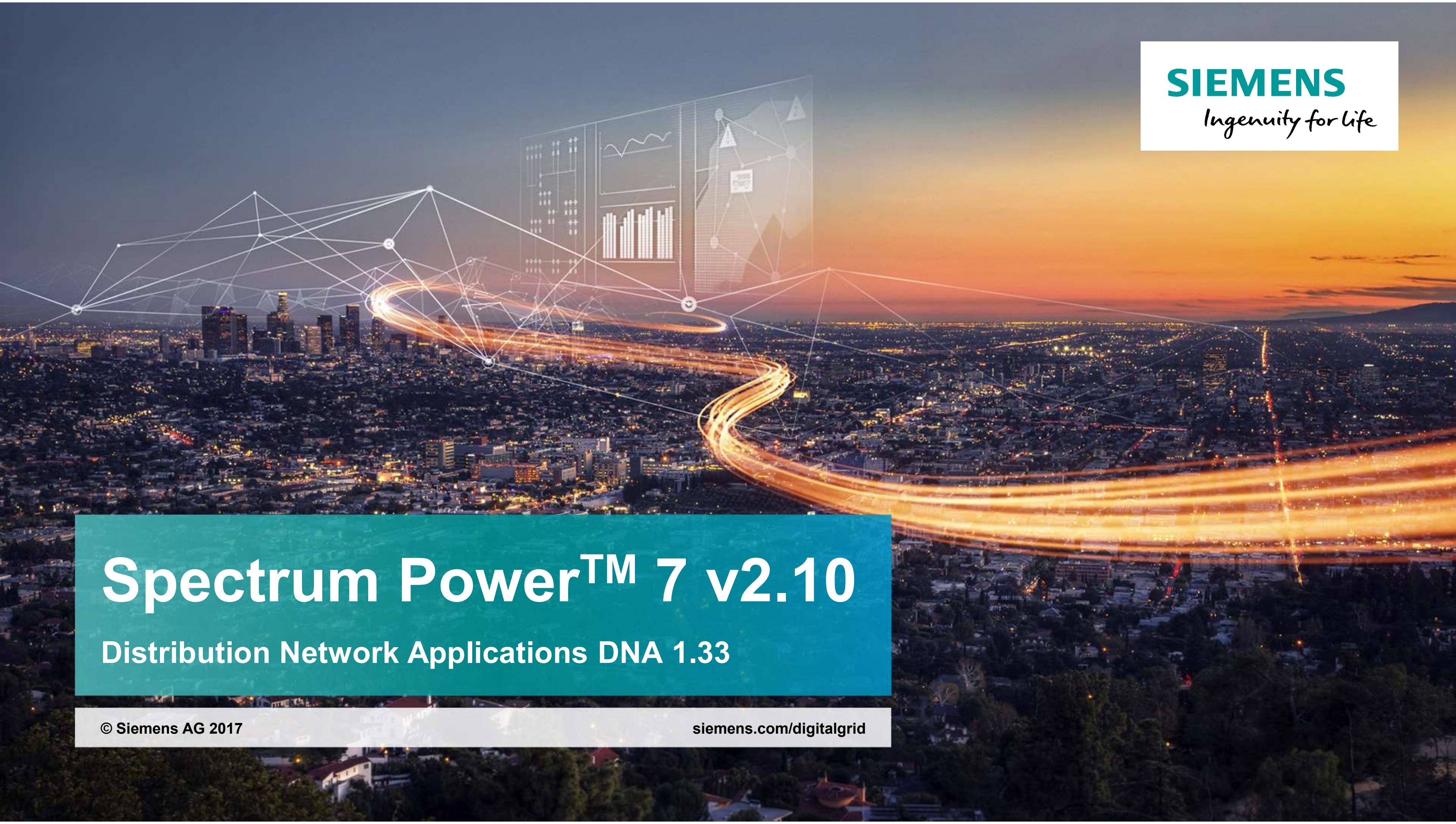

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Ingenuity for life

Spectrum Power™ 7 v2.10

Distribution Network Applications DNA 1.33

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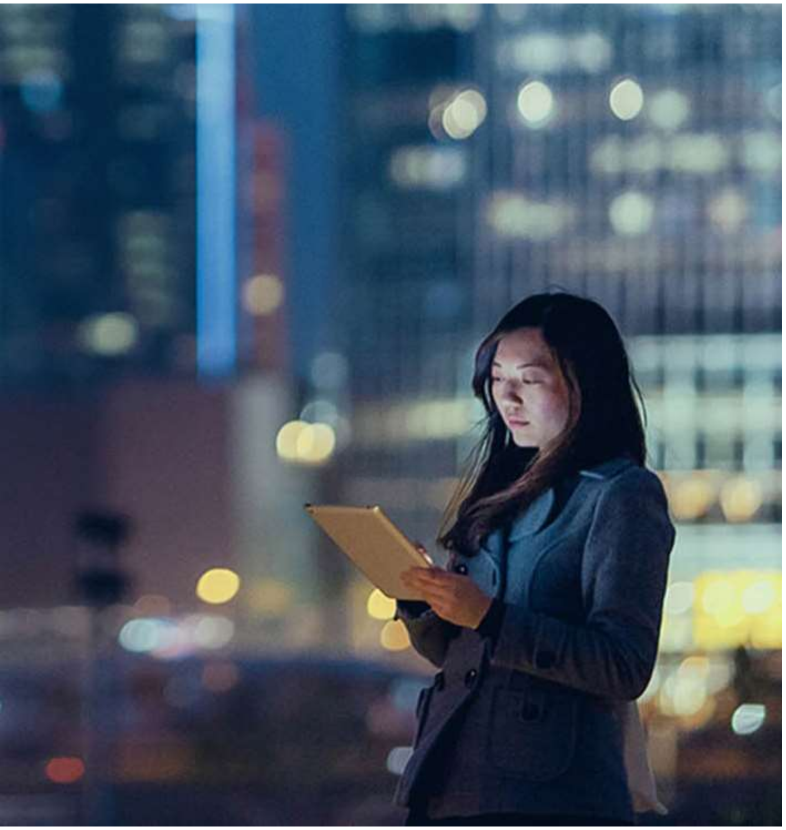

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What's new in v2.10?

- 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

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Spectrum Power^{TM} 7 – Distribution Network Applications
Definition

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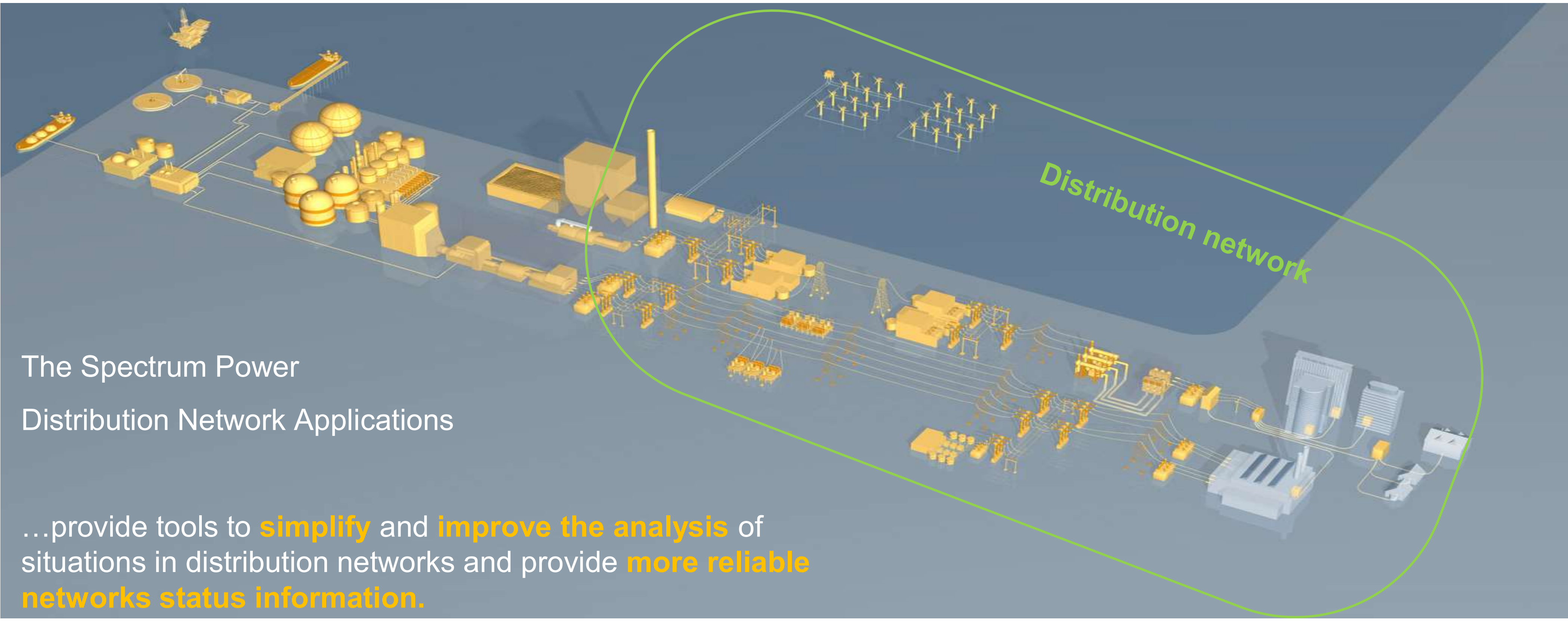

The Spectrum Power

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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Spectrum Power™ 7 – Distribution Network Applications
Motivation

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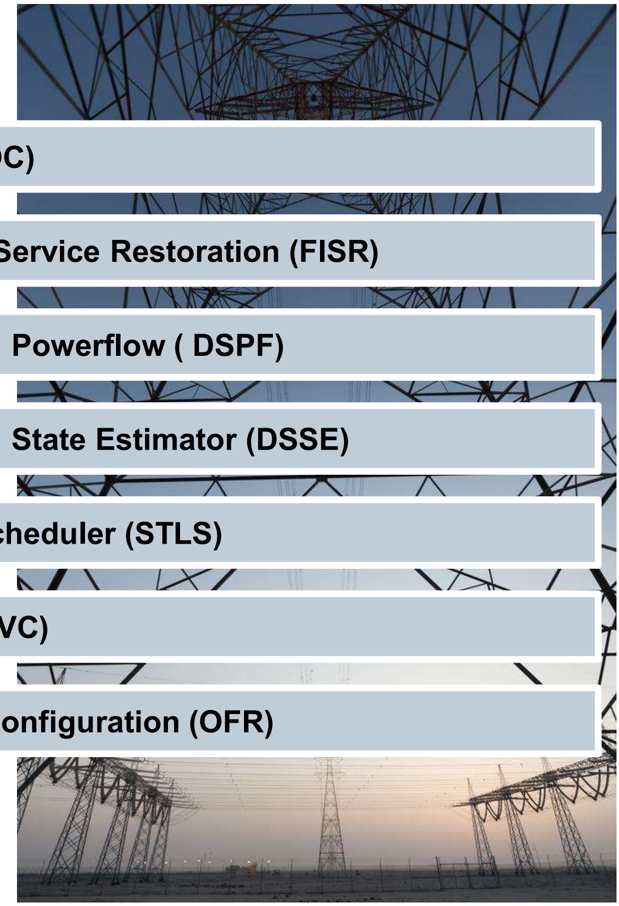
Distribution Network Analysis (DNA)

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)**

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Spectrum Power^{TM} 7 – Distribution Network Applications Functional Overview

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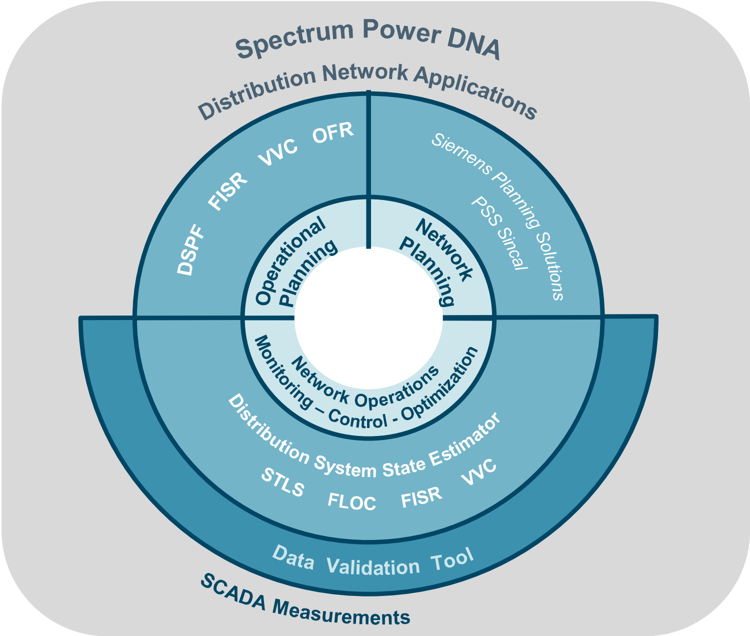
The Distribution Network Applications (DNA) provide Smart Grid tools for the

- **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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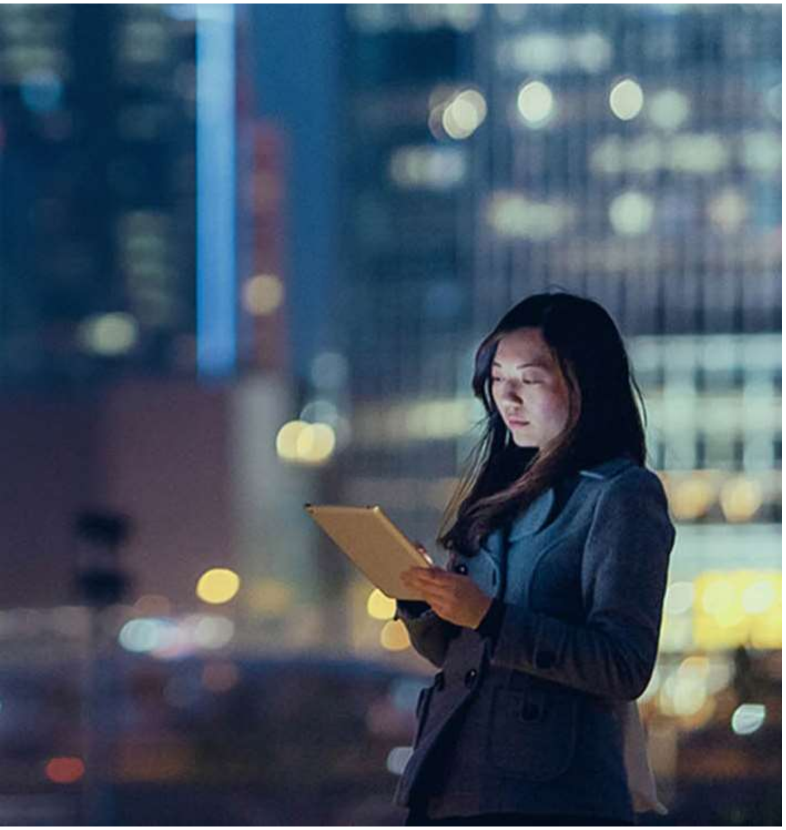

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Spectrum Power^{TM} 7 – Distribution Network Applications
Fault Location (FLOC)

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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**

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

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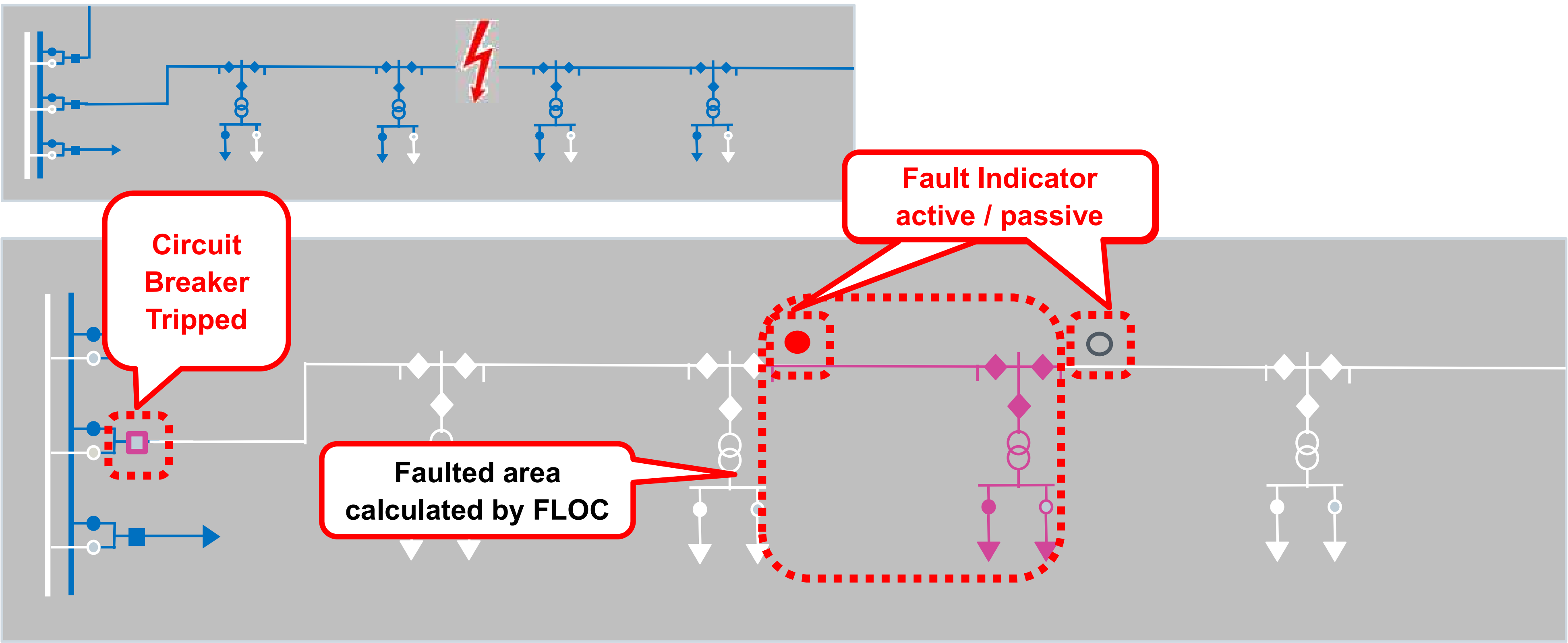

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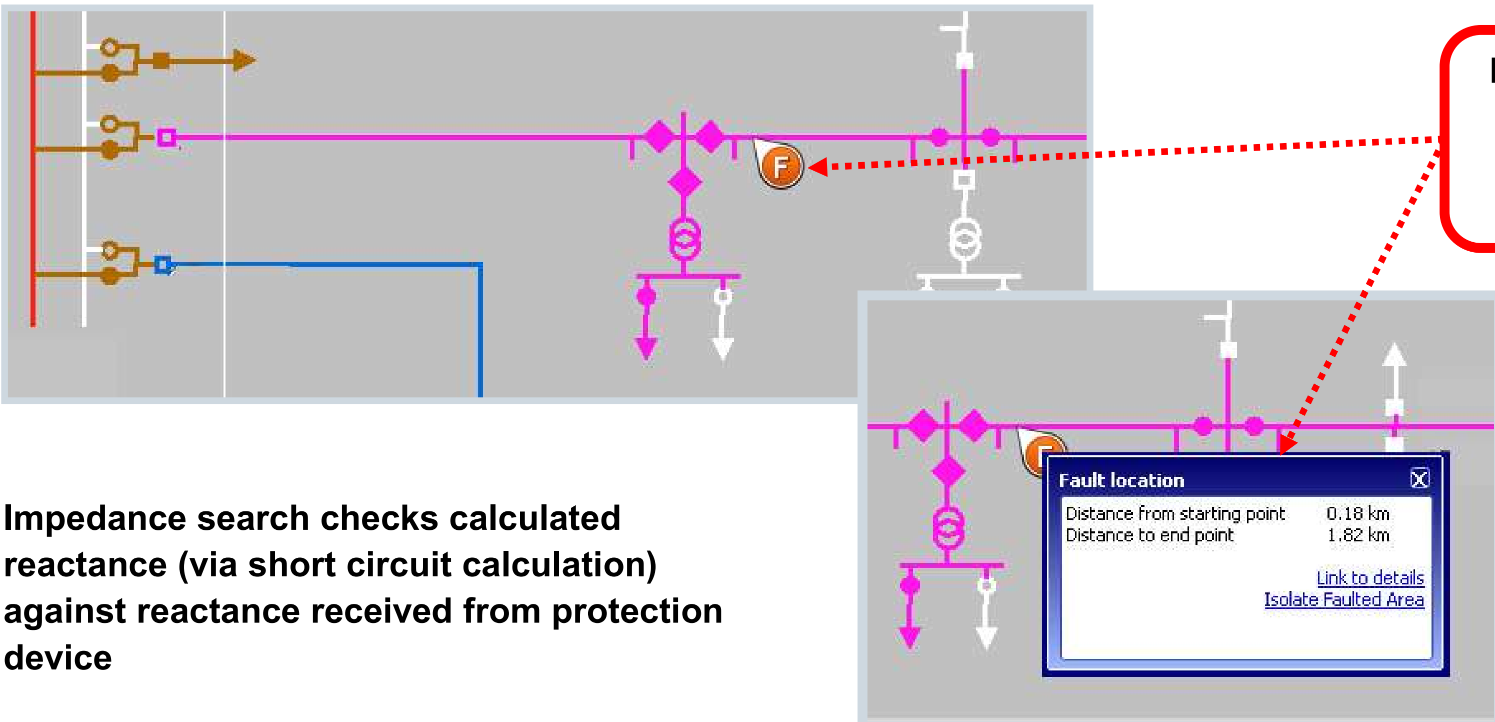
Fault Location with impedance search



Detailed Fault location with **impedance search** in addition to the colored potentiallly faulted area

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

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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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Spectrum Power™ 7 – Distribution Network Applications
Fault Management Workflow

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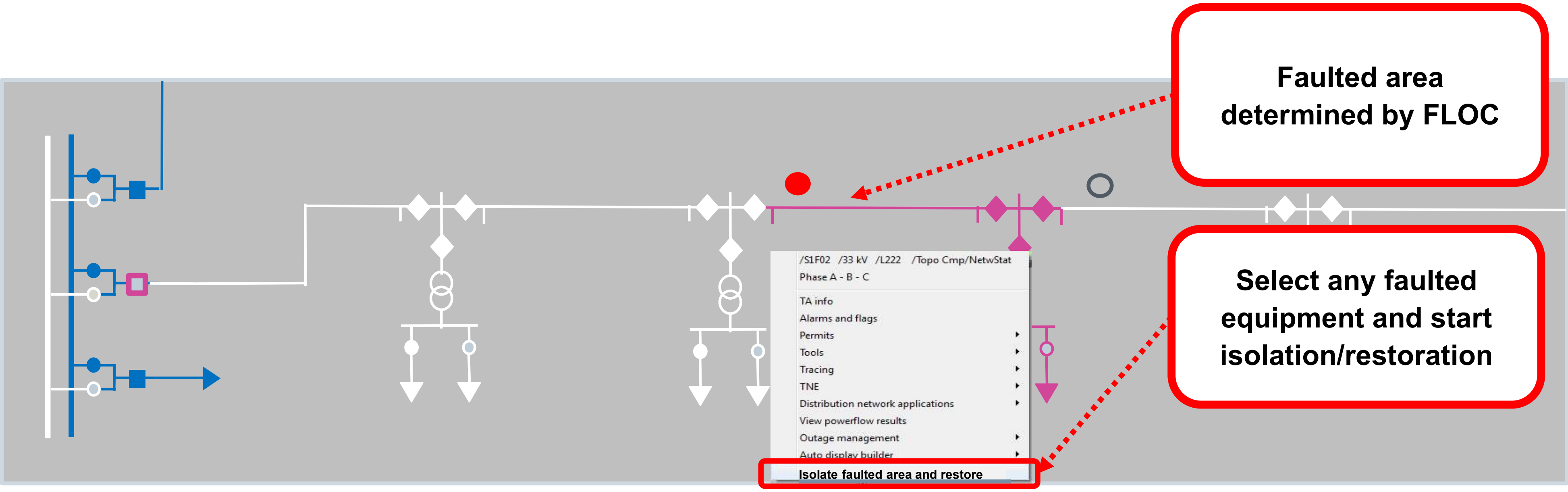

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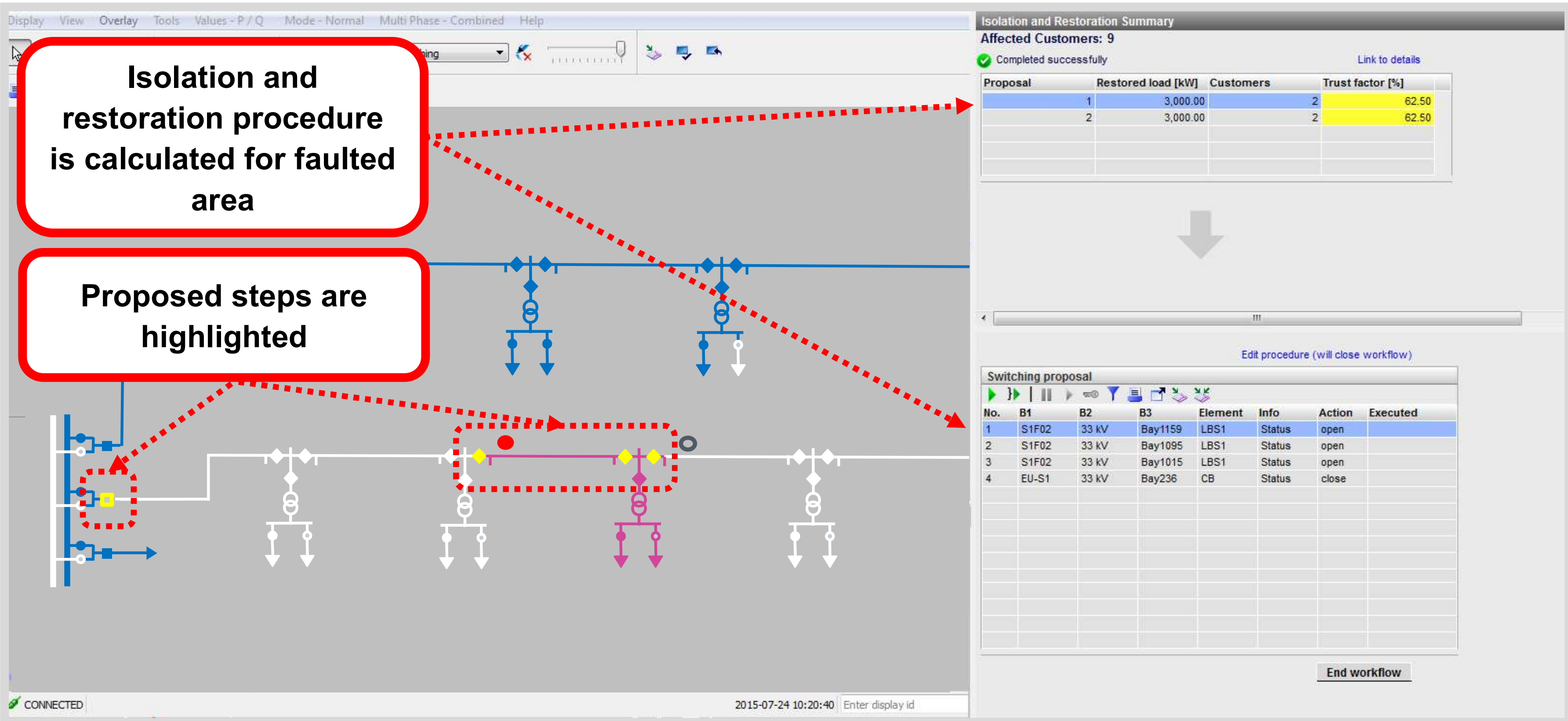
Spectrum Power^{TM} 7 – Distribution Network Applications
Fault Management Workflow



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Isolate equipment for planned outages utilizing FISR

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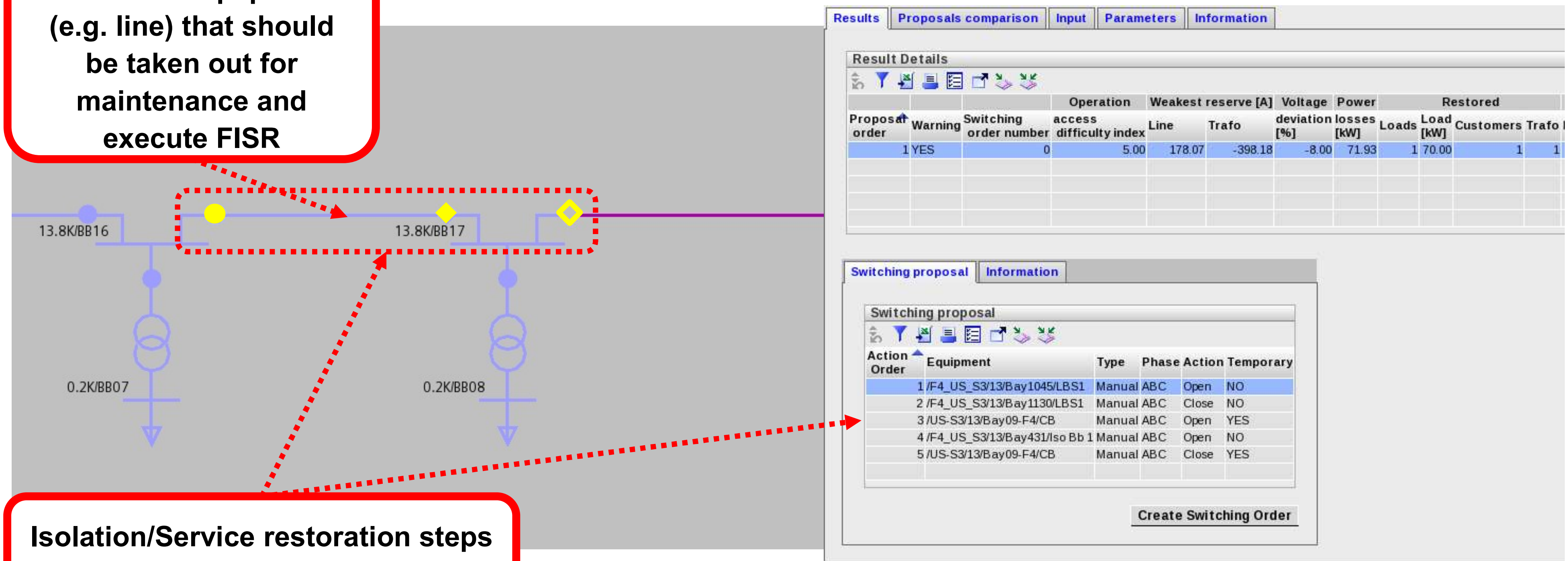
Select the equipment (e.g. line) that should be taken out for maintenance and execute FISR



Isolation/Service restoration steps are calculated and highlighted

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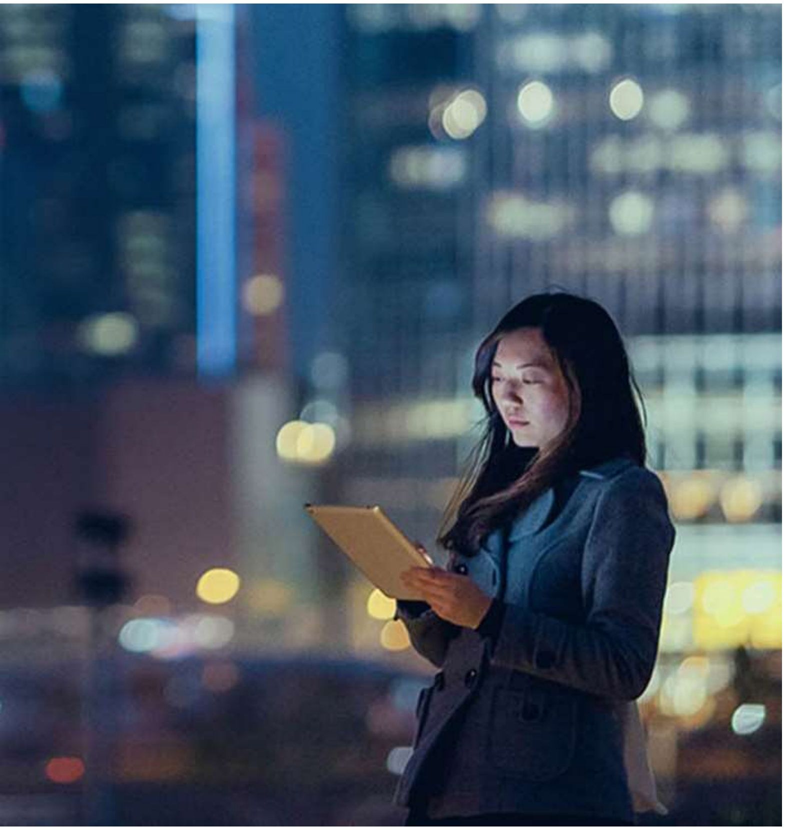

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Spectrum Power™ 7 – Distribution Network Applications
Distribution State Estimator (DSSE)

- 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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Spectrum Power^{TM} 7 – Distribution Network Applications
Improved Network Monitoring with State Estimation

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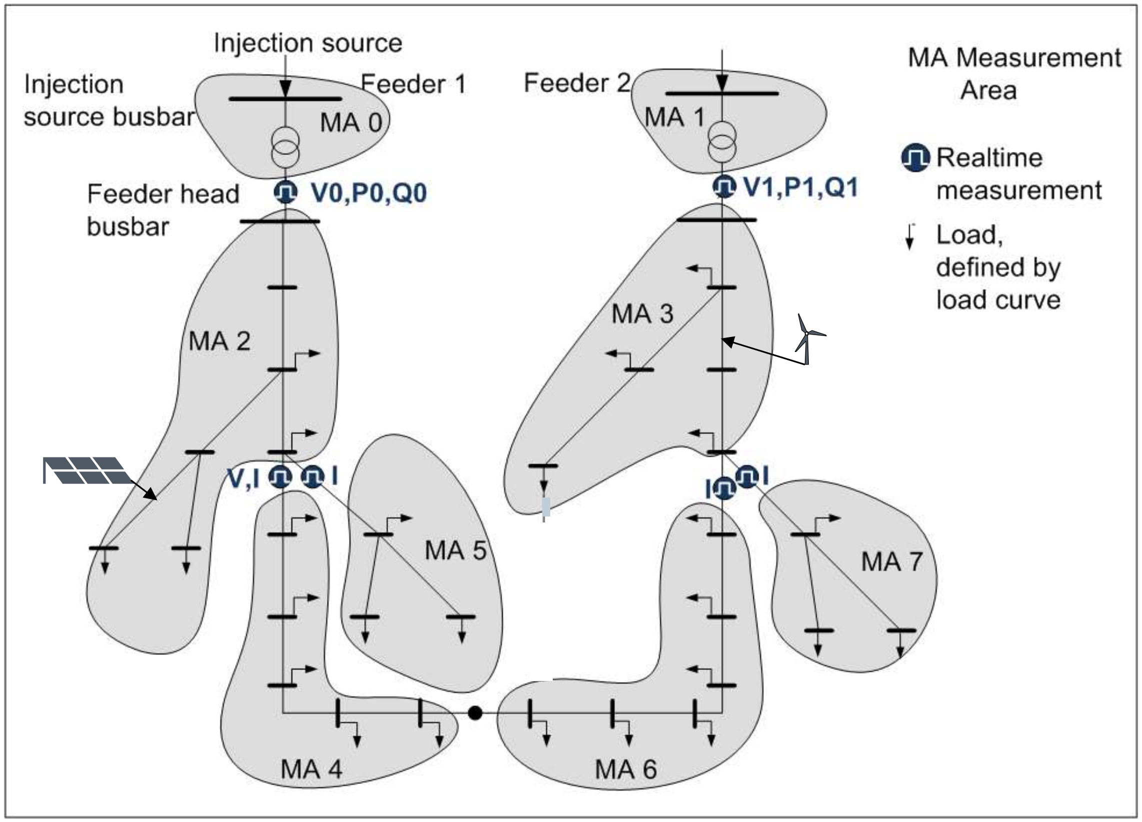
Input
- P, Q, I, V measurements at substations and a limited set of additional measurements along the feeders
- Load models

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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Spectrum Power™ 7 – Distribution Network Applications
DSSE Use Case "Network Monitoring"

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DSSE continuously calculates network

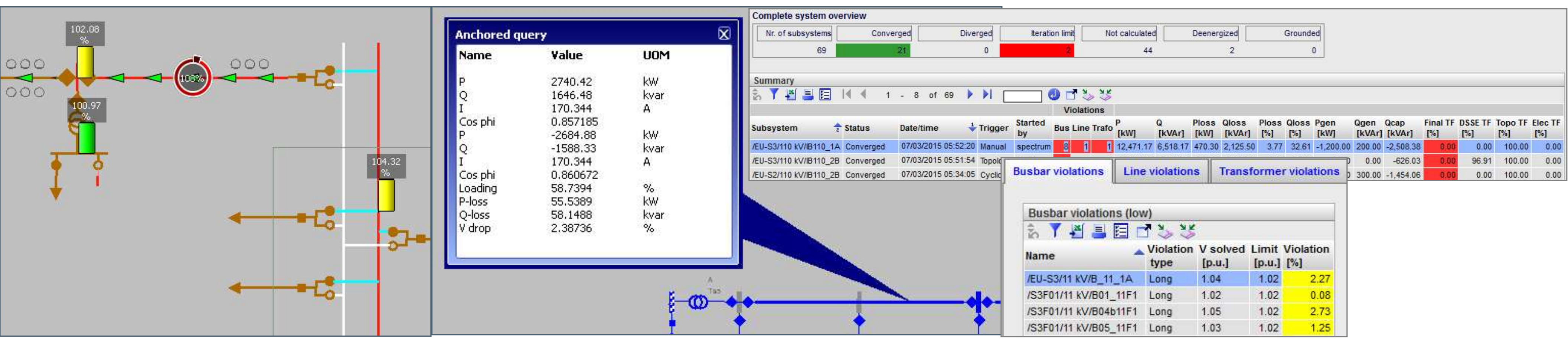
- DSSE runs cyclically / triggered by topology changes
- DSSE calculates voltages, active and reactive power, etc. based on available measurement and the load schedules

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 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



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Spectrum Power^{TM} 7 – Distribution Network Applications
Distribution System Power Flow (DSPF)




- 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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Spectrum Power™ 7 – Distribution Network Applications
DSPF Use Case "Validate Switching Procedure"

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Switching procedure is executed in a study

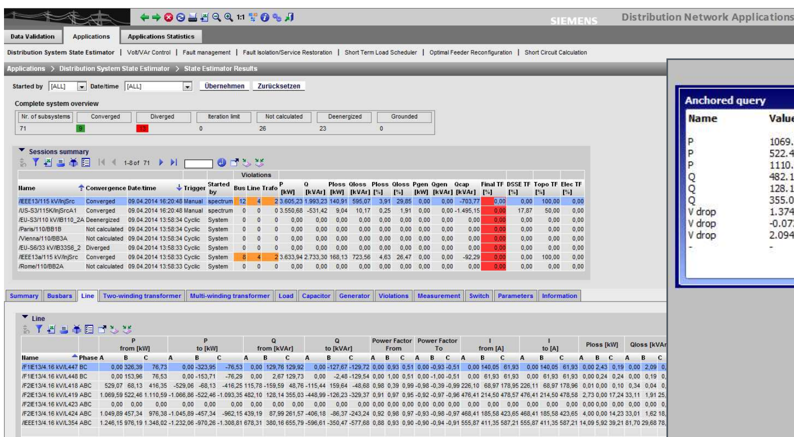
- A switching procedure is executed in a study, i.e. based on a save case
- DSPF runs on the resulting topology and calculates voltage, active and reactive power, etc.

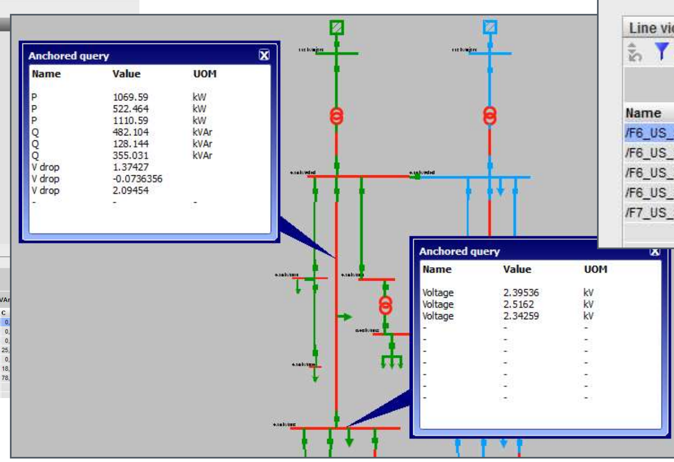
DSPF checks for violations

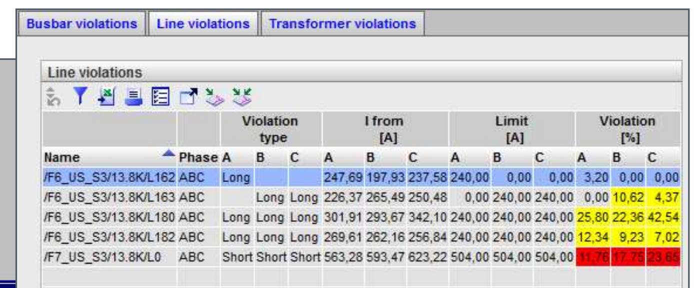
- DSPF checks for overloads and voltage limit violations
- Detected violations are reported in the violation list and the violated equipment are highlighted in the single line diagrams

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







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Spectrum Power™ 7 – Distribution Network Applications
Security Checked Switching

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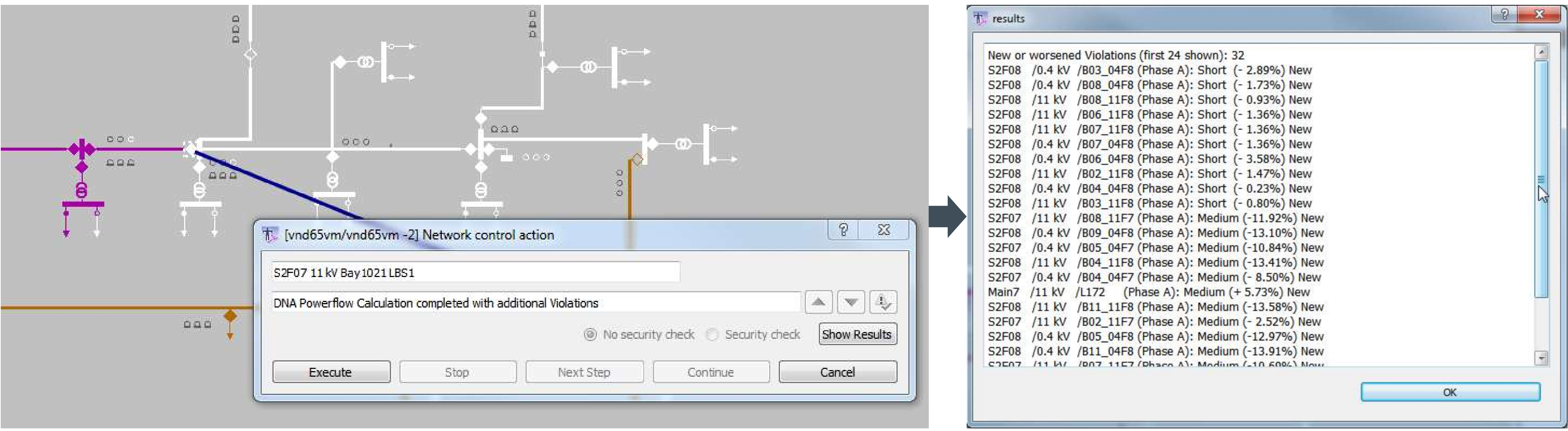

- DSPF simulates target state and checks whether target state would cause a more critical situation (additional, changed or worsened violations)
- Based on the power flow findings the user decides can decide to either continue or cancel the operation
- Relaxation can be configured in the DNA WebUI to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

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Short Term Load Scheduler (STLS)

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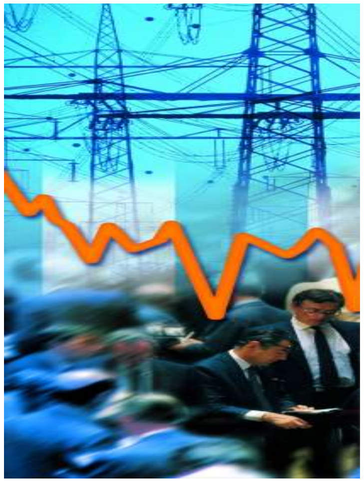
STLS maintains **load schedules** that provide the load data **for power flow calculations**



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 φ
- 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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Spectrum Power^{TM} 7 – Distribution Network Applications
Processing of conforming loads based on load profiles

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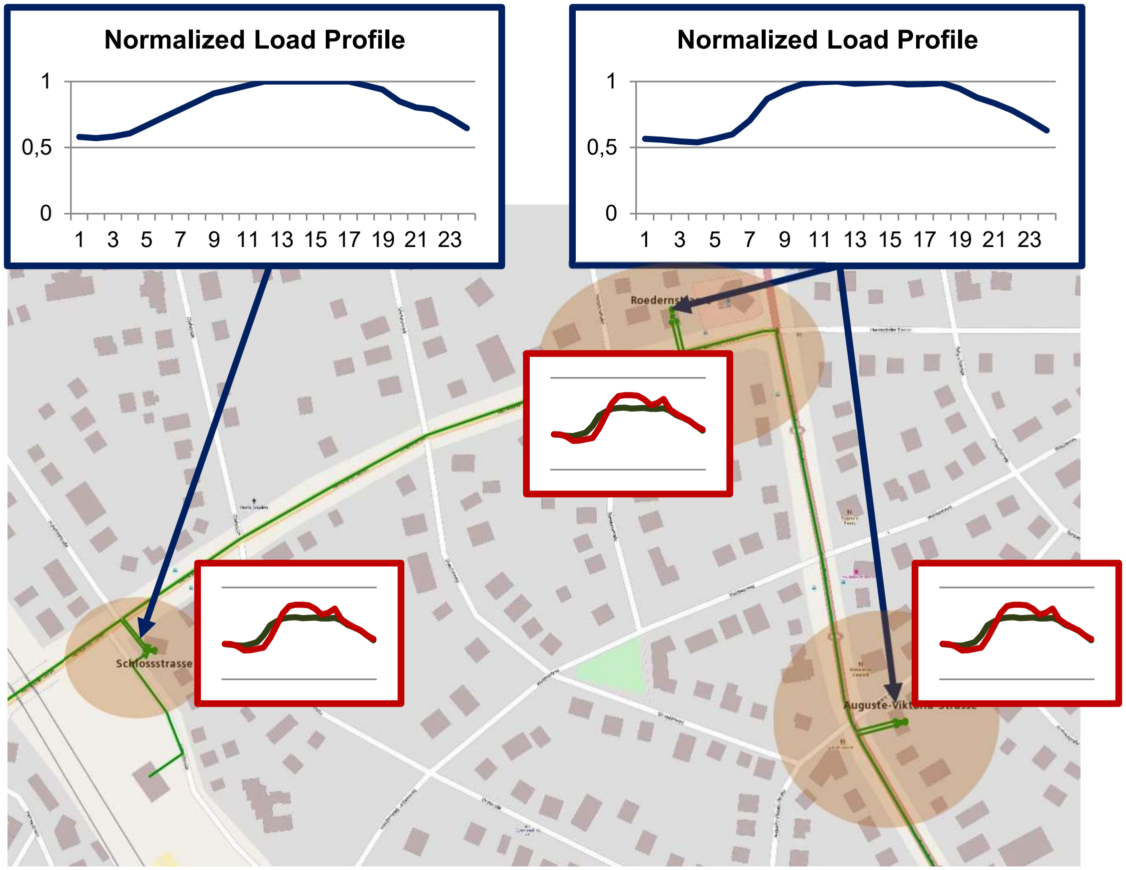

Load profiles for conforming loads (load curve depends on day and time)

- **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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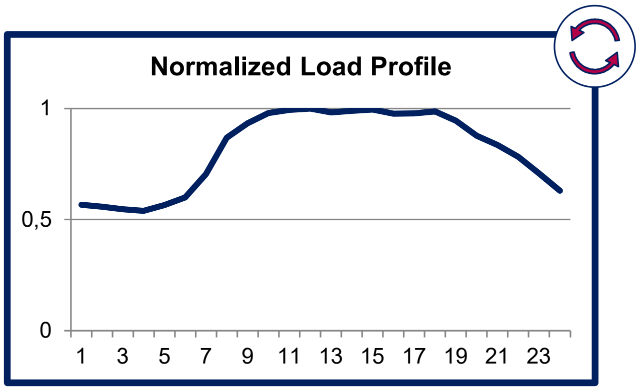
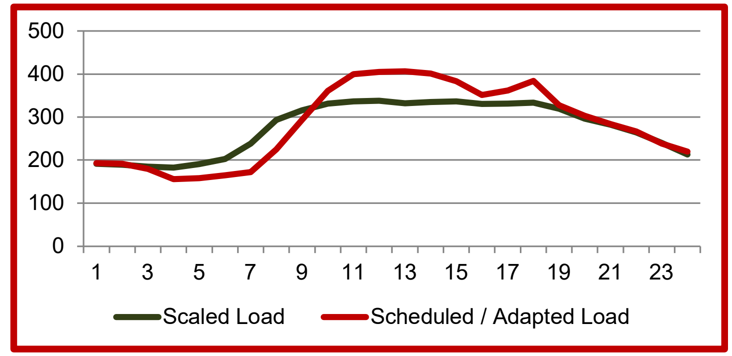
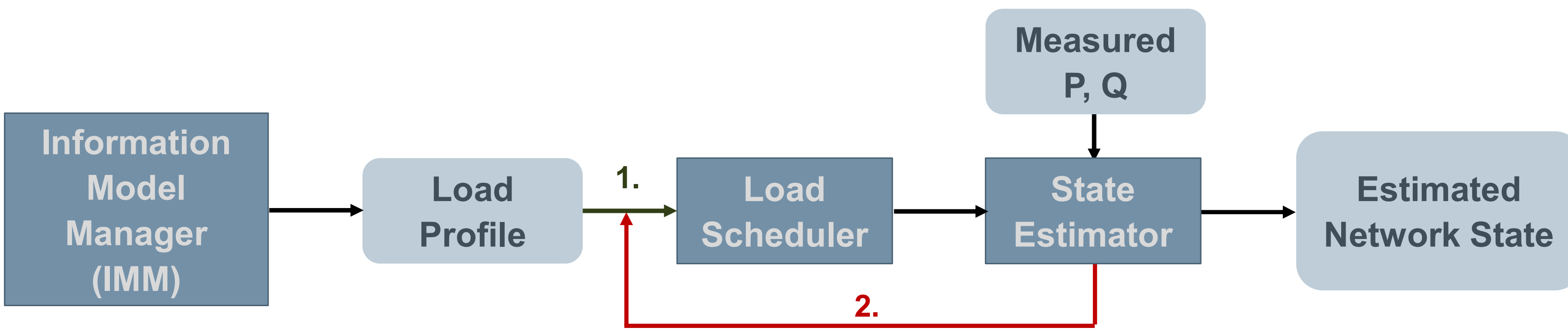


1. **Scaling of loads based on normalized load profile and nominal load**
2. **Adaptation of loads according to measured and estimated values**



Scheduled load after a learning phase of several weeks



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Spectrum Power^{TM} 7 – Distribution Network Applications
Phase Imbalance Calculation in unbalanced systems

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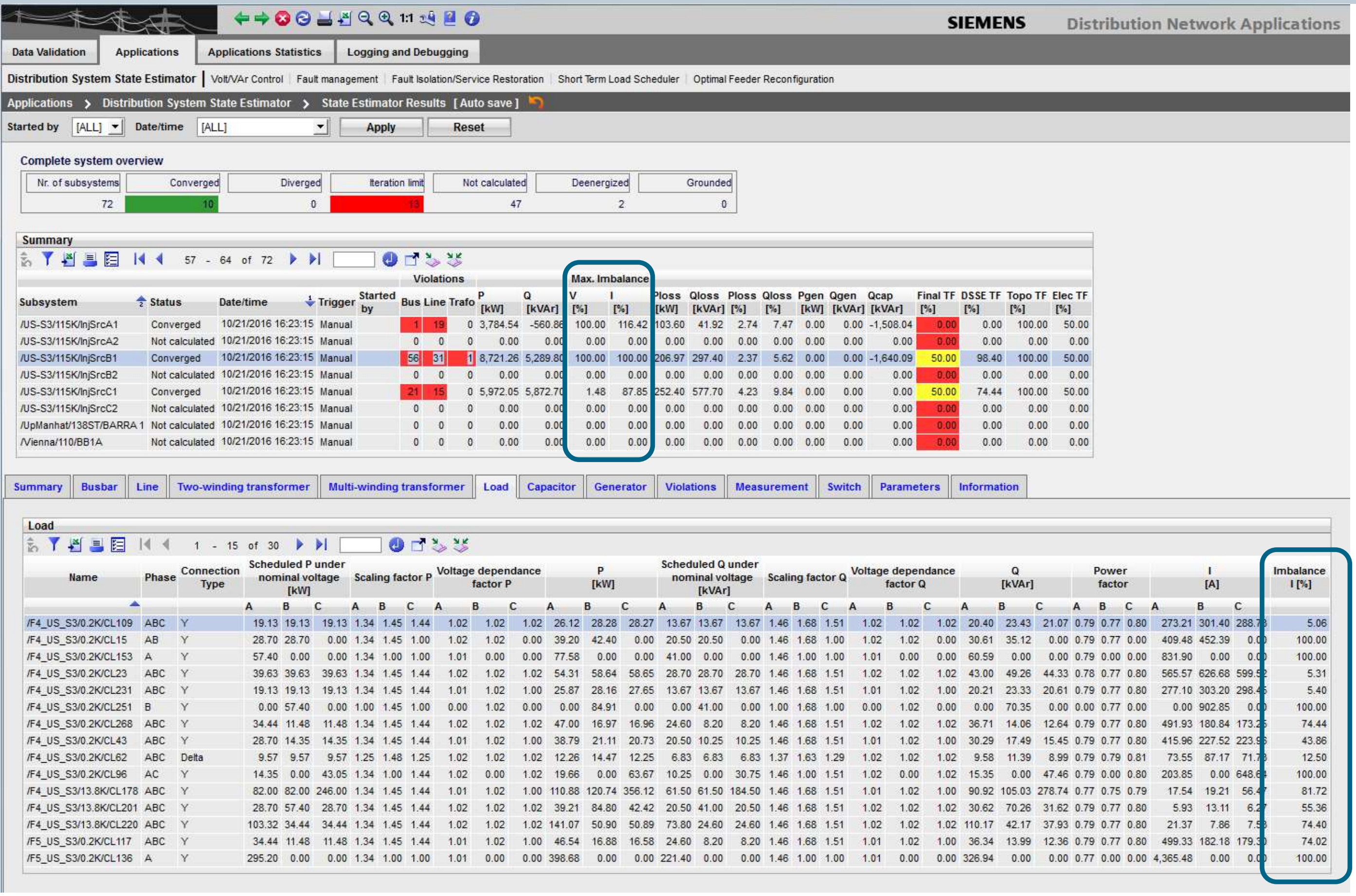

Even small voltage imbalances inside an unbalanced operated network can lead to high current imbalances and high currents which can be devastating for electrical equipment like motors, compressors, or other inductive devices.

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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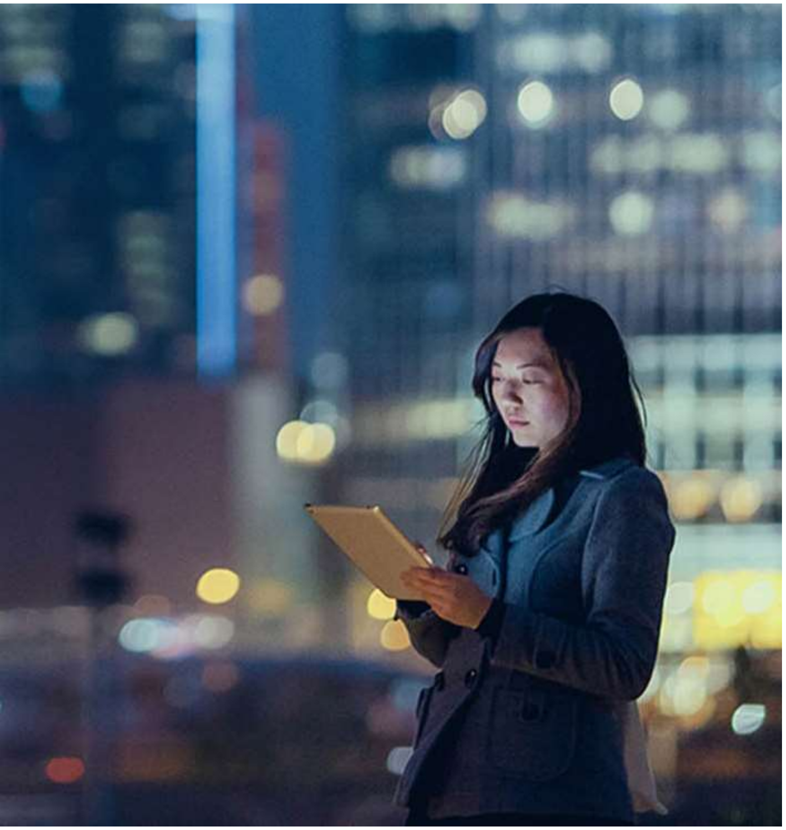

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Spectrum Power^{TM} 7 – Distribution Network Applications
Optimal Volt/Var Control (VVC)

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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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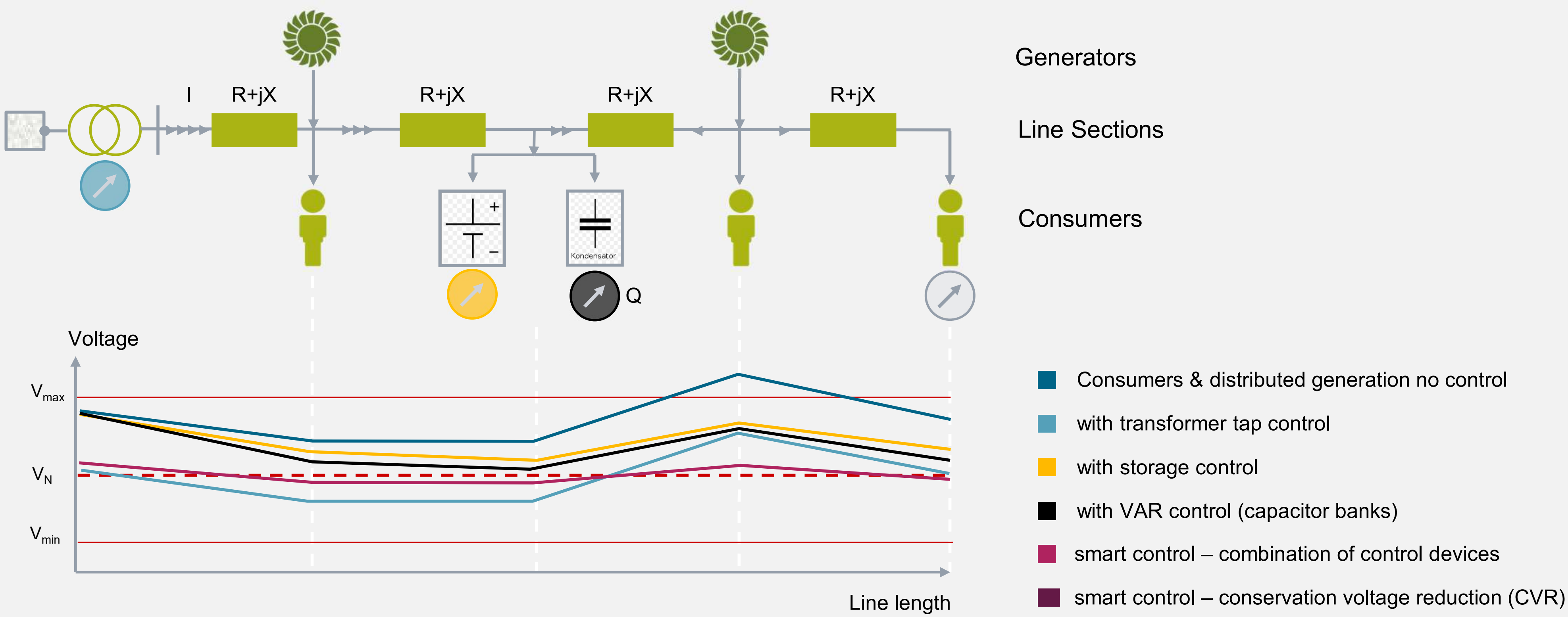
Spectrum Power™ 7 – Distribution Network Applications
Smart voltage control and conservation voltage reduction



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Spectrum Power^{TM} 7 – Distribution Network Applications
VVC Use Case "Voltage stabilization"

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DSSE detects violations

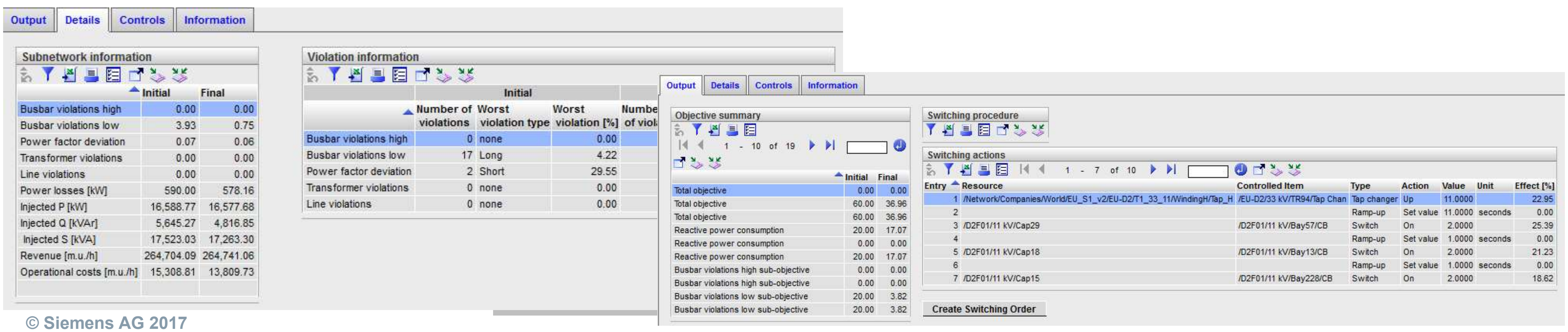
- Network is monitored continuously by DSSE
- Voltage violations are indicated in single line diagram and reported as alarm

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



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Spectrum Power DNA
Optimal Feeder Reconfiguration - OFR

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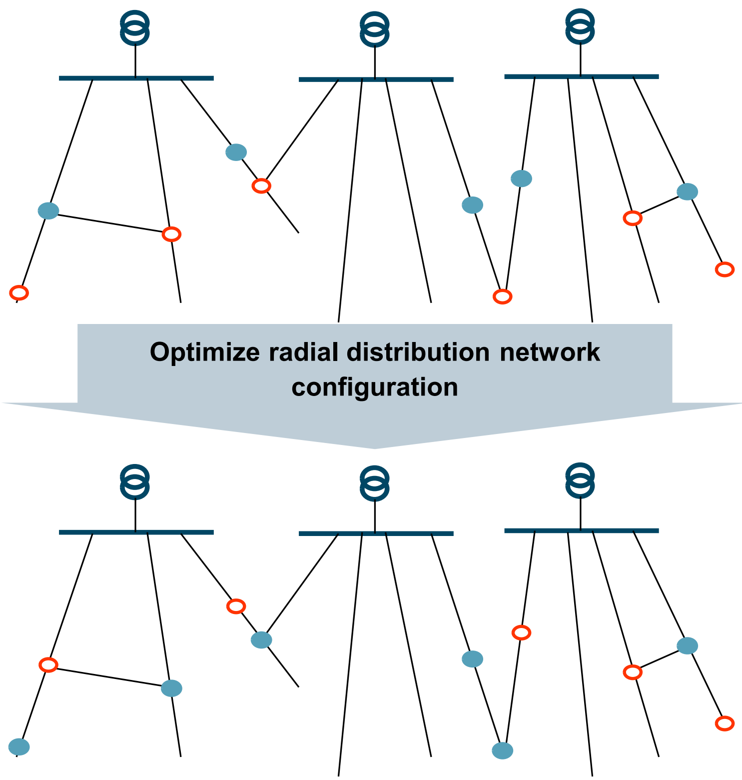

OFR determines the optimal radial distribution network configuration, means the specification of the normally open switches, accounting for equipment loading limits, voltage limit, and feeder losses. The user may select any combination of the following individual objectives:

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

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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

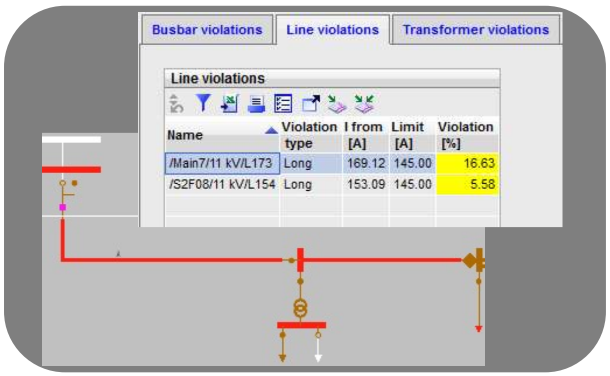
Run OFR

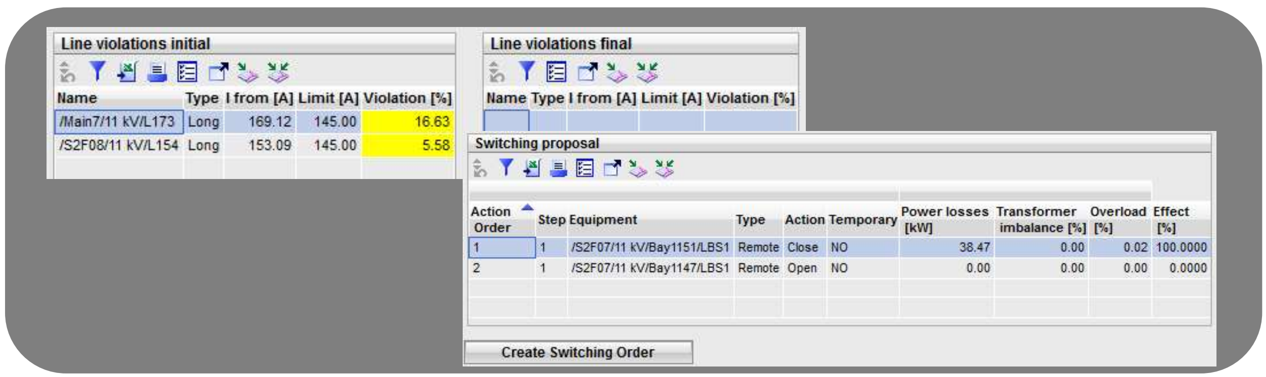
- Manual start:
- User selects violated part, defines objective and other settings and starts OFR

- 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





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Spectrum Power DNA
OFR Example - Scenario

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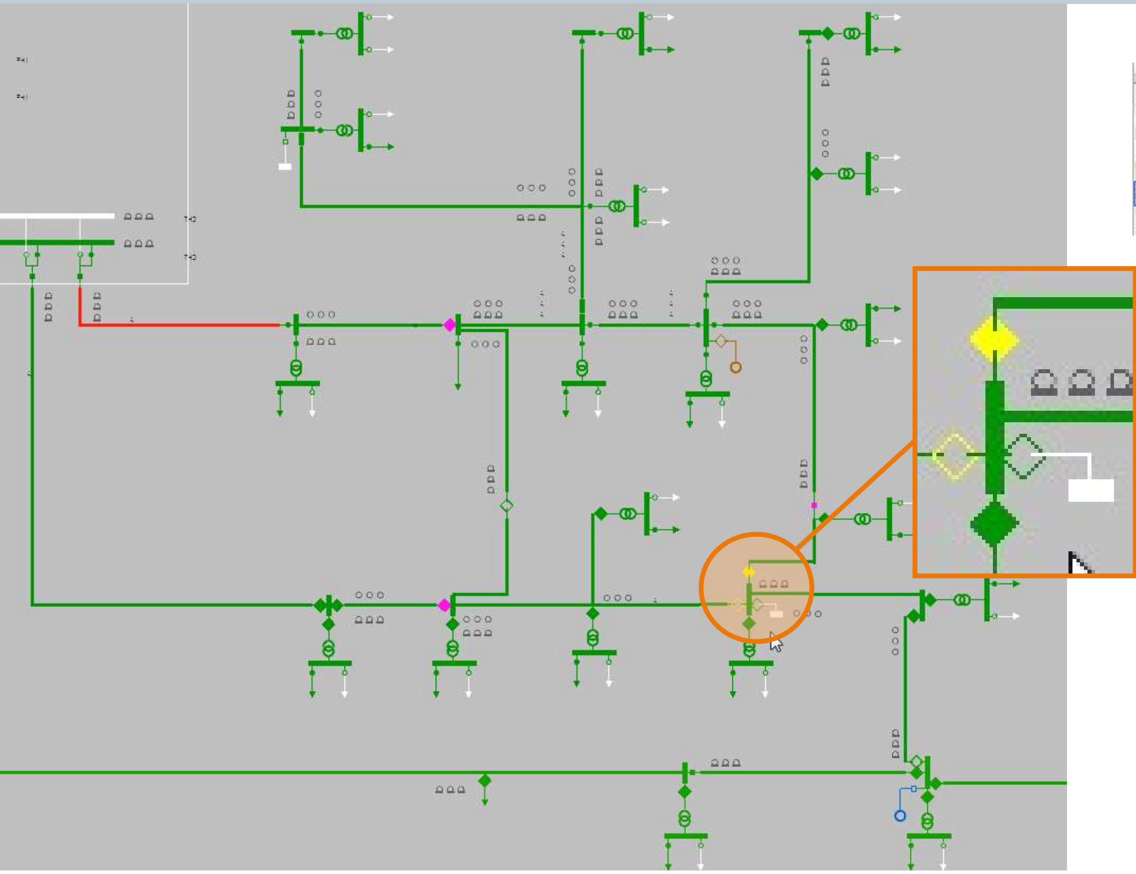

Summary

					Violations								
Subsystem	Status	Date/time	Trigger	Started by	Bus	Line	Trafo	P [kW]	Q [kVAr]	Ploss [kW]	Qloss [kVAr]	Ploss [%]	Qloss [%]
/EU-S2/110 kV/IB110_2B	Converged	06/22/2017 14:34:03	Manual	spectrum	0	1	0	11,259.94	6,431.25	560.12	1,131.33	4.97	17.59
/EU-S2/110 kV/IB110_1A	Converged	06/22/2017 14:30:09	Manual	spectrum	0	0	0	13,366.48	9,457.11	926.59	2,477.39	6.93	26.20

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

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Spectrum Power DNA
OFR Example – OFR results

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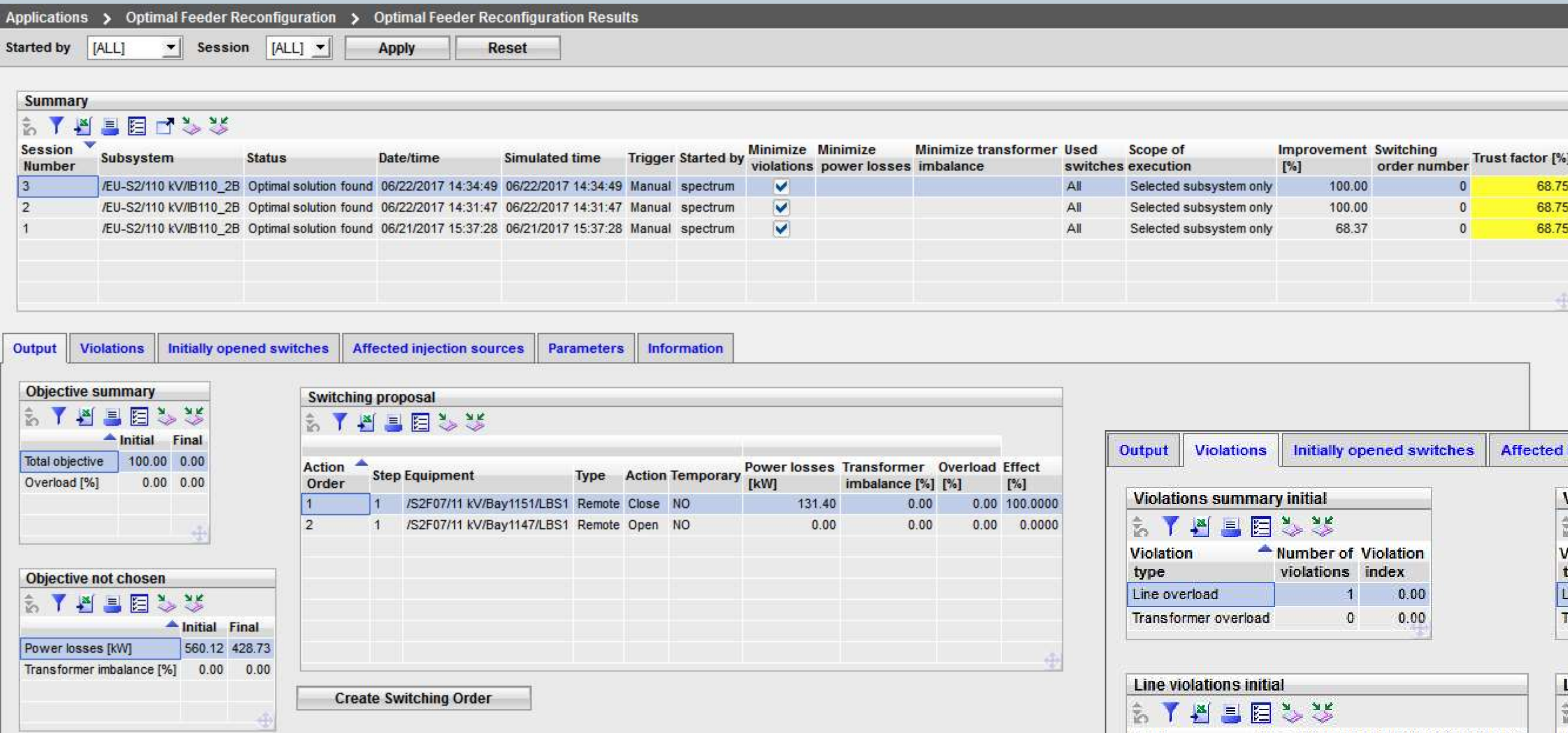
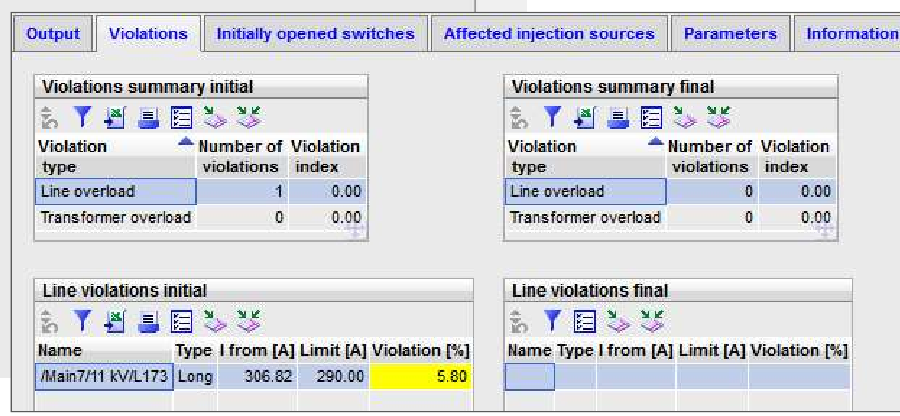


- OFR generates a switching proposal for optimized feeder configuration
- OFR lists violations before and after optimization



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Spectrum Power DNA
OFR Example – State estimation after OFR proposal is executed

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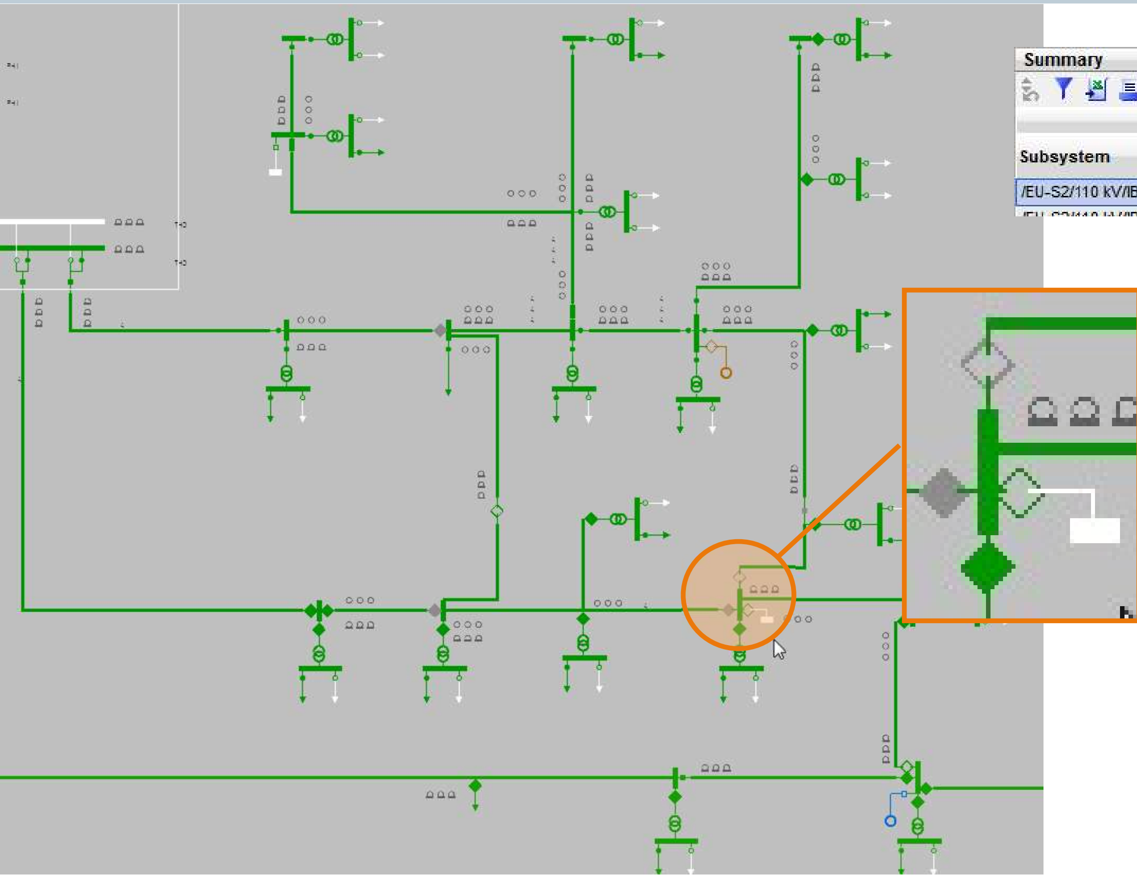

Summary

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					Violations								
Subsystem	Status	Date/time	Trigger	Started by	Bus	Line	Trafo	P [kW]	Q [kVAr]	Ploss [kW]	Qloss [kVAr]	Ploss [%]	Qloss [%]
/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	15.52

Line violations

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

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

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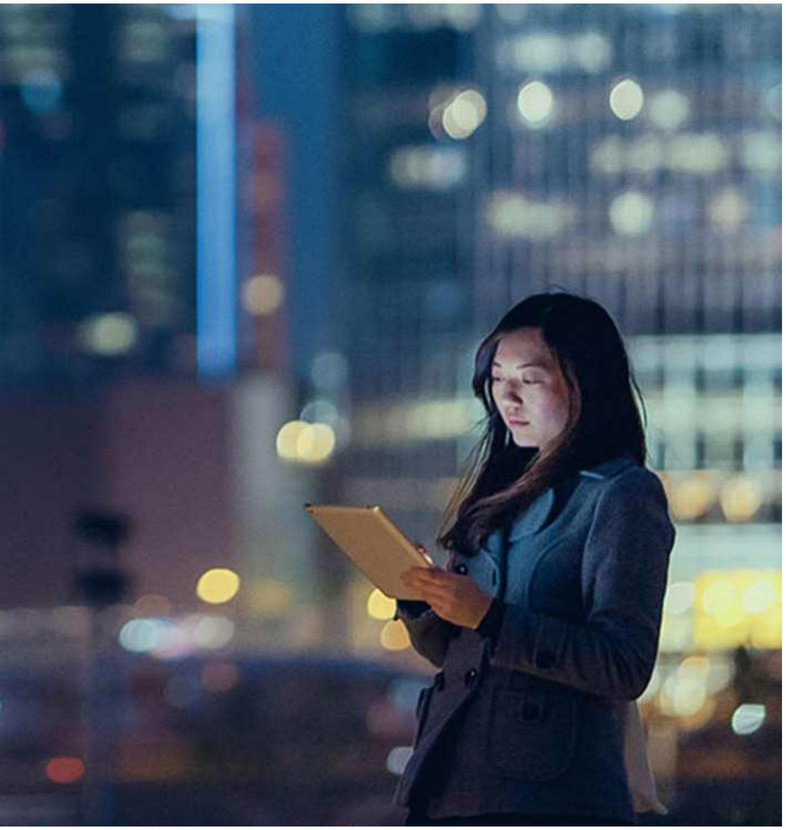

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Spectrum Power^{TM} 7 – Distribution Network Applications
Summary

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

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