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PROTECTION MONITORING & DIAGNOSTICS

PROTECTION MISOPERATIONS

USA

Years	2018	2019	2020	2021	2022
Protection System Operations	19,744	19,283	18,296	17,448	17,769
Protection System Misoperations	1,536	1,346	1,170	1,186	1,170
%	**7,78%**	**6,98%**	**6,39%**	**6,80%**	**6,58%**

(From NERC 2023 State of Reliability report)

Russia

Years	2019	2020	2021	2022	2023
Protection System Operations	50,322	57,696	60,919	55,851	58,755
Protection System Misoperations	1,616	1,699	1,668	1,646	1,572
%	**3,21%**	**2,94%**	**2,74%**	**2,95%**	**2,68%**

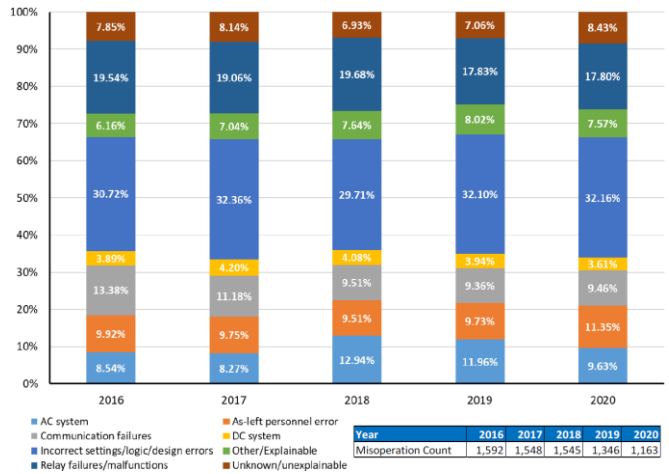
(From https://www.so-ups.ru/functioning/tech-base/rza/rza-account-analys/rza-results-info/2024)

Major causes:

- Incorrect settings, logic or design errors
- Relay failures / malfunctions
- Communication failures
- As-left personnel error

…

- Unknown / unexplainable



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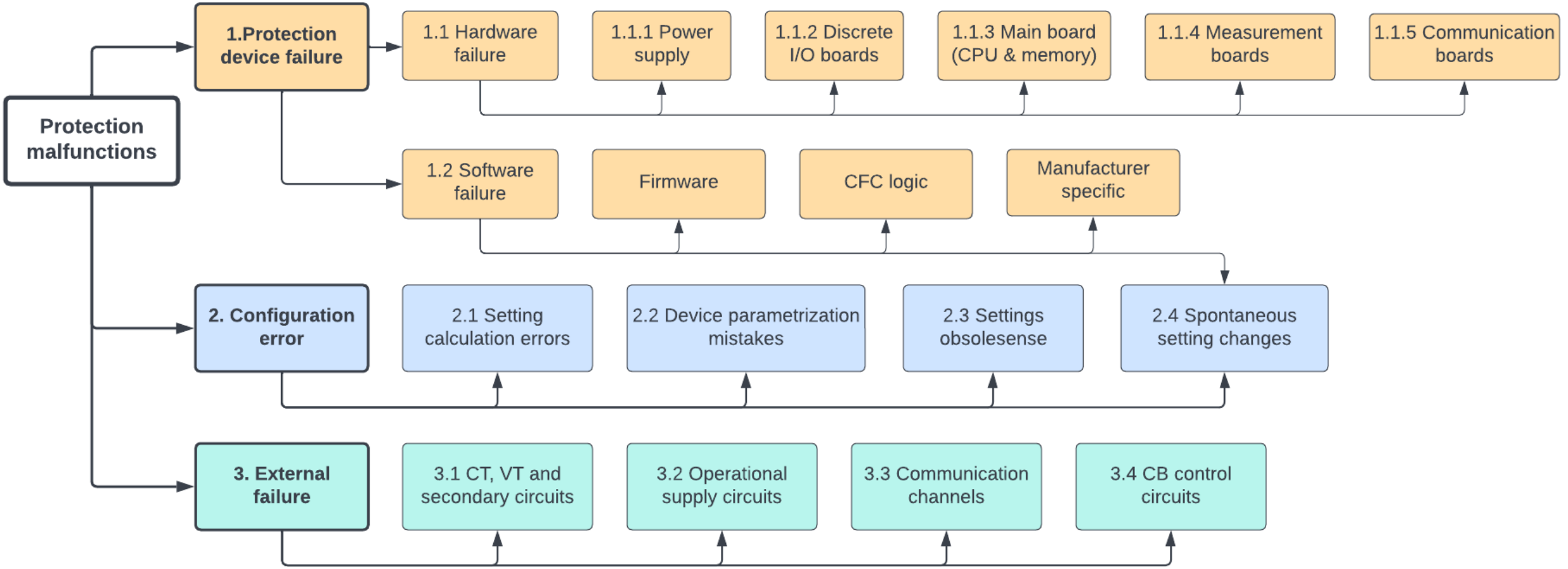
PROTECTION MALFUNCTION GROUPS



Systematic protection monitoring is not widely adopted due to:

- A large number of protection devices (10^4 – 10^6) in a power system
- The diversity of devices, formats and signals
- A lack of automation in fault and protection event analysis

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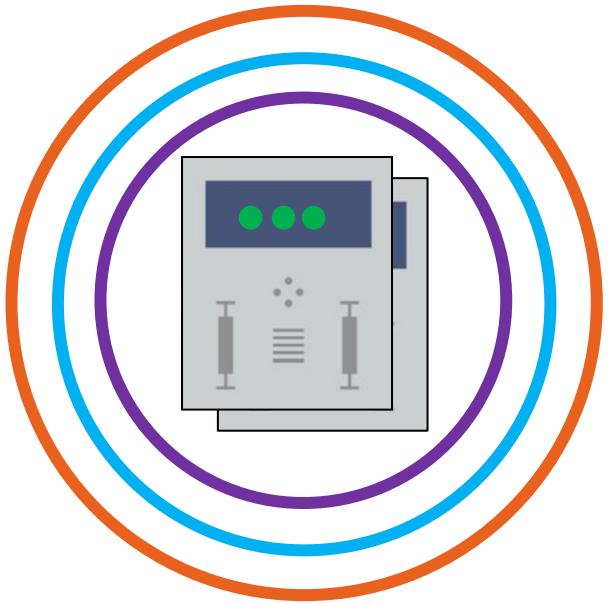
PROTECTION MONITORING AND DIAGNOSTICS (PMD)



Targets of deployment

- Protection failure risks reduction
- Protection engineers' effort reduction

Main tasks

- Online remote monitoring and condition diagnostics of protection IEDs
- Analysis of fault events and evaluation of correct protection operations
- Creation of preconditions for condition-based maintenance

Main benefits

- **2 times** reduction in risk of protection malfunction
- **10 times** reduction in time for protection analysis for Power System restoration
- **3 times** reduction in cost of protection maintenance when CBM is used

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PMD REFERENCE

Russian Grid, TSO South

- Psou 220 kV – 91 IEDs *(EKRA, GE, …)*
- Poselkovaya 220 kV – 57 IEDs *(EKRA, GE, …)*
- Chernomorskaya 220 kV – 53 IEDs *(EKRA, GE, …)*

Russian Grid, Moscow DSO

- Belorusskaya 220 Kv – 169 IEDs (*ABB, EKRA, Relematica)*
- Kozhevnicheskaya 220 kV – 180 IEDs (*ABB, EKRA, Relematica)*
- Liublino 110 kV – 44 IEDs (*EKRA, Relematica)*
- Tiutchevo 110 kV – 60 IEDs (*EKRA, Relematica)*

United Energy Company, Moscow

- Kotlovka 220 kV – 160 IEDs (*Relematica. ABB)*

Russian Grid, TSO Center

- 2024 PMD design – 40 Substations

SO UPS

- 57 Dispatching centers (PMD + modeling)

Vietnam NTPS

- Lab – 8 (Toshiba, NARI, Siemens Siprotec4 and 5)

Slovenia FERI (Maribor)

- University Lab – 8 *(Siemens Siprotec5)*

Russia Industrial

- **East Port** 7 Substations, 130 IEDs *(Siemens, ABB)*

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PMD REFERENCE: IN SO UPS

System Operator of the Unified Power System of Russia

- Deployment scale – implemented at more than 950 power plants /substations

Functions

- Identification of emergency events and determination of damage location
- Real-time detection of malfunctions in protection IEDs
- Identification of false trips and failures of protection IED functions that may lead to incorrect operation
- Generation of reports on all protection IED operations

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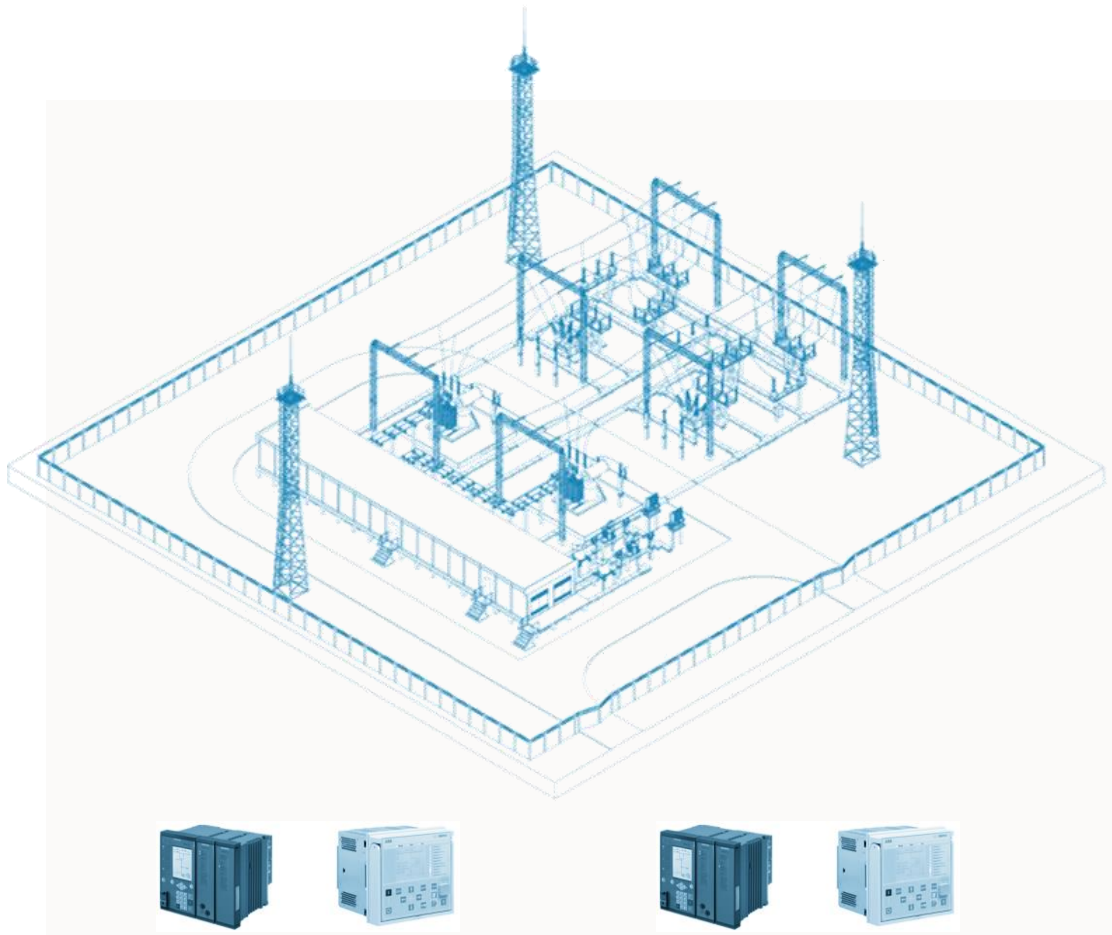
PMD FUNCTIONS



Remote on-line monitoring and health diagnostics of protection IEDs:

- Detection of malfunctions and early proactive diagnostic of hidden device failures in real time:
  - self-diagnostic signals
  - integrity of AC circuits from CT and VT
  - power supply and DC current
  - accuracy of starts and trips
- Automatic verification and checking of IED settings vs reference

Fault event analysis and assessment of correct protection operations:

- Automatic disturbance records synchronization
- Precise fault location and events identification
- Protection maloperations detection

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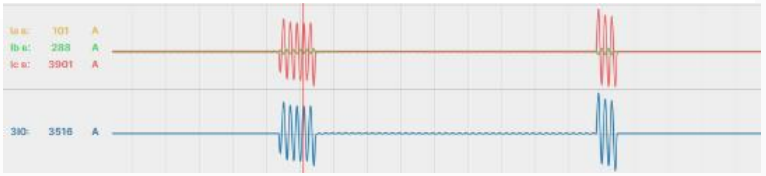
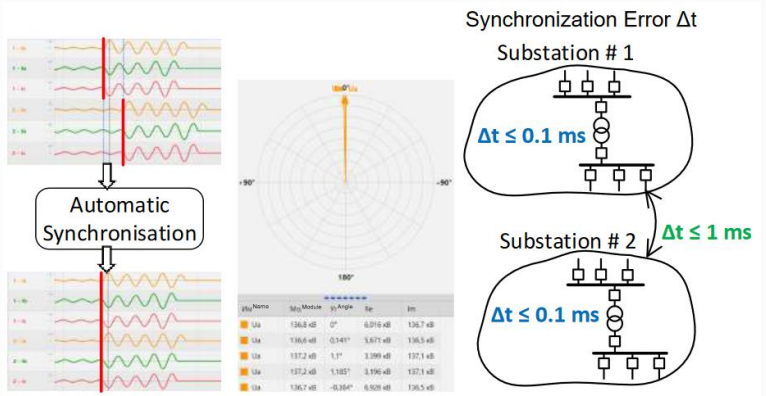
FAULT ANALYSIS

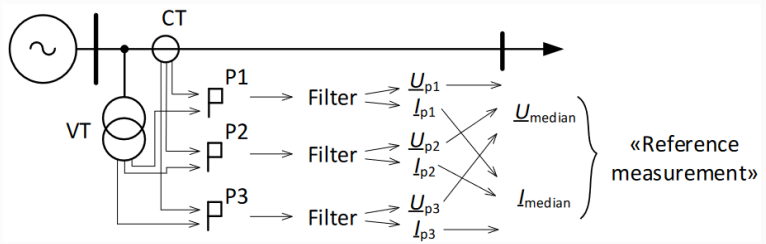
1. Optional. Fault event identification on the control center level based on SCADA and EAM information. Association of incoming disturbance records with fault events.
2. Current and Voltage signals extraction, check of disturbance presence



3. Disturbance records time synchronization between devices on the same or neighboring substations
4. Estimation of disturbance start and end time
5. Calculation of a) pre-fault and b) initial fault Current and Voltage phasors



6. Pre-fault and fault phasors verification using median filtering. In case of significant deviations notification is triggered about a possible secondary circuit failure.
7. Detection of the fault type, phases and location. Single or double-end for OHL
8. Fault clearing time identification for further disturbance evolution analysis



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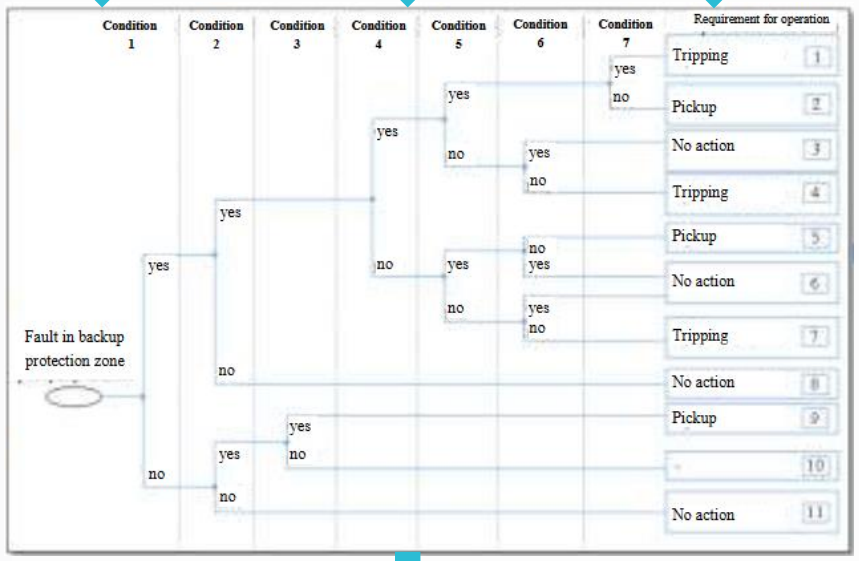
PROTECTION OPERATION ANALYSIS

1) Event logical tree analysis

Fault parameters

Network topology

Protection operation



Operation requirements

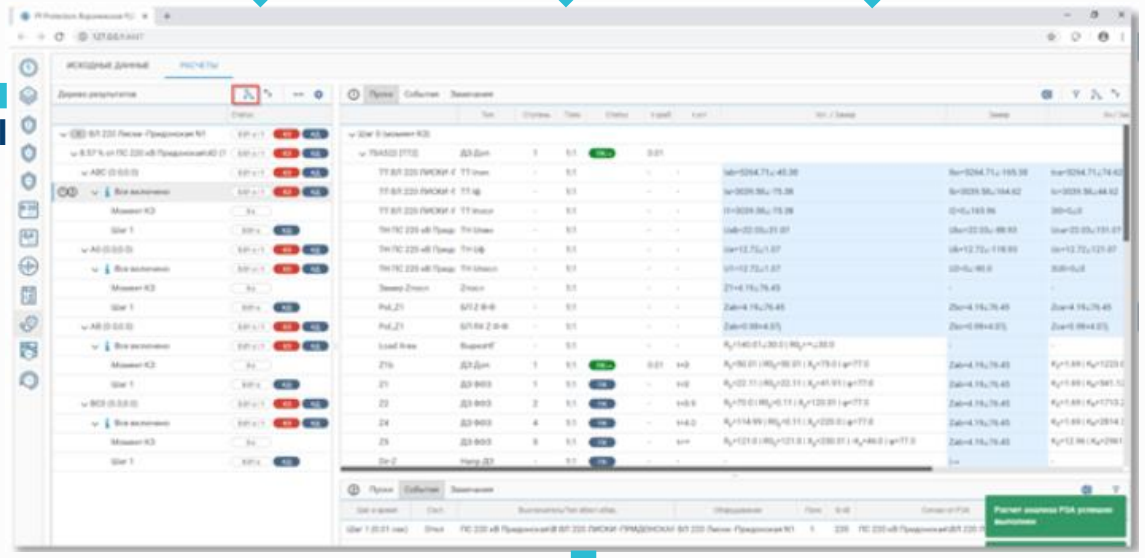
2) Model-based analysis

Fault parameters

CB positions

Switched off protections

Fault U and I



Operation requirements

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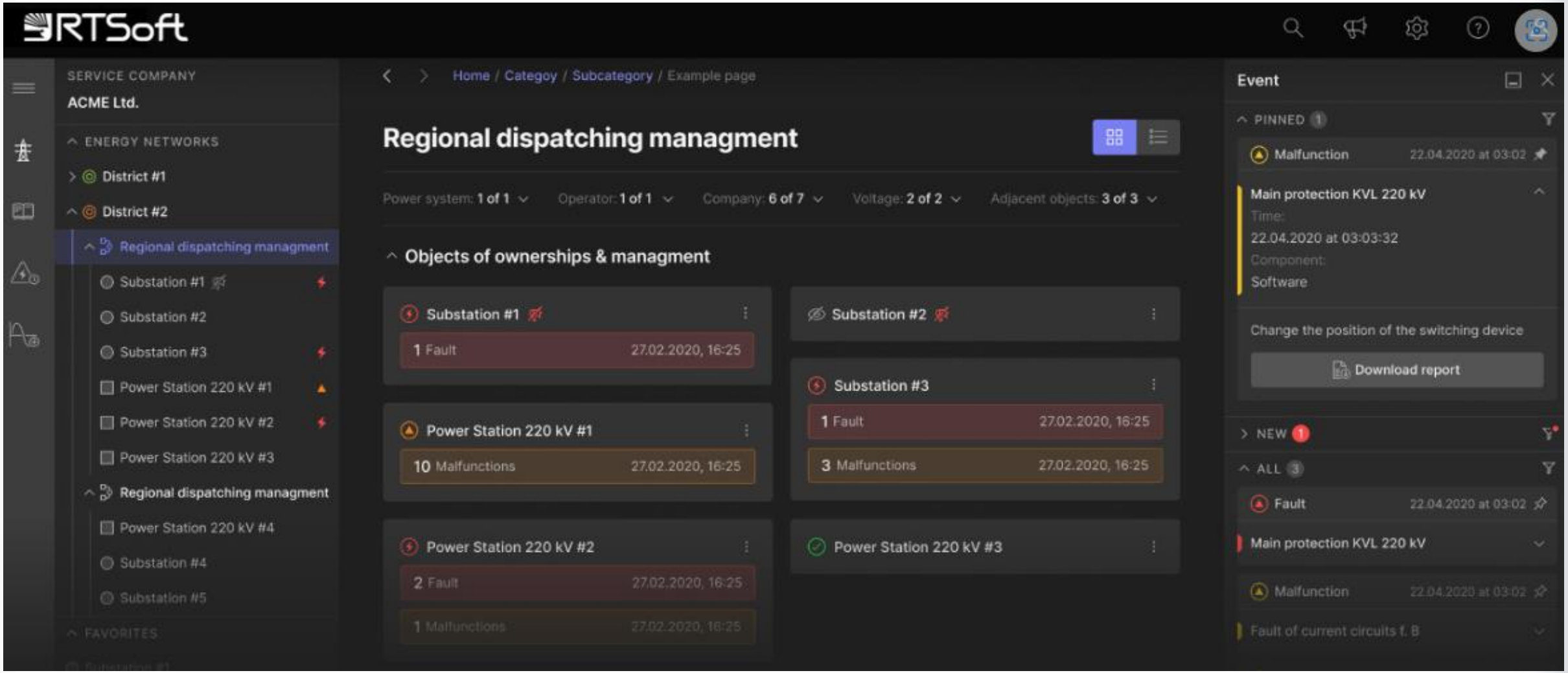
PMD SYSTEM INTERFACE

MAIN SCREEN



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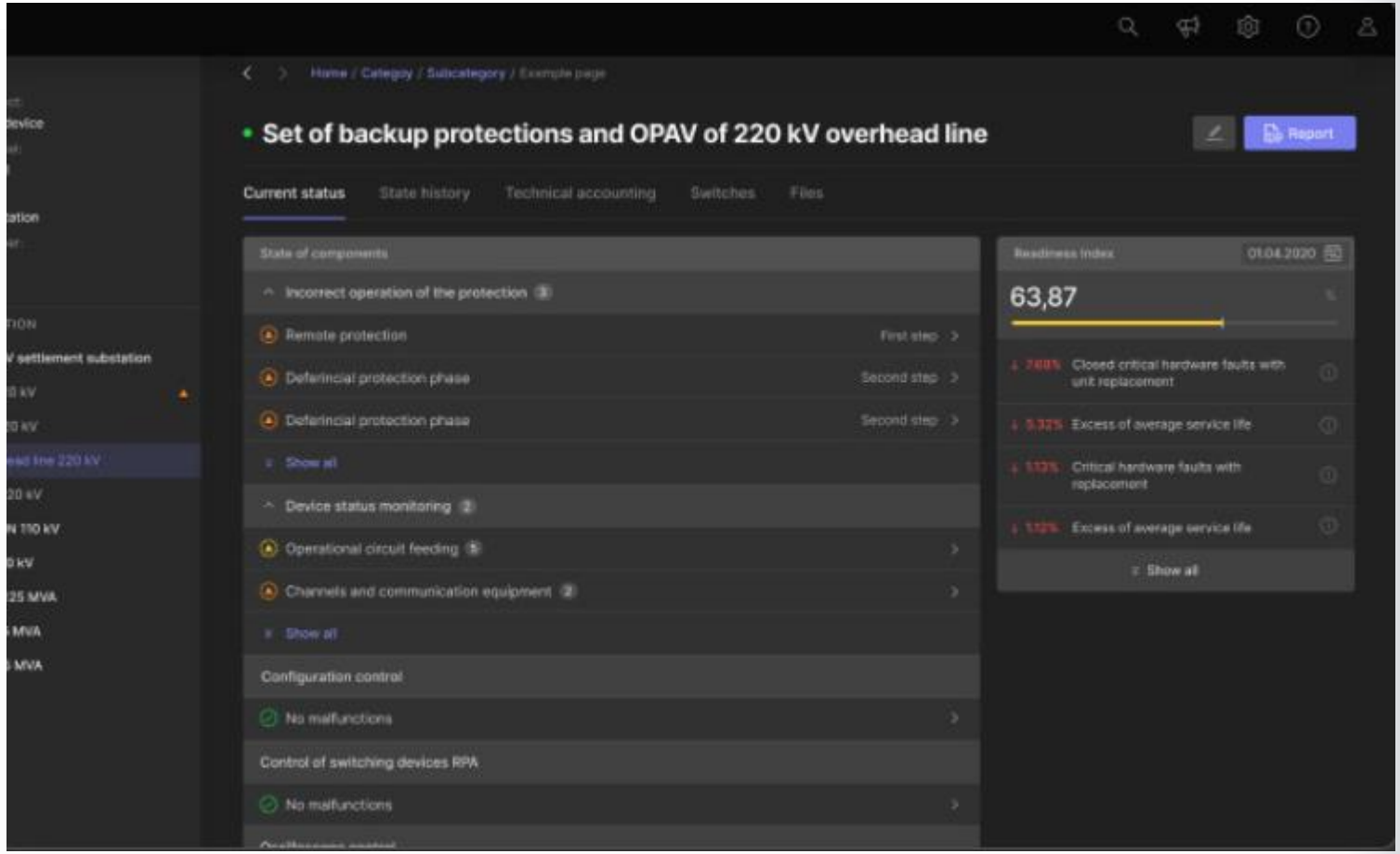
REAL-TIME REMOTE MONITORING AND HEALTH DIAGNOSTICS

- Timely detection and notification of malfunctions, with proactive diagnostics to identify hidden failures
- Automatic verification of IEDs settings against reference values
- Support of condition-based maintenance strategies



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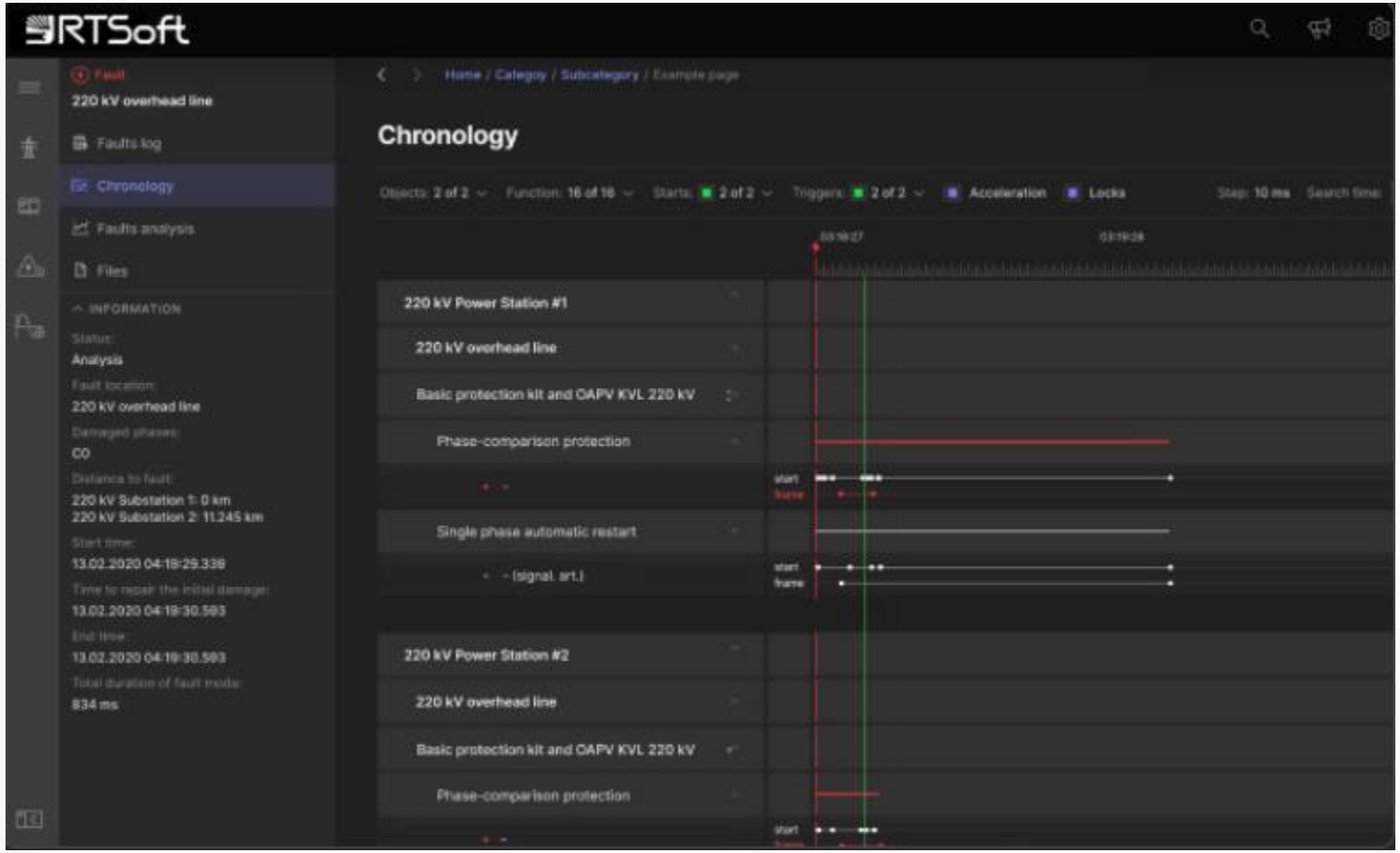
FAULT EVENT ANALYSIS IN HV & MV ELECTRICAL GRIDS, WITH ASSESSMENT OF PROTECTION OPERATIONS CORRECTNESS



- Automatic data collections from IEDs & SCADA
- Notifications about fault events and protection operations
- In-depth analysis of fault events using real-time signals, event logs, and fault records
- Automated generation of reports with analysis results

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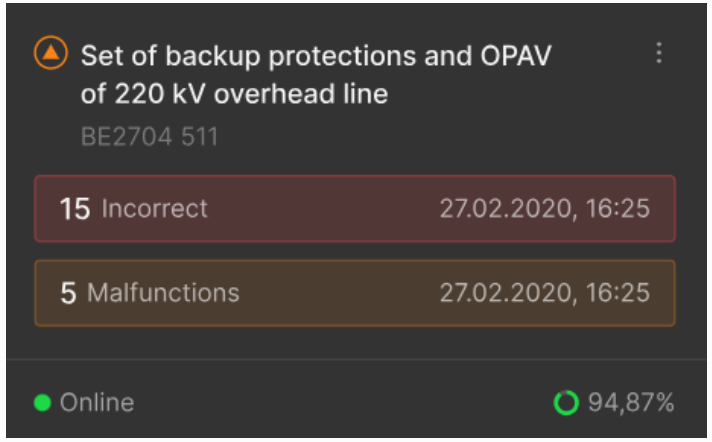
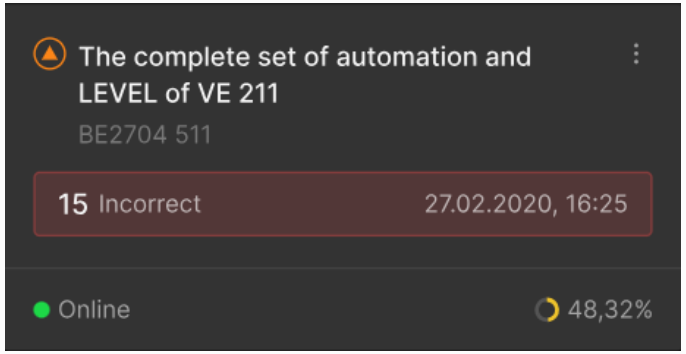
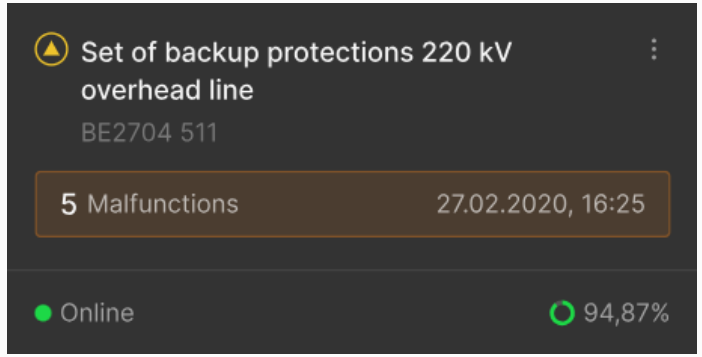
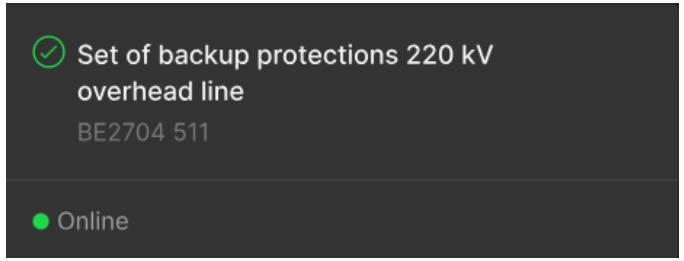
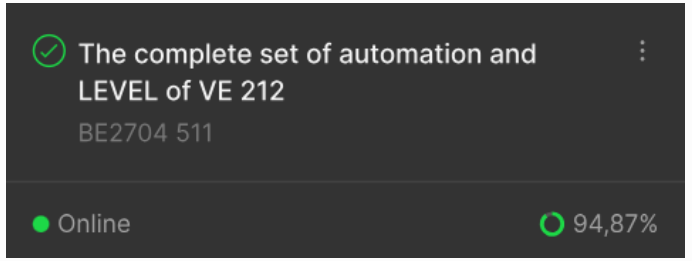
PROTECTION IED CONDITION DIAGNOSIS











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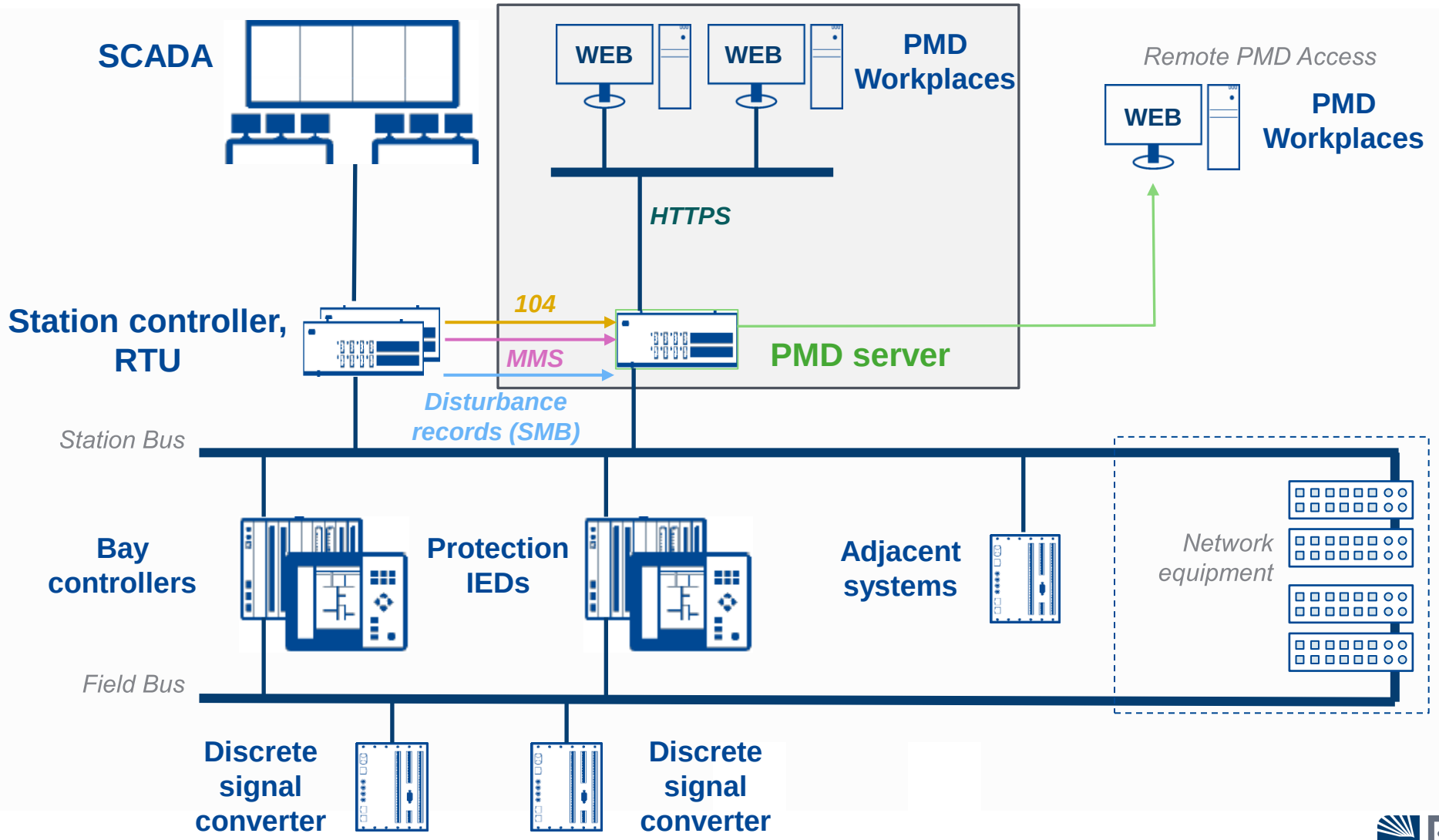
PMD TECHNICAL DETAILS

OBJECT LEVEL PMD ARCHITECTURE EXAMPLE



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PROTECTION MANUFACTURERS SUPPORT

✓ Supported protocols

- IEC 61850-8-2
- IEC 60870-5-104
- IEC 60870-5-103
- MODBUS
- FTP*, SMB*

*Disturbance file collection from existing servers

✓ Integration experience

- Siemens Siprotec 5;
- Siemens Siprotec 4
- Hitachi – ABB 670, SPAC
- Micom P64x
- GE UR
- Toshiba GRZ200

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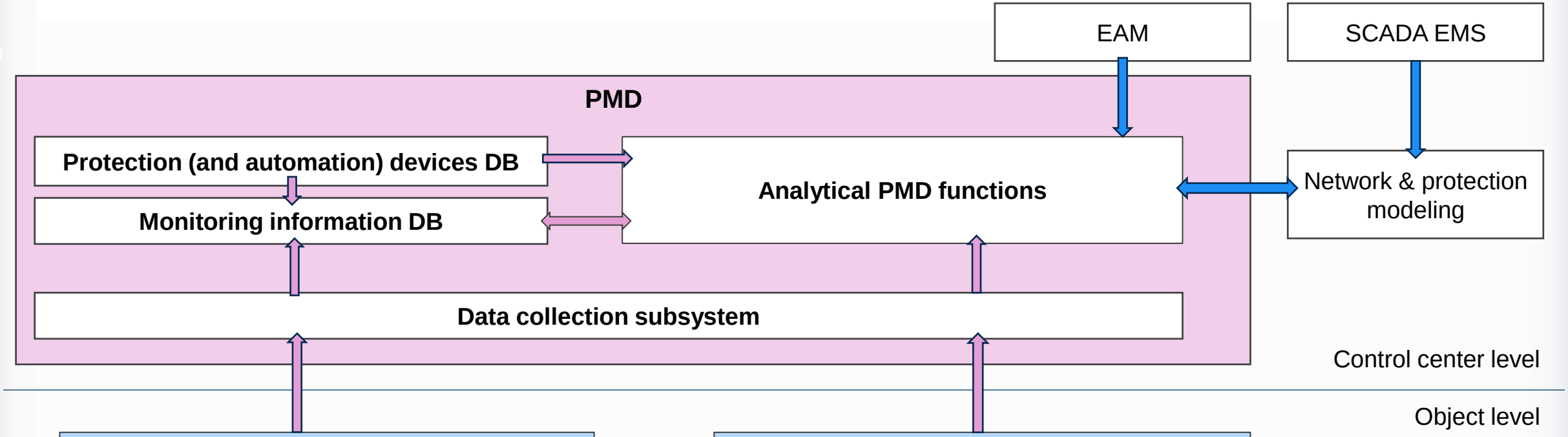
OVERALL PMD FUNCTIONAL ARCHITECTURE



Data collection from non-automated substation

- disturbance records from protection IEDs and fault recorders[6]
- protection IED event logs (if possible);
- protection IED configuration files (if possible);
- protection IED failures, revealed from self-diagnostic signals;
- protection IED switching key positions (if possible);
- communication channels state (if possible); [7]
- power supply (if possible);
- circuit breaker state (if possible);

Data collection from automated substation

- disturbance records from protection IEDs and fault recorders[6]
- protection IED event logs;
- protection IED configuration files;
- protection IED failures, revealed from self-diagnostic signals;
- protection IED switching key positions;
- protection IED functional keys position;
- communication channels state; [7]
- power supply;
- circuit breaker state;
- analogue measurements comparison results;
- current state of protection IED discrete inputs and outputs;

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PMD BENEFITS

CHANGES IN MAINTENANCE BUSINESS PROCESS

BEFORE

Operating personnel at substation → SCC dispatcher → Relay protection specialist

- Downloading disturbance files to a flash-card
- Renaming files to visually align with relay protections
- Sending files to a System Control Center (SCC) dispatcher

- Preliminary calculation of a fault location
- Sending oscillogram files to a relay protection specialist

- Clarification of the calculation of an error point
- Manual synchronization of the oscillogram
- Manual evaluation of a protection operation
- Sending fault record files to a relay protection specialist at the TSO dispatching center
- Analysis of faults of relay protection devices in short-circuit operation

AFTER

Operating personnel at substation → Automated workstation at a power facility → Automated workstation at an enterprise → Relay protection specialist, SCC dispatcher

- Automatic collection of disturbance records

- Automatic synchronization of the oscillogram
- Calculation of the fault location
- Evaluation of the action of each protection in case of short circuits
- Automatic generation of a relay protection operation reference
- Automatic fault analysis

- Clarifying calculation of the fault location
- Final evaluation of the relay protection operation

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ECONOMIC EFFECT OF REDUCING MAINTENANCE COSTS

Maintenance schedule for microprocessor relay protection devices with maintenance elements on condition

Year	Room category	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
4 (TC)	relay cabinet, substation control building	N	C1			TC				TC				TC				TC				TC				TC	
8 (B+C)		N	C1			~~C~~				~~B~~				~~C~~				~~B~~				~~K~~				~~B~~	
3 (TC)	indoor switch-gear, packaged transformer substation	N	C1		TC			TC			TC			TC			TC			TC			TC			TC	
6 (B+C)		N	C1		~~C~~			~~B~~			~~C~~			~~B~~			~~C~~			~~B~~			~~C~~			~~B~~	

N – Checking at a new start (termination)
C1 – The first preventive control
TC –Technical control, maintenance measures for relay protection devices after automated workstation integration
C – Preventive control
B – Preventive recovery

Labor costs per device for 8 years

BEFORE

Type	Maintenance cycle, years	Labor costs, person * hour			Travel costs, person * hour	Total, staff-hours
		B	C	TC		
Back-up protection 220 kV	8(B+C)	52	23		11	86

AFTER

Type	Maintenance cycle, years	Labor costs, person * hour			Travel costs, person * hour	Total, staff-hours
		B	C	TC		
Back-up protection 220 kV	2*4(TC)	0	0	43	6	49

SAVINGS AND BENEFITS

Metrics	BEFORE	AFTER
Scheduled monitoring time for one PAC IED	1 hour/quarter	0 - Not required (automatically)
Time to prepare an operation reference for specific PAC device	2 hours	10 min
Average labor costs for reconciling the positions of operational elements	2 hours/month only by planned presence at substation	10 min/month online
Average number of observed fault signals per one microprocessor relay protection device	1 PC One signal of general device malfunction	≈35 PC
Frequency of monitoring of secondary current and voltage circuits	Rarely, only upon detection of incorrect operation	Often, each time an oscillogram is recorded
Frequency of tracking repeating HW and SW malfunctions within a specific PAC device	1 time/quarter	Automatically
Time to collect primary information about disturbances in a power system, including collection from adjacent substations	30 min	10 min
Average number of microprocessor protection IEDs which are analyzed within one disturbance in the power system	≈6 PC within a damaged equipment	≈60 PC three zones from a fault

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