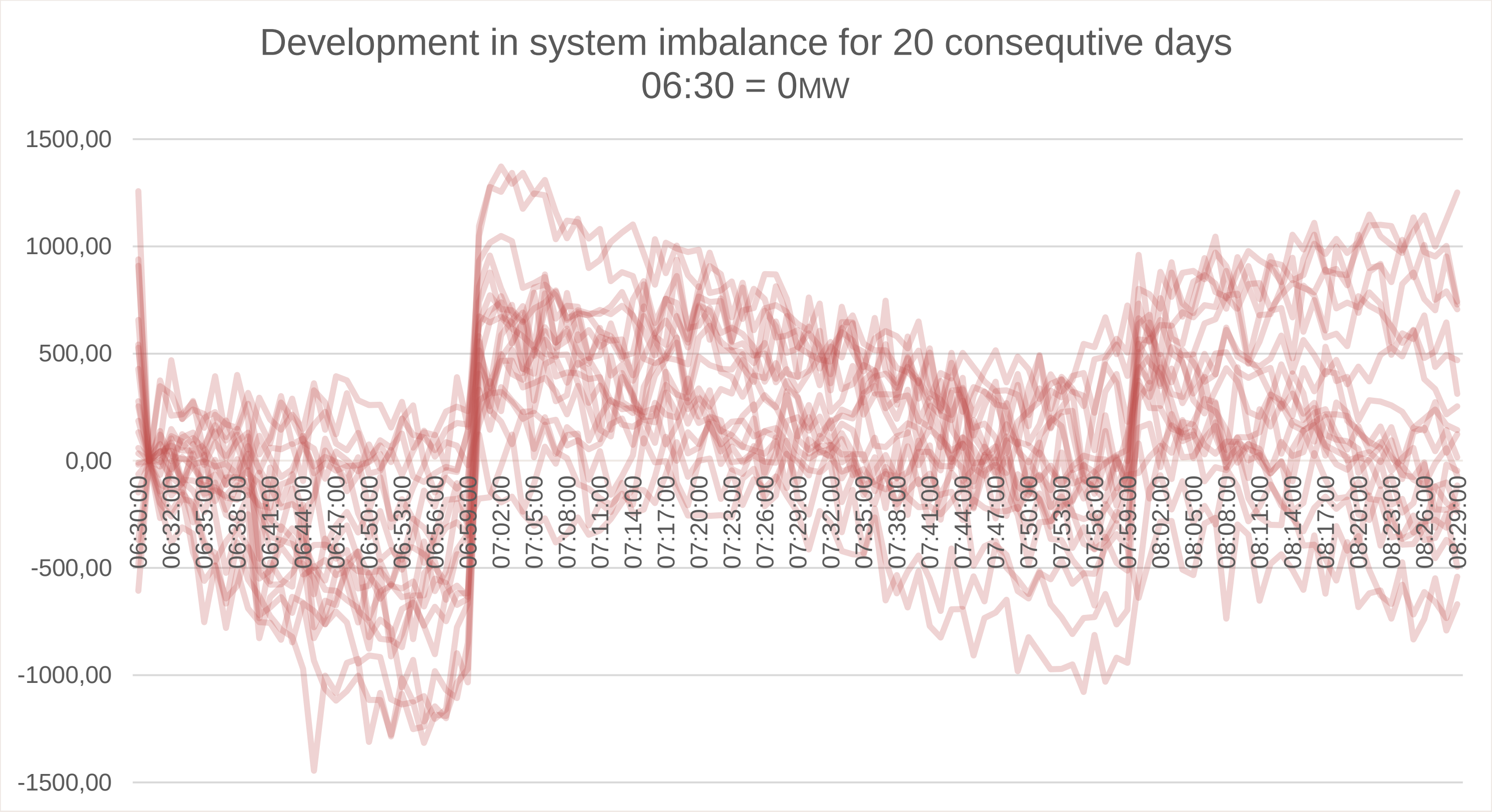


The challenge is growing

Optimeering Statnett



Patterns!



Development in system imbalance for 20 consequtive days
06:30 = 0MW
1500,00
1000,00
500,00
0,00
-500,00
-1000,00
-1500,00
06:30:00
06:32:00
06:35:00
06:38:00
06:41:00
06:44:00
06:47:00
06:50:00
06:53:00
06:56:00
06:59:00
07:02:00
07:05:00
07:08:00
07:11:00
07:14:00
07:17:00
07:20:00
07:23:00
07:26:00
07:29:00
07:32:00
07:35:00
07:38:00
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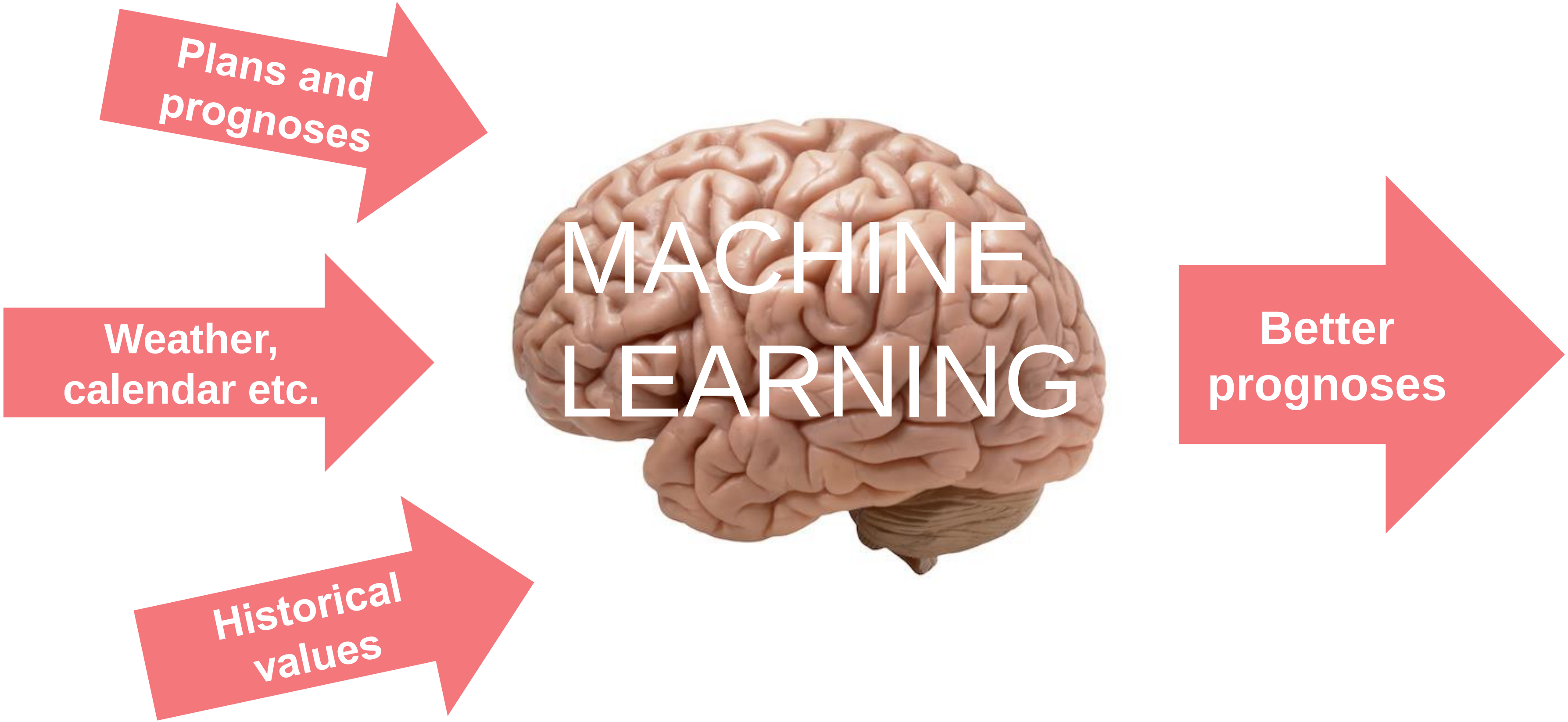
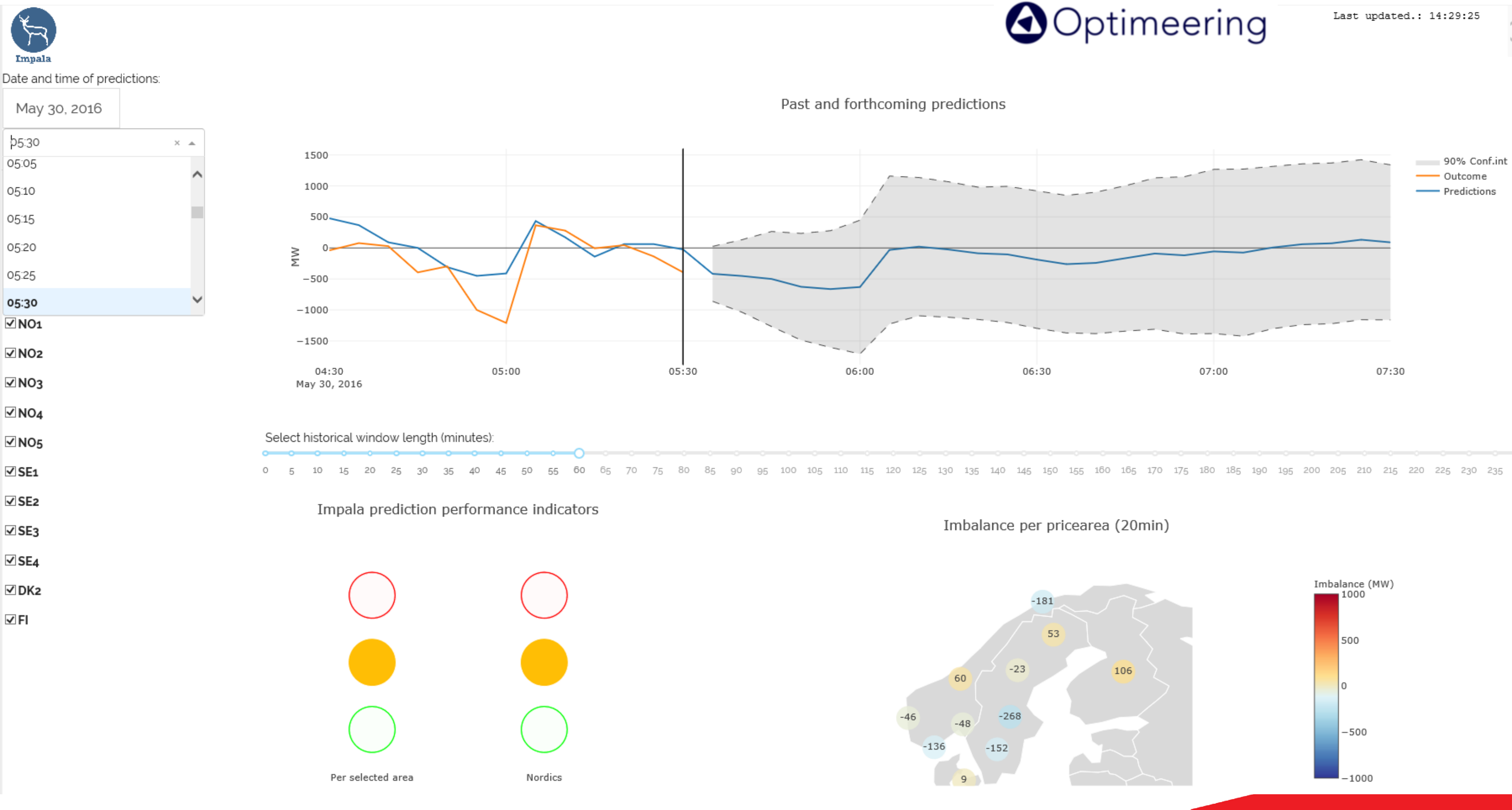
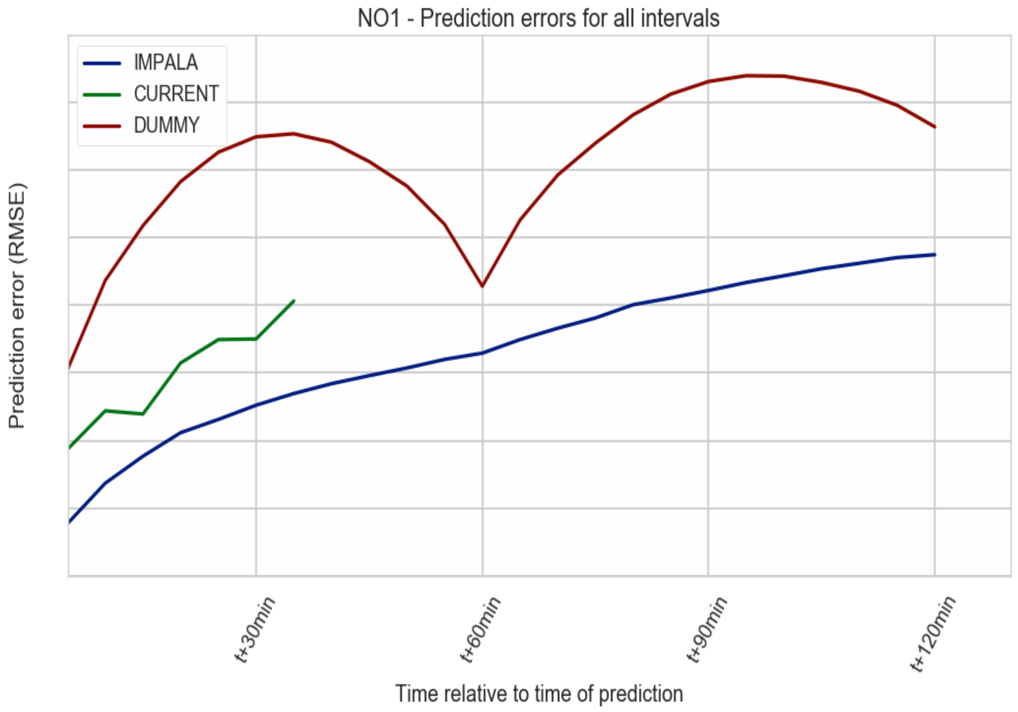
08:20:00
08:23:00
08:26:00
08:29:00

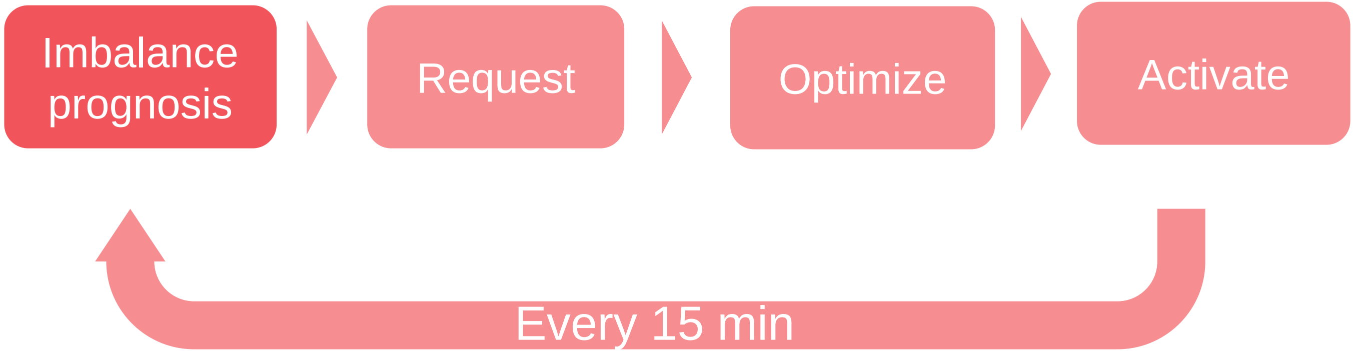

Plans and prognoses
Weather, calendar etc.
Historical values
MACHINE LEARNING
Better prognoses


Impala
Optimeering
Last updated.: 14:29:25
Date and time of predictions:
May 30, 2016
05:30
05:05
05:10
05:15
05:20
05:25
05:30
NO1
NO2
NO3
NO4
NO5
SE1
SE2
SE3
SE4
DK2
FI
Past and forthcoming predictions
90% Conf.int
Outcome
Predictions
MW
04:30
May 30, 2016
05:00
05:30
06:00
06:30
07:00
07:30
Select historical window length (minutes):
Impala prediction performance indicators
Per selected area
Nordics
Imbalance per pricearea (20min)
Imbalance (MW)
-181
53
-23
106
60
-46
-48
-268
-136
-152
9


NO1 - Prediction errors for all intervals
IMPALA
CURRENT
DUMMY
Prediction error (RMSE)
t+30min
t+60min
t+90min
t+120min
Time relative to time of prediction

Nordic balancing model:

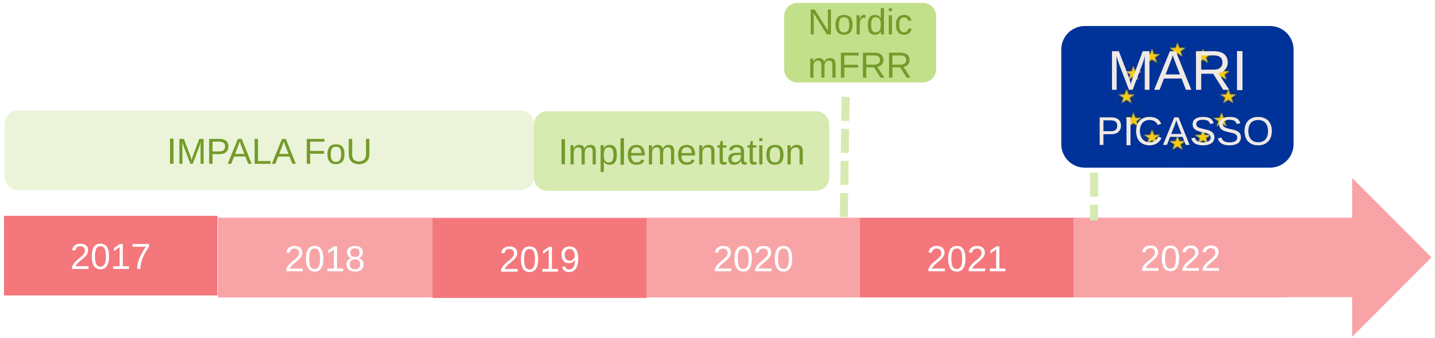
Automated balancing



Market development requires mFRR per biddig zone, per 15 minutes.

5 BZ • 4Q • 24h = 480 mFRR-loops per day

"Just-in-time research"



Road ahead

IMPALA
IMBALANCE

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Strategic development
"In-housing"

Commercial software

Optimeering

Challenges and success factors

- Relevance!
  - We solve a problem that needs to be solved
- Data!
  - The good – we had complete data set of imbalances
  - The bad – real-time data has been a proper challenge.
- Partners!
  - Competent and resourceful partners with self-interest in project success

Further reading

- https://www.groundai.com/project/forecasting-intra-hour-imbalances-in-electric-power-systems/

Large Scale Demand Response – myth or reality?

Oslo 2. April 2019

Knut Hornnes
Statnett

Main goals

- Motivate development and cooperation between TSO, technology suppliers, BRP and electric energy end user.

- Test and validate a technical concept for demand control. The concept shall be scalable and progressive.

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Specific goals in the project

- Test a full scale technical solution which is able to disconnect a number of loads from Regional Control Centre North in Alta.
- Test and validate a technical concept for demand control. The concept shall be scalable and enable progressive development.
- Test disconnection of loads with a response time of 2 minutes.
- Obtain participation of loads with different characteristics.

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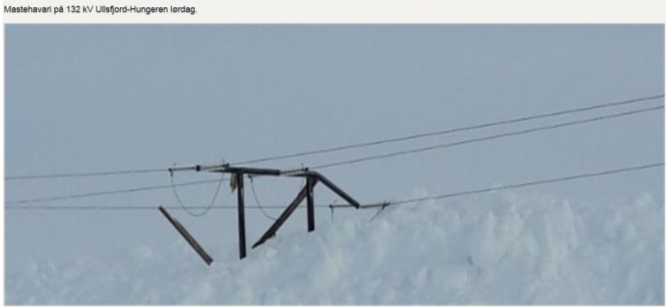
Why?



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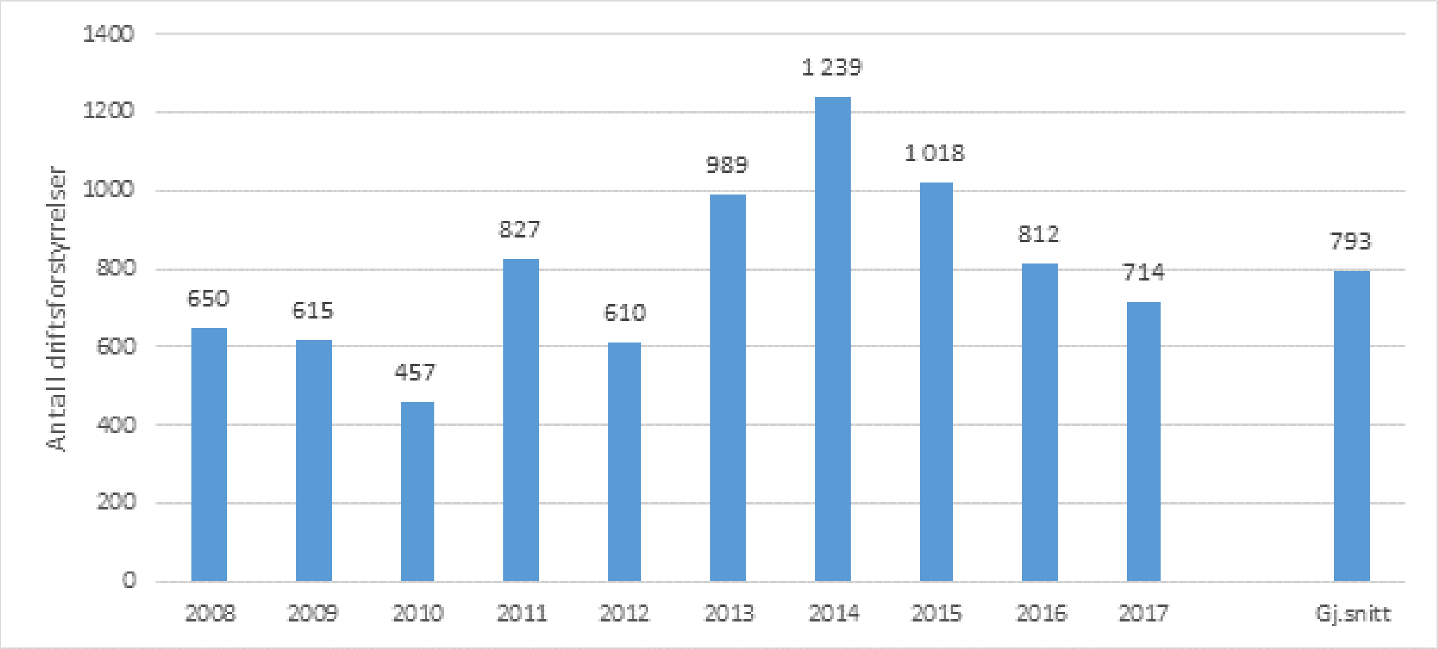
Number of disturbances in 33-420 kV grid



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Increasing need for flexibility in the Nordic power system

More and another type of consumption

Increasing share of renewable energy production (wind/PV), **2 - 5 TWh** per/year

2013 Oskarshamn 2 **- 640 MW**

Ringhals 2 **- 870 MW**

Olkiluoto 3 **+1600 MW**

NordLink **+/-1400 MW**

Ringhals 1 **- 880 MW**

Oskarshamn 1 **- 470 MW**

NSL **+/-1400 MW**

2016 2017 2018 2019 2020 2021

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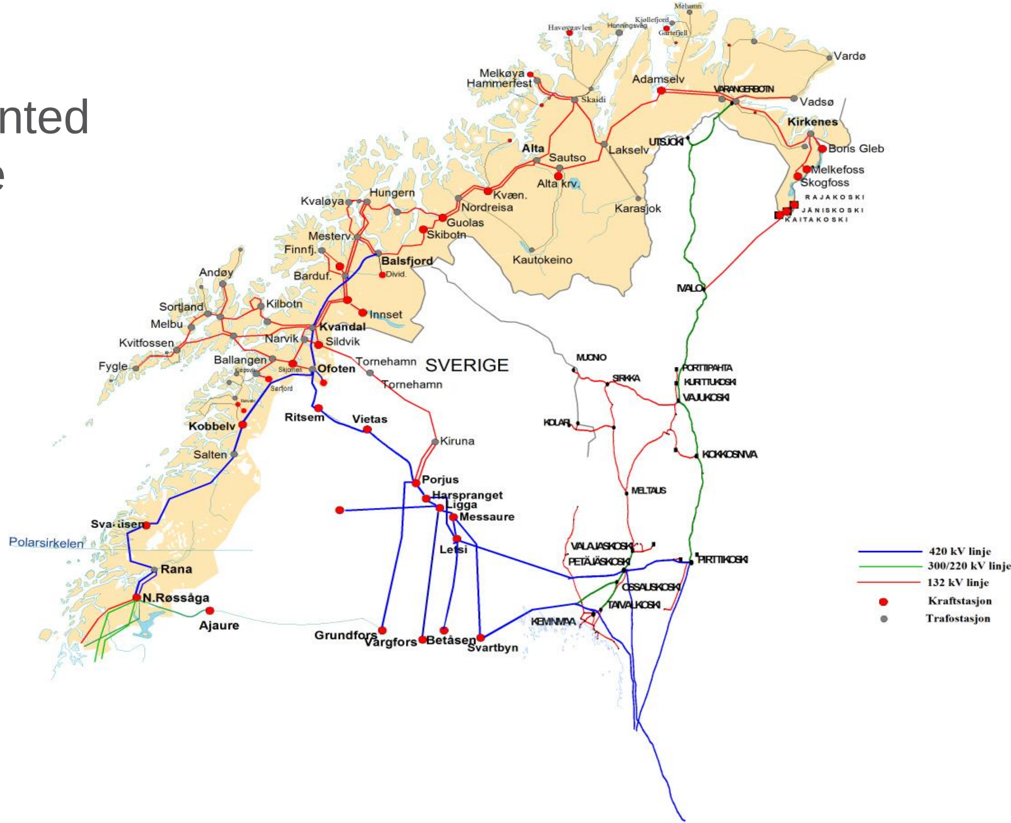
Area in focus – Northern Norway

- The Demand Response project wanted to include loads in a large area, the counties of Nordland, Troms and Finnmark

- The solution must be scalable and enable progressive development



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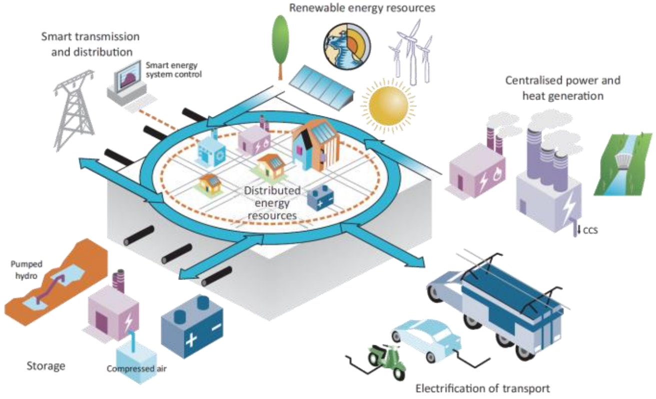
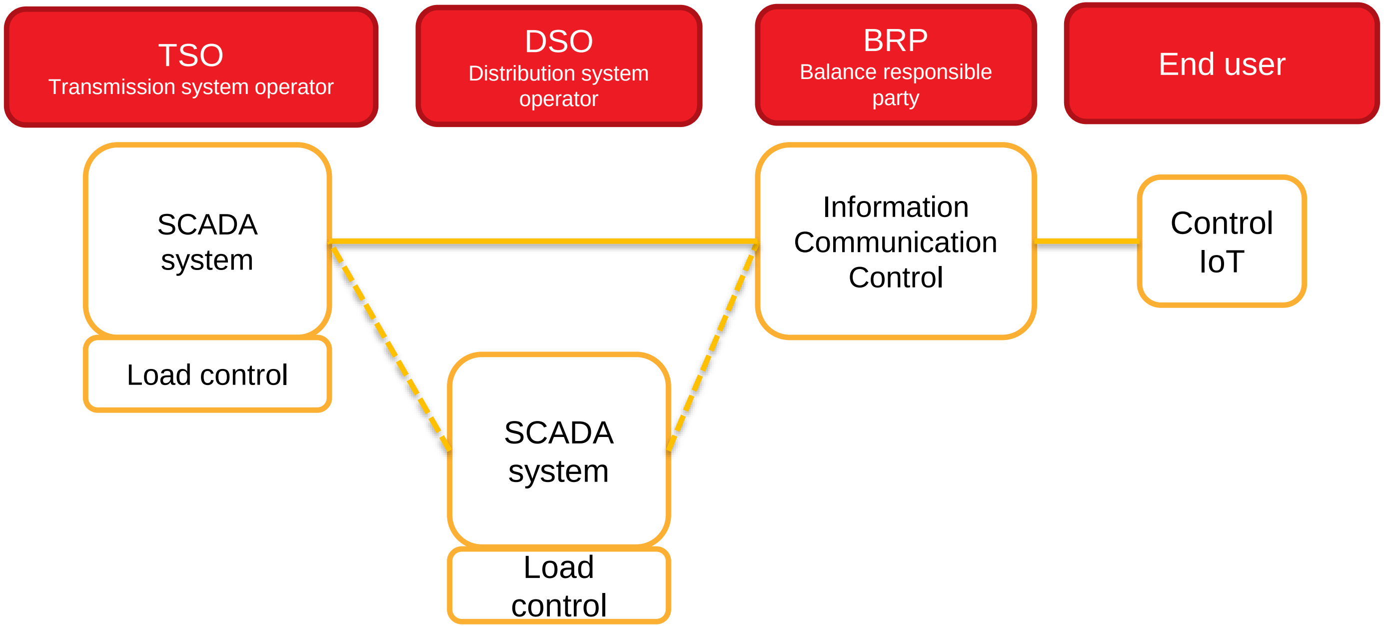
System solutions

- Two possible infrastructures for communication
  - AM(S) with two-way communication and control
  - IP addressable via fiber, GSM, GPRS (IoT)

- Depending on future roles
  - Grid companies
  - Aggregators
  - Balance responsible parties
  - Power retailers



Demand response concept



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R&D partners

- eSmart as
  - Contract counterpart
  - Technical solution
  - Function as aggregator
  - E2U as supplier of control hardware

- Ishavskraft as BRP
  - Elekctrical boilers in Tromsø and Alta
  - A number of residential houses with electric radiators

- Statkraft as BRP for Alcoa
  - Industrial load

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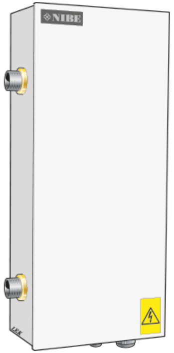
Participation in Demand response pilot

- It takes a lot of time end effort to get access to loads that can be disconnected
- The pilot got access to a total of 21,4 MW of demand
  - Tromsø: 6,5 MW electrical boilers
  - Alta: 2,9 MW electrical boilers
  - 12 MW industrial load
  - Some residential houses with electric radiators
- Activation from Regional Control Centre North via aggregator

Fleksible loads in Tromsø and Alta

		kW
Tromsø	El-kjel	993
Tromsø	El-kjel	204
Tromsø	El-kjel	200
Tromsø	El-kjel	210
Tromsø	El-kjel	197
Tromsø	El-kjel	226
Tromsø	El-kjel	274
Tromsø	El-kjel	106
Tromsø	El-kjel	146
Tromsø	El-kjel	3970

		kW
Finnmark	El-kjel	537
Finnmark	El-kjel	800
Finnmark	El-kjel	170
Finnmark	El-kjel	189
Finnmark	El-kjel	122
Finnmark	El-kjel	245
Finnmark	El-kjel	245
Finnmark	El-kjel	138
Finnmark	El-kjel	125
Finnmark	El-kjel	174
Finnmark	El-kjel	218



- Response time less than 2 minutes
- Duration of activation 30, 60, 120 and 240 minutes

API Regional Control Centre North

Statnett | Storskala Laststyring | Welcome : ADMIN@ROLE_ADMIN | Logout

Refresh

disconnectL...	Market Participant Id	GridNodeId	GridNodeName	EnergyGroupId	Load...	Disco...	Categor...	RespTim...	Duration...	Disconnected...	Availabl...	DisconnectStartTime...	DisconnectEndTime	reconnectLi...
Disconnect	Ishavskraft	null	60min 5min	f9aee92b-6e51-5d3d-a88e-95cd2d16de8a	15	0	B	2	60	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Hungeren	Hungeren 7min 5min	f04b1915-27c9-5314-aa86-8c105f59f2c1	87	0		2	7	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	null	5min 5min	ea2b75d4-6712-55cd-bb1b-6f001f7fc60c	752	0		2	5	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Hungeren	Hungeren 15min 5min	e6ccbf88-166f-5328-bfb1-8e73369f345c	166	0		2	15	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Hungeren	Hungeren 30min 5min	e522a961-a9bd-5dc7-8af0-8984b880cce6	134	0	A	2	30	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	null	30min 5min	e46e7b2d-d035-506b-b8a5-222a827a226e	30	0	A	2	30	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Mestervik	Mestervik 9min 5min	d19117d9-d944-51cb-a92f-50eb3e10016c	1666	0		2	9	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Aronnes	Aronnes 15min 5min	d0b4f059-11cb-5244-a31f-ed1cb22a9887	106	0		2	15	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Hungeren	Hungeren 6min 5min	96cd5ced-b628-5629-9514-161b3c91f1a5	47	0		2	6	No	Yes	N/A	N/A	Reconnect
[illegible]	[illegible]	[illegible]	[illegible]	95843120-c8b7-5da3-b5d2-680d29d8ede7	10000	0		2	5	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Aronnes	Aronnes 60min 7min	89538a43-b6dc-56de-a406-6ce28a56dd1e	95	0	B	2	60	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Charlottenlund	Charlottenlund 30mi...	83e300da-4ec1-5475-80d2-f19b6573d6c0	406	0	A	2	30	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Aronnes	Aronnes 30min 5min	6e9b079a-7aa7-5b4c-be96-b453786c2fd7	42	0	A	2	30	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Aronnes	Aronnes 5min 5min	61f81fe8-75bf-5865-923d-ad8c5492b6ec	752	0		2	5	No	Yes	N/A	N/A	Reconnect
[illegible]	[illegible]	[illegible]	[illegible]	4ffcd638-846a-52d7-9d5d-6859b140ff40	2000	0		2	6	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Aronnes	Aronnes 60min 5min	3cab2c72-9f3f-5b5b-a329-0d659d2188f2	126	0	B	2	60	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Mestervik	Mestervik 15min 5min	35234dc4-238e-5b35-8566-0cf780b19396	26	0		2	15	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Aronnes	Aronnes 0min 0min	33dcc59b-3932-5765-9e3d-9dce2c701d38	127	0		2	0	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Hungeren	Hungeren 8min 5min	3145e8e0-c478-5bae-804c-77672cc5fb66	159	0		2	8	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Mestervik	Mestervik 30min 5min	1029cea2-881d-554e-ba40-9ee1f0c632bc	143	0	A	2	30	No	Yes	N/A	N/A	Reconnect
Disconnect	Ishavskraft	Test	Test 5min 5min	0648ca3d-f5aa-531b-bebc-329dc205365b	154	0		2	5	No	Yes	N/A	N/A	Reconnect

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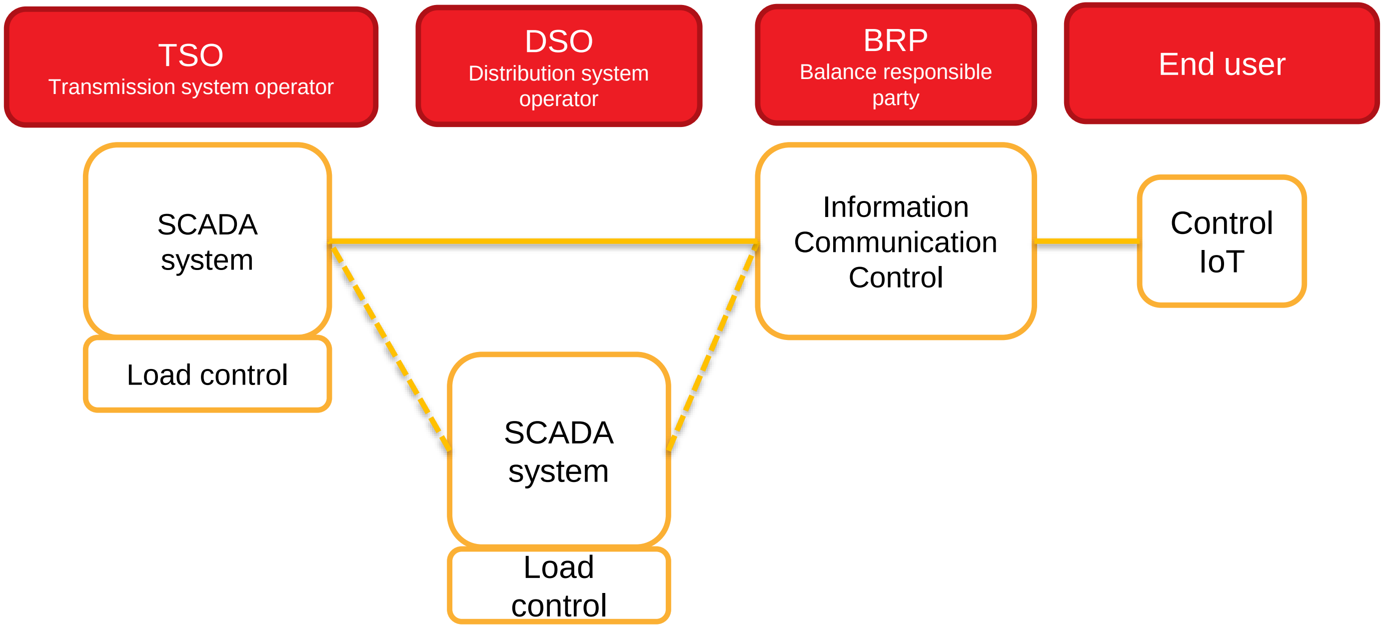
Demand response concept



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Conclusions

- It takes time and a lot of effort to get access to loads that can be disconnected
- Several different consumption categories are well suited for disconnection with low consequences
- The technology for communication and control is available
- The roles of the actors must be understood and further developed
- Standards for communication and control should be developed
- Markets suitable for demand response resources should be developed
- It's already here!

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Report Large Scale Demand Response

- Report from Thema after interviews with actors involved in the project
- Public report (in Norwegian)
- Report available at statnett.no


THEMA CONSULTING GROUP

Offentlig

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Evaluering av storskala laststyring

På oppdrag fra Statnett

november, 2018

THEMA Rapport 2018-16

- Contact: knut.hornnes@statnett.no

Thank you for your attention

Automatic inspection by drone

Automatic mission for inspection

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Automatic inspection by drone

Mobile sensor

- Gauge-reading
- Mechanical deviations
- EO-camera
- IR-camera
- UV-camera

Unmanned stations

- Distance
- Criticality
- Physical layout
- Support regional centrals

Prediktive maintenance

- Sensordata
- Verify condition or state

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3 main components

Localization and navigation

Nordic weather

- Sense & avoid
- Turnaround
- Sensor(s)

- Machanism
- Interaction w/drone

- Functionality
- Multiple drones
- Operator friendly

Automatic inspection by drone

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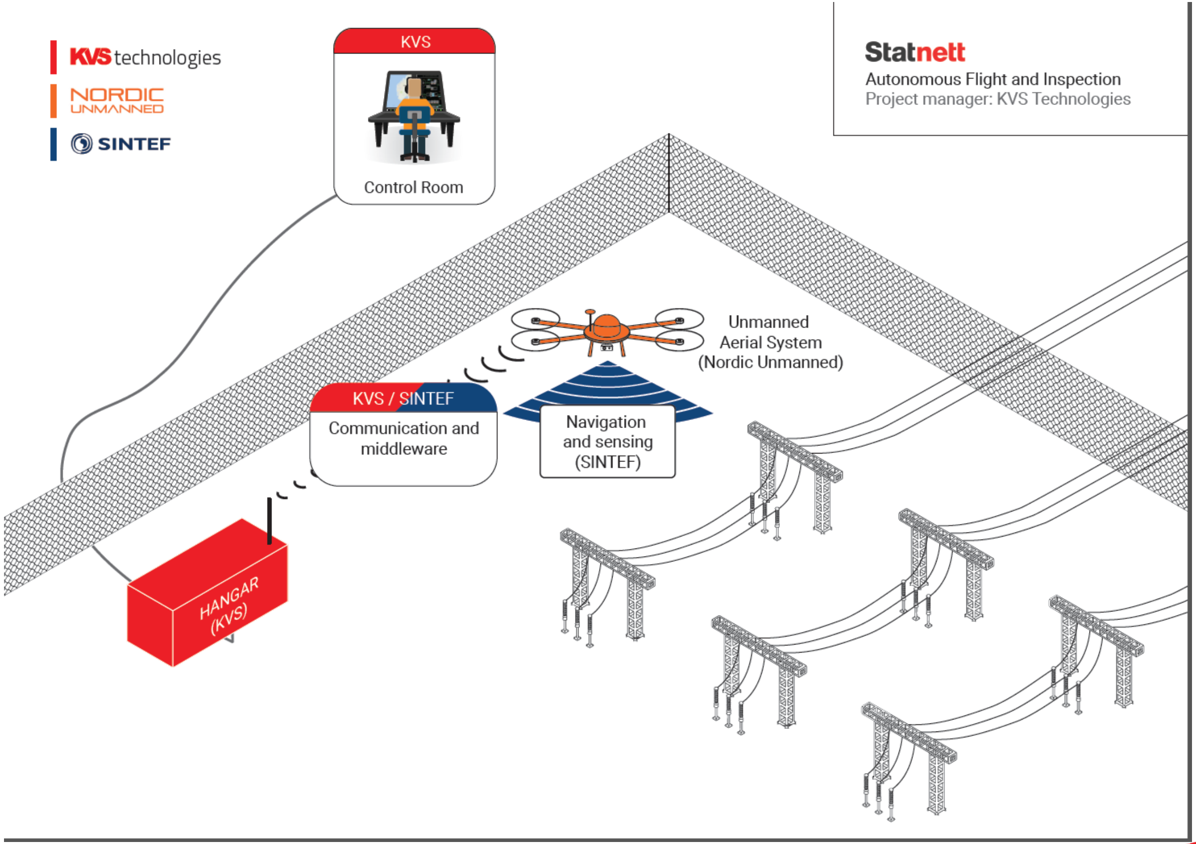

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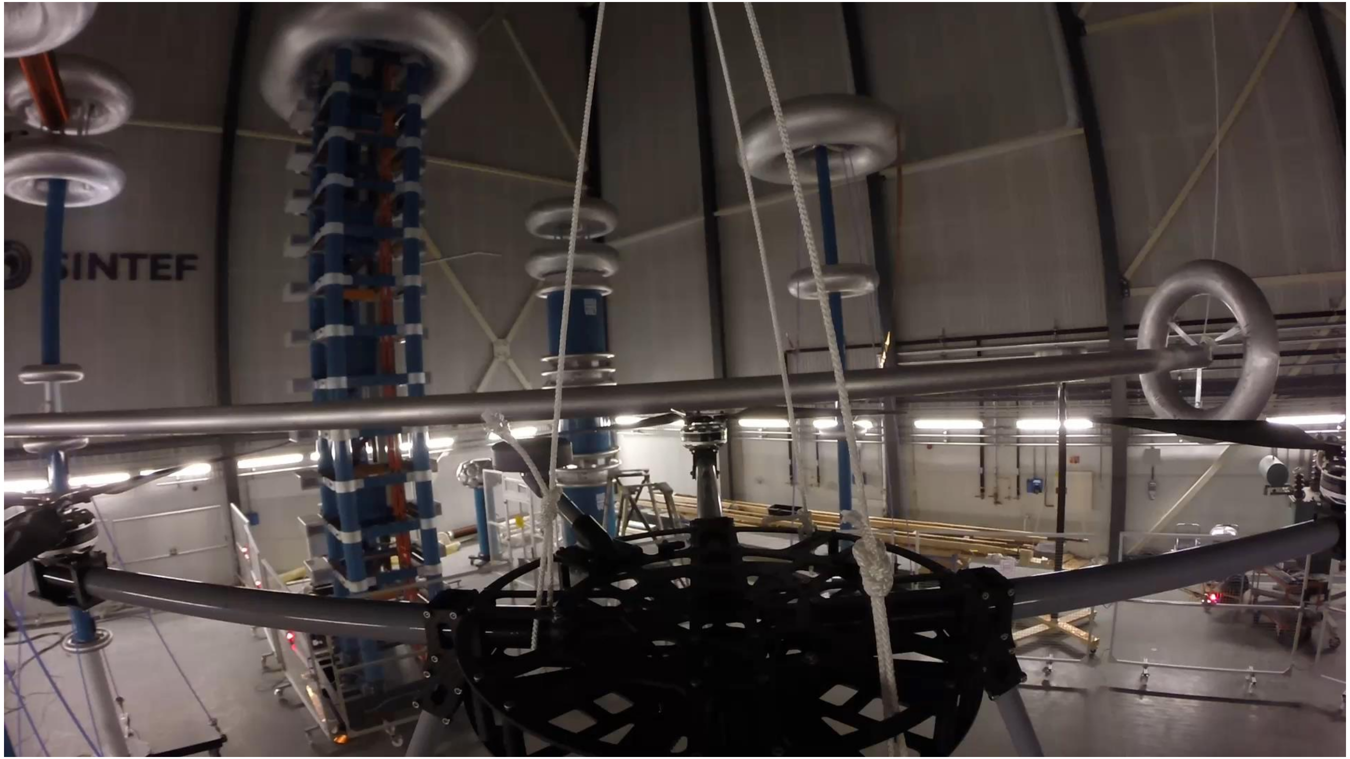
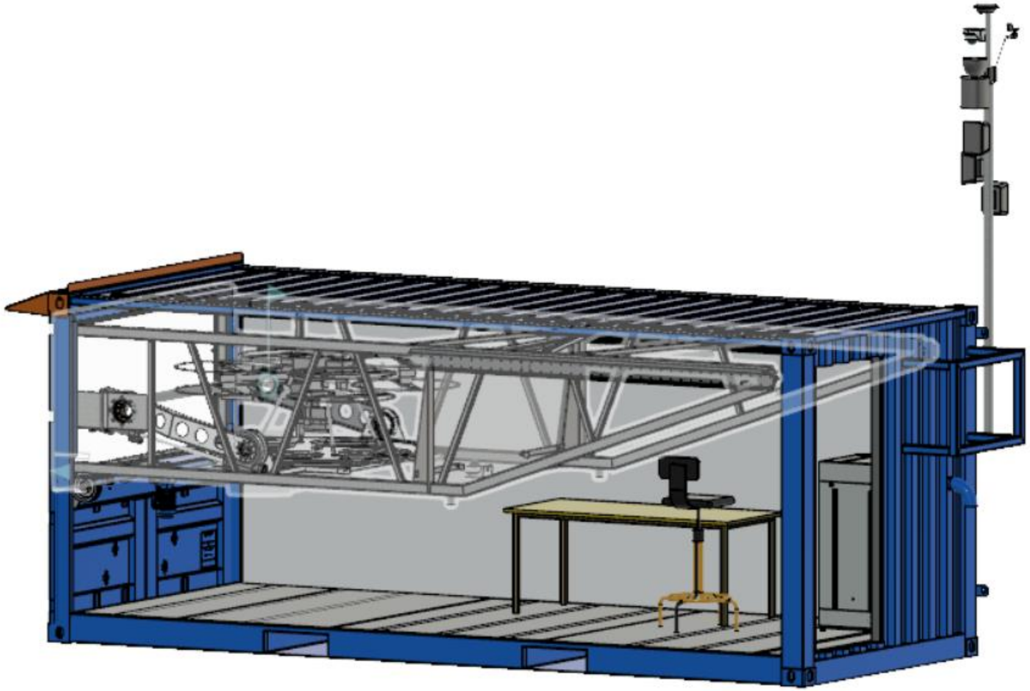
Onboard equipment:

- 8 motors
- 2 GPS-antennas
- 2 computers
- 1 lidar-scanner
- 3 depthsensors, EO and IR
- double flightcontrollers
- 24-105mm zoomcamera
- radiometric IR camera
- ++

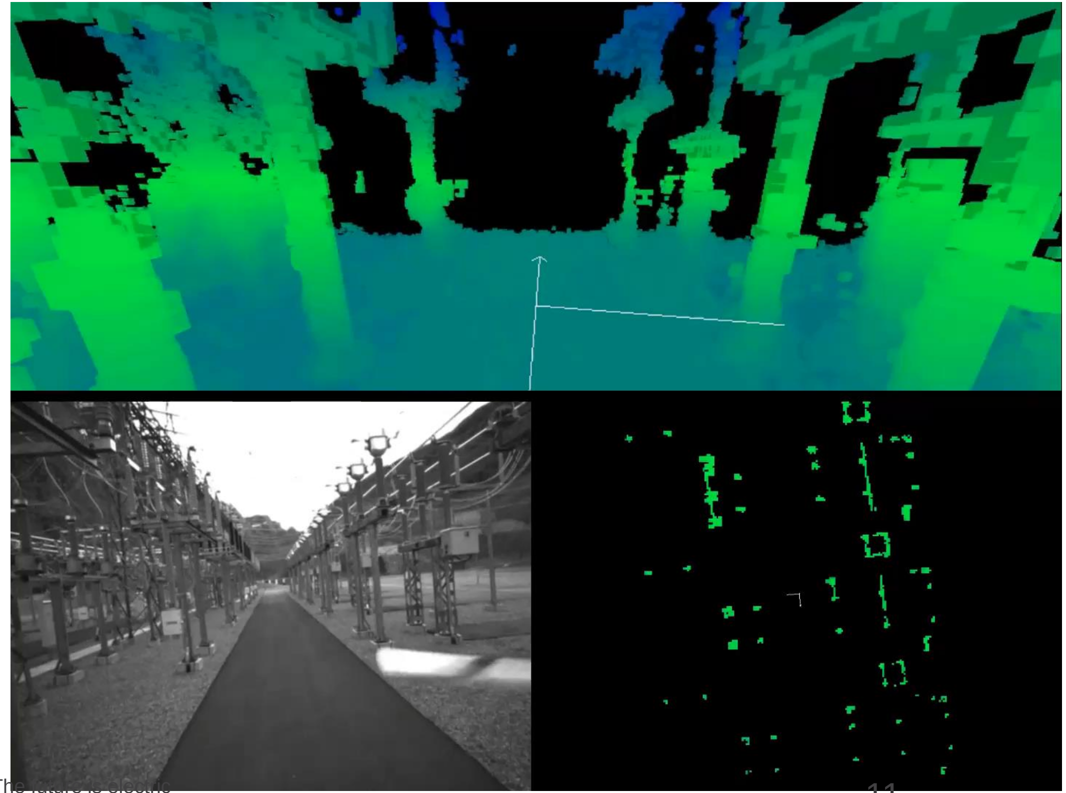
Sintef HV-lab



Hangardesign



Navigation and route planning



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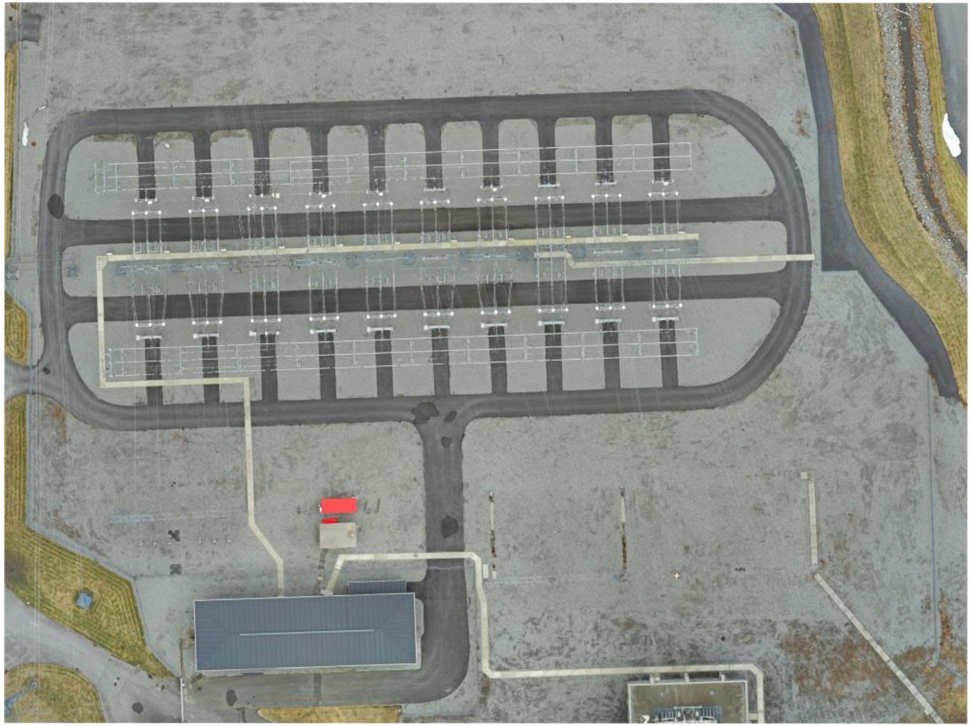
Controll system

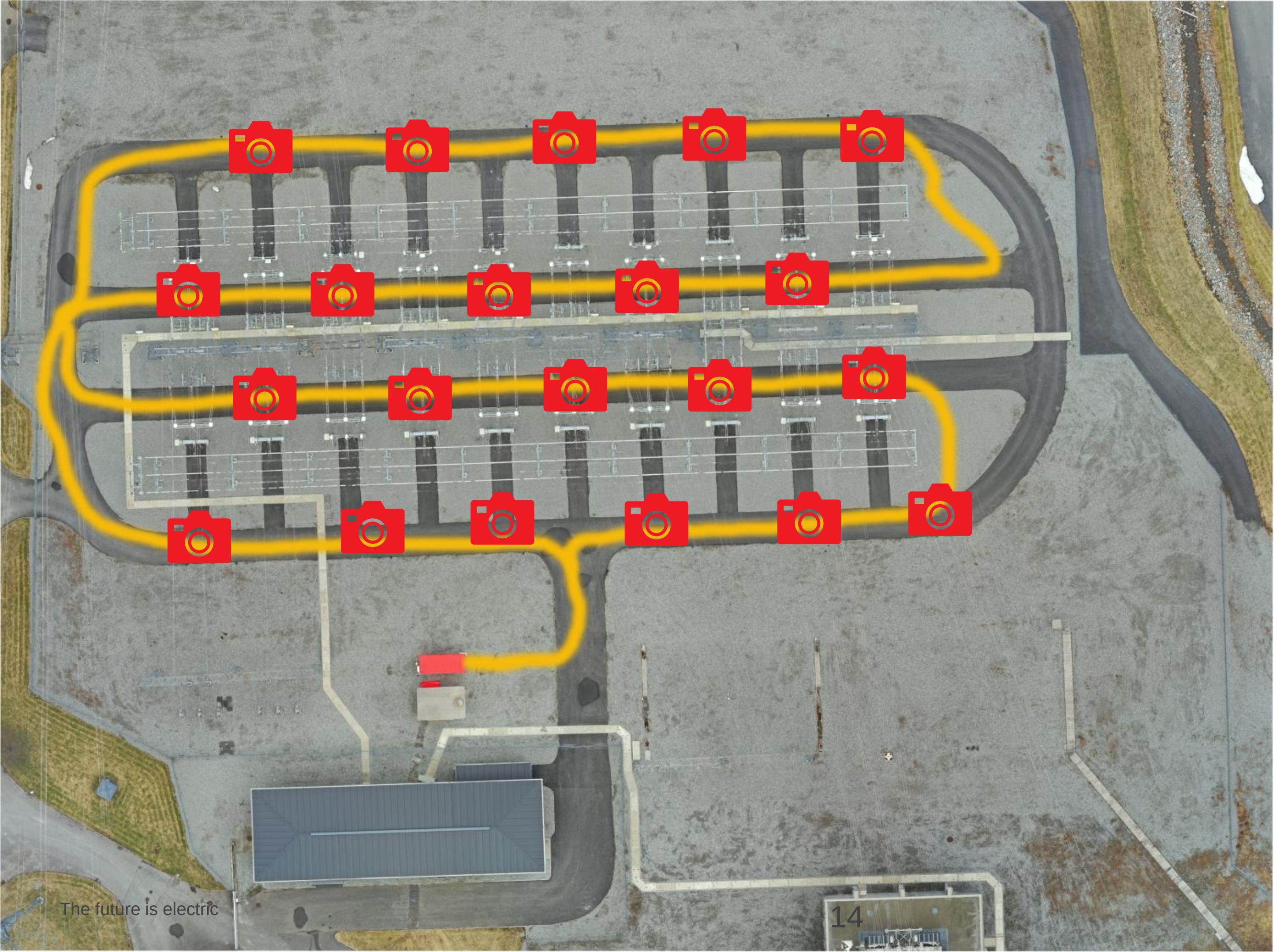
The future is electric

12

Location, date

Mapping of Aura in 3D…..with a drone






-285551
L3

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Discoveries so far

- Size of drone is important
- Operational in GNSS-denied areas
- Sense & avoid is a safety measure
- Connecting with BIM/3D gives us advantages
- Lessons learned, that we can put into Lineinspection

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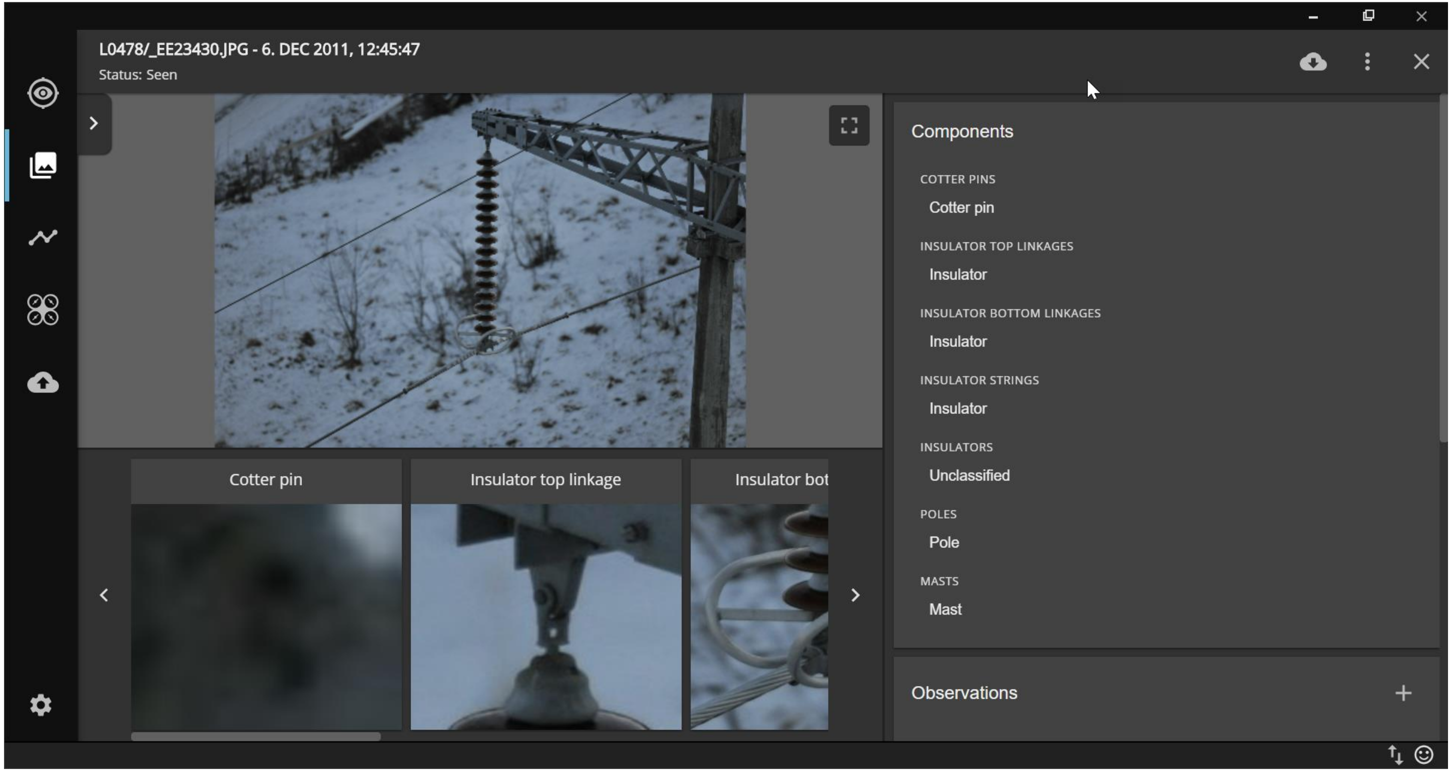
AI – 4 – UAS



Project goal(s)

- Develop a solution which will, using artificial intelligence, detect faults based on information from sensors.

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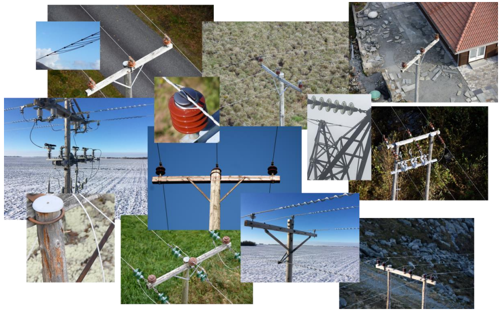
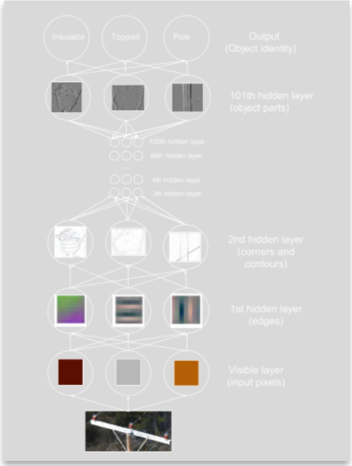
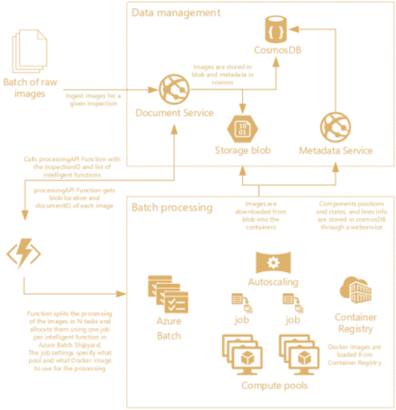
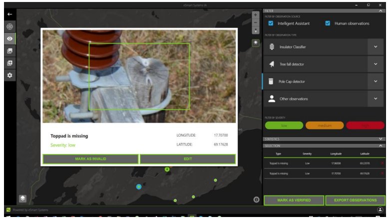
How to add new intelligence to the system?

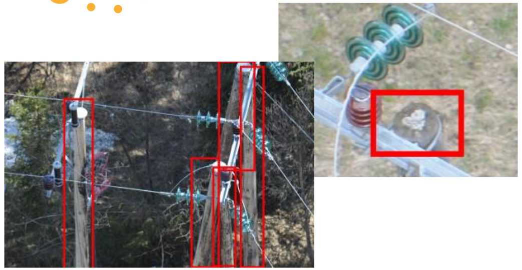






Collect Images → Tag Images → Train AI Model → Deploy





eSmart SYSTEMS

Collect images

Tag & Classify

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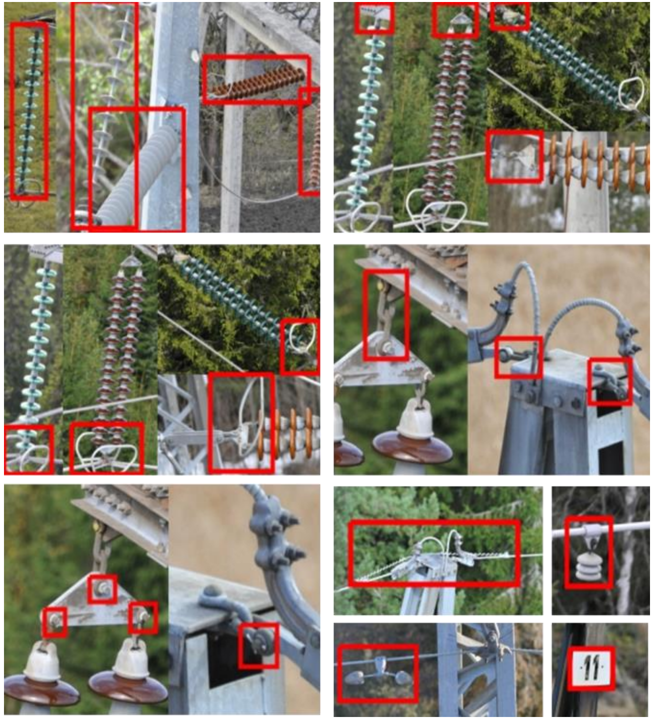
Tag & Classify



Object type	# Tagged objects
insulator_string	22 077
cotter_pin	21 059
ins_bottom_link_assembly	18 861
ins_top_link_assembly	15 617
shield_wire_pylon_top_assembly	9 721
chain_shackle	5 393
weight	5 245
damper	2 665
pylon_number	2 081

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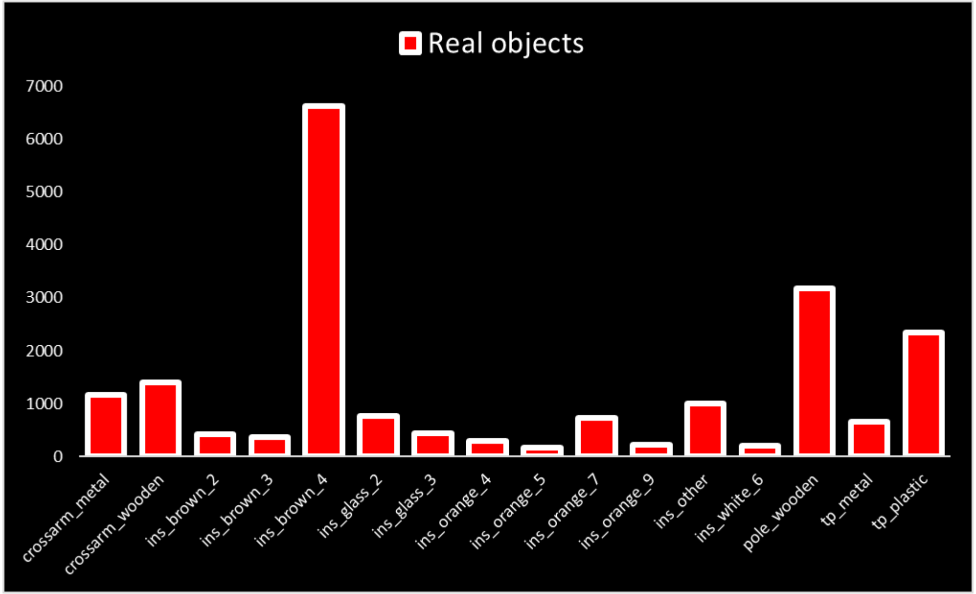
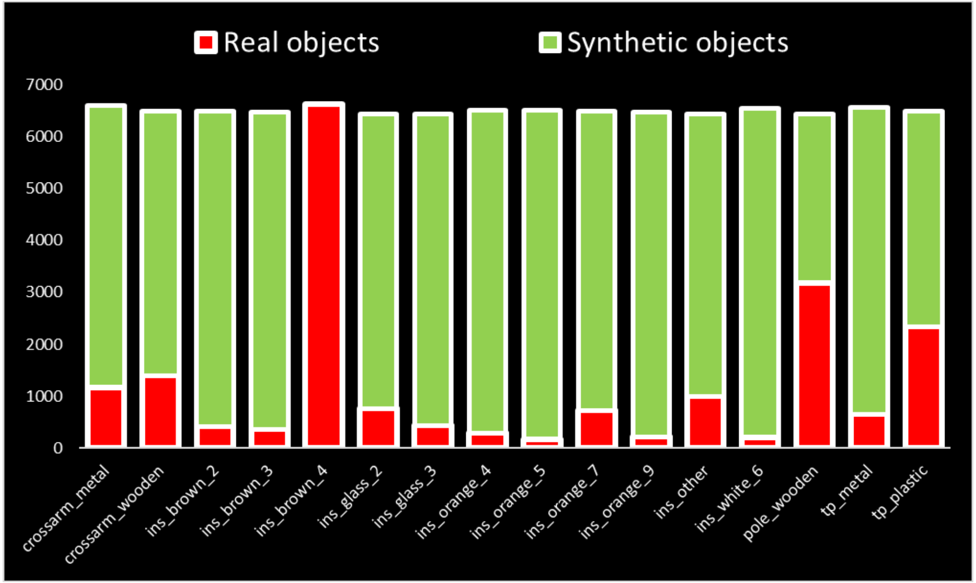
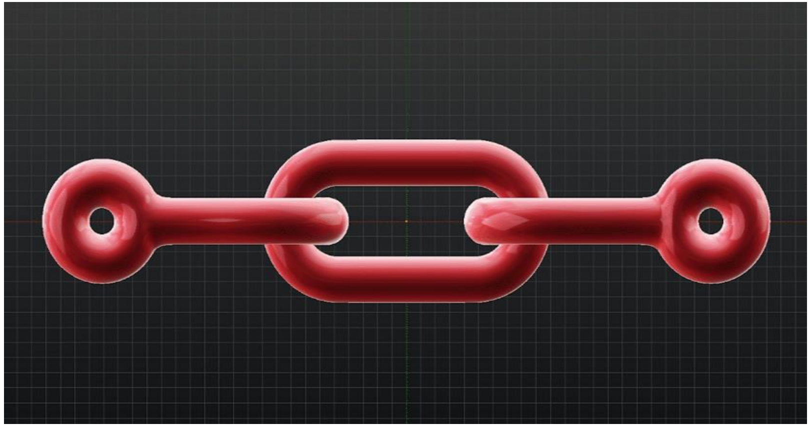
Train model

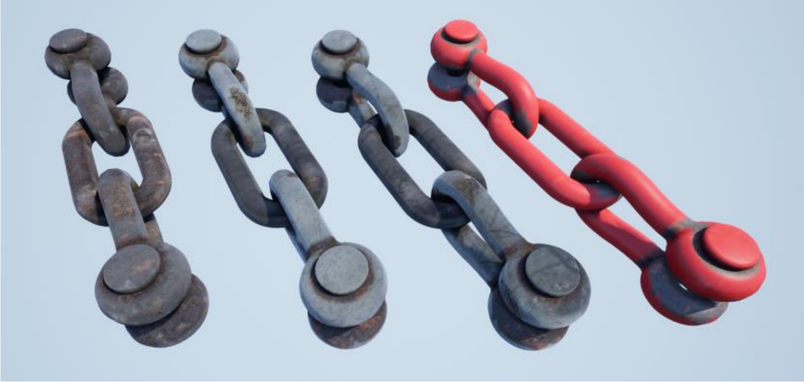


Train model


Real objects
Synthetic objects
7000
6000
5000
4000
3000
2000
1000
0
crossarm_metal
crossarm_wooden
ins_brown_2
ins_brown_3
ins_brown_4
ins_glass_2
ins_glass_3
ins_orange_4
ins_orange_5
ins_orange_7
ins_orange_9
ins_other
ins_white_6
pole_wooden
tp_metal
tp_plastic

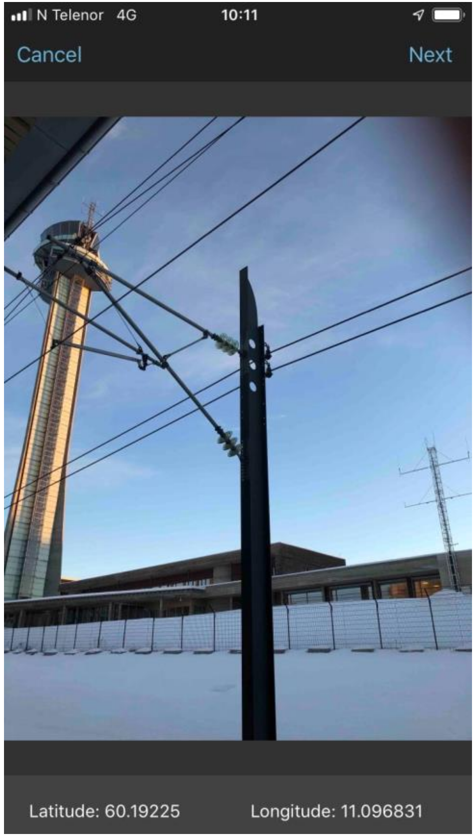
Synthetic data





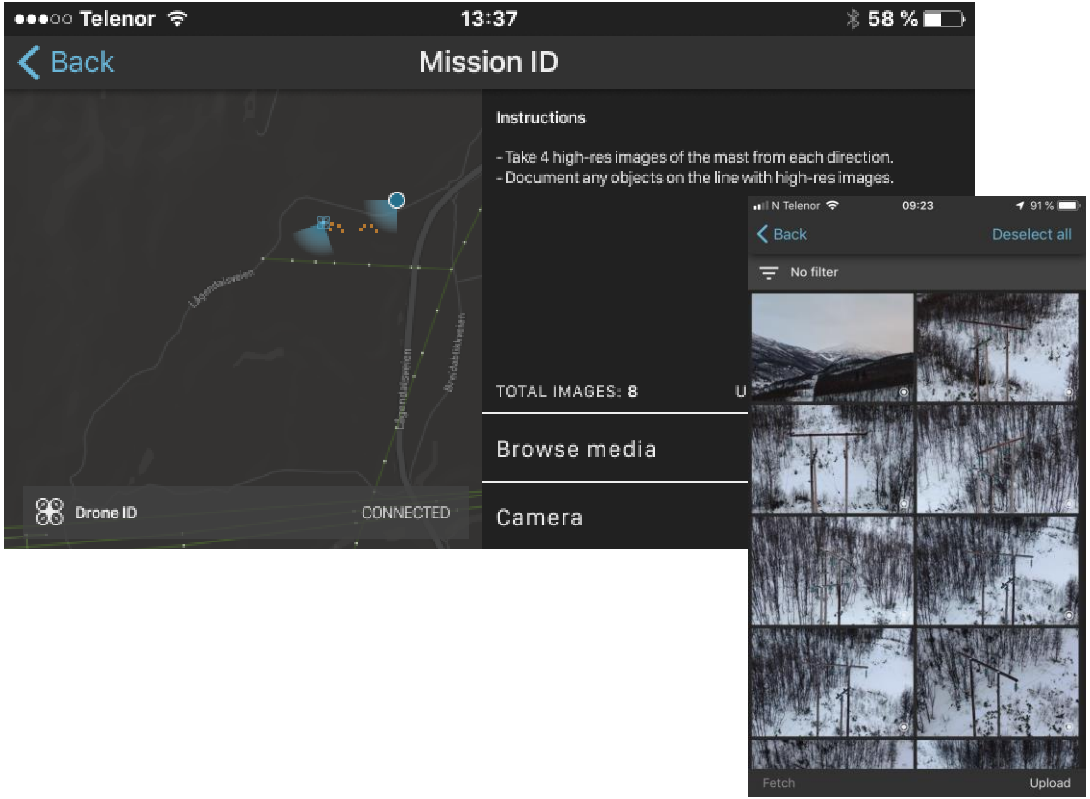
Deploy

- Field Inspector



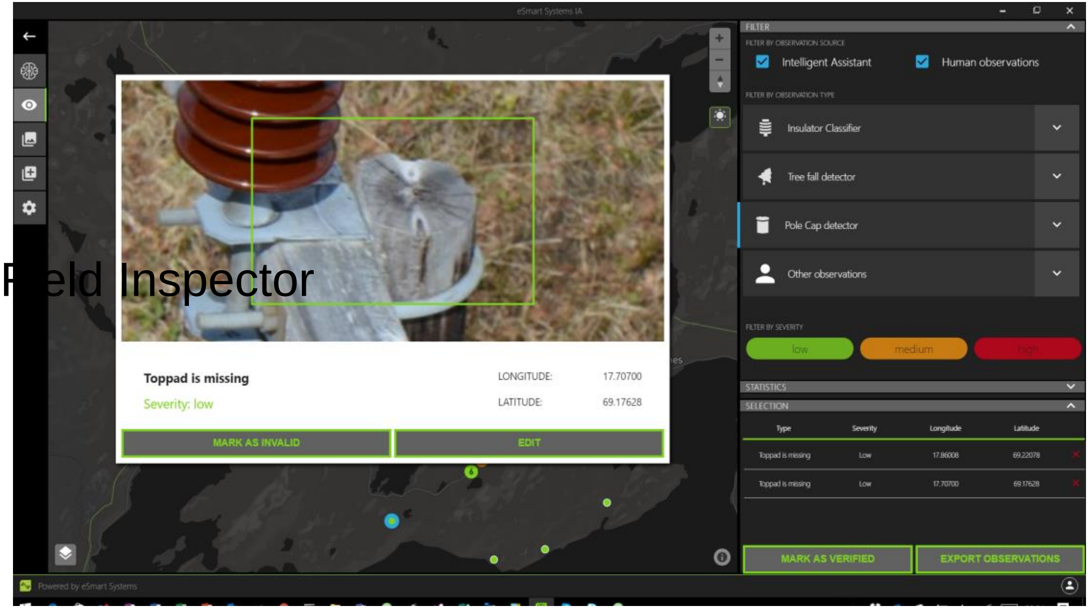
Deploy

- Field Inspector
- Mobile Ground Station



Deploy

- Field Inspector
- Mobile Ground Station
- IA client



Field Inspector

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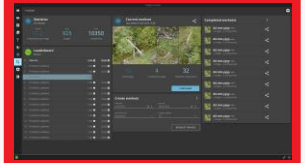
The road ahead

- More images to train the model and enable the AI to identify more components and defects
- Generation of reports after fault verification
- Live view from the drones to the operations center

Human QC

Data tagging



Assets in map

Live operations