

Spectrum Power™ 7 v2.10

Distribution Network Applications DNA 1.33

Spectrum Power™ 7 – Distribution Network Applications

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- **Overview**
- Fault Management
- Distribution Network Analysis
- Distribution Network Optimization
- Summary

Spectrum Power™ 7 Distribution Network Applications

What's new in v2.10?

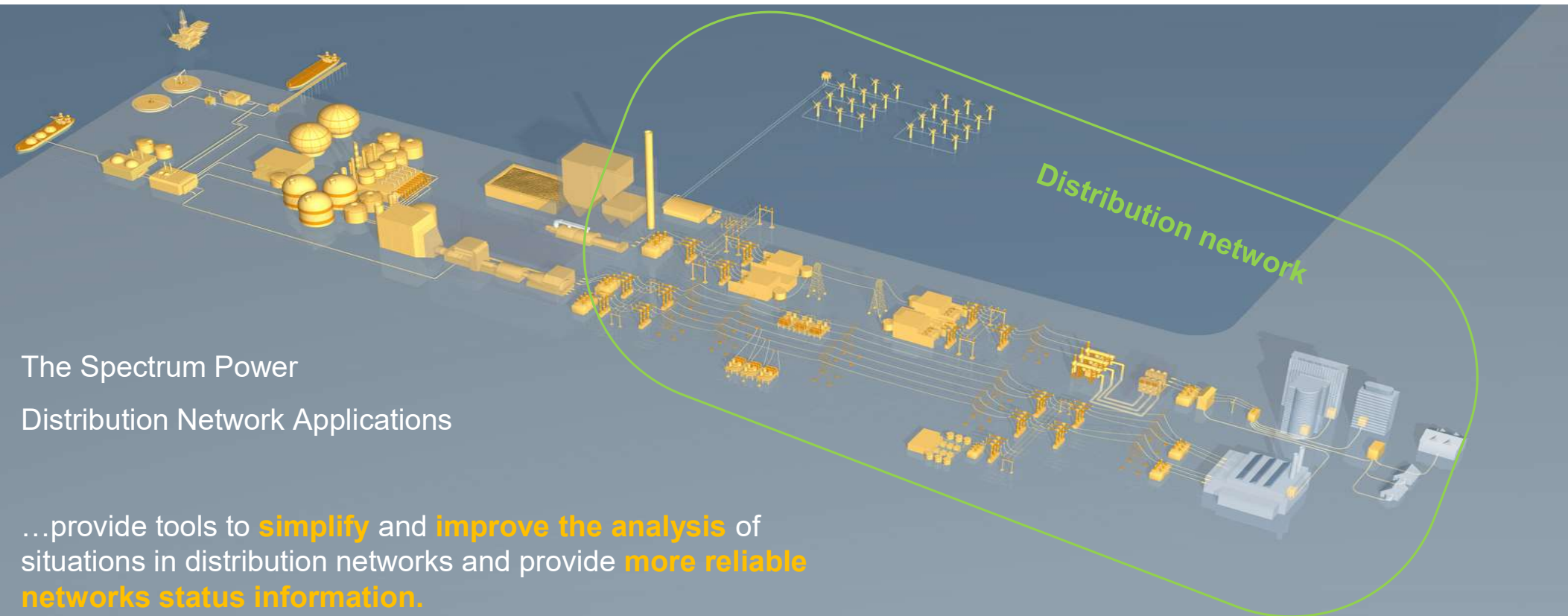
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What's new in v2.10?

- [Optimal Feeder Reconfiguration](#) proposes switching procedures for optimized radial network configuration
- [Secured Checked Switching](#) supports switching action with load flow validation
- [Volt/Var Control](#) includes [batteries](#) as controls to optimize the voltage profile as well as the load flow
- [State Estimation](#) calculates [phase imbalances](#) in unbalanced networks

Spectrum Power™ 7 – Distribution Network Applications Definition

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The Spectrum Power
Distribution Network Applications

...provide tools to **simplify** and **improve the analysis** of
situations in distribution networks and provide **more reliable**
networks status information.

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Motivation

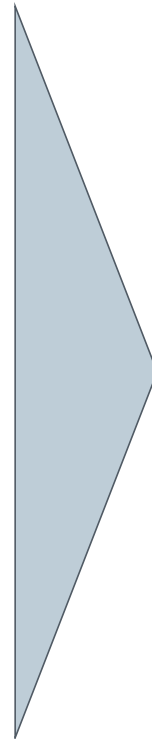
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Distribution Network Analysis (DNA)

Smart Grid challenges:

- Network sizes increase, e.g. with LV integration
- Distributed generation causes reverse powerflow and network instabilities
- Increasing need to know real-time operation conditions better
- Reliability of supply is getting more important

**DNA: the essential component
for any Smart Grid solution**



Fault Location (FLOC)

Fault Isolation and Service Restoration (FISR)

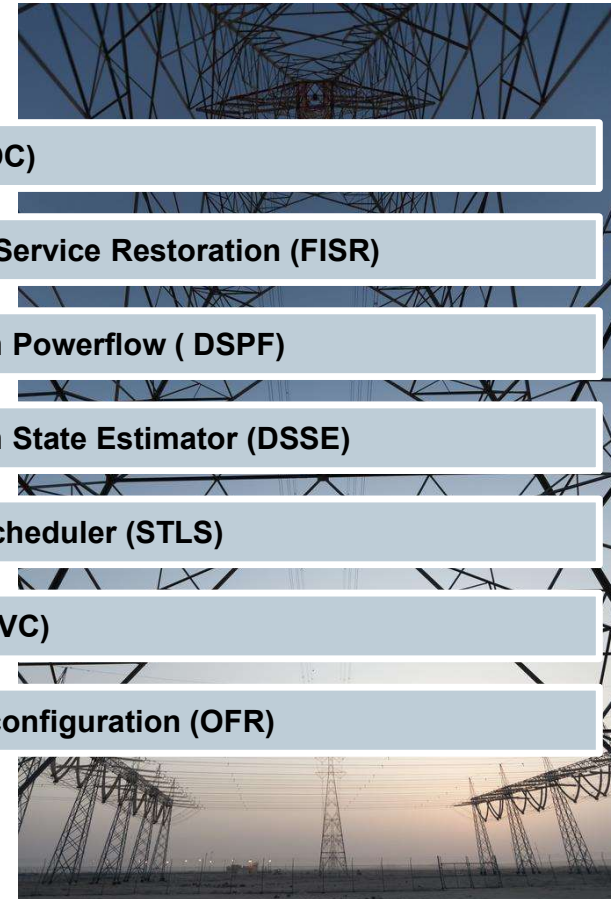
Distribution System Powerflow (DSPF)

Distribution System State Estimator (DSSE)

Short Term Load Scheduler (STLS)

Volt-/Var Control (VVC)

Optimal Feeder Reconfiguration (OFR)

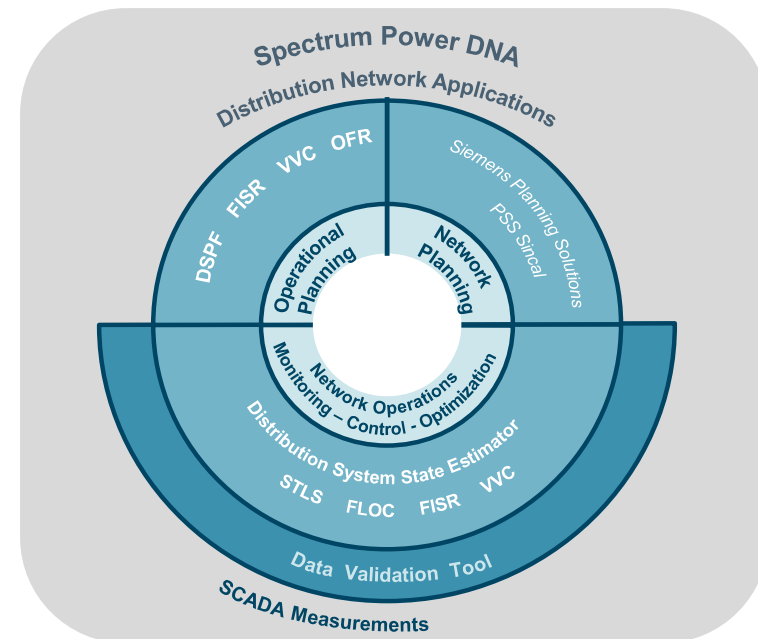


Spectrum Power™ 7 – Distribution Network Applications Functional Overview

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The Distribution Network Applications (DNA) provide Smart Grid tools for the

- **Analysis & Isolation of network faults** with
 - Fault Location (FLOC)
 - Fault Isolation & Service Restoration (FISR)
- **Analysis of the network** with
 - Short Term Load Scheduler (STLS)
 - Distribution System Power Flow (DSPF)
 - Distribution System State Estimator (DSSE)
- **Optimization of network operation** with
 - Optimal Volt/VAr Control (VVC)
 - Optimal Feeder Reconfiguration (OFR)



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Spectrum Power™ 7 – Distribution Network Applications Fault Location (FLOC)

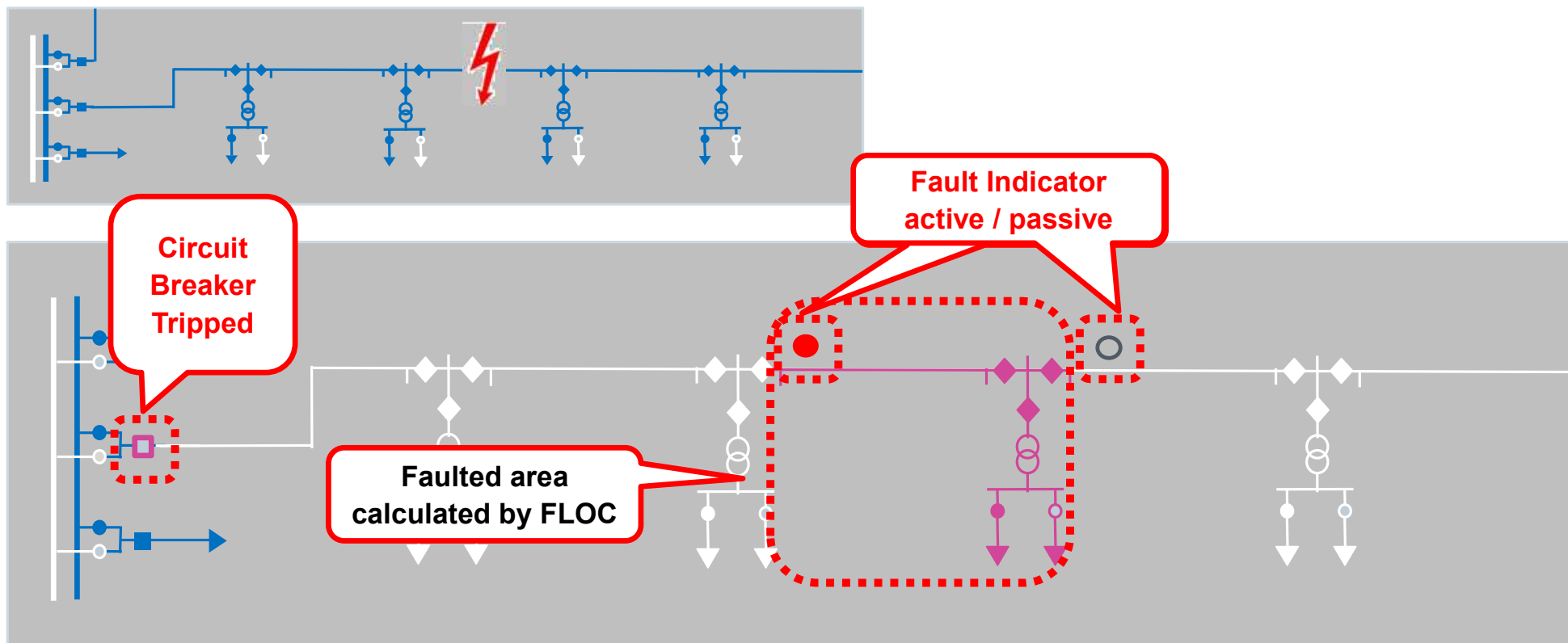
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- Handles **outage faults** (i.e. short-circuit faults) and **non-outage faults** (i.e. earth faults)
- Triggered on state change of fault indicators and feeder CB's unexpected tripping
- **Fast localization of faulty section**
- Designed to **determine the smallest possible faulted section** based on available real-time information
- Essential to **restore supply fast and to as many customers as possible**
- Uses remote metered and manually updated information such as:
 - **Protective devices' tripping** (CB's, re-closers, etc.)
 - Status of **fault passing indicators**
 - Status of **earth fault relays**
 - Fault information from **Impedance fault relays**



Spectrum Power™ 7 – Distribution Network Applications Fault Location (FLOC)

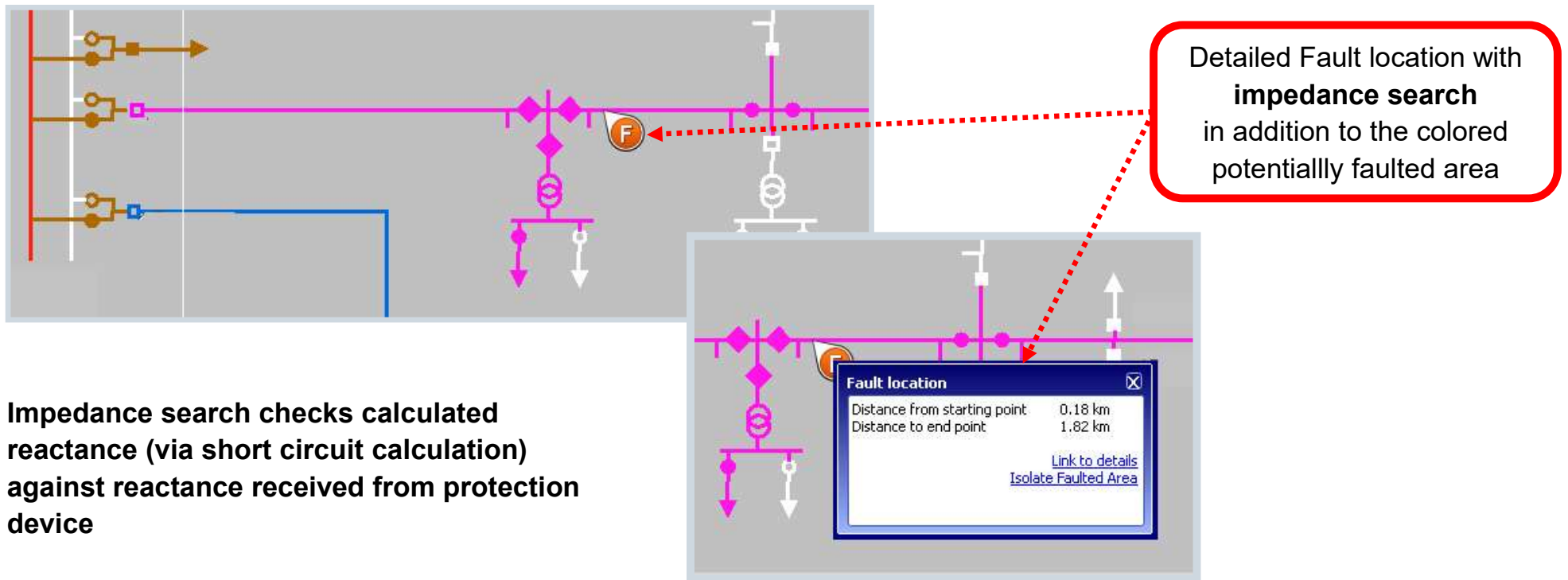
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Fault Location with impedance search

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Impedance search checks calculated reactance (via short circuit calculation) against reactance received from protection device

Spectrum Power™ 7 – Distribution Network Applications Fault Isolation and Service Restoration (FISR)

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Once the faulty segment has been identified (e.g. by FLOC):

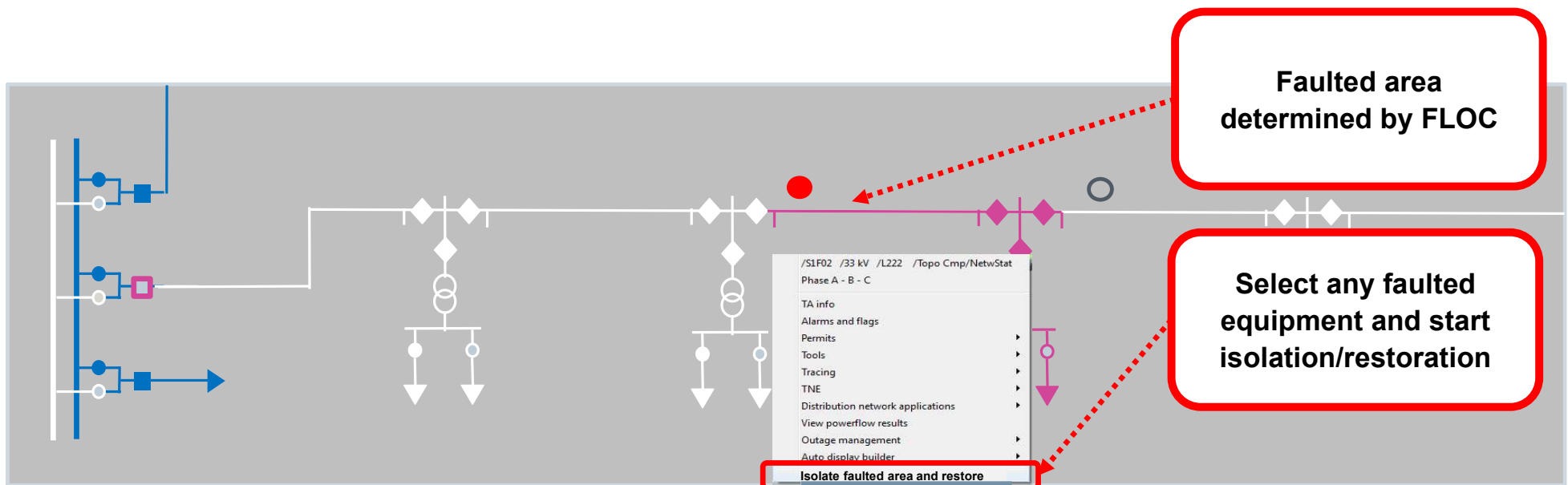
- FISR finds out how to isolate the faulty segment
 - FISR finds out how to restore power to all related non-faulty segments
-
- ✓ **Minimizes the outage time for the affected customers**
 - ✓ **Establishes the series of required switching operations**
 - ✓ **Used also for outage planning (equipment isolation for planned maintenance)**



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Fault Management Workflow

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Fault Management Workflow

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Isolation and restoration procedure is calculated for faulted area

Proposed steps are highlighted

Isolation and Restoration Summary
Affected Customers: 9
Completed successfully

Proposal	Restored load [kW]	Customers	Trust factor [%]
1	3,000.00	2	62.50
2	3,000.00	2	62.50

Switching proposal

No.	B1	B2	B3	Element	Info	Action	Executed
1	S1F02	33 kV	Bay1159	LBS1	Status	open	
2	S1F02	33 kV	Bay1095	LBS1	Status	open	
3	S1F02	33 kV	Bay1015	LBS1	Status	open	
4	EU-S1	33 kV	Bay236	CB	Status	close	

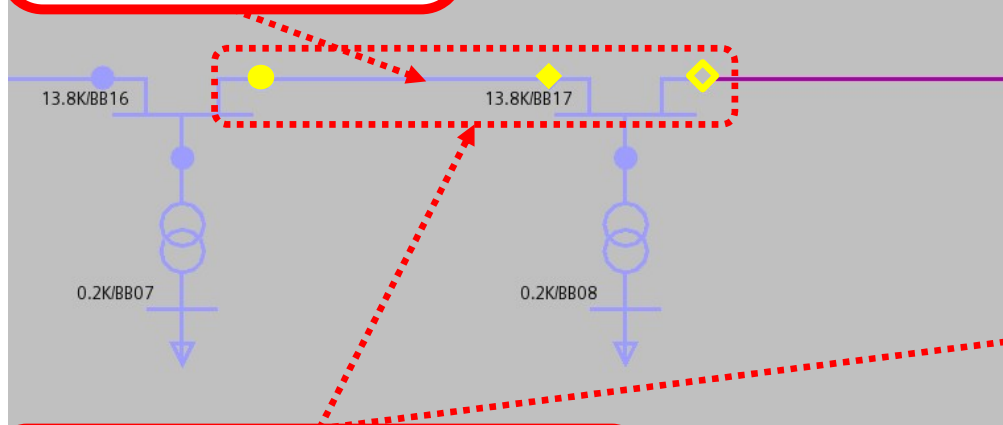
End workflow

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Isolate equipment for planned outages utilizing FISR

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Select the equipment
(e.g. line) that should
be taken out for
maintenance and
execute FISR



Isolation/Service restoration steps
are calculated and highlighted

Results | Proposals comparison | Input | Parameters | Information

Result Details

Proposal order	Warning	Switching order number	Operation access difficulty index	Line	Trafo	Weakest reserve [A]	Voltage deviation [%]	Power losses [kW]	Restored Loads	Load [kW]	Customers	Trafo
1	YES	0	5.00	178.07	-398.18	-8.00	71.93	1	70.00	1	1	

Switching proposal | Information

Switching proposal

Action Order	Equipment	Type	Phase	Action	Temporary
1	/F4_US_S3/13/Bay1045/LBS1	Manual	ABC	Open	NO
2	/F4_US_S3/13/Bay1130/LBS1	Manual	ABC	Close	NO
3	/US-S3/13/Bay09-F4/CB	Manual	ABC	Open	YES
4	/F4_US_S3/13/Bay431/Iso Bb 1	Manual	ABC	Open	NO
5	/US-S3/13/Bay09-F4/CB	Manual	ABC	Close	YES

Create Switching Order

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Spectrum Power™ 7 – Distribution Network Applications Distribution State Estimator (DSSE)

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- DSSE **estimates loads** (active and reactive power) based on existing measurements using weighting factors for measurements and loads
 - DSSE calculates **voltages for all busbars, flows through lines and transformers** (active and reactive power and currents) and **active and reactive power losses**
 - For unbalanced networks, DSSE also calculates **current and voltage imbalances**.
 - DSSE is used to assess the real-time operating conditions of the distribution grid and to detect **overloads** and/or **voltage limit violations**
 - Solves for both, **balanced representation of the network** (i.e. positive sequence only) and for **three phase unsymmetrical representation of the network**
 - Operation from and visualization in the one-lines
 - Executes periodically, on event and on demand
-
- ✓ **Provides an improved load model via STLS**
 - ✓ **Provides a reliable basis for optimal network operation**
 - ✓ **Used to identify gross measurement errors and measurement inconsistencies**



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Improved Network Monitoring with State Estimation

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Input

- P, Q, I, V measurements at substations and a limited set of additional measurements along the feeders
- Load models

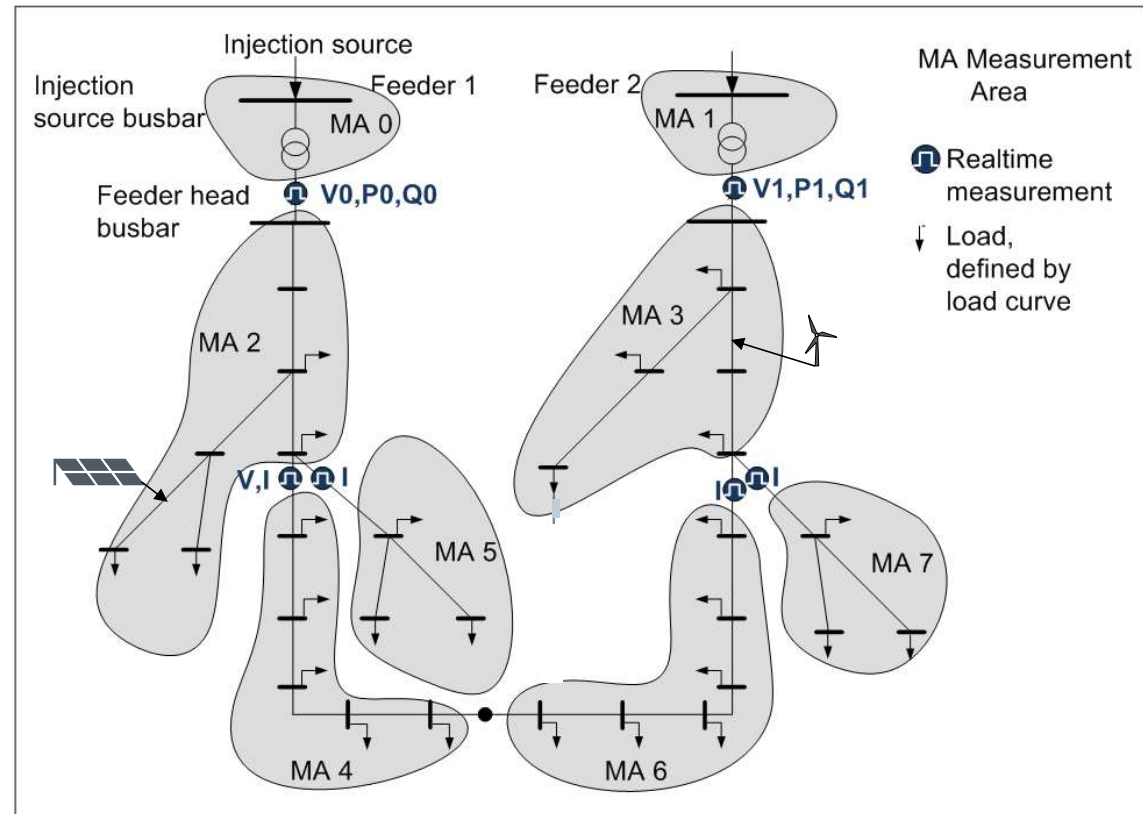
Algorithm

The estimation problem is mathematically defined as minimization function - nearest estimate to a given measurement set (measurement area) consisting of

- P and Q measurements
- Pseudo P and Q measurements at loads/load groups
- Current and voltage magnitude measurements

Output

- Detailed current, voltage and power information for every single element in the network
- Voltage and thermal limit violations
- Active and reactive power losses



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DSSE Use Case “Network Monitoring”

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DSSE continuously calculates network

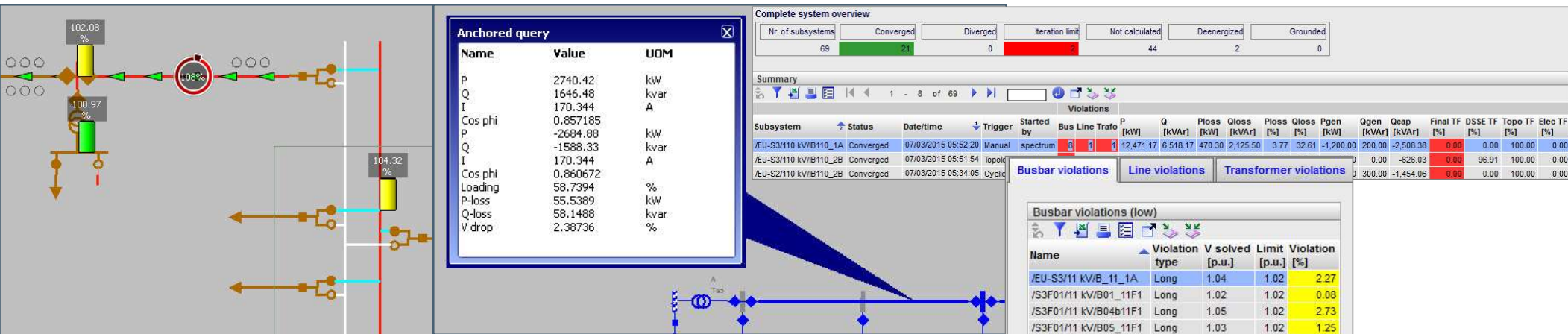
- DSSE runs cyclically / triggered by topology changes
- DSSE calculates voltages, active and reactive power, etc. based on available measurement and the load schedules

DSSE checks for violations

- DSSE checks for overloads and voltage limit violations
- Detected violations are reported as alarm
- Flow direction is shown and violated equipment are highlighted in the single line diagram

User analyzes violations

- User may view violations and navigate to the single line diagram to locate the violated equipment
- User may request detailed DSSE results via query from the single line diagram



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Distribution System Power Flow (DSPF)

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- DSPF calculates **voltages for all busbars, flows through lines and transformers** (active and reactive power and currents) and **active and reactive power losses**
- For unbalanced networks, DSPF also calculates **current and voltage imbalances**.
- DSPF checks for **equipment overloads and violation of voltage limits**
- DSPF is used to study electric power distribution networks under various loading conditions and configurations
- DSPF is used to support **planned and unplanned outage** switching procedures
- Solves for both, **balanced representation of the network** (i.e. positive sequence only) and for **three phase unsymmetrical representation of the network**
- Operation from and visualization in the one-lines

✓ **Used to study “what if” scenarios**

✓ **Used to support operator’s training together with other applications**

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DSPF Use Case “Validate Switching Procedure”

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Switching procedure is executed in a study

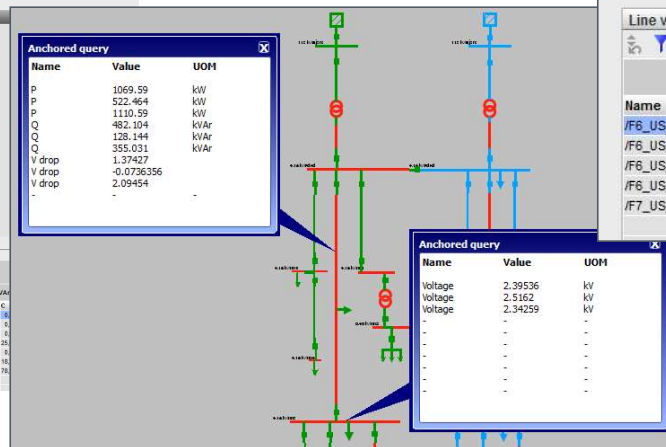
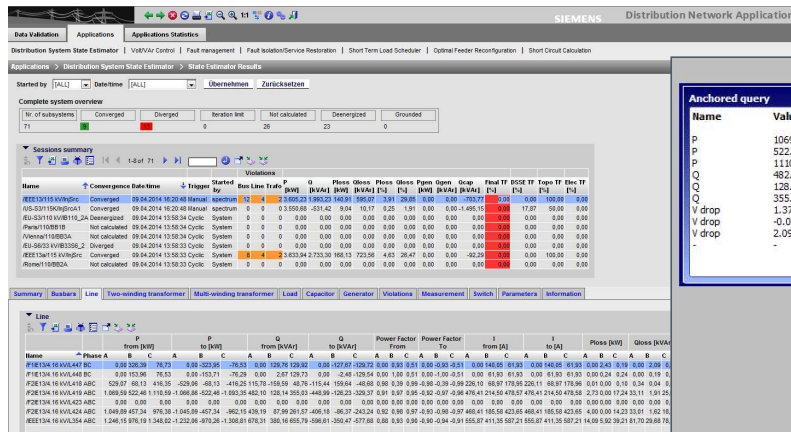
- A switching procedure is executed in a study, i.e. based on a save case
- DSPF runs on the resulting topology and calculates voltage, active and reactive power, etc.

DSPF checks for violations

- DSPF checks for overloads and voltage limit violations
- Detected violations are reported in the violation list and the violated equipment are highlighted in the single line diagrams

User analyzes violations

- User may view violations and navigate to the single line diagram to locate the violated equipment
- User may request detailed DSSE results via query from the single line diagram

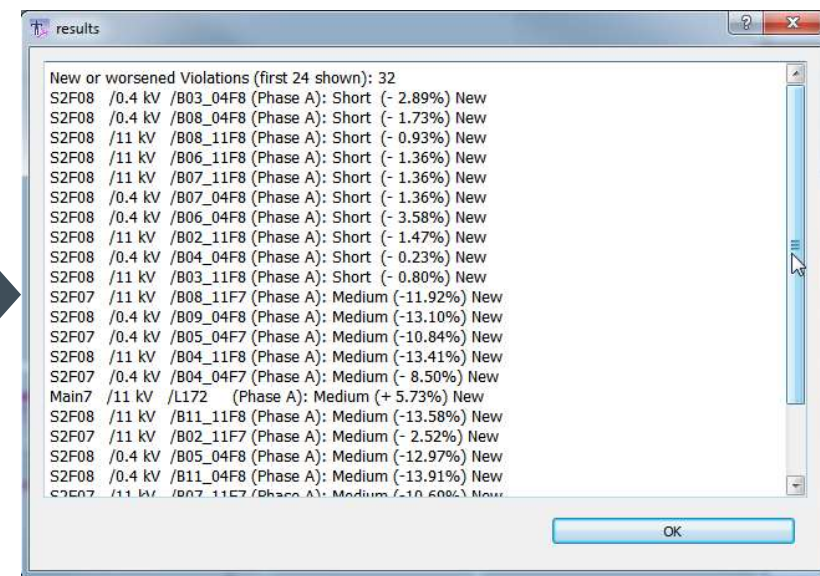
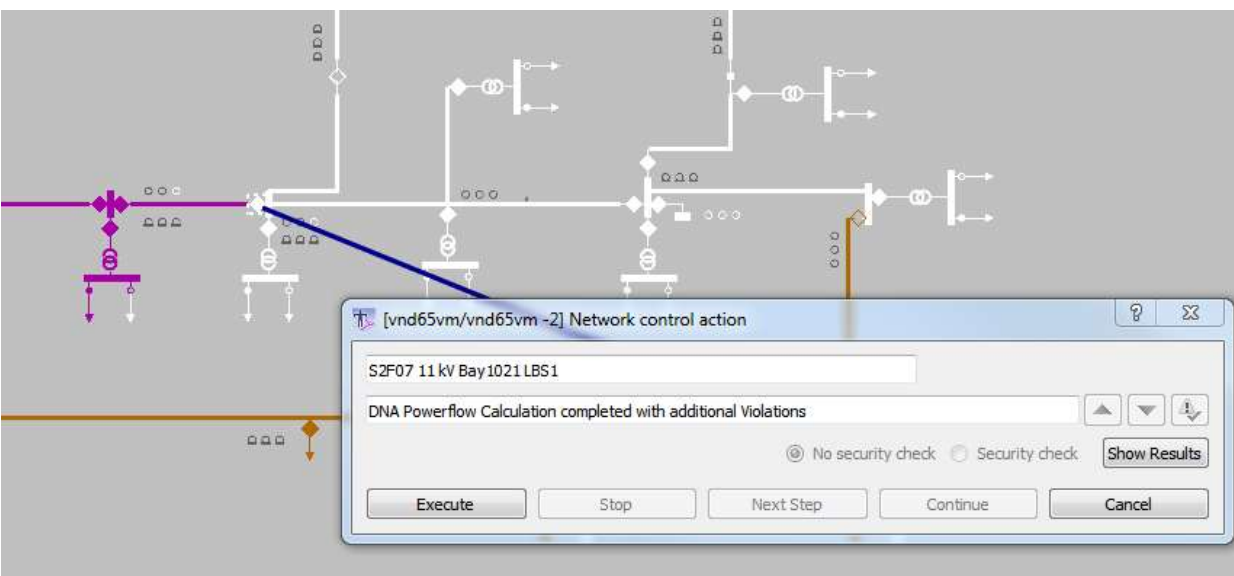


Busbar violations											
Line violations											
Name	Phase	Violation type	I from [A]			Limit [A]			Violation [%]		
			A	B	C	A	B	C	A	B	C
/F6_US_S3/13.8kV162 ABC	ABC	Long	247,69	197,93	237,58	240,00	0,00	0,00	3,20	0,00	0,00
/F6_US_S3/13.8kV163 ABC	ABC	Long	226,37	265,49	250,48	0,00	240,00	240,00	0,00	10,62	4,37
/F6_US_S3/13.8kV180 ABC	ABC	Long	301,91	293,67	342,10	240,00	240,00	240,00	25,80	22,36	42,54
/F6_US_S3/13.8kV182 ABC	ABC	Long	269,61	262,16	256,84	240,00	240,00	240,00	12,34	9,23	7,02
/F7_US_S3/13.8kV0 ABC	ABC	Short	563,28	593,47	623,22	504,00	504,00	504,00	11,78	17,75	23,65

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Security Checked Switching

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- DSPF simulates target state and checks whether target state would cause a more critical situation (additional, changed or worsened violations)
- Based on the power flow findings the user decides can decide to either continue or cancel the operation
- Relaxation can be configured in the DNA WebUI to suppress warning messages for changes that can be considered insignificant

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Short Term Load Scheduler (STLS)

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STLS maintains **load schedules** that provide the load data **for power flow calculations**

Input Data

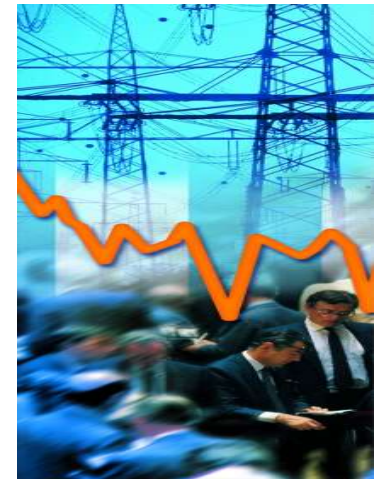
- Initial nominal loads and typified static load curves.
- Loads can be defined as constant Power or Current or Impedance
- Conforming loads (load curve follow a date/time depending pattern) and non-conforming loads
- Reactive load based on $\cos \varphi$
- Results of the Distribution System State Estimator

Processing

STLS recursively calculates a short term load schedule while adapting values of the past to new estimated load values. The degree of adaption can be influenced by a smoothing factor. Initial load schedule is either the scaled load curve or the nominal load.

Results

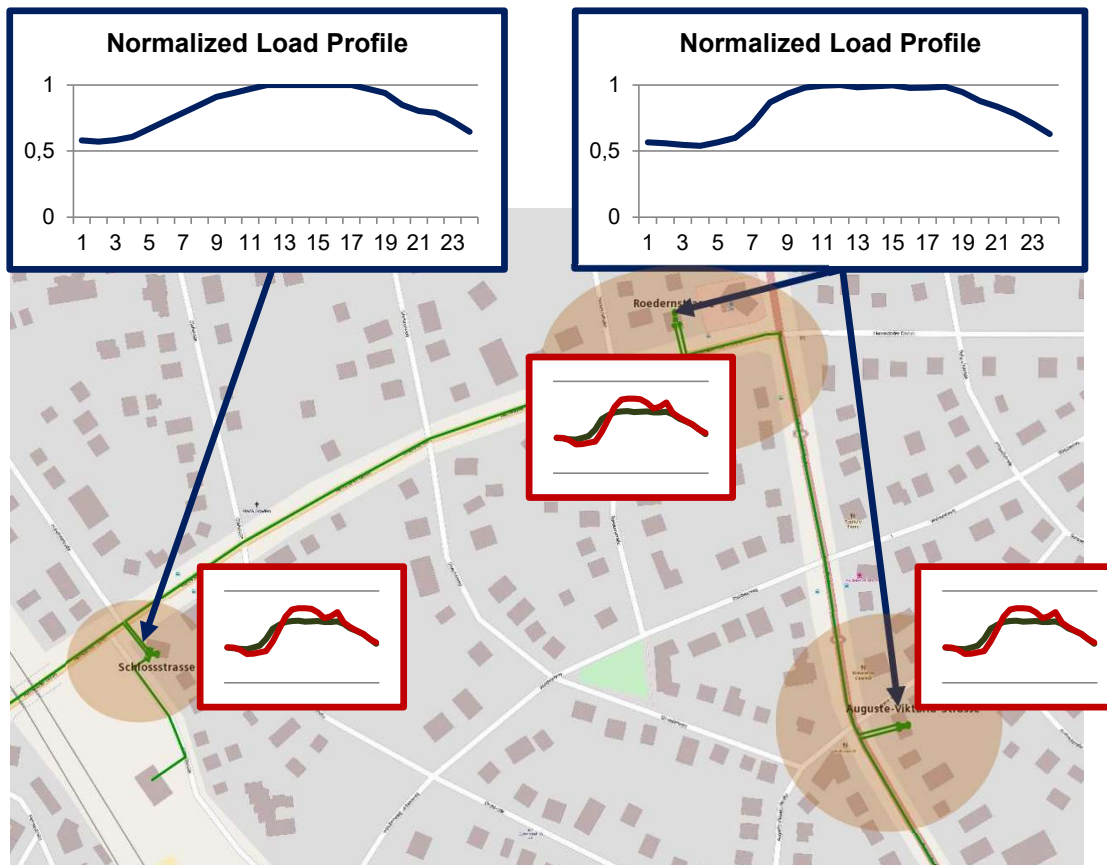
Load schedules for one week in a 15 minutes interval



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Processing of conforming loads based on load profiles

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Load profiles for conforming loads (load curve depends on day and time)

- Normalized profile for 24 hours
- Different profiles for various day types (weekday, holiday, etc.)
- Typified or instance specific profiles
- Static load profiles configured via IMM

**Load scheduling:
Load scaling and load adaptation**

Load curves for individual loads or load groups according to the model

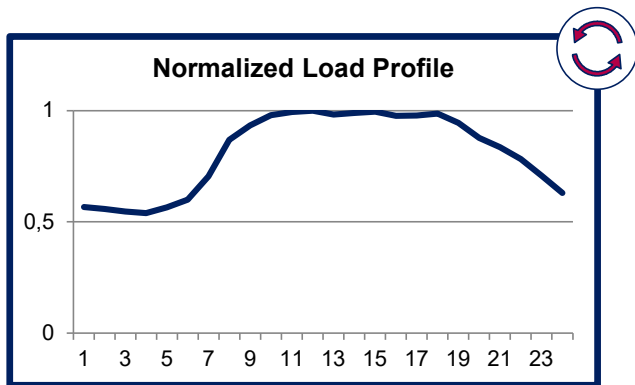
**State Estimation & Power Flow
use scheduled load**

Network Monitoring, Case Studies
and further Distribution Network Optimization

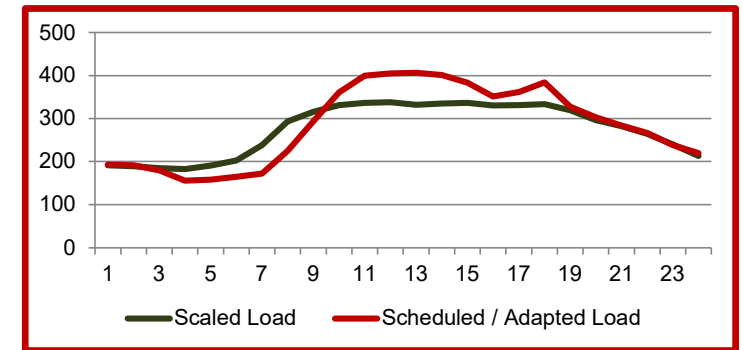
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Load Scheduling based on static load profiles

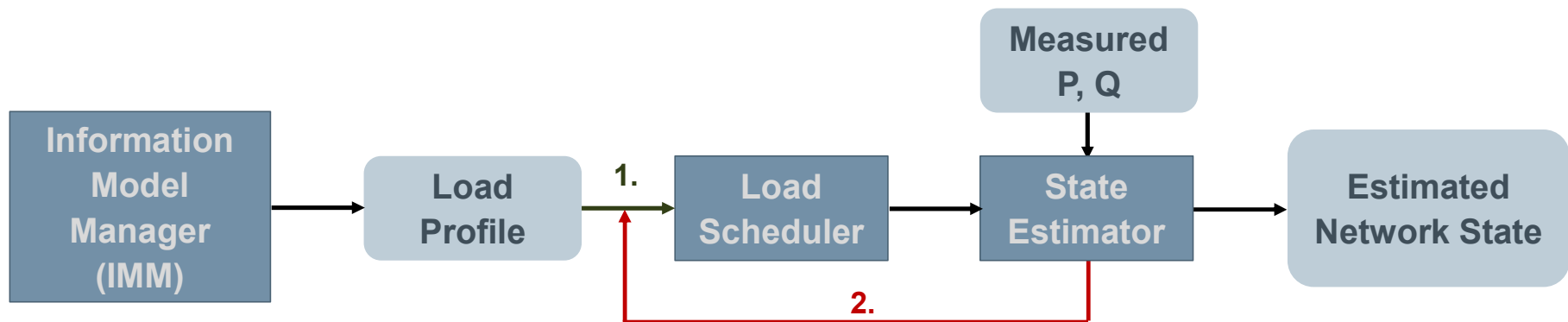
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1. Scaling of loads based on normalized load profile and nominal load
2. Adaptation of loads according to measured and estimated values



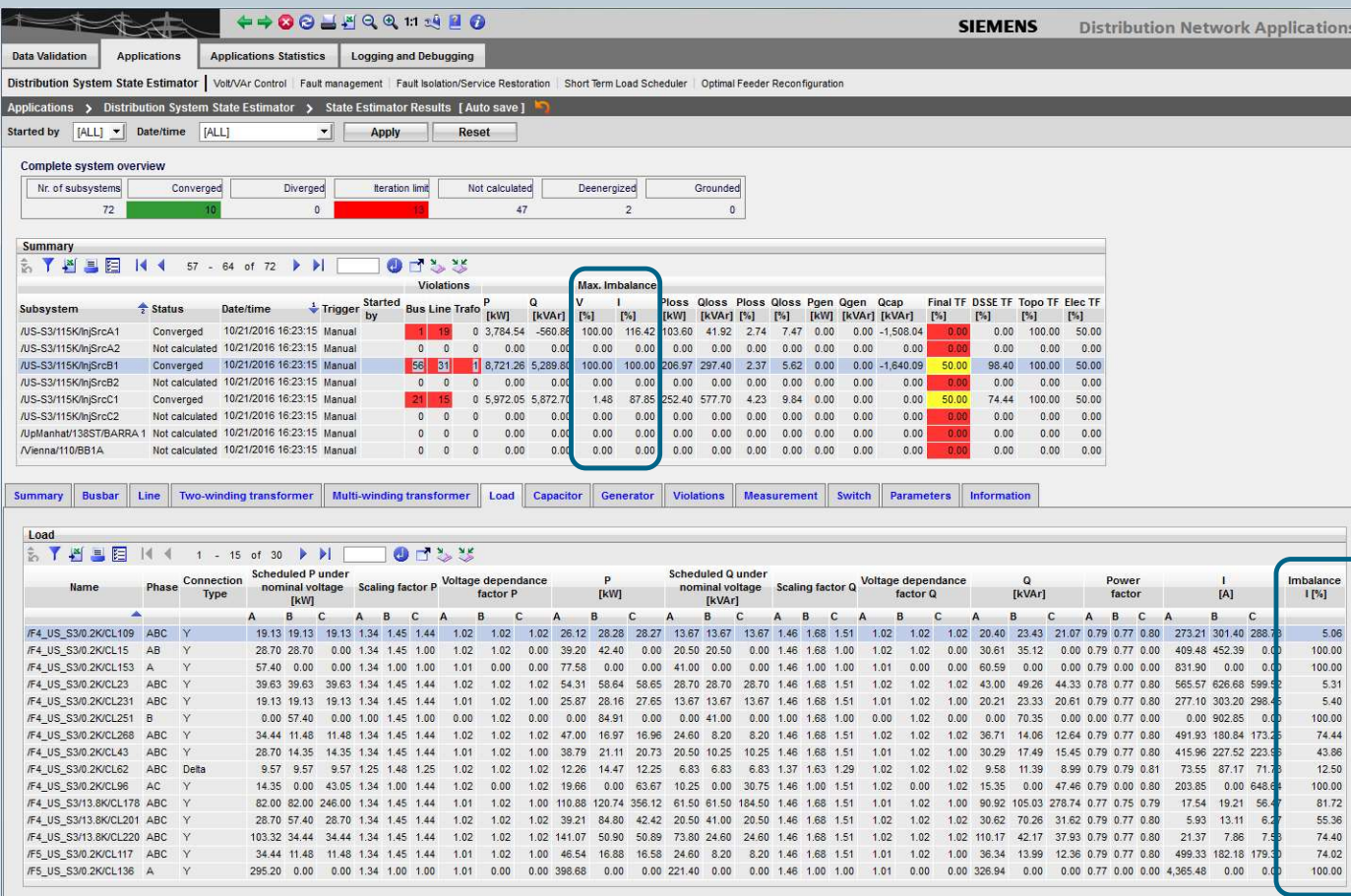
Scheduled load after a learning phase of several weeks



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Phase Imbalance Calculation in unbalanced systems

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Even small voltage imbalances inside an unbalanced operated network can lead to high current imbalances and high currents which can be devastating for electrical equipment like motors, compressors, or other inductive devices.

The consequences of current imbalance are high wire temperatures, shorter life of equipment, shutdowns, or even burn outs.

Imbalance factors are calculated according to the IEEE definitions

- Voltage imbalance factor is calculated for each busbar
- Current imbalance factor is calculated for lines, transformers, loads, and generators.
- The summary shows the highest voltage and current imbalance seen in the respective subsystem

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Spectrum Power™ 7 – Distribution Network Applications Optimal Volt/Var Control (VVC)

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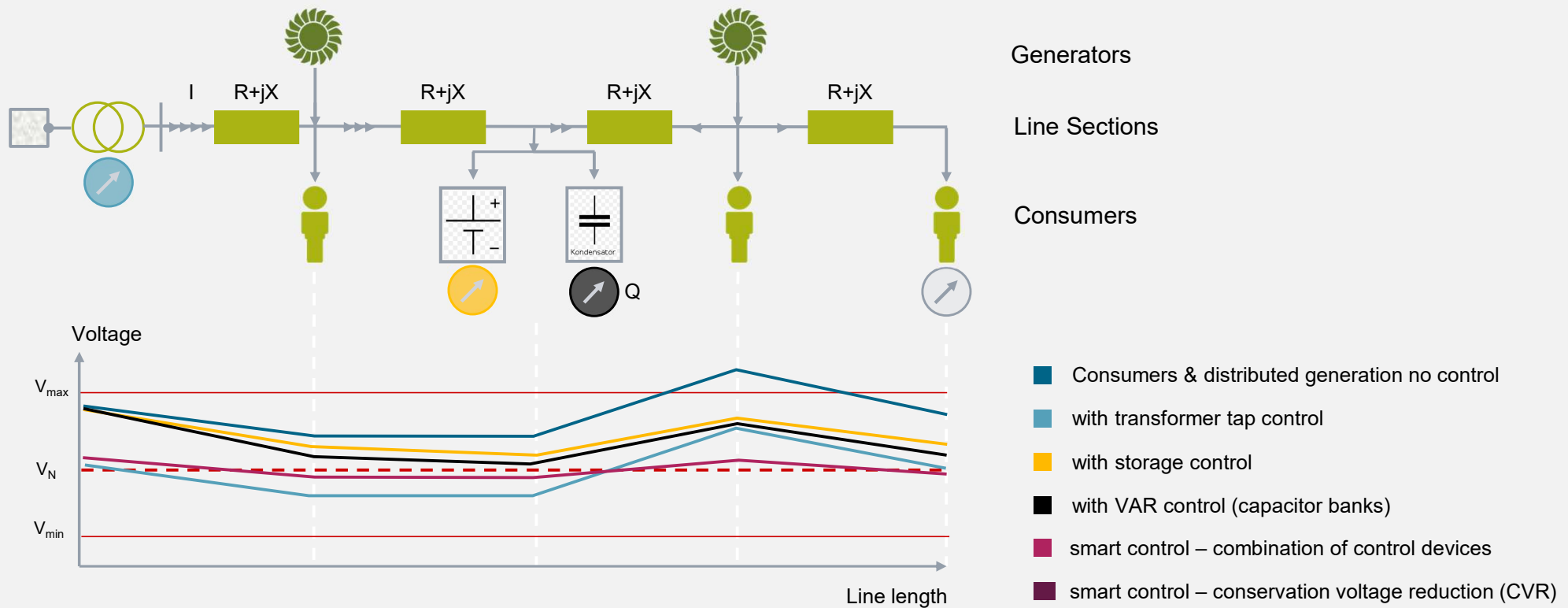


- The VVC application provides distribution network optimization, typically loss minimization, using **voltage, var and watt controls** like Load Tap Changers/Line Voltage Regulators and Regulating Capacitors as well as Batteries
- This optimization consists in minimizing an objective function that is user selectable as one of the following objectives:
 - **Minimize violations**
 - **Minimize active power consumption / CVR**
 - **Minimize reactive power consumption**
 - **Minimize power losses**
 - **Maximize voltage reserve**
- The optimization is subject to the network constraints, i.e. the load flow equations and the operational like. voltage, transformer, etc. limits
- VVC is executed periodically and upon events in the real-time context and on user request in the study context.
- All proposed switching actions can be reviewed and forwarded to SPM for implementation

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Smart voltage control and conservation voltage reduction

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VVC Use Case “Voltage stabilization”

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DSSE detects violations

- Network is monitored continuously by DSSE
- Voltage violations are indicated in single line diagram and reported as alarm

Run VVC

- VVC manual start: User selects violated equipment, defines objective and other settings and starts VVC
- VVC automatic start - DSSE violations trigger VVC with preconfigured settings
- VVC proposes switching actions for volt / var controls to improve the voltage profile

Forward solution to SPM and execute

- User may review the proposed changes/optimization
- The switching actions are forwarded as switching procedure to SPM (Switching Procedure Management)
- The switching actions are executed via SPM

The screenshot displays the Spectrum Power 7 software interface with several key panels:

- Subnetwork information:** A table showing initial and final values for various metrics.

	Initial	Final
Busbar violations high	0.00	0.00
Busbar violations low	3.93	0.75
Power factor deviation	0.07	0.06
Transformer violations	0.00	0.00
Line violations	0.00	0.00
Power losses [kW]	590.00	578.16
Injected P [kW]	16,588.77	16,577.68
Injected Q [kVar]	5,645.27	4,816.85
Injected S [kVA]	17,523.03	17,263.30
Revenue [m.u./h]	264,704.09	264,741.06
Operational costs [m.u./h]	15,308.81	13,809.73
- Violation information:** A table showing the number of violations, worst violation type, and worst violation percentage.

	Number of violations	Worst violation type	Worst violation [%]
Busbar violations high	0	none	0.00
Busbar violations low	17	Long	4.22
Power factor deviation	2	Short	29.55
Transformer violations	0	none	0.00
Line violations	0	none	0.00
- Objective summary:** A table showing initial and final values for various objectives.

	Initial	Final
Total objective	0.00	0.00
Total objective	60.00	36.96
Total objective	60.00	36.96
Reactive power consumption	20.00	17.07
Reactive power consumption	0.00	0.00
Reactive power consumption	20.00	17.07
Busbar violations high sub-objective	0.00	0.00
Busbar violations high sub-objective	0.00	0.00
Busbar violations low sub-objective	20.00	3.82
Busbar violations low sub-objective	20.00	3.82
- Switching procedure:** A table showing the controlled item, type, action, value, unit, and effect percentage.

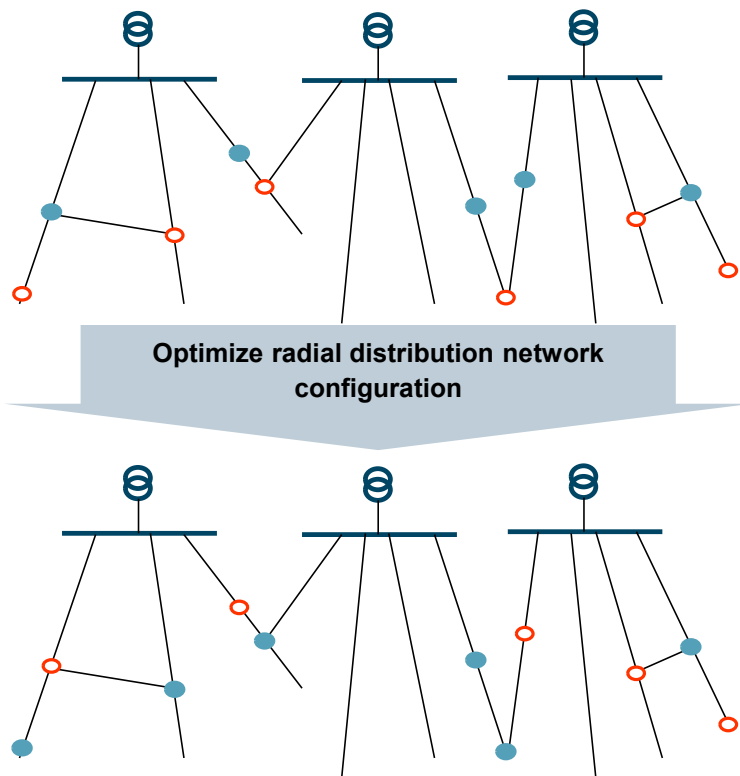
Entry	Resource	Controlled Item	Type	Action	Value	Unit	Effect [%]
1	/NetworkCompanies/World/EU_S1_v2/EU-D2/T1_33_11/WindingH/Tap_H	/EU-D2/33 kV/TR94/Tap Chan	Tap changer	Up	11.0000	seconds	22.95
2			Ramp-up	Set value	11.0000	seconds	0.00
3	/D2F01/11 kV/Cap29	/D2F01/11 kV/Bay57/CB	Switch	On	2.0000	seconds	25.39
4			Ramp-up	Set value	1.0000	seconds	0.00
5	/D2F01/11 kV/Cap18	/D2F01/11 kV/Bay13/CB	Switch	On	2.0000	seconds	21.23
6			Ramp-up	Set value	1.0000	seconds	0.00
7	/D2F01/11 kV/Cap15	/D2F01/11 kV/Bay228/CB	Switch	On	2.0000	seconds	18.62

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Optimal Feeder Reconfiguration - OFR

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OFR determines the optimal radial distribution network configuration, means the specification of the normally open switches, accounting for equipment loading limits, voltage limit, and feeder losses. The user may select any combination of the following individual objectives:

- **Minimize violations**
- **Minimize active power losses on feeders**
- **Load balancing among supply substation transformers**

Spectrum Power DNA

OFR – Use Case “Reduce violations”

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DSSE detects violations

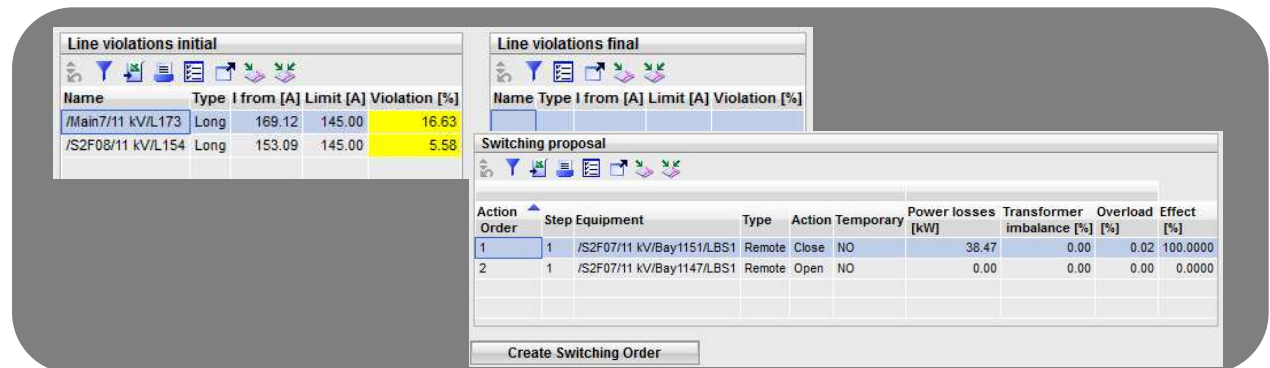
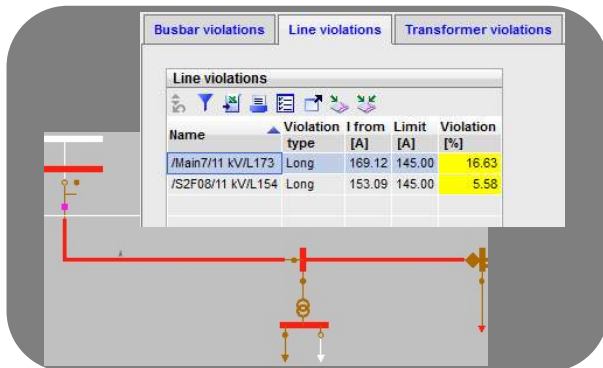
- Network is monitored continuously by DSSE
- Violations are indicated in single line diagram and reported as alarm

Run OFR

- Manual start:
- User selects violated part, defines objective and other settings and starts OFR
- Automatic start
- DSSE violations trigger OFR. OFR runs with preconfigured settings

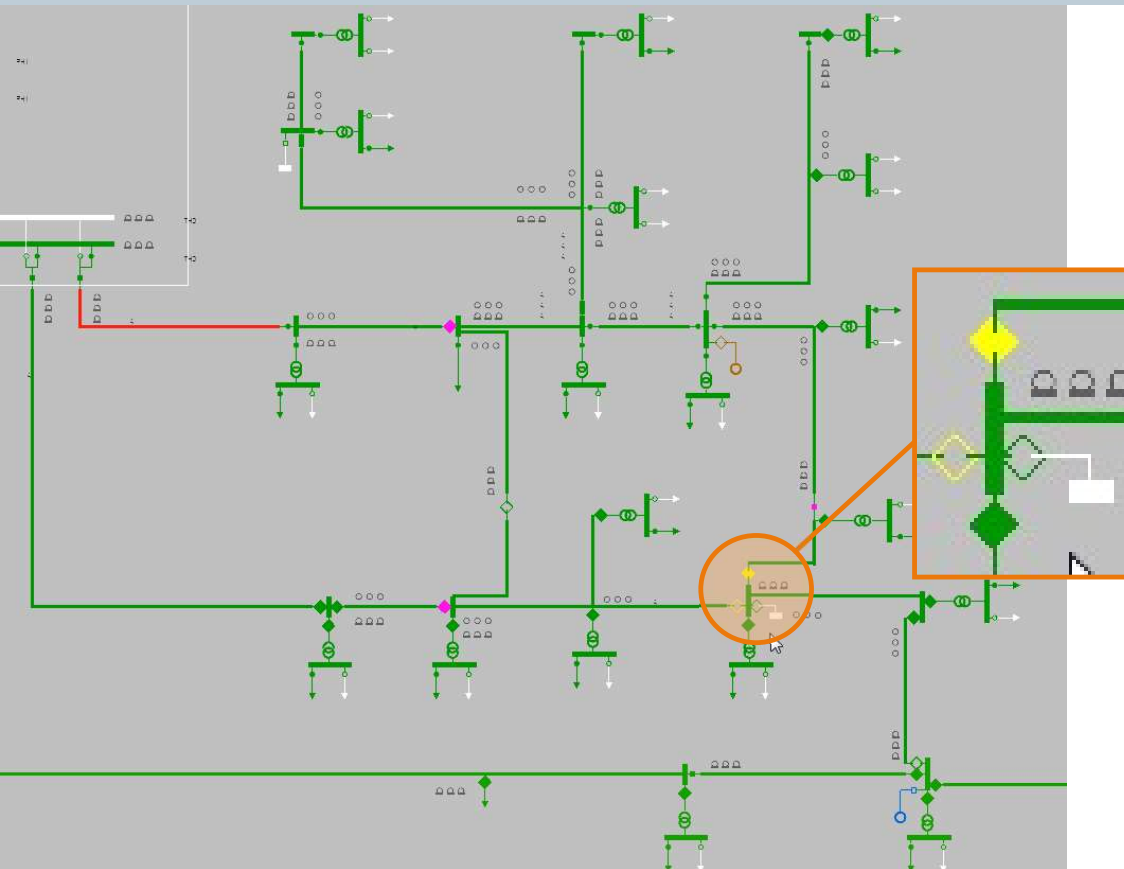
Forward solution to SPM and execute

- OFR proposes switching actions to reconfigure feeder
- User may review the proposed changes/optimization
- The switching actions are forwarded as switching procedure to SPM (Switching Procedure Management)
- The switching actions are executed with SPM



Spectrum Power DNA OFR Example - Scenario

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Summary											
Subsystem	Status	Date/time	Trigger	Started by	Violations		P [kW]	Q [kVar]	Ploss [kW]	Qloss [kVar]	Ploss [%]
					Bus	Line					
/EU-S2/110 kV/IB110_2B	Converged	06/22/2017 14:34:03	Manual	spectrum	0	1	11,259.94	6,431.25	560.12	1,131.33	4.97
/EU-S2/110 kV/IB110_1A	Converged	06/22/2017 14:30:09	Manual	spectrum	0	0	13,366.48	9,457.11	926.59	2,477.39	6.93

Line violations				
Name	Violation type	I from [A]	Limit [A]	Violation [%]
/Main7/11 kV/L173	Long	306.82	290.00	5.80

- DSSE results show violations, including one line overload
- Violated equipments are highlighted in the network diagram

Spectrum Power DNA OFR Example – OFR results

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Applications > Optimal Feeder Reconfiguration > Optimal Feeder Reconfiguration Results

Started by [ALL] Session [ALL] Apply Reset

Summary

Session Number	Subsystem	Status	Date/time	Simulated time	Trigger	Started by	Minimize violations	Minimize power losses	Minimize transformer imbalance	Used switches	Scope of execution	Improvement [%]	Switching order number	Trust factor [%]
3	/EU-S2/110 kV/IB110_2B	Optimal solution found	06/22/2017 14:34:49	06/22/2017 14:34:49	Manual	spectrum	<input checked="" type="checkbox"/>			All	Selected subsystem only	100.00	0	68.75
2	/EU-S2/110 kV/IB110_2B	Optimal solution found	06/22/2017 14:31:47	06/22/2017 14:31:47	Manual	spectrum	<input checked="" type="checkbox"/>			All	Selected subsystem only	100.00	0	68.75
1	/EU-S2/110 kV/IB110_2B	Optimal solution found	06/21/2017 15:37:28	06/21/2017 15:37:28	Manual	spectrum	<input checked="" type="checkbox"/>			All	Selected subsystem only	68.37	0	68.75

Output Violations Initially opened switches Affected injection sources Parameters Information

Objective summary

	Initial	Final
Total objective	100.00	0.00
Overload [%]	0.00	0.00

Objective not chosen

	Initial	Final
Power losses [kW]	560.12	428.73
Transformer imbalance [%]	0.00	0.00

Switching proposal

Action Order	Step	Equipment	Type	Action	Temporary	Power losses [kW]	Transformer imbalance [%]	Overload [%]	Effect [%]
1	1	/S2F07/11 kV/Bay1151/LBS1	Remote	Close	NO	131.40	0.00	0.00	100.0000
2	1	/S2F07/11 kV/Bay1147/LBS1	Remote	Open	NO	0.00	0.00	0.00	0.0000

Create Switching Order

Output Violations Initially opened switches Affected injection sources Parameters Information

Violations summary initial

Violation type	Number of violations	Violation index
Line overload	1	0.00
Transformer overload	0	0.00

Violations summary final

Violation type	Number of violations	Violation index
Line overload	0	0.00
Transformer overload	0	0.00

Line violations initial

Name	Type	I from [A]	Limit [A]	Violation [%]
/Main7/11 kV/L173	Long	306.82	290.00	5.80

Line violations final

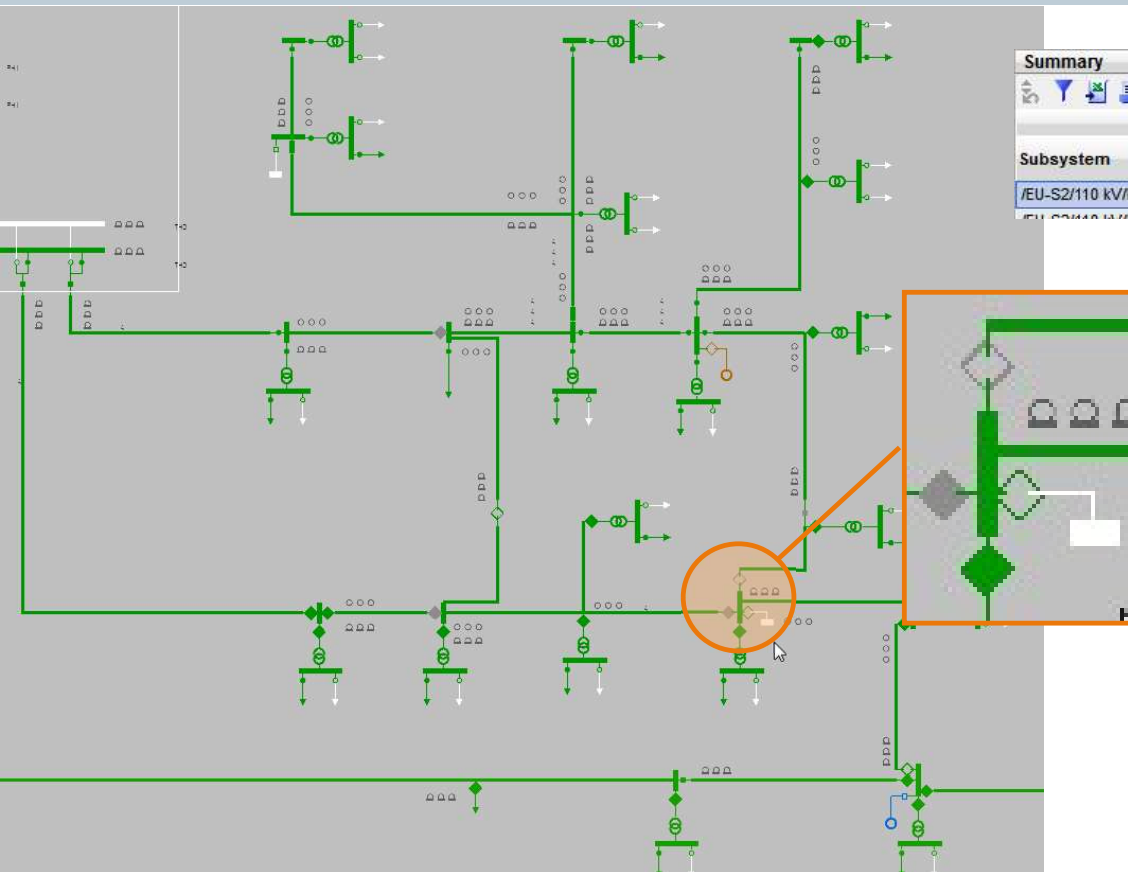
Name	Type	I from [A]	Limit [A]	Violation [%]

- OFR generates a switching proposal for optimized feeder configuration
- OFR lists violations before and after optimization

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OFR Example – State estimation after OFR proposal is executed

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Summary												
Violations												
Subsystem	Status	Date/time	Trigger	Started by	Bus	Line	Trafo	P [kW]	Q [kVAr]	Ploss [kW]	Qloss [kVAr]	Ploss [%]
/EU-S2/110 kV/IB110_2B	Converged	06/22/2017 14:35:44	Manual	spectrum	0	0	0	11,128.58	6,273.14	428.73	973.44	3.85

Line violations				
Name	Violation type	I from [A]	Limit [A]	Violation [%]

- DSSE results show that the line overload disappeared
- No remaining violations therefore nothing highlighted anymore in the network diagram

Spectrum Power™ 7 – Distribution Network Applications

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Spectrum Power™ 7 – Distribution Network Applications Summary

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Benefits for the Distribution Utilities from Distribution Network Analysis:

- **Improve the dispatchers' ability to observe the distribution grid** during normal, abnormal, and emergency conditions
- **Consistent management of** planned (maintenance) and unplanned (disturbance) **outages**
- **Improve quality of service and customer relations** by responding to service interruptions more rapidly
- **Reduce operating costs** by optimal use of field crews, improved power system efficiency and reduced technical losses