SUBSTATION DIGITAL TWIN

LEVERAGING IEC 61850 AND MACHINE LEARNING TO ACHIEVE ADVANCED MONITORING AND SIMULATION OF SUBSTATION SYSTEMS

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Fraunhofer

IFF

IEC 61850 Global 2019

14-18 October 2019

London, UK

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Who is the guy talking?

André Naumann

- Diploma in Electrical Engineering
- PhD from Otto-von-Guericke University Magdeburg in 2012
- Since 2012 a research manager at Fraunhofer IFF, Magdeburg
- Since 2019 group leader for energy systems and components
- Special field of interest: Protection and resilience in electrical energy systems and communication technologies for energy systems

Fraunhofer IFF

- Plan, Develop, Equip and Operate manufacturing and supply chain systems and their supply infrastructures
- About 200 employees
- One of 72 institutes of the Fraunhofer Family

AGENDA

1. Bringing more intelligence to substation → the possible toolset
2. Digital twins
3. Artificial intelligence
4. Using IEC 61850 for intelligent substation
5. Some use case examples
6. Conclusion

Substations today

Automated substation tasks

- Protection according to fixed parameter sets
- Tap changing
- Some adaptive protection functions
- Report everything to the control center and wait for commands

Limited Intelligence: Dull continuation of current operation state in case of communication loss

Existing Computing power in Substations

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What‘s the point?

- Increasing complexity of energy systems
  - Connecting different infrastructures
  - Increasing number of system components
  - Higher dynamics in power systems
- Need for increased safety and security

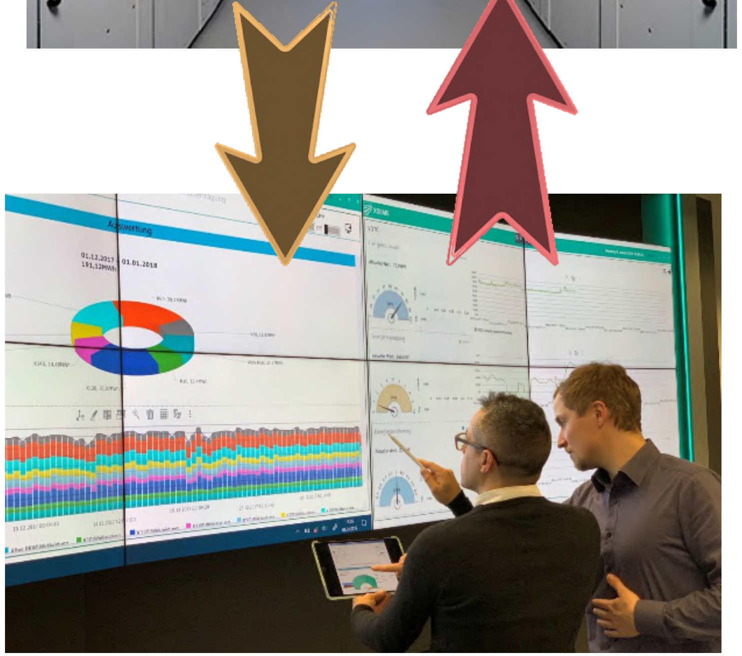
Use decentralized computing power for

→ More intelligence and automation in the substation

→ Discharging the control centre from data load

→ Making things easier for operators

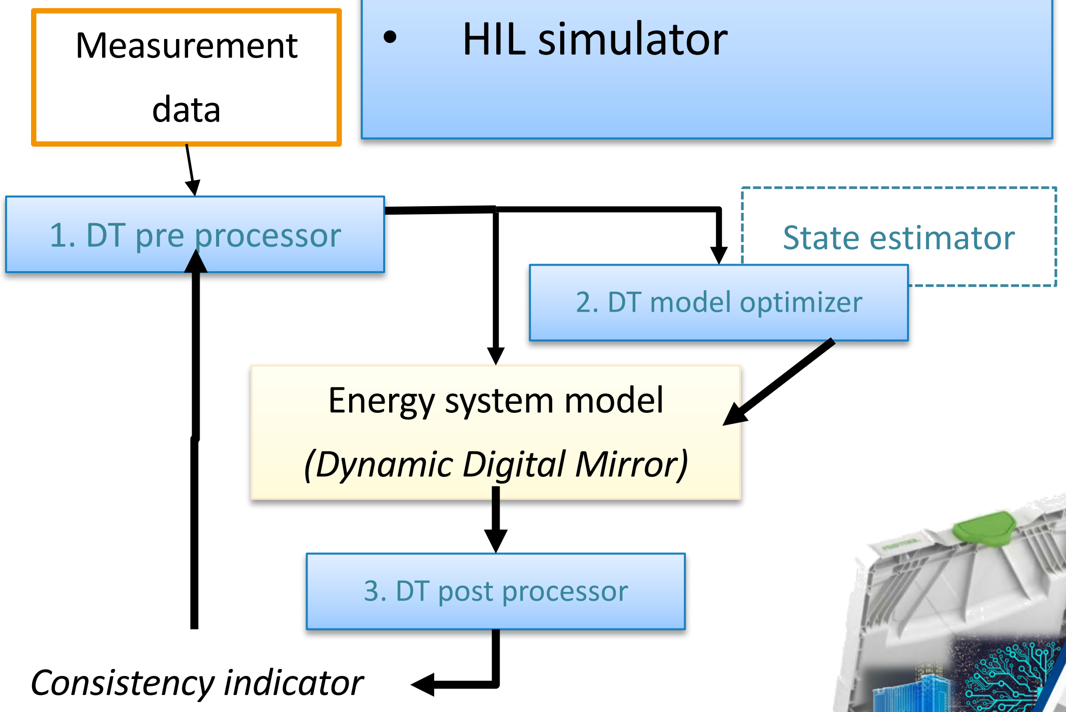
https://w3.siemens.com/smartgrid/global/en/products-systems-solutions/brands/eneas/solutions-substation/PublishingImages/NXAir_PTD0000453_72dpi.jpg



The toolbox

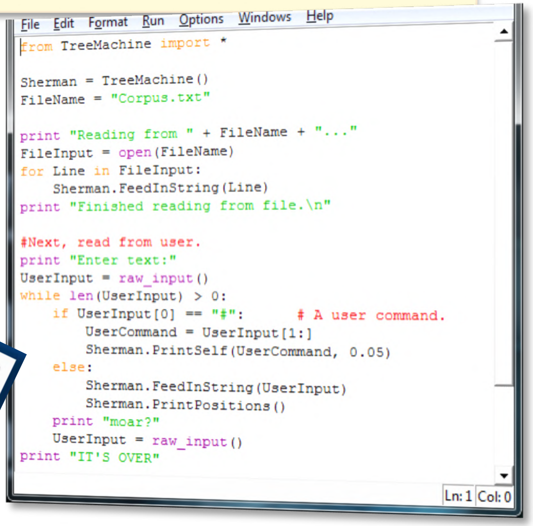
Digital Twin

- Power network simulation
- HIL simulator



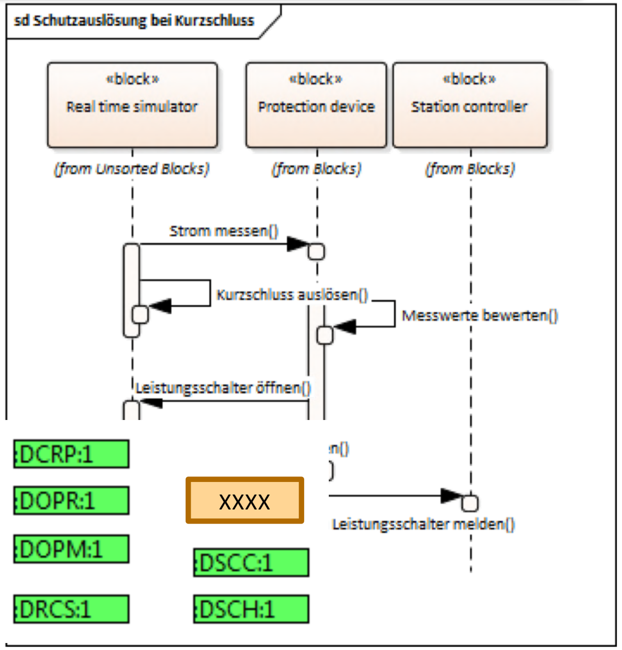
Artificial Intelligence

- Python based AI tools
- Pattern recognition
- Time series forecast



Standard based information exchange

- IEC 61850
- IEC 61970 (CIM)



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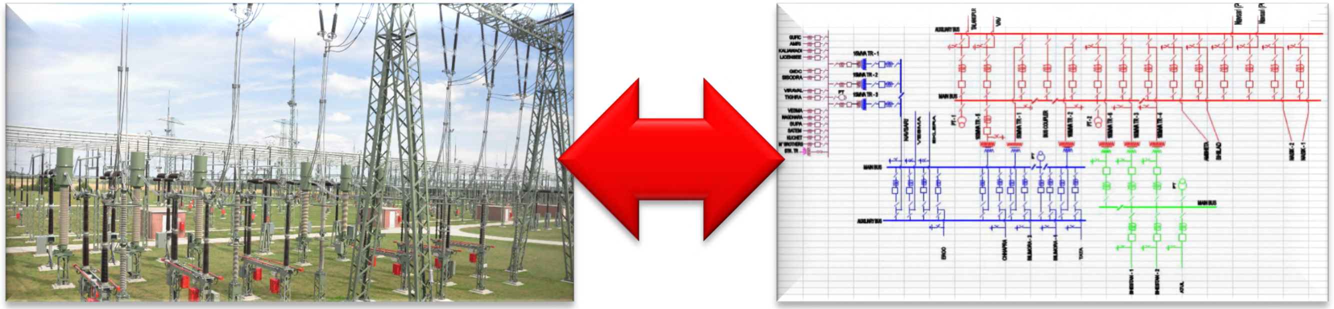
The (Dynamic) Digital Twin

Definitions

- A Digital Twin is the digital representation of a unique asset (product, machine, service, etc.), that compromises its properties, condition and behaviour by means of models, information and data.
  [R. Stark, S. Kind, and S. Neumeyer, “Innovations in digital modelling for next generation manufacturing system design,” CIRP Annals, vol. 66, no. 1, pp. 169–172, 2017]
- Digital Twins are software-based abstractions of complex physical systems or objects which are connected via a communication link to the real object through a continuous data flow from the real world.
  [Christoph Brosinsky, Rainer Krebs, Dirk Westermann, “Recent and Prospective Developments in Power System Control Centers: Adapting the Digital Twin Technology for Application in Power System Control Centers,” in *Proceedings Energycon 2018, Limassol, Cyprus*, pp. 1–6]
- Digital twins contain the individual, virtual representation of a physical object or process, using data from the physical object for different intelligent use cases.
  [R. Klostermeier, S. Haag, and A. Benlian, “Digitale Zwillinge – Eine explorative Fallstudie zur Untersuchung von Geschäftsmodellen,” HMD, 2018]



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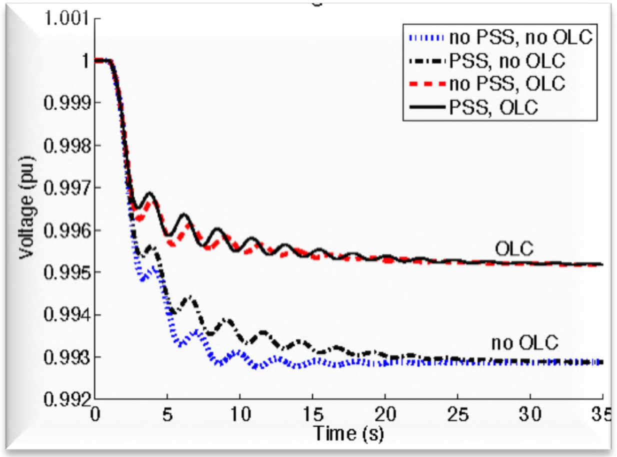
The (Dynamic) Digital Twin

Features

- A DT makes it possible to reflect the physical conditions
  - In real-time (even faster)
  - → Exact knowledge of your system/device state
- Behavioral forecast
  - Possibility of identifying problems before they occur
  - Identifying needs for maintenance
  - Identifying countermeasures in advance
- A dynamic DT supports dynamic modeling
  - Constantly running modelling engine
  - Describes the dynamic system behavior,
- Access to non-measurable parameters (using analytical algorithms or other technologies)



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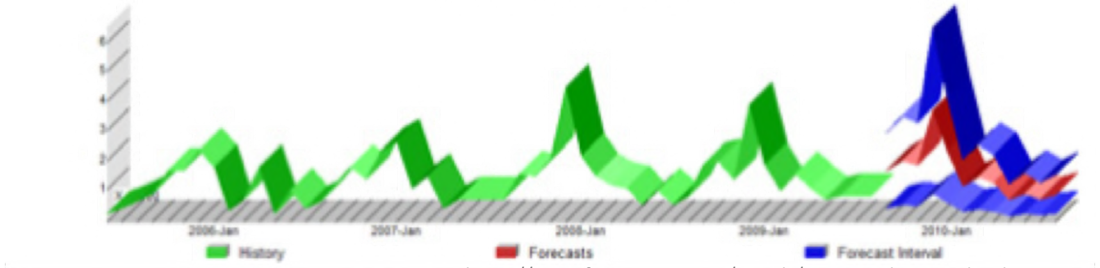

https://www.forecastpro.com/Trends/FPU6October2009.html

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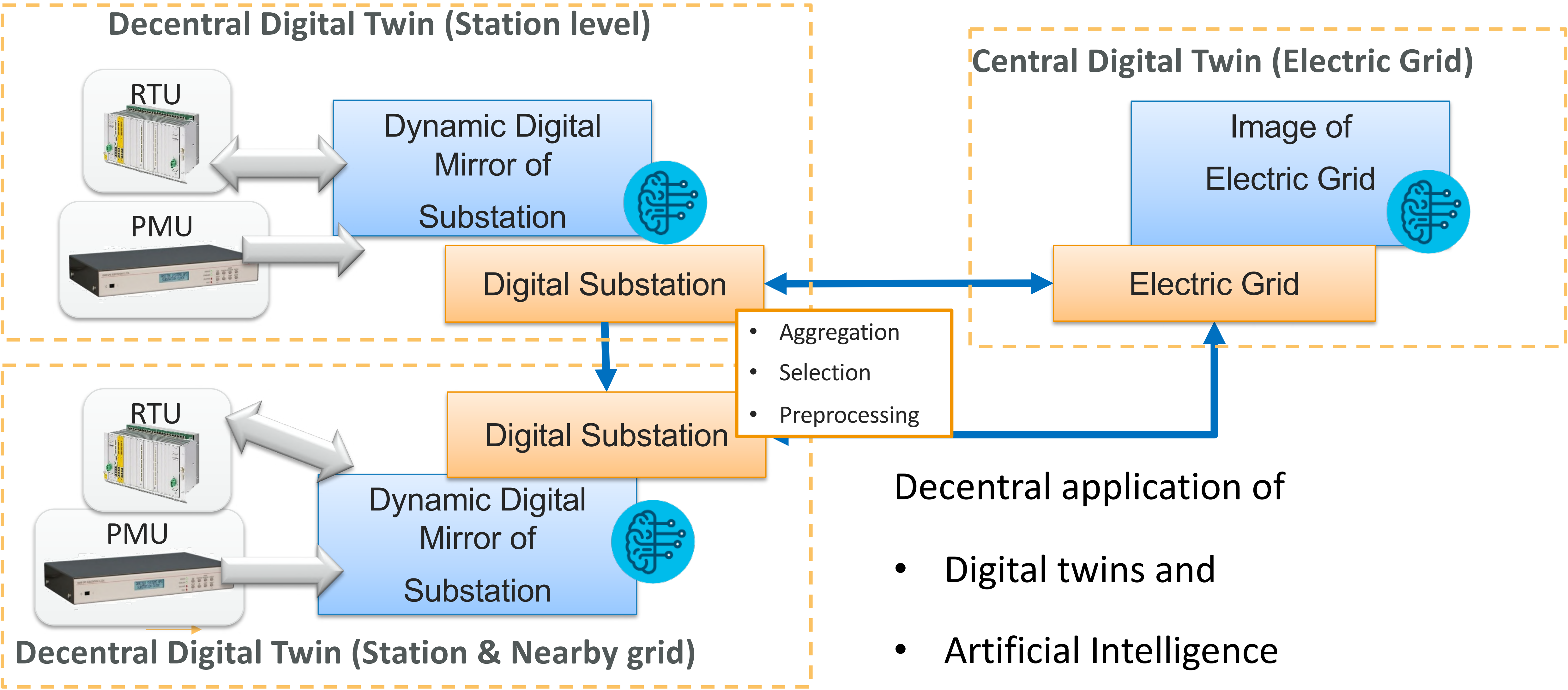
Decentral organization of system operation calculations



Decentral application of

- Digital twins and
- Artificial Intelligence

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The (Dynamic) Digital Twin

Use cases in the energy system and substation

- Data preprocessing
  - Reduction of data load
  - Usage of system state indicators
- Accurate Models of system and its components
  - Real time simulation (rapid system analysis and control feedback using RTU and PMU sensor data)
  - For standard simulation
  - Higher level analyses
- DT-based Recognition of anomalies
  - Data manipulation
  - Model insufficiency
  - inplausible Data from control center

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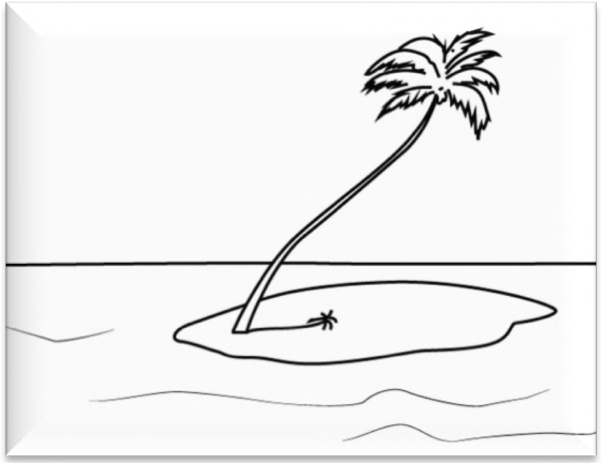
The (Dynamic) Digital Twin

Use cases in the energy system and substation

- Providing substitute values (in case of missing/wrong measurements)
- Separated/islanded Operation
  - Substitute values for control center information
  - Autonomous Operation
  - Resynchronization of system state parameters after reconnection
- Augmentation of predictability of plant starts considering multiple objectives (time, output, emissions, fuel)
- Product life cycle management (PLM)



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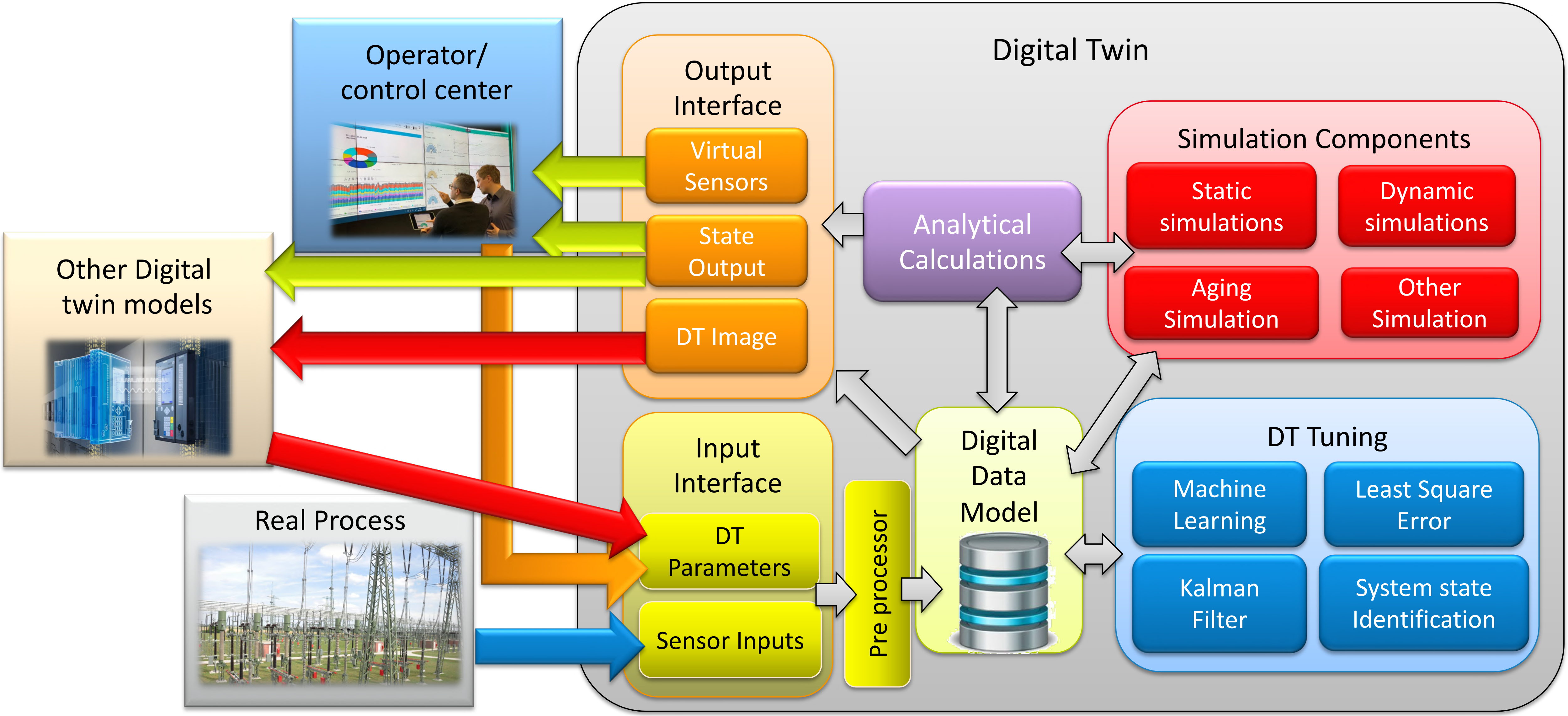
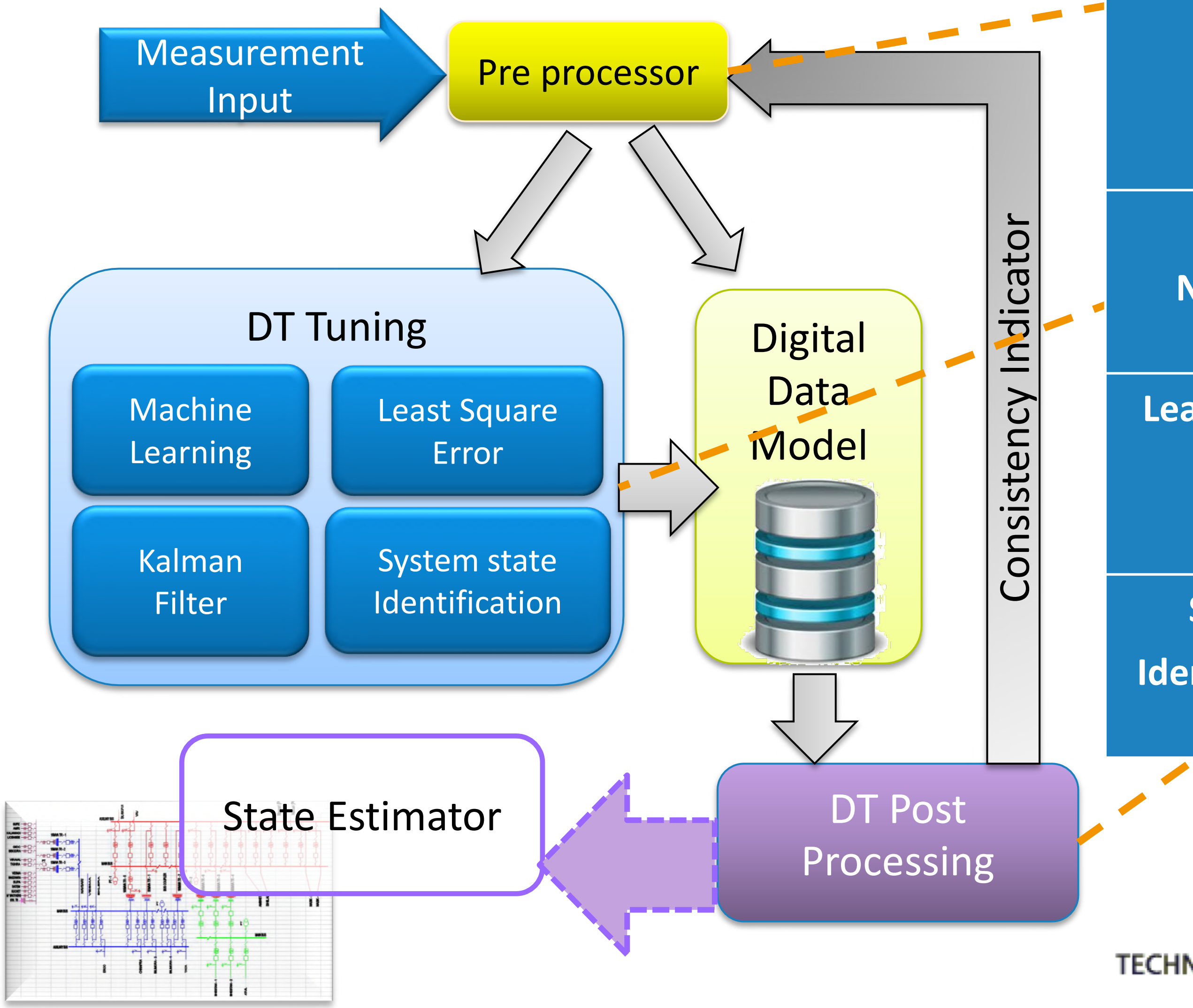
Digital Twin Components



Digital Twin Tuning



Method	Pros	Cons
Kalman Filter	+ Online and dynamic Parametrization + Measurement Noise Cancelling + Suitable for Generator parameter estimation	– Low accuracy
Neural Network	+ Online Parametrization + Automatic Training of AI + High Accuracy	– Huge data amount for training – Definition of NN structure difficult
Least Square Error	+ High Accuracy + Improved Parametrization for all model parameters + Low amount of data handling	– Time consuming iteration process – Offline Parametrization
System Identification	+ Definition of Model Equation (analytical approach) + Suitable for grey and black box model	– Low accuracy for big systems

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Digital Twin Implementation

- Combine:
  - HIL simulator (real time simulation, approved simulation models)
  - DT developer environment (Toolbox für DT tuning, AI, etc.)
- Data exchange via API
- Data archive in workstation

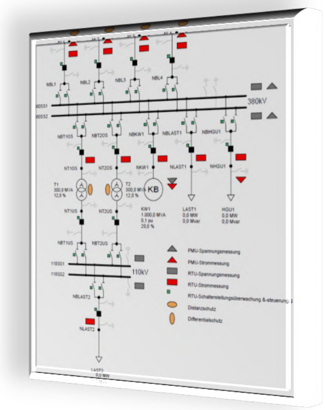
Developer Workstation

Matlab

- DT-Tuning
- Machine Learning
- Analyzing algorithms
- Virtual sensors
- Digital image

Simulation System

OPAL-RT TECHNOLOGIES



- HIL real time simulator
- Hypersim Simulation Model
- Device controllers
- Logic Functions
- Analog Interfaces (Voltage, Current)
- Digital Interfaces

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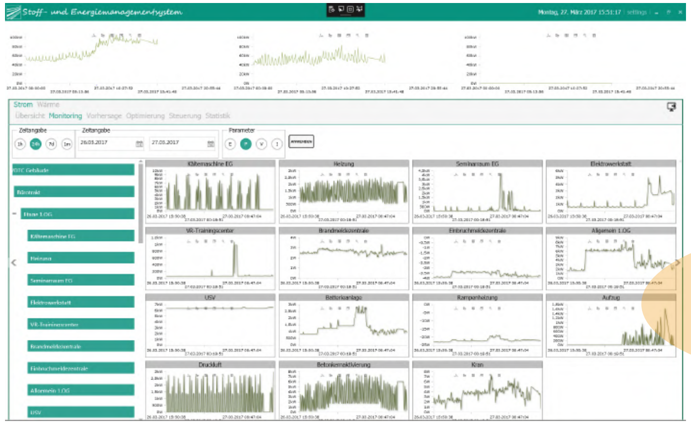
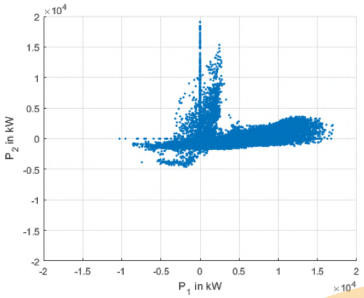
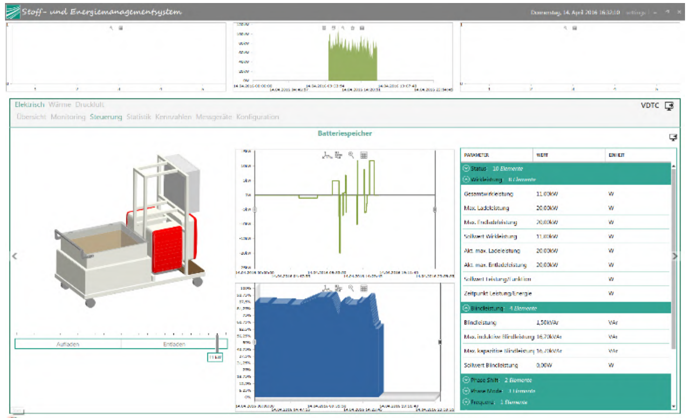
Aspects of Artificial Intelligence







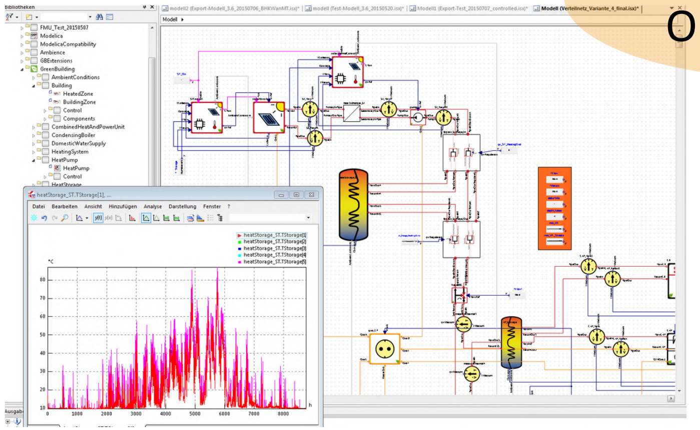
Big Data Analytics

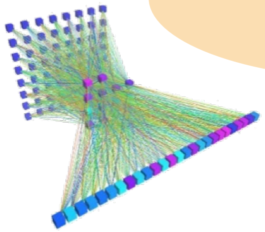
Clustering

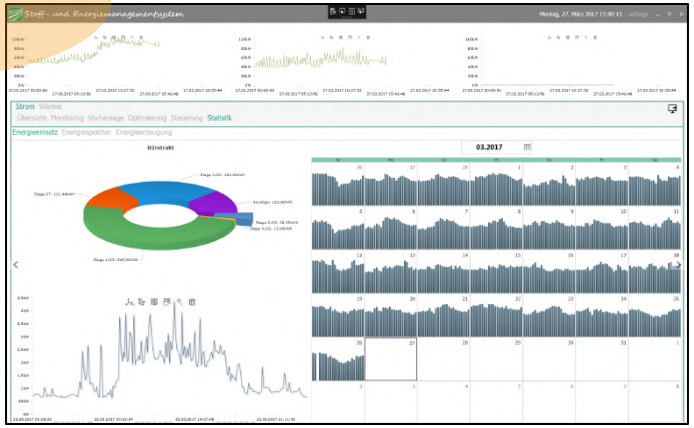
Non-linear Optimization

Forecast

Artificial Neural Networks







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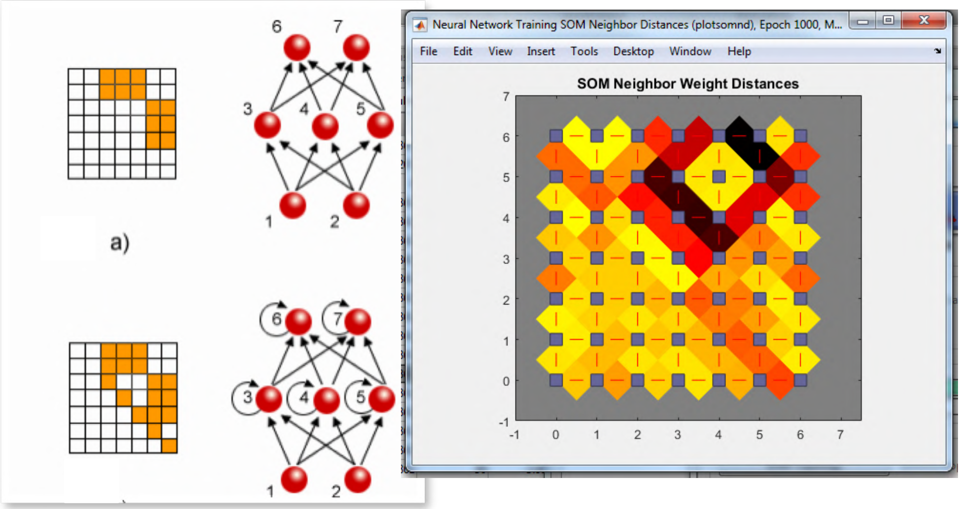
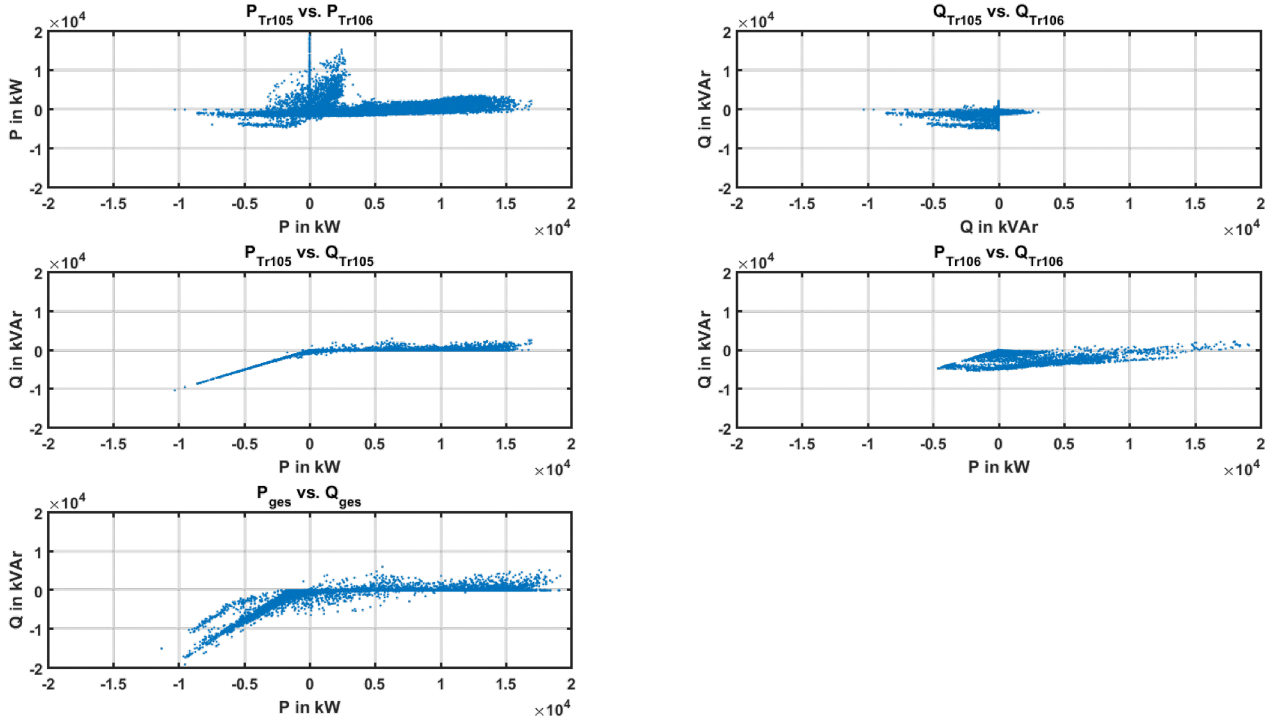
What can AI do in Energy Systems?

Pattern recognition



- Find characteristic situations
- Identify system states
- Aggregate data
- Calculate characteristic indices



- Characteristic situations based on multidimensional input parameters

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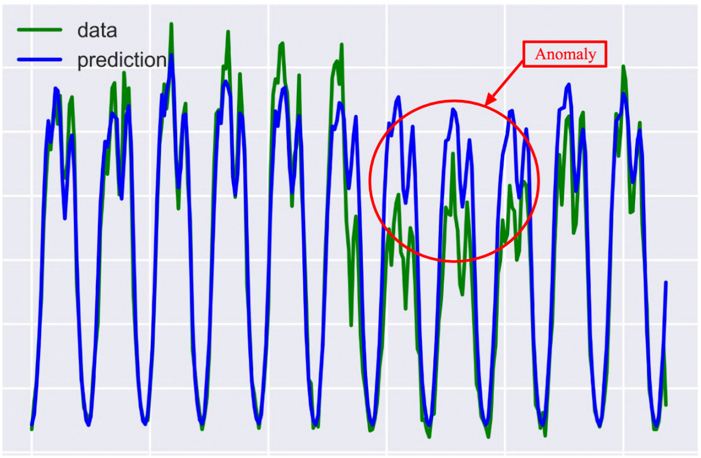
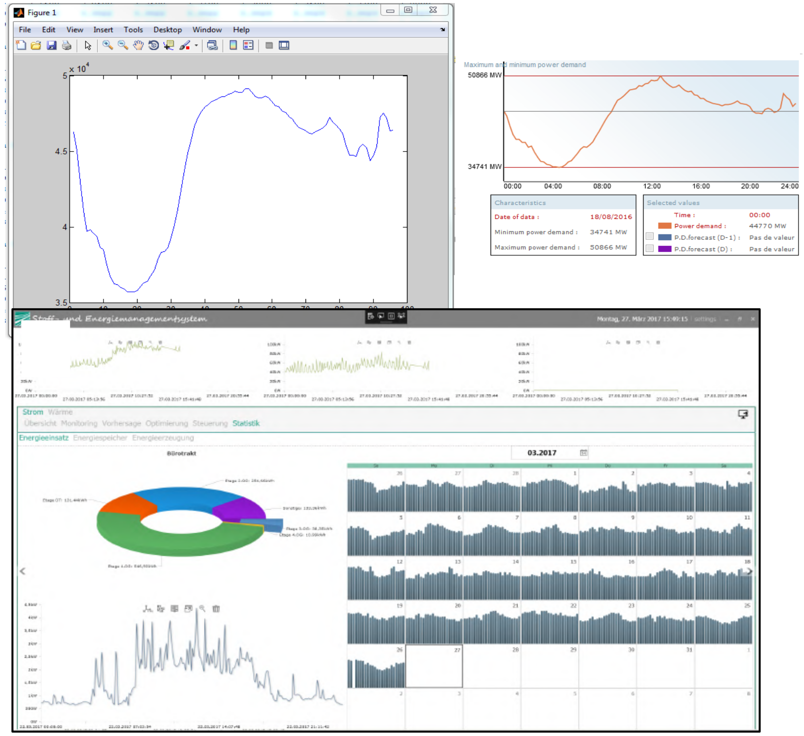
What can AI do in Energy Systems?

Anomaly detection



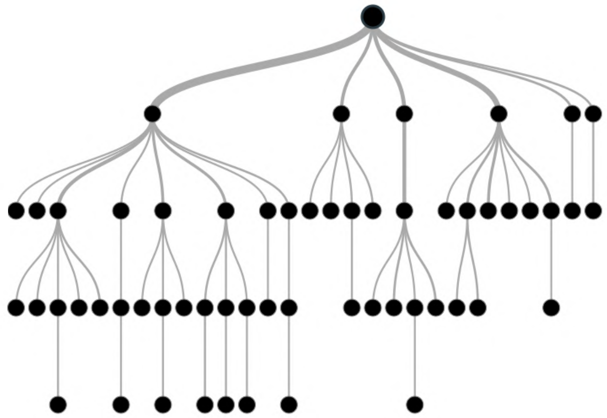
- Detect abnormal behaviour in
  - Load flows
  - Switching states
  - Information flow
- Intrusion detection
- Malfunctioning Assets

Forecast



- Time series forecast based on
  - Historic data
  - Current state parameters

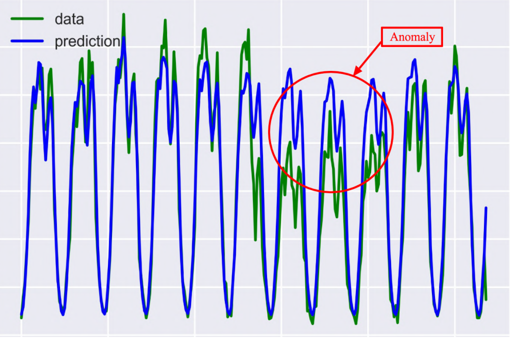
Decision making



- Tree based trained decisions
- Automatic or assisting functionality
- Based on Expert knowledge and historical training data

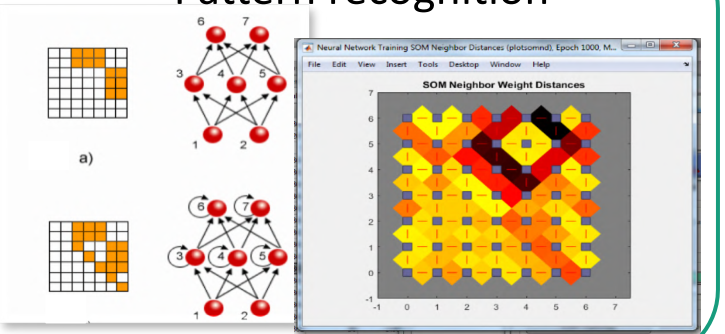
AI for sub stations

Anomaly detection



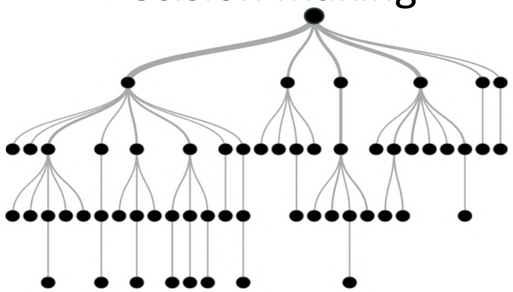
- Immediate detection of
  - Malfunctioning assets
  - Corrupted data transfer
  - Abnormal system states

Pattern recognition



- System state identification
- Data aggregation
- Need for action?

Decision making



- Go to autonomous mode?
- Take action in autonomous mode
- Fast autonomous action and notice to control center

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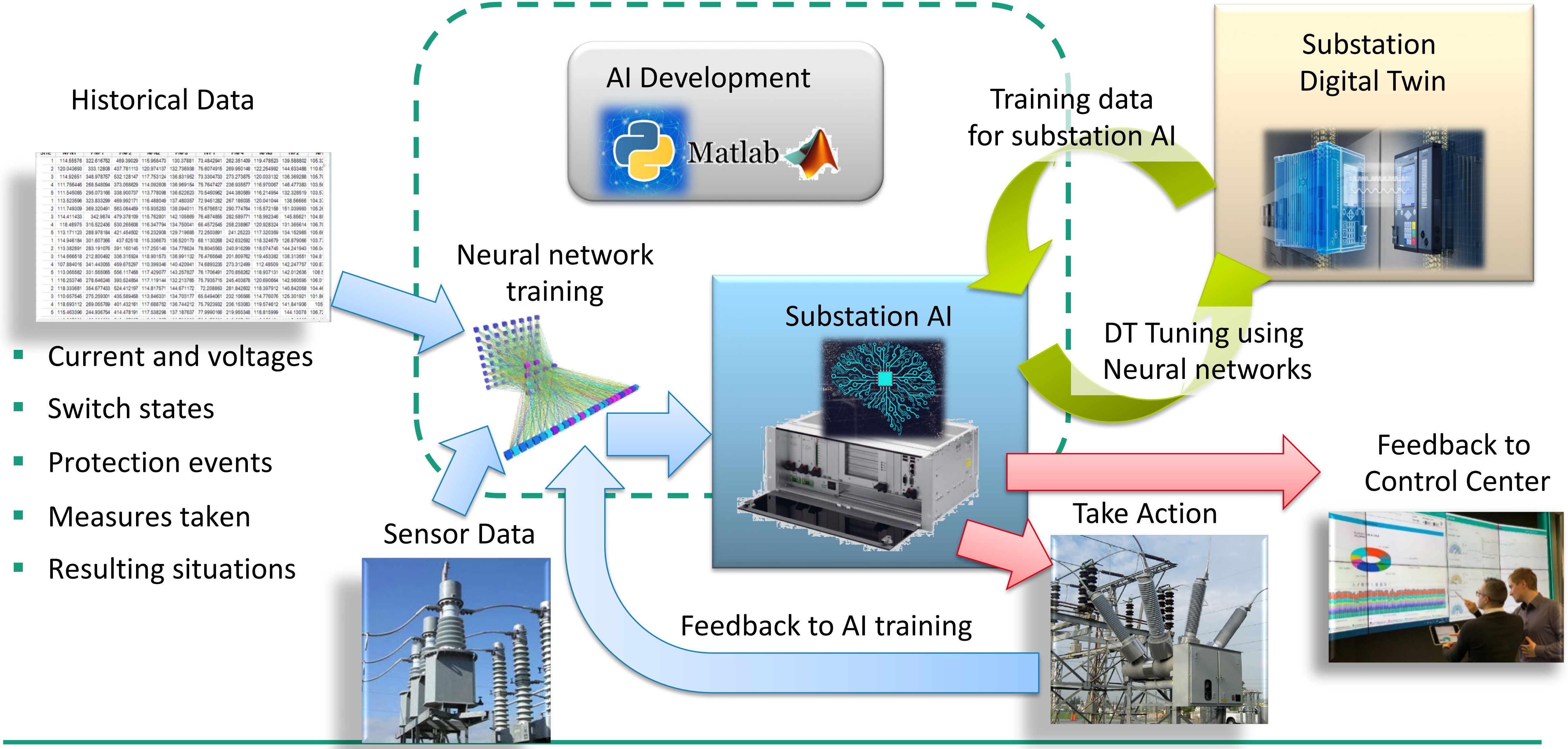
AI implementation in sub stations



Digital twins and AI for Digital Substations

Digital Twins

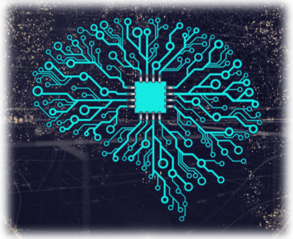
- Detailed models of system
- Self tuning
- Anomaly detection by mismatch between model and real system
- Behavioral Forecast
- System state estimation

Artificial Intelligence

- Training based system model
- Anomaly and pattern detection and cause identification by training
- System state optimization
- System state forecast

- Subsidiary stand-alone system control
- Anticipatory system optimization
- Preprocessed data exchange with control center
- Robust system operation

https://assets.new.siemens.com/siemens/assets/publi c.640.high.1560767262.b03a24e1-38fe-4a0e-9a63-17476b623fb9.digital-twin-keyvisual-1600x900.jpg/digital-twin-keyvisual-1600x900.jpeg



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DT and AI information exchange based on IEC 61850

Which data is to be exchanged (next to existing data exchange)? - A choice

Neighbour

Substation

Substation internal

What	How	How often
Configuration of Field devices	Structured data	At data change
Models of Field devices	Complex data structures (e.g. XML-Style or JSON)	At data change

Operator/ control center

System Digital Twin

What	How	How often
System state parameters	Tables or XML-style	At data change
DT model parameters	Complex data structures (e.g. XML-Style or JSON)	At data change
Configuration data	Structured data	At data change

Substation

AI

DT

What	How	How often
Aggregated state parameters	Simple values	continously
DT model parameters	Complex data structures (e.g. XML-Style or JSON)	At data change
AI Teaching parameters	Structured data	Initial and at major changes

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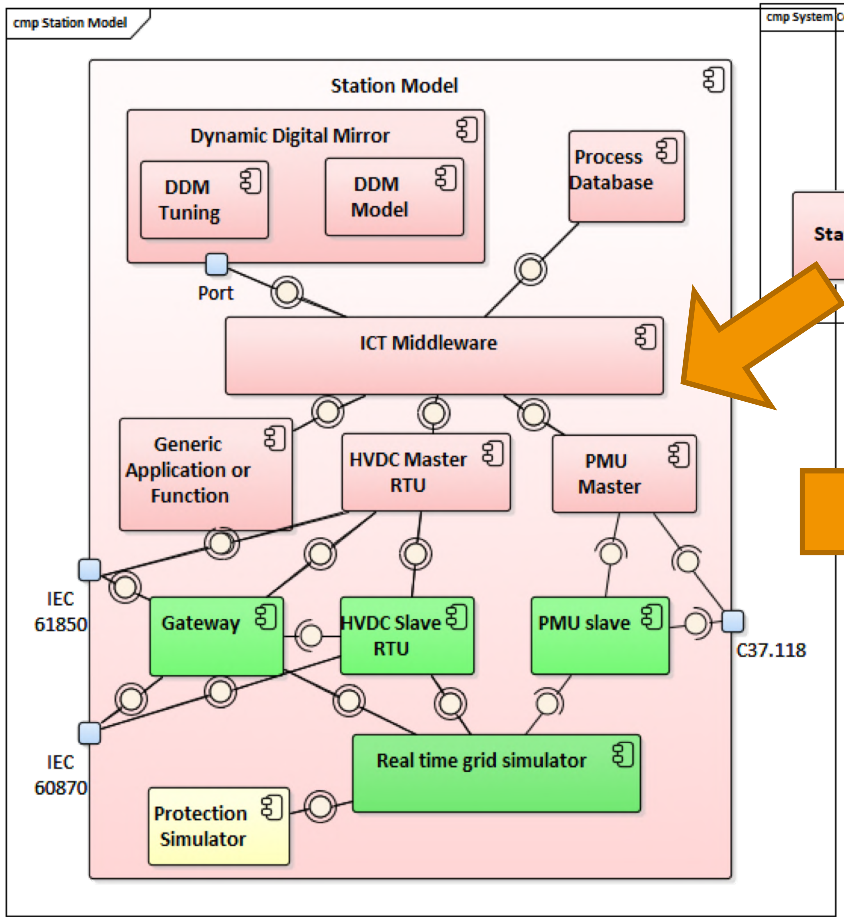
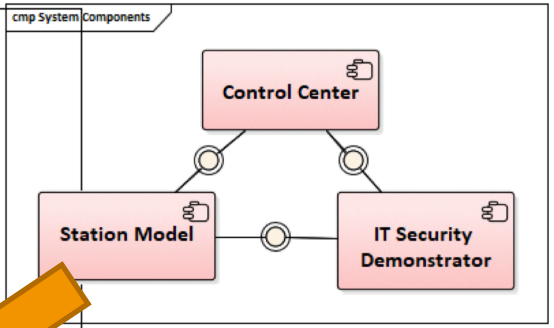
DT and AI information exchange based on IEC 61850

Domain	What	How	How often	Usable IEC 61850 models
Station internal	Configuration of Field devices	Structured data	At data change	Standard LNs available (prop. Manufacturer data)
	Models of Field devices	Complex data structures (e.g. XML-Style or JSON)	At data change, mostly initial	Not really, maybe some SCL extension. Not the real scope of IEC 61850. Other modells usable? CIM?
Station ←→ Station	System state parameters	Tables or XML-style	At data change	No models defined. Definition on state parameters necessary.
	DT model parameters	Complex data structures (e.g. XML-Style or JSON)	At data change	No models available. Scope of IEC 61850?
	Configuration data	Structured data	At data change	Standard LNs available (prop. Manufacturer data)
Station ←→ Control Center	Aggregated state parameters	Simple values	continously	No models defined. Definition on state parameters necessary. Workarounds usable?
	DT model parameters	Complex data structures (e.g. XML-Style or JSON)	At data change	No models available. Scope of IEC 61850?
	AI Teaching parameters	Structured data	Initial and at major changes	No models available. Out of scope for IEC 61850? Filetransfer with proprietary data?

Some Lab results

System components Overview





HIL Simulator

HyLITE

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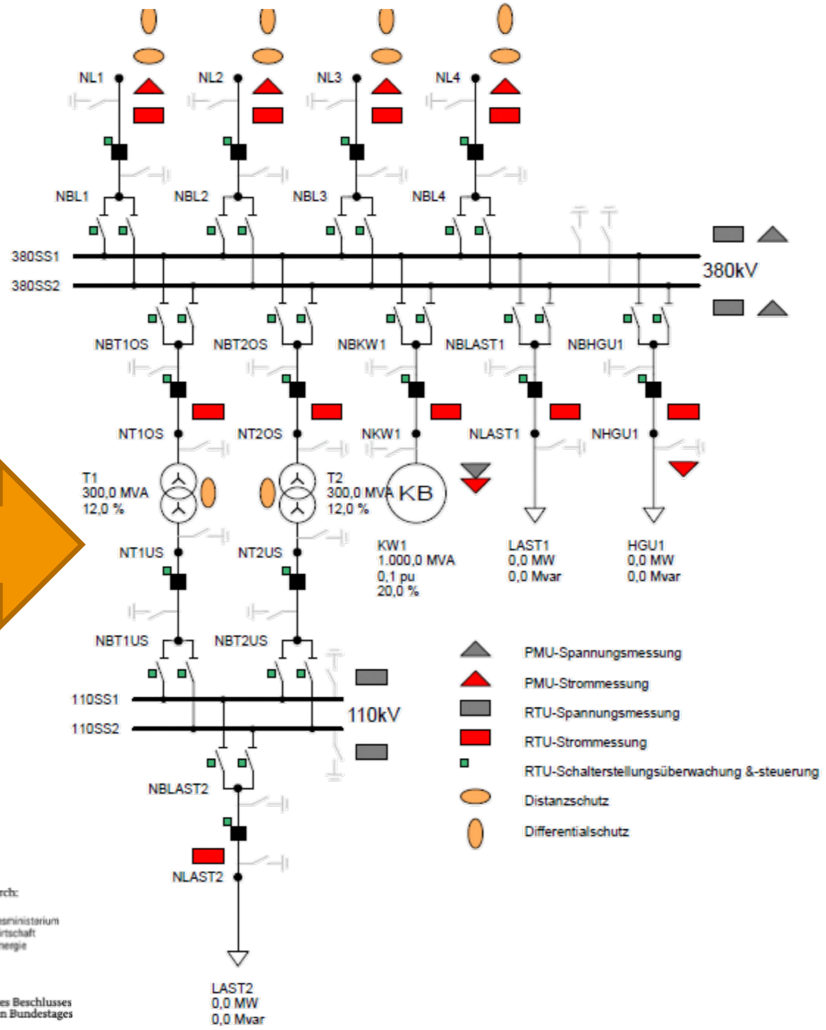
SIEMENS

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

Station Model



Use Case 1: HVDC control, corrective Measures

Requirements

- Integration of HVDC links to AC networks
- In normal Operation: Setpoint for converters from control center
- In abnormal events, fast reaction and high dynamics necessary

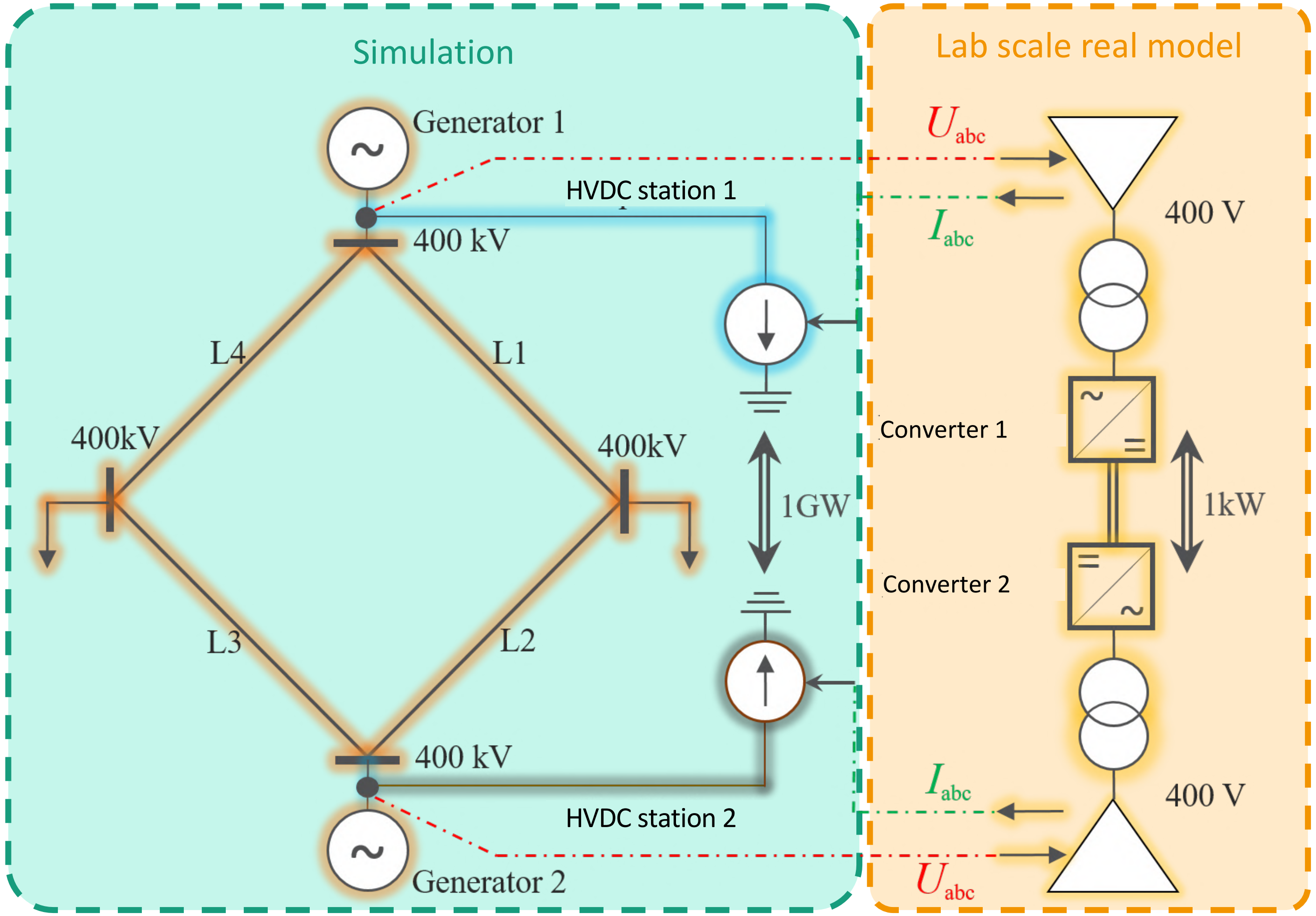
Approach

→ Precalculated Measures and events are sent to the station controller

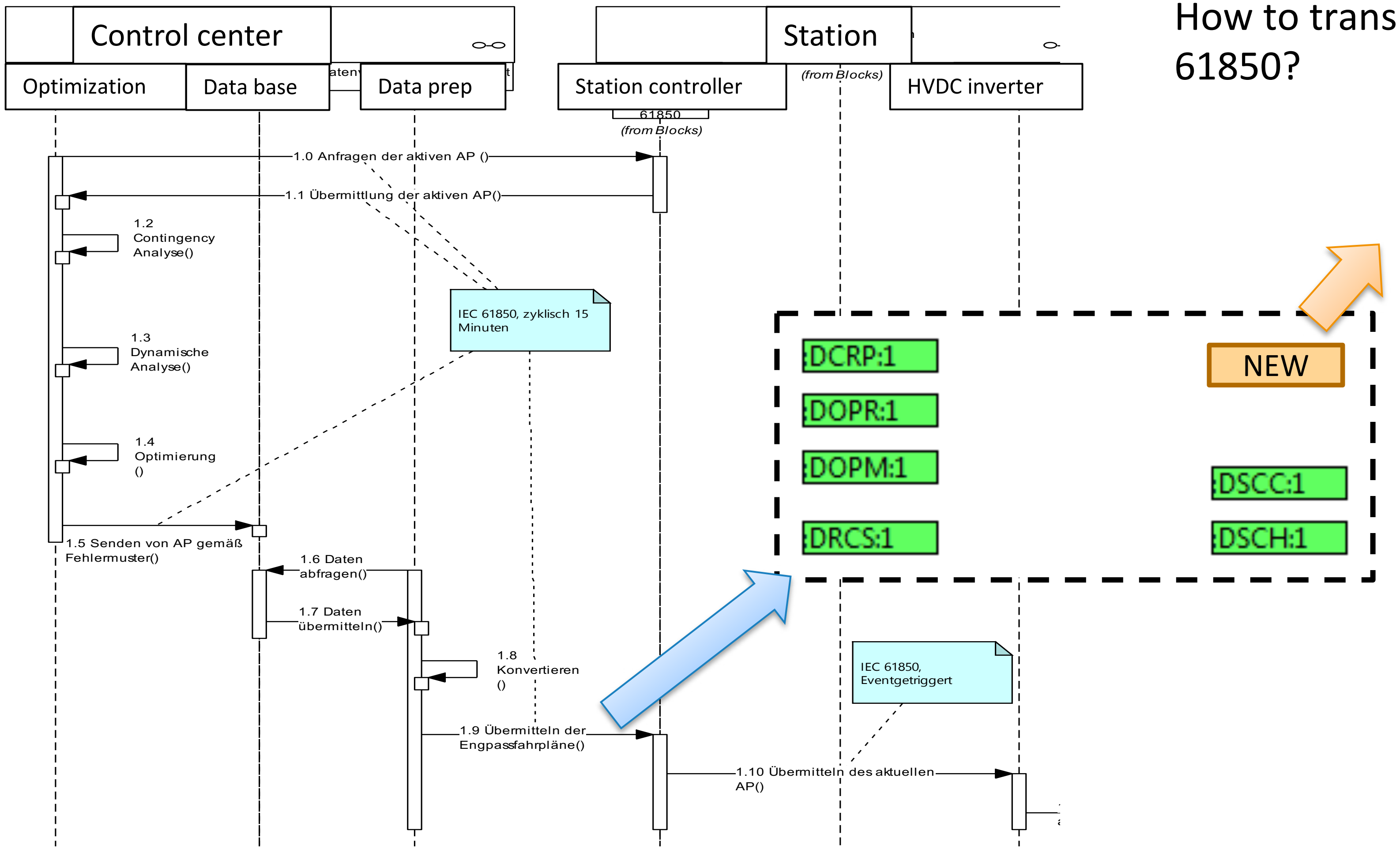
→ Station controller monitors measured values for pattern match

→ Assigned measures are taken instantaneously

→ Information to control center is sent



Use Case 1: HVDC control, corrective Measures

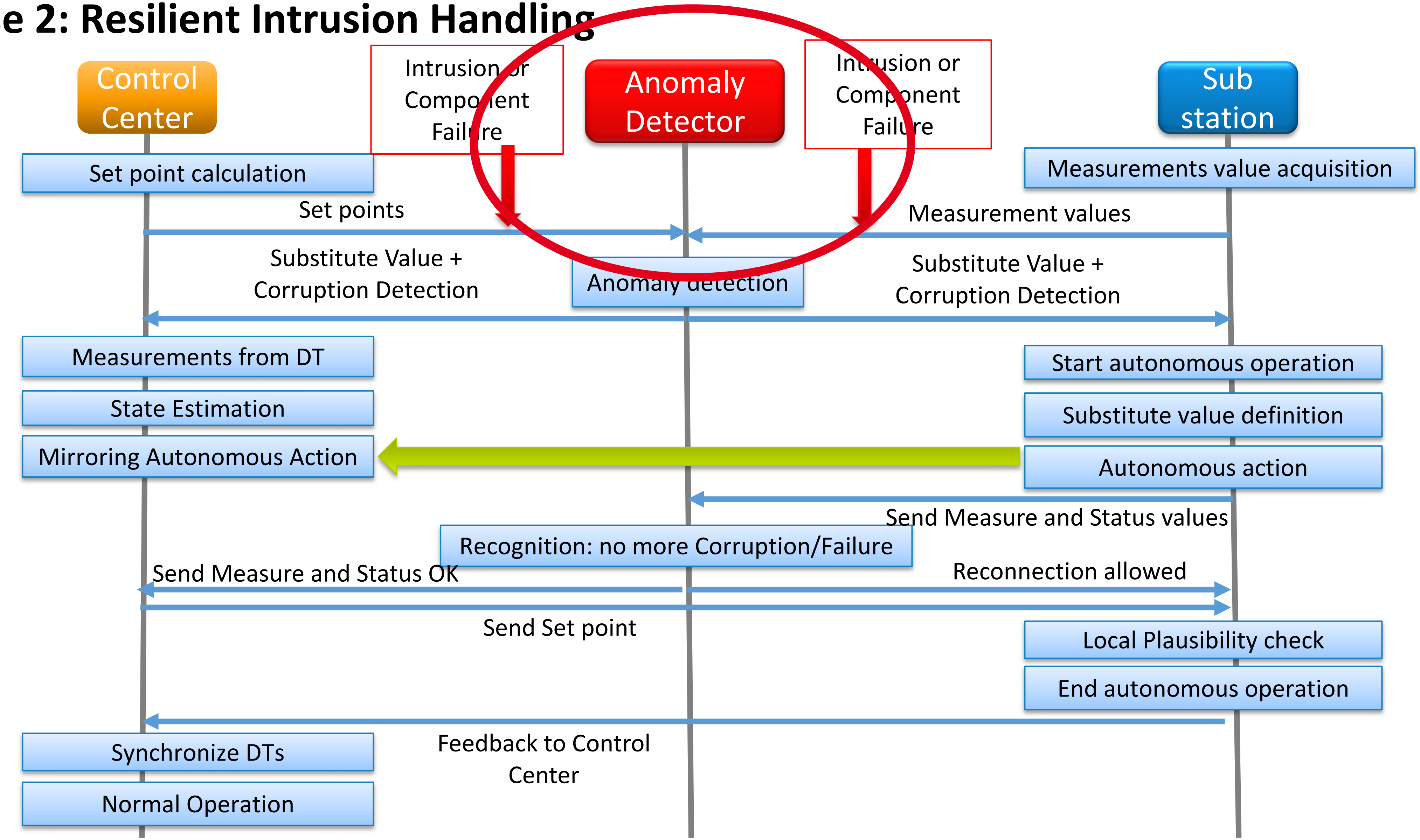


Graphic simplified

How to transmit patterns and measures in IEC 61850?

Name	Type	M/O/C
LNName	Inherited	M
…	Inherited	M
patternValues1	ERY	M
patternValues2	ERY	O (C1)
measIds1	VRY	M
measIds2	VRY	O (C1)
setPoints1	ERY	M
setPointIds1	VRY	M
setPoints2	ERY	O (C2)
setPointIds2	VRY	O (C2)
setPoints3	ERY	O (C3)
setPointIds3	VRY	O (C3)
… 4?		

Use Case 2: Resilient Intrusion Handling



Use Case 2a: Anomaly/Failure Detection

- Anomalies caused by puckish Intrusion
- Unwanted manual disturbances
- System failures

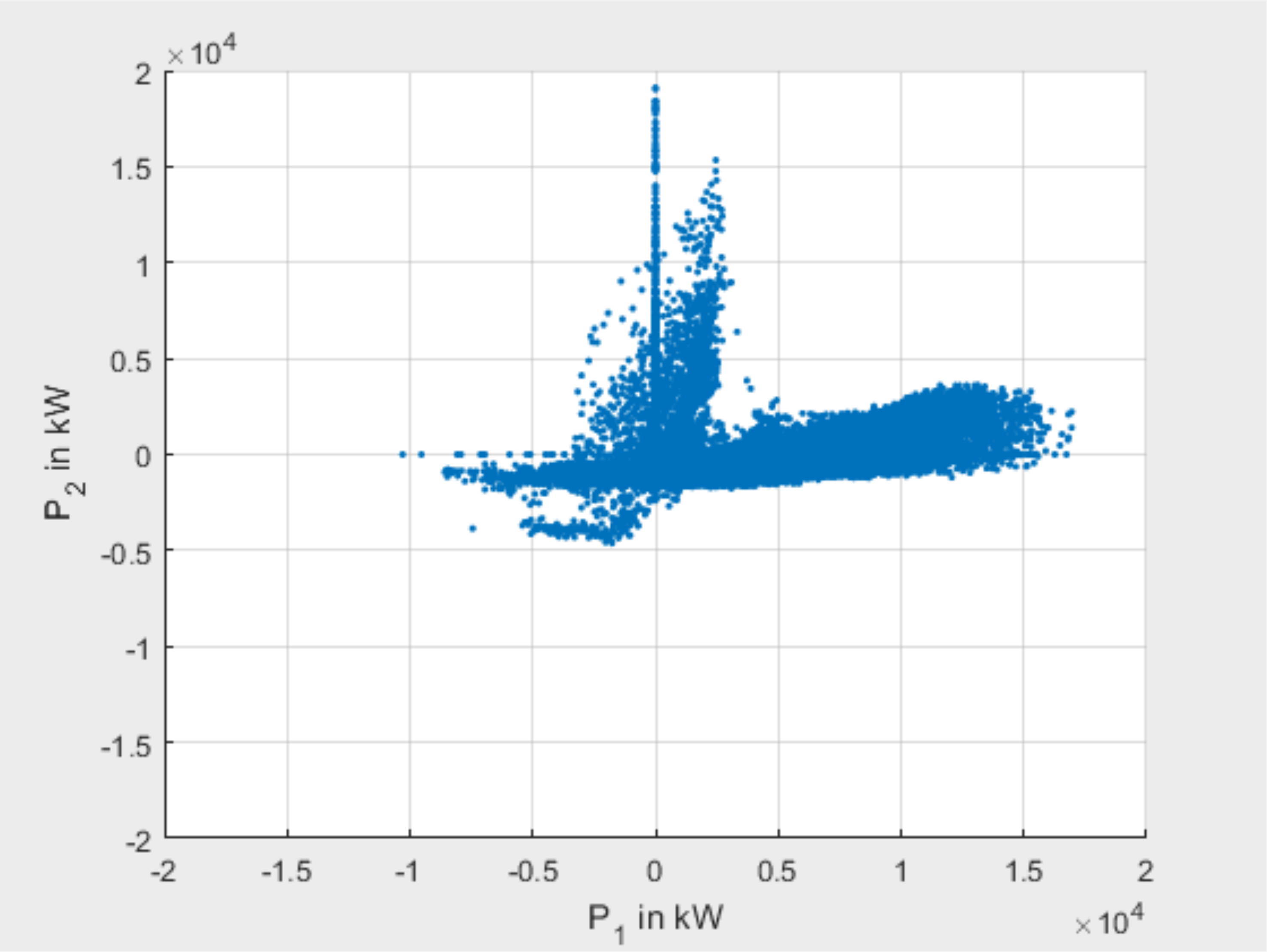
Approach 1: Rule based Detection system

- Huge rule set necessary,
  high probality of loosing some events
- Based on ruleset reliable

Approach 2: AI-based pattern recognition

- Sufficient training data necessary
- Comprehensive detection of suspicious events
- Multi dimensional pattern analyses

3 input parameters characteristics



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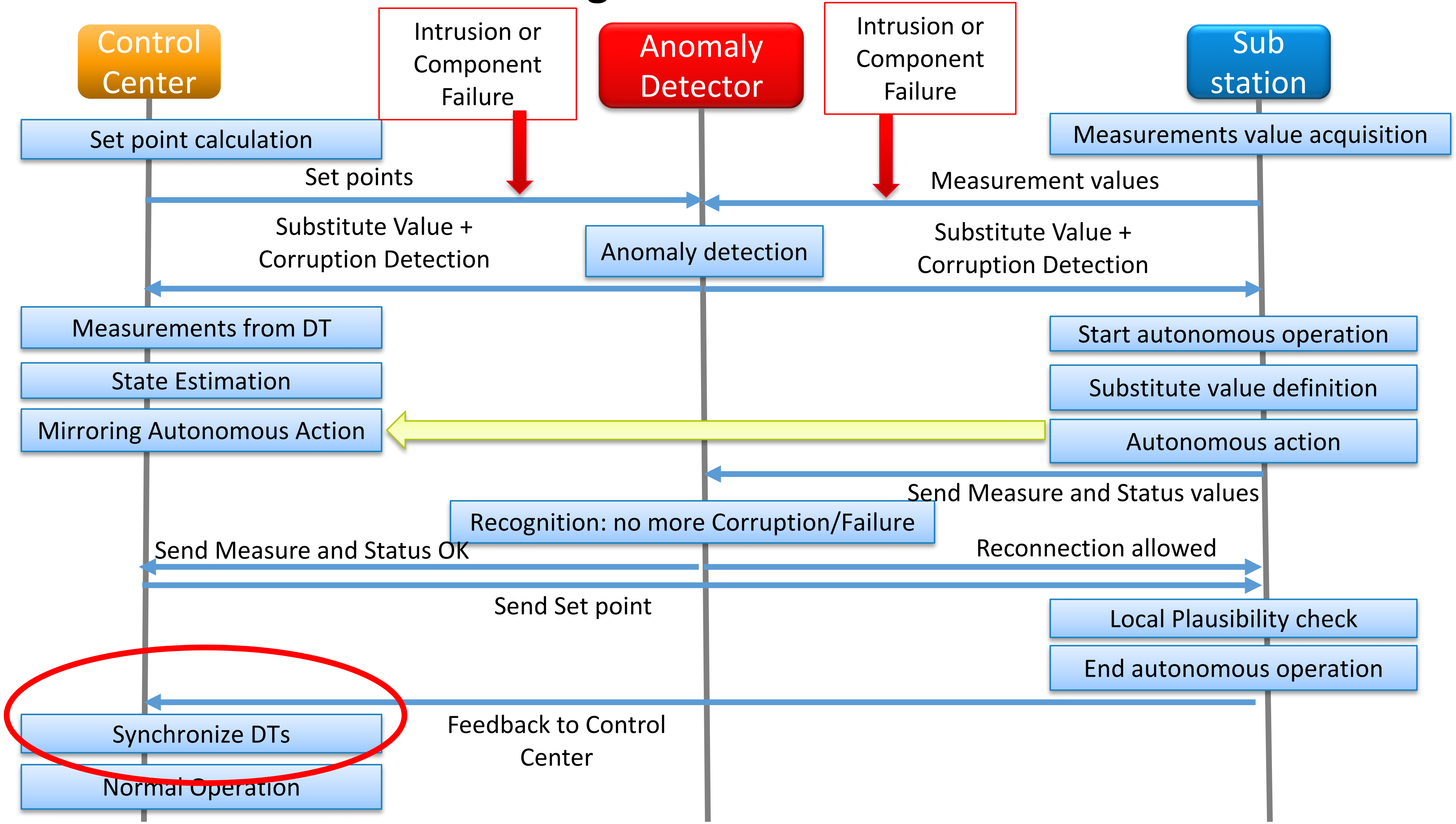
Approach 2: AI-based pattern recognition

- Sufficient training data necessary
- Comprehensive detection of suspicious events
- Multi dimensional pattern analyses

Data to be transferred

- Initial:
  - Knows pattern data (many tables/arrays)
  - Mainly complex voltage, current and frequency data
  - Known anomalies (and their causes)
- Continously / on event:
  - Updated pattern data (tables/arrays)
  - Pattern corrections
  - Information on false positive detections

Use Case 2: Resilient Intrusion Handling



Use Case 2b: Digital Twin synchronization

- DT of Control center and Substation need to be synchronized
  - Reporting of local situation to control center
  - Unified parameter set of all system components
  - Synchronous behaviour in case of information loss


```
<parameterDefaultValues>
    <param description="UEL (1,2 or 3)" name="Icon_UEL" value="0"/>
    <param description="VOTHSG (1 or 2)" name="Icon_VOTHSG" value="0"/>
    <param description="TR (sec)" name="TR" value="0"/>
    <param description="VI MAX" name="VI_MAX" value="0"/>
    <param description="VI MIN" name="VI_MIN" value="0"/>
    <param description="TC (sec)" name="TC" value="0"/>
    <param description="TB (sec)" name="TB" value="0"/>
    <param description="TC1 (sec)" name="TC1" value="0"/>
    <param description="TB1 (sec)" name="TB1" value="0"/>
    <param description="KA" name="KA" value="0"/>
    <param description="TA (sec)" name="TA" value="0"/>
    <param description="VA MAX" name="VA_MAX" value="0"/>
    <param description="VA MIN" name="VA_MIN" value="0"/>
    <param description="VR MAX" name="VR_MAX" value="0"/>
    <param description="VR MIN" name="VR_MIN" value="0"/>
    <param description="KC" name="KC" value="0"/>
    <param description="KF" name="KF" value="0"/>
    <param description="TF &gt;0 (sec)" name="TF" value="0"/>
    <param description="KLR" name="KLR" value="0"/>
    <param description="ILR" name="ILR" value="0"/>
```


When to synchronize

- Continously during normal operation at data change
- After reconnection from autonomuos mode

What to synchronize

- Model parameters (static and dynamic) or local/regional power network
- State parameters, aggregated measurements
- Adapted configurations

- XML-based data sets
- Currently proprietary, system specific data
- Especially dynamic parameters quite complex
- Use of File transfer or API
- Lag of models in IEC 61850 and CIM

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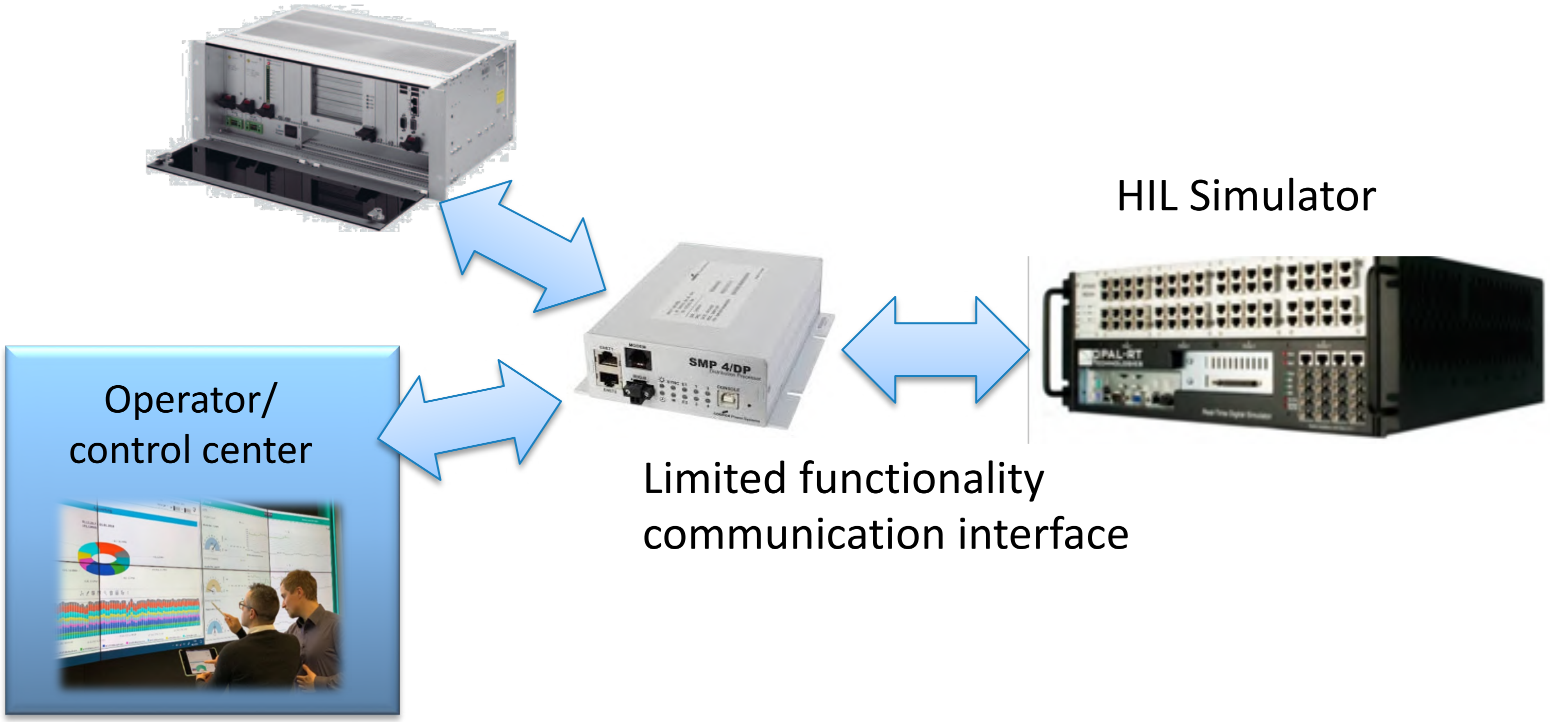
Current state

- Necessary data objects identified
- Only few of them tranferrable according to standards
- Bottleneck: Lag of free configurable interface solution to HIL-simulator (IEC 61850)
- Current work:
  - Build some Interface for testing new IEC 61850 models with HIL simulator
  - Test other ways of complex data model transer
  - Test DT and AI functionalities
- Test more use cases for DT application
- → 2 more project years to go



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Conclusion

- DT and AI are powerful tools for handling increasing complexity of energy systems
- Supporting resilient system behaviour
- Makes decentralized computing power usable
- Challenges:
  - (Dynamic) System modeling in necessary depth
  - Getting/Generating teaching data
- Current data exchange mainly via proprietary data models → Need for standarduzed data models will be identified

Questions? Contact us!

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