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SiGuard®
System Security Solutions

Dynamic Network and Protection Security
of Transmission Systems

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SiGuard® DSA (Dynamic Security Assessment)
SiGuard® PSA (Protection Security Assessment)

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The Solution:

To Avoid Large Scale Outages
To Make Use of all Transfer Capabilities
To Define and Verify Countermeasures

All This for the Interacting
Primary and Protection System

That is: **SiGuard®**

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Dynamic Network Security Assessment

SiGuard®-DSA

SiGuard® DSA System Structure Overview

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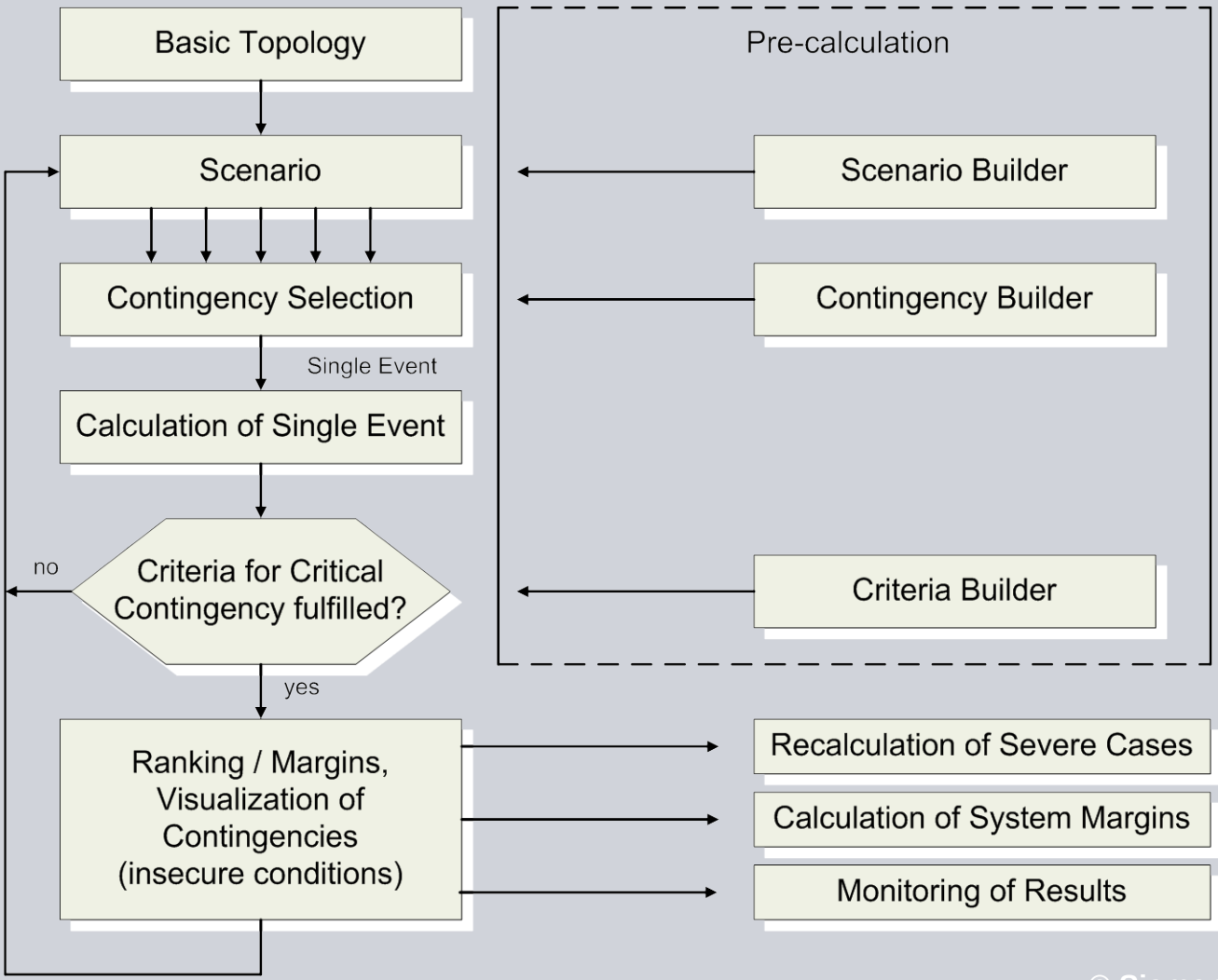

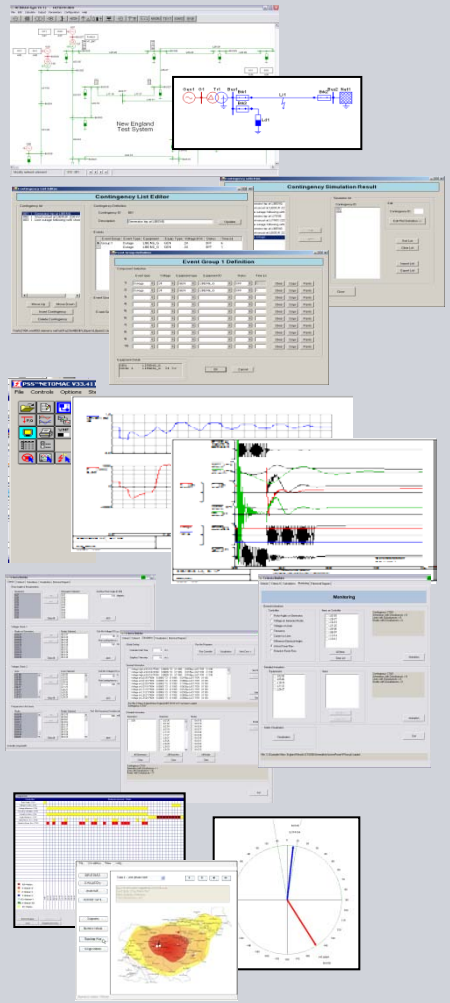

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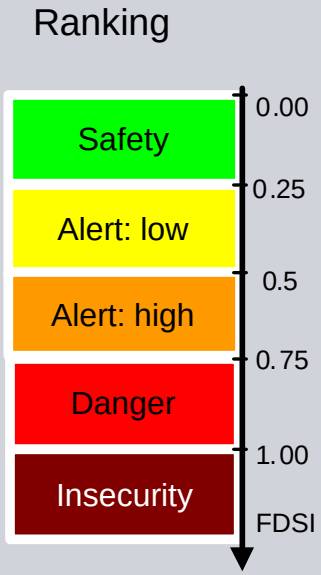
DSA Ranking – Security Indices (11 of 20 indices)

1. Angle index (AI)
2. Maximum frequency deviation index (MFDI)
3. Frequency recovery time index (FRTI)
4. Dynamic voltage index (DVI)
5. Quasi-stationary voltage index (QSVI)
6. Power flow index (PFI)
7. Load shedding index (LSI)
8. Small signal stability index (SSSI)
9. Nodal loading index (NLI)
10. Approximate collapse power index (ACPI)
11. Power transfer stability index (PTSI)



DSA Ranking - Security Indexes

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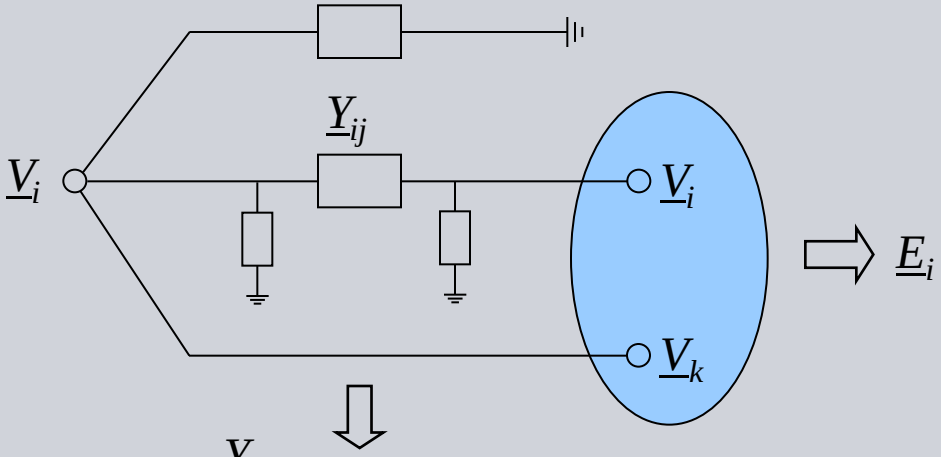
9. Nodal loading index (NLI) - (1)



$$V_i \angle\theta_i \qquad E_i \angle\phi_i \qquad \underline{E}_i = \sum_{\substack{K=1 \\ K\neq j}}^{n} \left(\underline{Y}_{iK} \,/\, \underline{Y}_{ii}\right)\underline{V}_K$$

$$e_i = \frac{V_i}{E_i}: \qquad e_i = \sqrt{\frac{1+2\,P_{ii}}{2}\left[1 \pm \sqrt{1-4\,\Delta_{ii}}\right]}$$

$$\sin\left(\psi_i\right) = -Q_{ii} \,/\, e_i$$

DSA Ranking – Security Indexes

9. Nodal loading index (NLI) - (2)

Solution exists, when

$$e_i \geq 0$$

$$\frac{|Q_{ii}|}{e_{ii}} \leq 1$$

and $$\Delta_{ii} = \frac{4 * \left(P_{ii}^2 + Q_{ii}^2\right)}{\left|\left(1 + 2\,P_{ii}\right)^2\right|} \leq 1$$

} existing condition and absolute system loading margins for each node

P_{ii}, Q_{ii} nodal loading in pu

$$NLI = \left\{1, \max_{i=1,\ldots N}\left(\Delta_{ii}\right)\right\}$$

DSA Ranking – 3-stages Fuzzy Logic System (FLS) with additional PMU data and trend analysis

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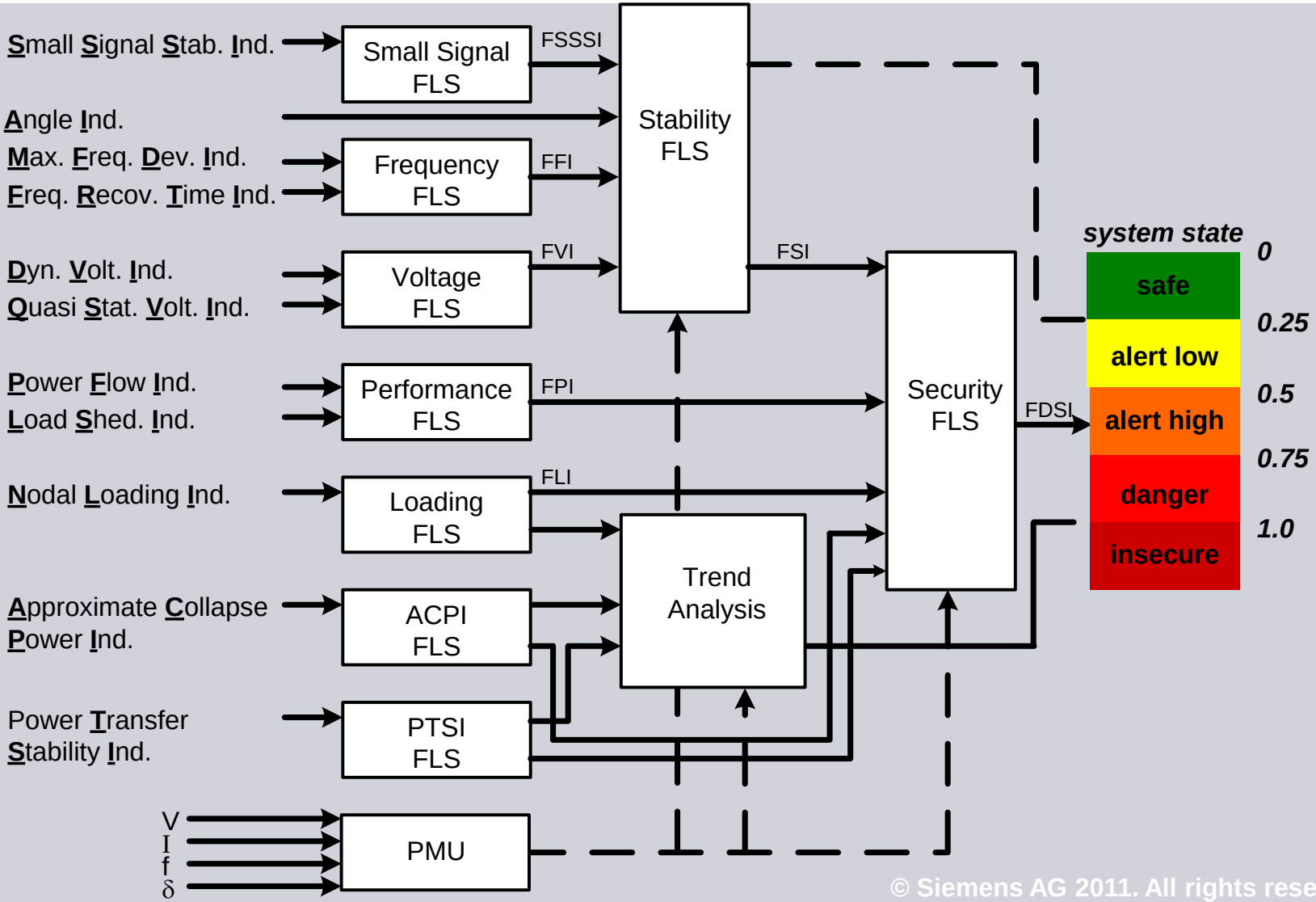
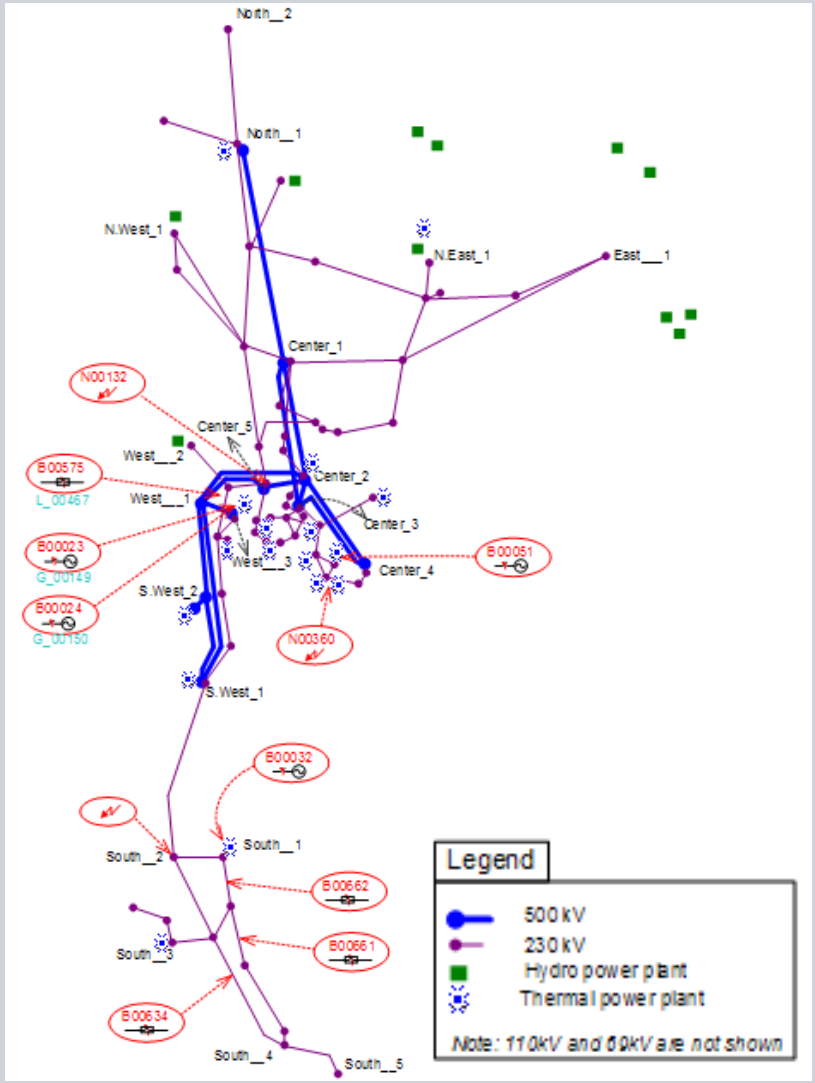


DSA Ranking – Security Indices – DSA Test network



~ 540 buses
~ 1.750 branches
~ 120 machines
~ 250 controller

~ 2,5x faster than real-time

DSA Ranking – Security Indexes

comparison of ACPI and PTSI (nodal load increase)

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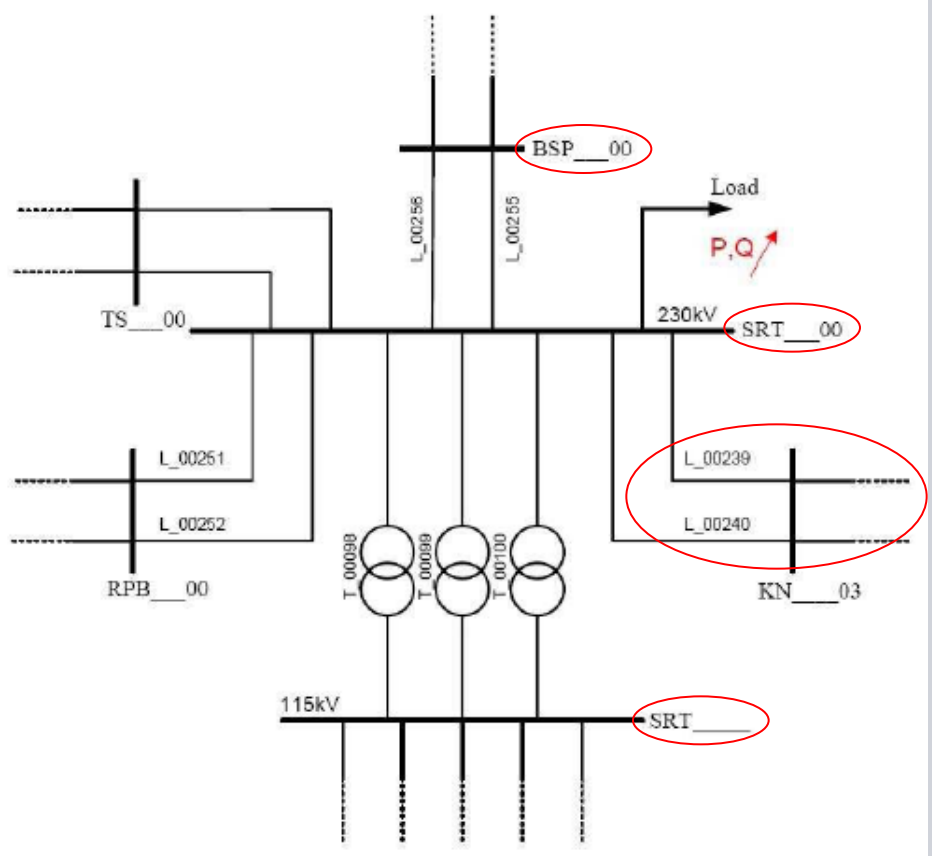
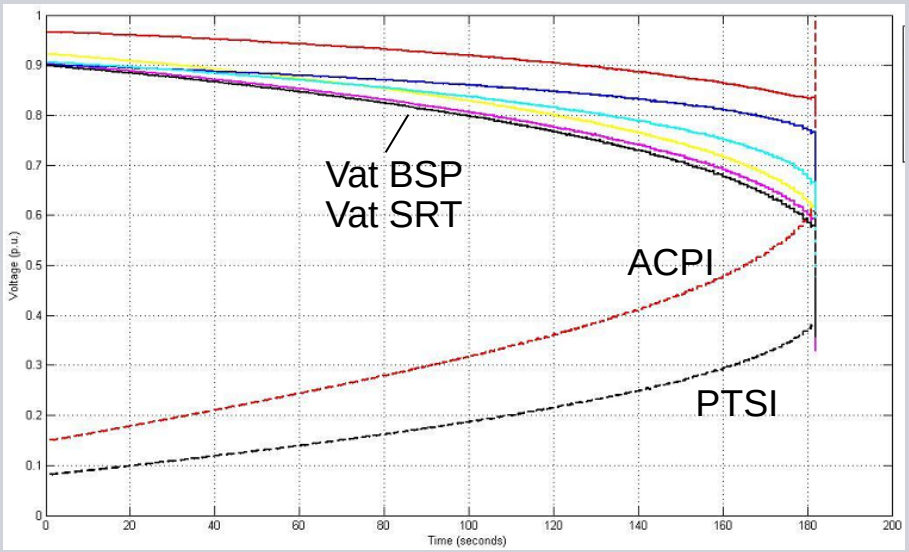


Local network topology

PTSI = Power Transfer Stab. Ind.
ACPI = App. Collapse Power Ind.



Load increase at SRT_00

P_0 = 300 MW, Q_0 = 150 MW,

load increase 0.02 pu/s

Necessity and General Functioning of Distance Protection Control Systems

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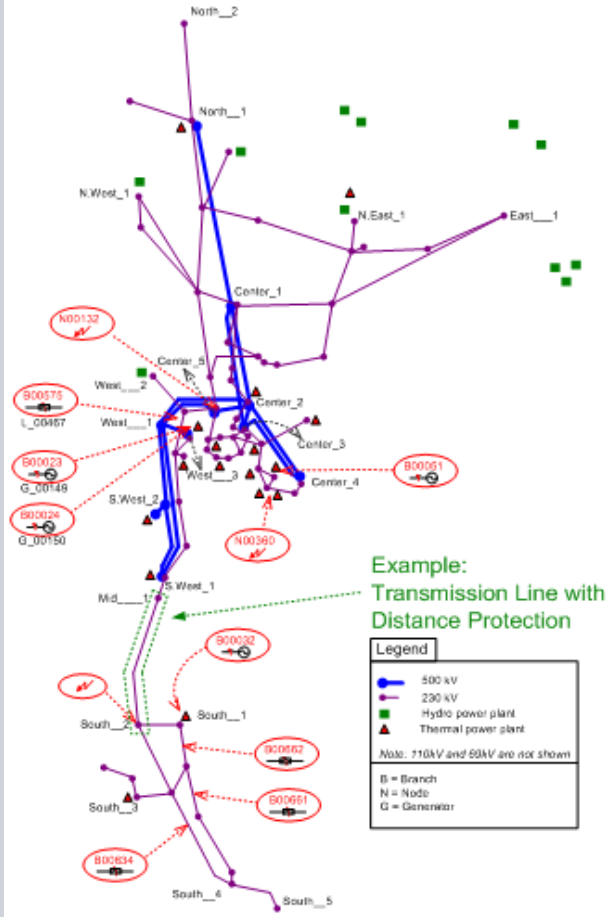

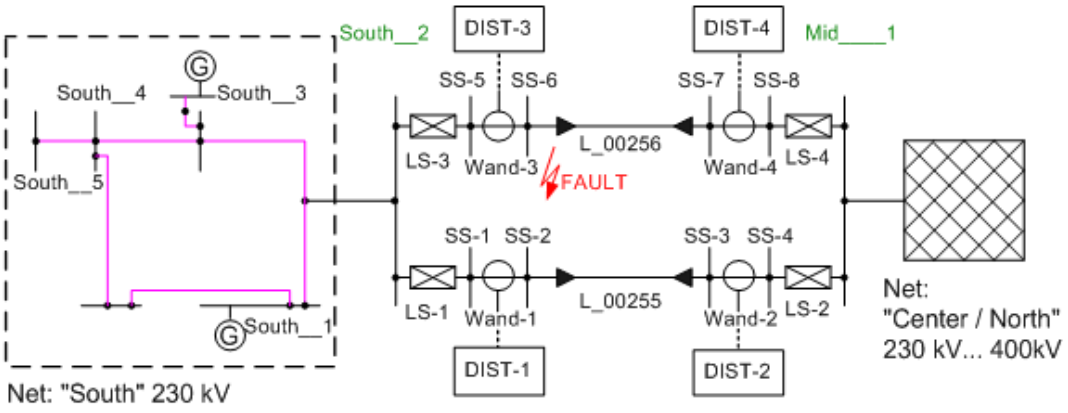

3-phase fault at node SS-6

Parallel line L_00255 / L_00256 is equipped with Distance Protection Functions

Zone	Zone 1	Zone 2	Zone 3
Reach	85%	120%	150%
Time	0.062 s	0.3 s	0.6 s

Power oscillation and system separation after trip of one line - loss of second line (Power Swing Blocking not active)

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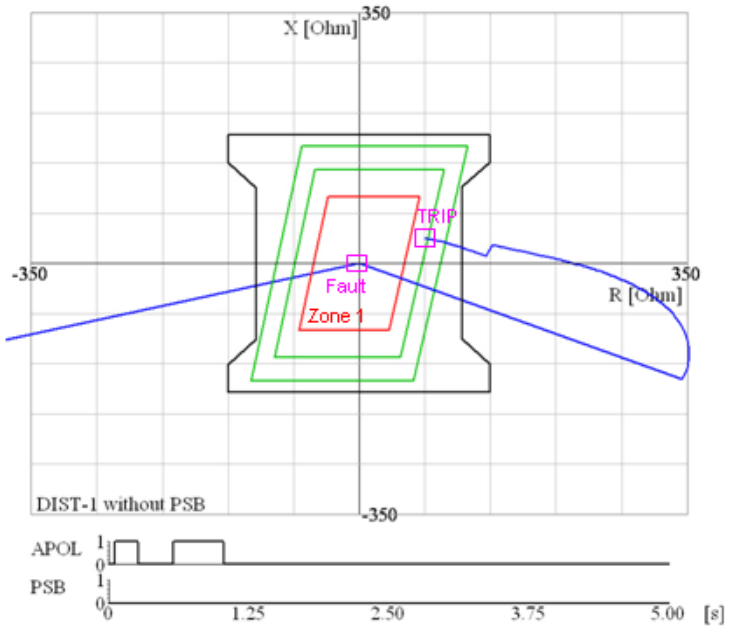
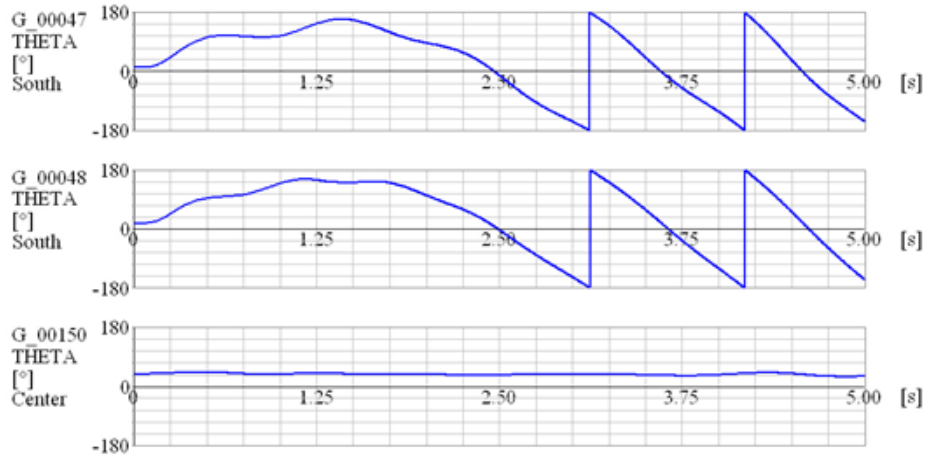
Relay DIST-1 on the healthy Line **without** Power swing Blocking





- Unintentional Trip of Relay DIST-1 in Zone 2
- Sub-network “South” is separated from the grid
- Loss of equilibrium between generation and load (→ drop of frequency)

Oscillation of the south system – no system separation (Power Swing Blocking active)

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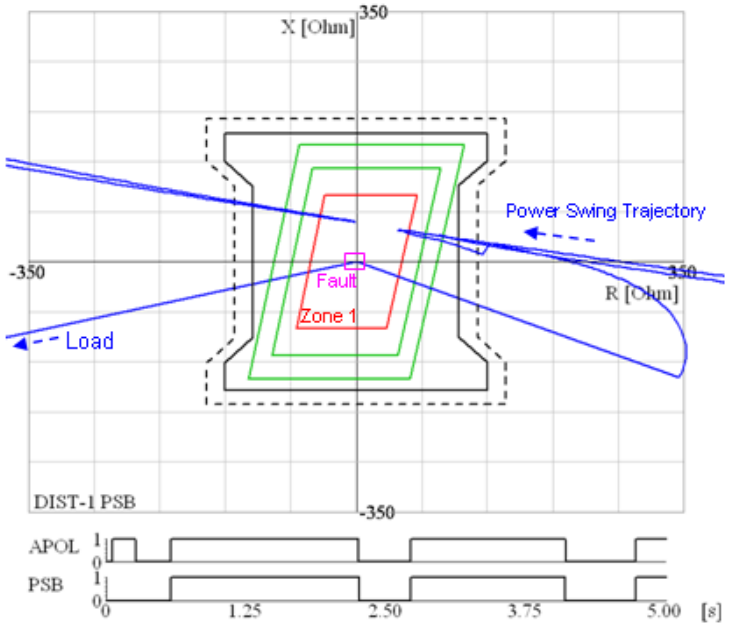
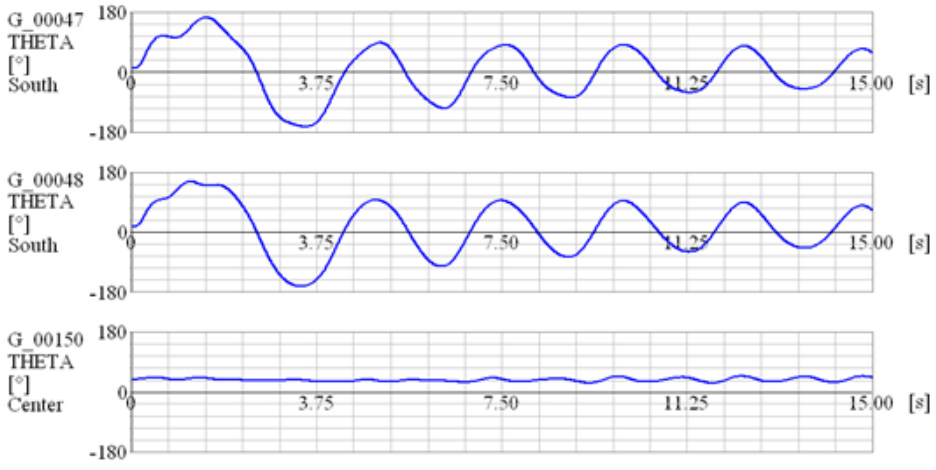
Relay DIST-1 on the healthy Line with Power swing Blocking (PSB)





Swings of Generator pole angle with high amplitude

→ Trajectory enters Relay characteristic

→ PSB algorithm detects power swing

SiGuard® DSA Assessment of the Dynamic Security Taking "Fingerprints" of the Dynamic System Behavior

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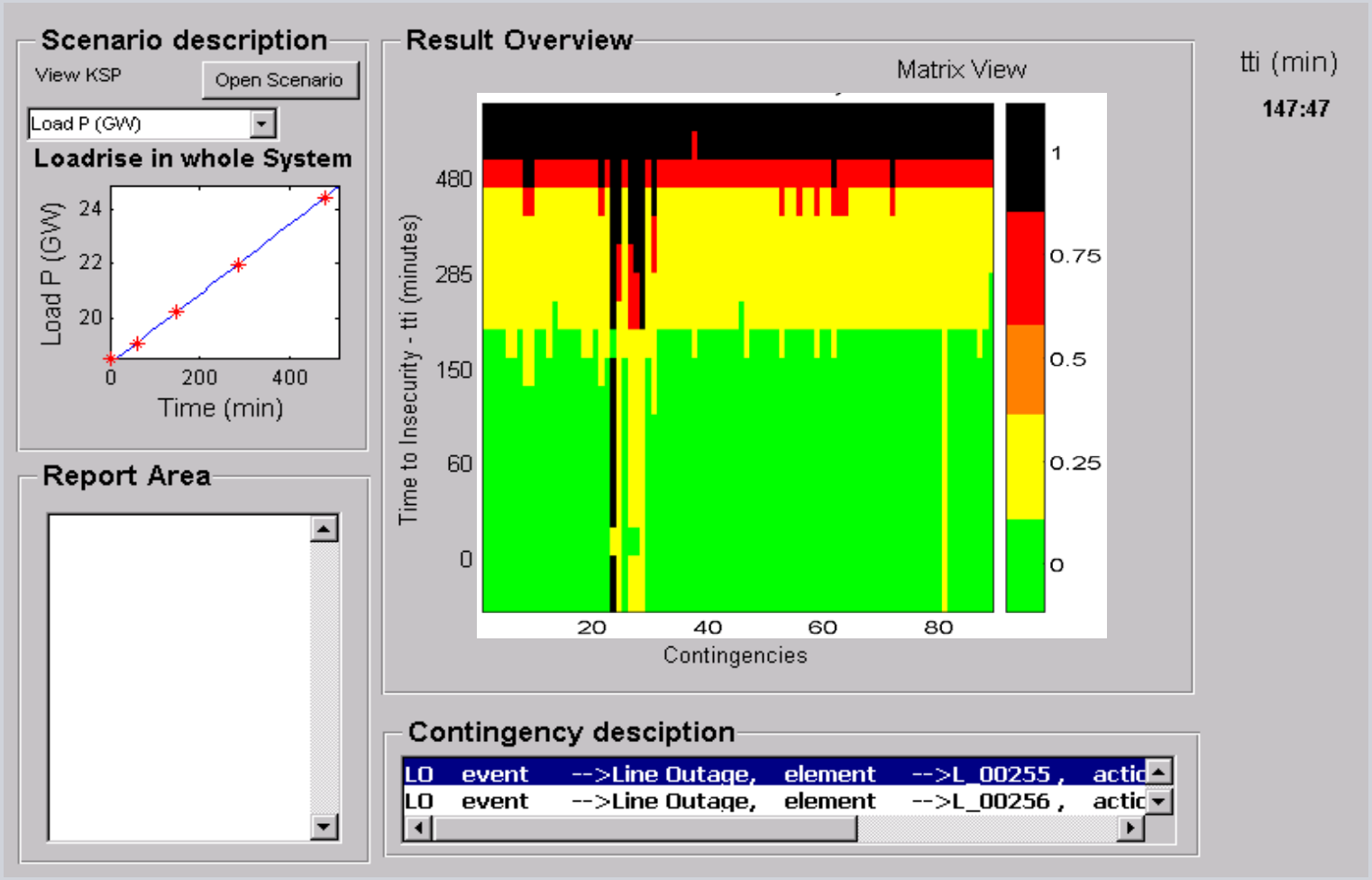

SiGuard® DSA Assessment of the Dynamic Security Contingencies and Proposed Countermeasures

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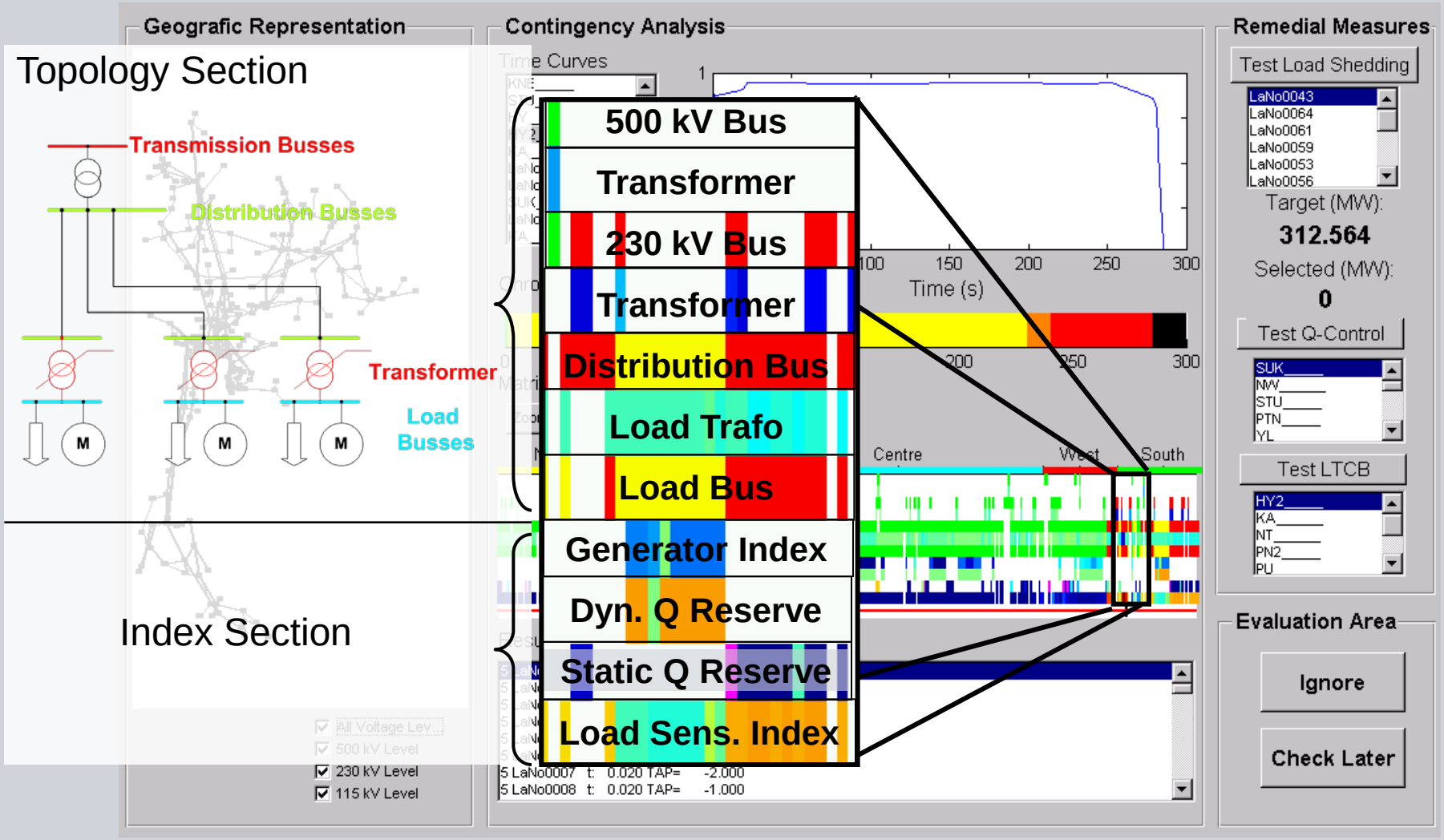

SiGuard®-DSA
Remote Computation on PC Cluster

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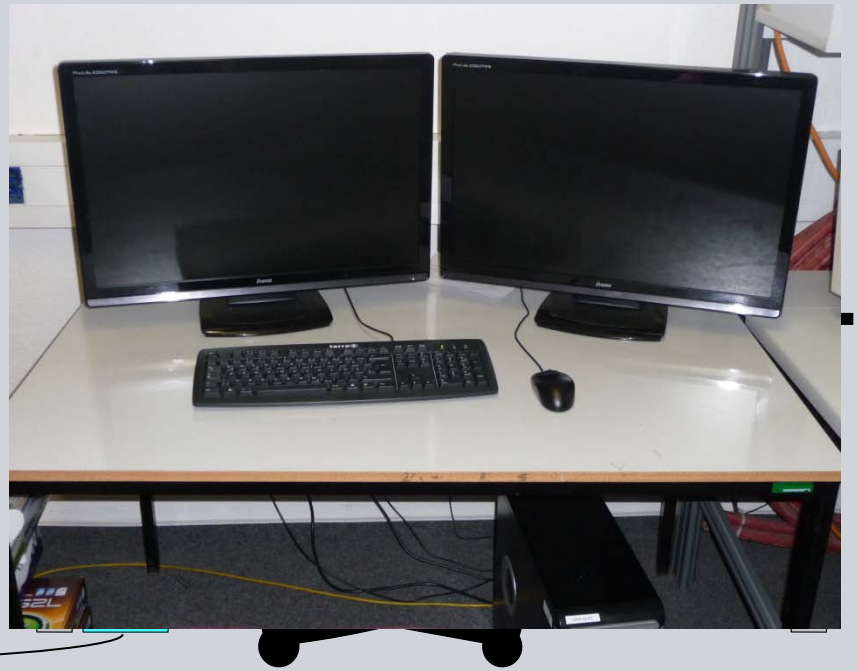
Component	Task
IPC CPU: 3,2 GHz RAM: 2 GB HDD: 500 GB LAN: Gbit OS: WinXP Pro	**(N-1) Contingency simulations for:** Voltage Stability Transient Stability Small Signal Stab.
NAS Speicher HDD: 4 x 1,5 TB LAN: Gbit	Central Storage (Backup, Archive)
Gigabit - Switch	Gigabit - Switch
USV Power: 6 kW Auton.: 10 min	USV – Power Supply

Price for the system lies at about:
550€ / CPU Core



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Protection Security Assessment

SiGuard®-PSA

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How to maintain Network Security?

NERC (North American Electric Reliability Council):

Protective relays are involved in ≈ 75% of major network disturbances

No Network Security without Protection Security!

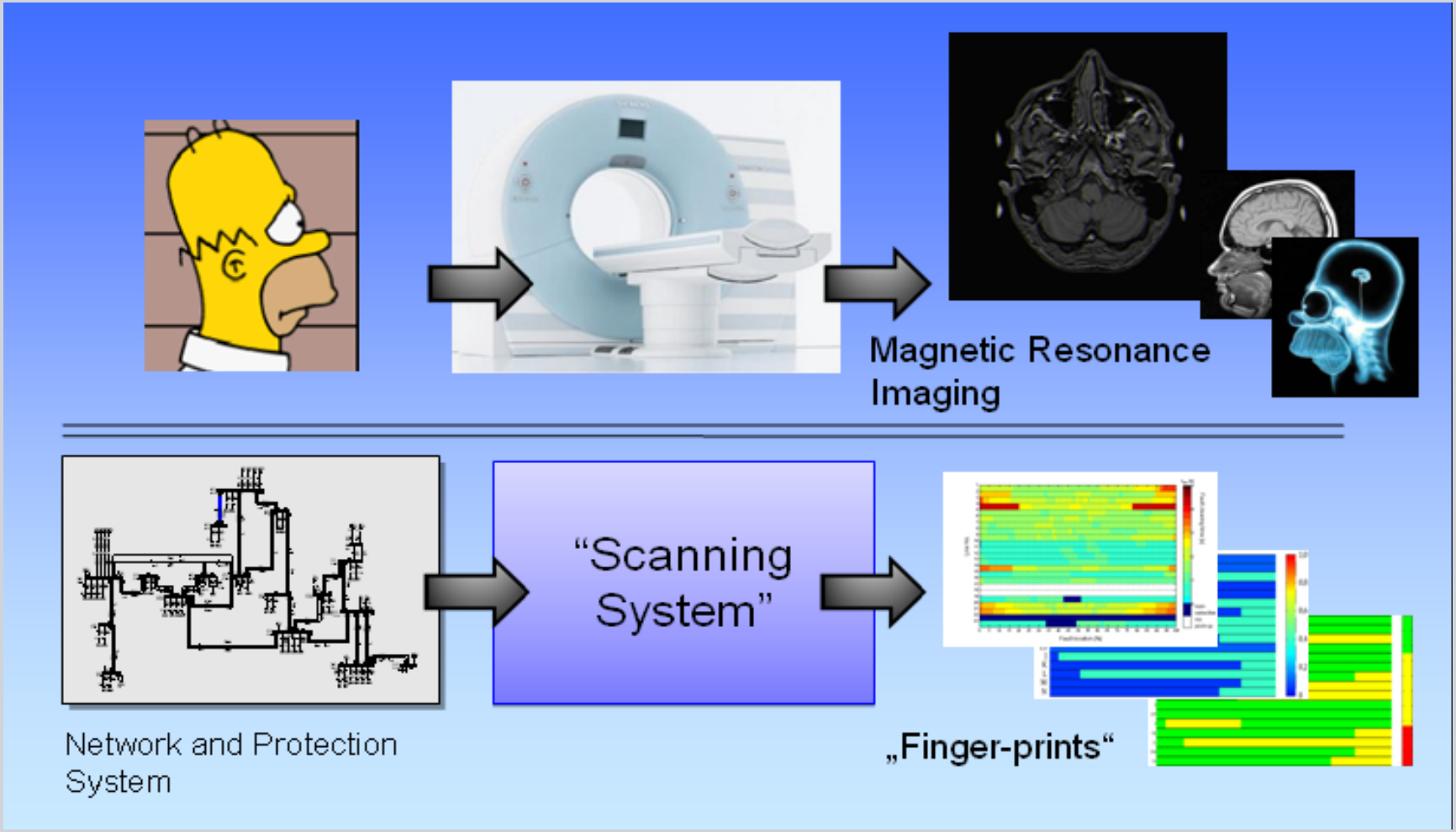
Dynamic Security Assessment

- Voltage stability,
- Transient stability
- …

Protection Security Assessment (PSA)

- Selectivity
- Dependability
- …

How to do Protection Security Assessment?



Evaluation of Simulation Results

„Fault Pattern Analysis“

Most overfunction
Zone 11 and 14

“sympathetic tripping”

Solution: Application of Directional Protection!
50/51 → 67

Question: Where?
How many?
Ranking of replacement

SiGuard®-PSA Assessment of the Protection Security Fingerprint of the Protection System

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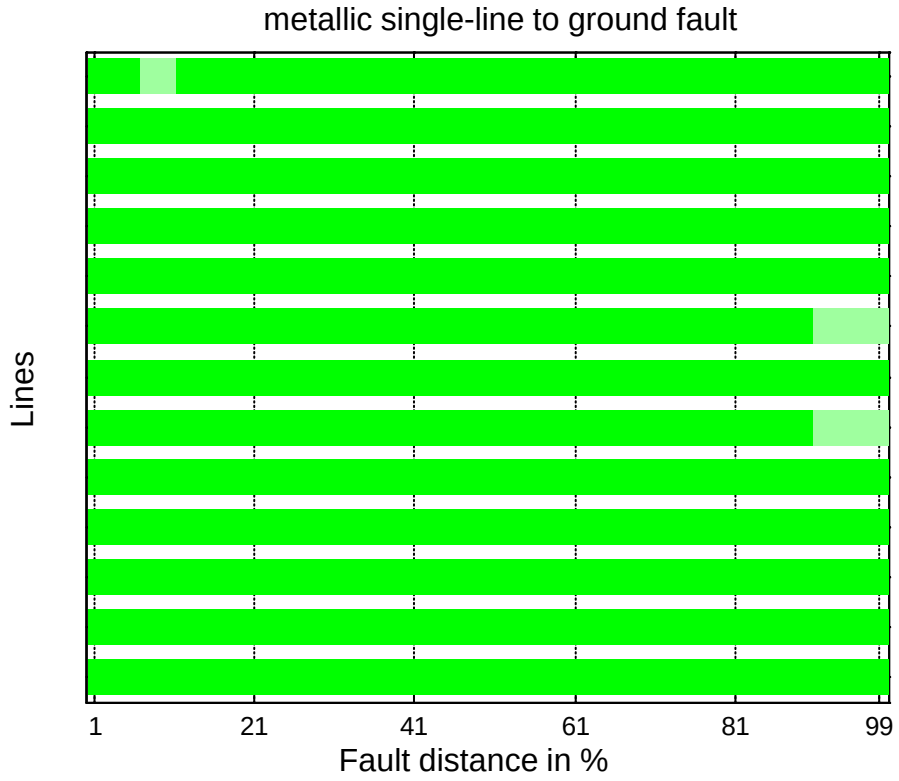

Fault Resistance

- < 2,5 Ohm
- < 2,4 Ohm
- < 2,3 Ohm
- < 2,2 Ohm
- < 2,1 Ohm
- < 2,0 Ohm
- < 1,9 Ohm
- < 1,8 Ohm
- < 1,7 Ohm
- < 1,6 Ohm
- < 1,5 Ohm
- < 1,4 Ohm
- < 1,3 Ohm
- < 1,2 Ohm
- < 1,1 Ohm
- < 1,0 Ohm
- < 0,9 Ohm
- < 0,8 Ohm
- < 0,7 Ohm
- < 0,6 Ohm
- < 0,5 Ohm
- < 0,4 Ohm
- < 0,3 Ohm
- < 0,2 Ohm
- < 0,1 Ohm
- < 0,0 Ohm

	All protection trips fast and selective
	Schutzgeräte an dem zu schützenden Betriebsmittel sollten in der zweiten Zone auslösen, lösen ab bereits in der ersten Zone aus - und umgekehrt
	Schutzgeräte an dem zu schützenden Betriebsmittel lösen erst in der dritten Zone, oder einer höheren Zone, aus
	bei einem Fehler auf dem zu schützenden Betriebsmittel löst mindestens ein nachgeordnetes Schutzgerät mit aus (Überfunktion)
	>1 relay(s) did not trip as desired

European Patent:
06775872.2 / 2052451

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Conclusion

- Several methods to observe the security of a system have been built and combined
- Fast margin calculation shows the state and trend of nodal and system loading
- Ranking of system loading, frequency, voltage, performance and stability allow a detailed view on the security state of a system after critical contingencies
- The combination of trend analysis and state analysis helps the operator to increase the security of his system
- Additional PMU-information's can be used to have an actual view on the system state

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Thank you for your attention!

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DSA Ranking – Security Indexes

1. Angle index (AI)

$$\mathrm{AI} = \min\left\{1, \max_{i=1\ldots NG}\left(\frac{\delta_{ci,\max}}{\delta_{c,\max adm}}\right)\right\}$$

DSA Ranking – Security Indexes

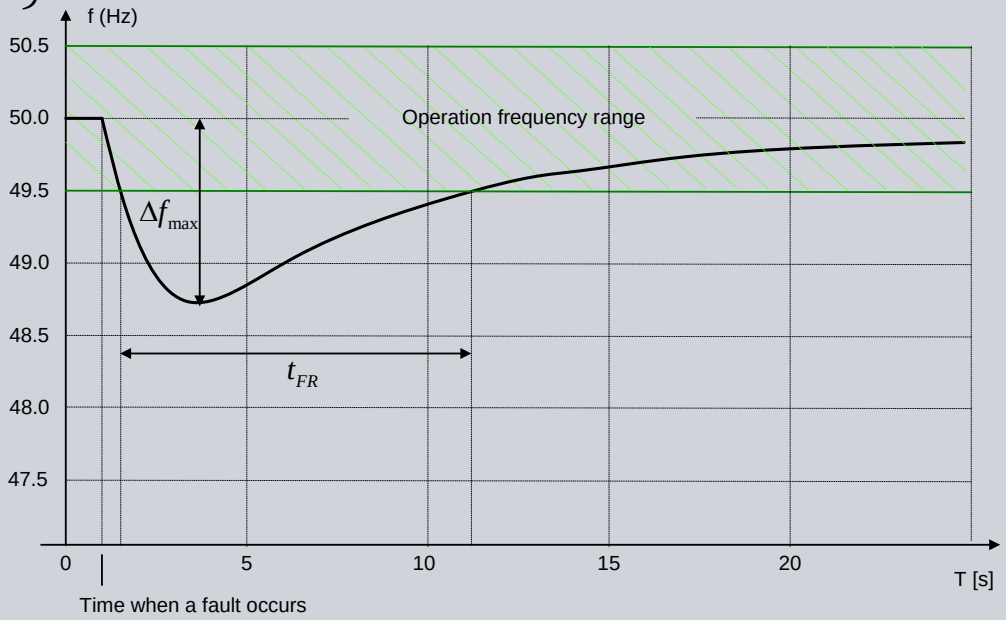
2. Maximum frequency deviation index (MFDI)

$$\mathrm{MFDI} = \min\left\{1, \max_{i=1\ldots NG}\left(\frac{\left|\Delta f_{i,\max}\right|}{\left|\Delta f_{\max adm}\right|}\right)\right\}$$

DSA Ranking – Security Indexes

3. Frequency recovery time index (FRTI)

$$FRTI = \min\left\{1, \max_{i=1\ldots NG}\left(\frac{t_{FRi,\max}}{t_{FR,adm}}\right)\right\}$$



DSA Ranking – Security Indexes

5. Quasi-stationary voltage index (QSVI)

$$QSVI = \min\left\{1, \max_{i=1\ldots N}\left(\frac{\left|\Delta V_{pi}\right|}{\left|\Delta V_{i,\max adm}\right|}\right)\right\}$$

$$Where \;\; \Delta V_{DVi} = V_{ni} - V_i$$

DSA Ranking – Security Indexes

6. Power flow index (PFI)

$$\mathrm{PFI} = \min\left\{1, \max_{i=1\ldots NL}\left(\left[\frac{P_{pi}}{P_{i,\lim}}\right]^{n}\right)\right\}$$

DSA Ranking – Security Indexes

7. Load shedding index (LSI)

$$\mathrm{LSI} = \frac{P_{Shed}}{P_{total}}$$

DSA Ranking – Security Indexes

10. Approximate collapse power index (ACPI)

Approximation of the PV-curve $\left(V_i = f\left(\lambda_i\right)\right)$

$$P_i = P_{io}\left(1 + d_i \lambda_i\right)$$

$$Q_i = Q_{io}\left(1 + q_i \lambda_i\right)$$

$$\lambda_i = a_i V_i^{\,2} + b_i V_i + c_i$$

$$ACPI_{\min} = \left\{1, \max_{i=1\ldots N}\left[\frac{P_i}{P_{ci}}\right]\right\} \qquad \frac{P_i}{P_{ci}} = \frac{1}{1 + d_i \lambda_{ci}} \qquad \lambda_{ci} = \lambda_i \;\; for \;\; \frac{d\lambda_i}{dV_i} = o$$

DSA Ranking – Security Indexes

11. Power transfer stability index (PTSI)

Approximation of the system as 2 node system (as for NLI)
Thevenin equivalent: max. transferred power when $Z_{load} = Z_{Thev}$

$$PTSI = \min\left\{1, \max_{i=1\ldots N}\left(\frac{2\,S_{Li}\left(1+\cos\left(\phi_{ii}-\phi_{Li}\right)\right)}{Y_{ii}E_i^{\,2}}\right)\right\}$$

S_{Li} load power, Φ_{Li} angle of load admittance

DSA Ranking – Security Indexes - Example

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Without AVR

```
<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
|--- Fault case: 3-phase busbar fault at node  SRT   00          ----------|
|---------------------------------------->> Normal loading /Without AVR|
| AIII = 1.00 ------------------------>|                                   |
|                                      |                                   |
| FRTI = 1.00 -->|                     |                                   |
|                |--> FFII = 1.00 --->|--> FSII =1.00 -->|                 |
| MFDI = 1.00 -->|                     |                  |                |
|                                      |                  |                |
| DVII = 1.00 -->|                     |                  |                |
|                |--> FVII = 1.00 --->|                  |--> FDSI = 1.00 |
| QSVI = 1.00 -->|                                        |                |
|                                                         |                |
| PFII = 1.00 -->|                                        |                |
|                |--> FPII = 1.00 ---------------------->|                |
| LSII = 0.00 -->|                                                         |
<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
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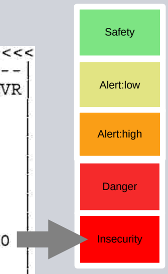

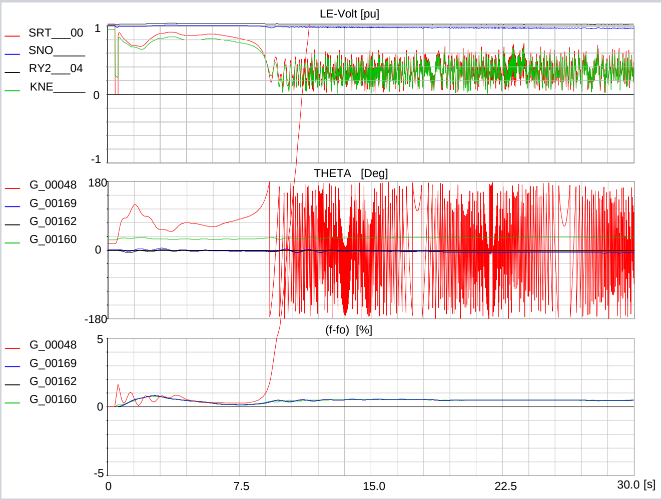

With AVR

```
<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
|--- Fault case: 3-phase busbar fault at node  SRT   00          ----------|
|---------------------------------------->> Normal loading /With AVR      |
| AIII = 0.61 ------------------------>|                                   |
|                                      |                                   |
| FRTI = 0.03 -->|                     |                                   |
|                |--> FFII = 0.37 --->|--> FSII =0.56 -->|                 |
| MFDI = 0.37 -->|                     |                  |                |
|                                      |                  |                |
| DVII = 0.15 -->|                     |                  |                |
|                |--> FVII = 0.54 --->|                  |--> FDSI = 0.57 |
| QSVI = 0.53 -->|                                        |                |
|                                                         |                |
| PFII = 0.58 -->|                                        |                |
|                |--> FPII = 0.44 ---------------------->|                |
| LSII = 0.00 -->|                                                         |
<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
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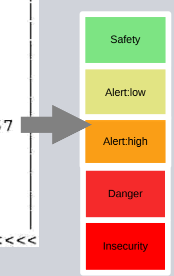

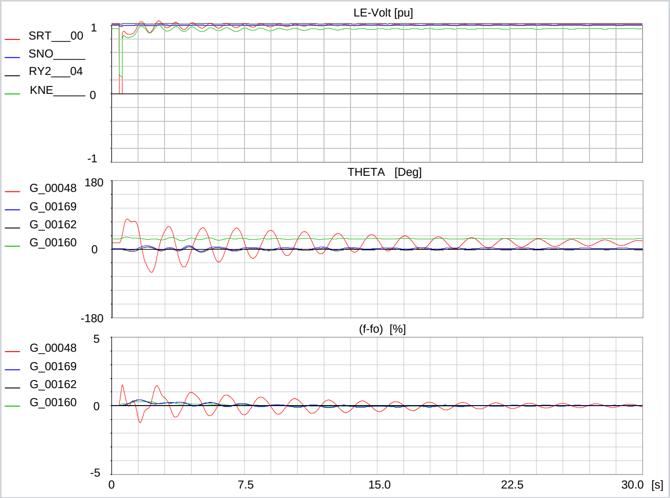

Parallel Computing – Software Structure

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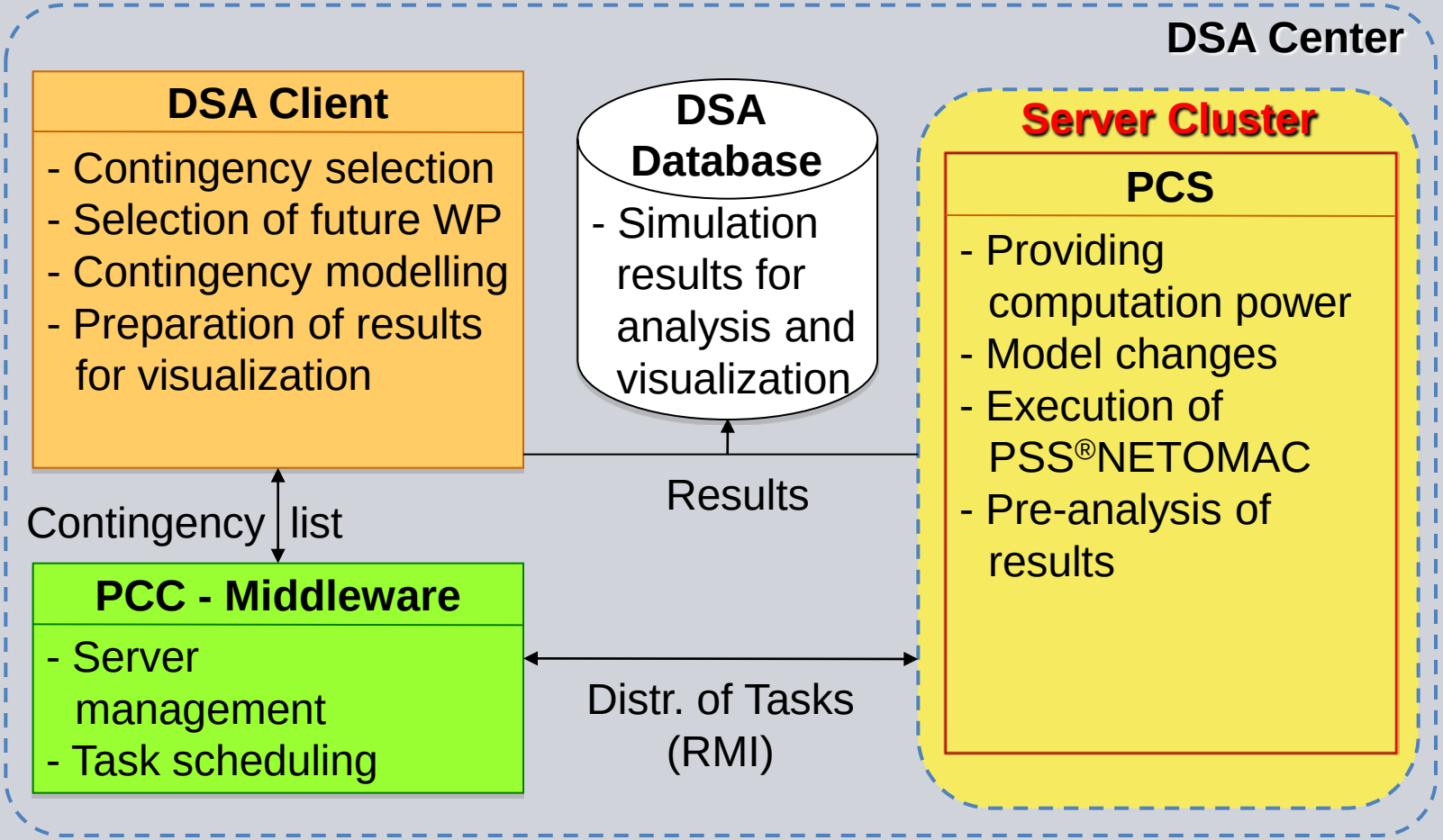

Base for the Dynamic Contingency Calculation
PSS®NETOMAC – Modules

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Steady-state	Time Domain	Linearized	Additional Tools

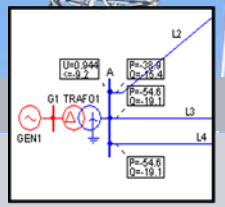
Common Data Base
for system components, machines, ...

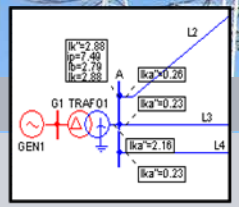
User Interface
NETDRAW (Light) − NetCad /GMB (Professional)

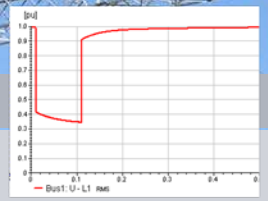
Engine for
PSS®E − PSS®SINCAL

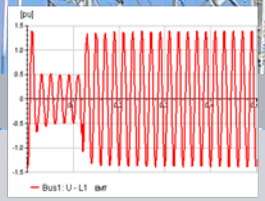
Block-Oriented Simulation Language (BOSL)

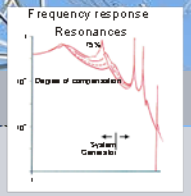
Load Flow Mode	Short Circuit Mode (IEC / ANSI)	Stability Mode	Transient Mode	Frequency Mode	Eigenvalue Mode	Pre- / Post-Processing
Balanced	IEC (3-, 2-, 1-phase)	Balanced	3-phase Representation	Passive Networks	Complete Solution	Import / Export Filter
Unbalanced	ANSI (3-, 2-, 1-phase)	Unbalanced	Differentiated Equations	Active Systems	Partial Solution	Program Automation
DC-Load Flow		Complex Representation	Non-Linearities		Eigenvalue Screening (in Time Domain)	Model Libraries
Controller in Load Flow		Single Line				Event Scenarios
						Optimization Identification
						Dynamic Network Reduction
						PC Real Time











PSS®NETOMAC DSA System Structure
Visualization

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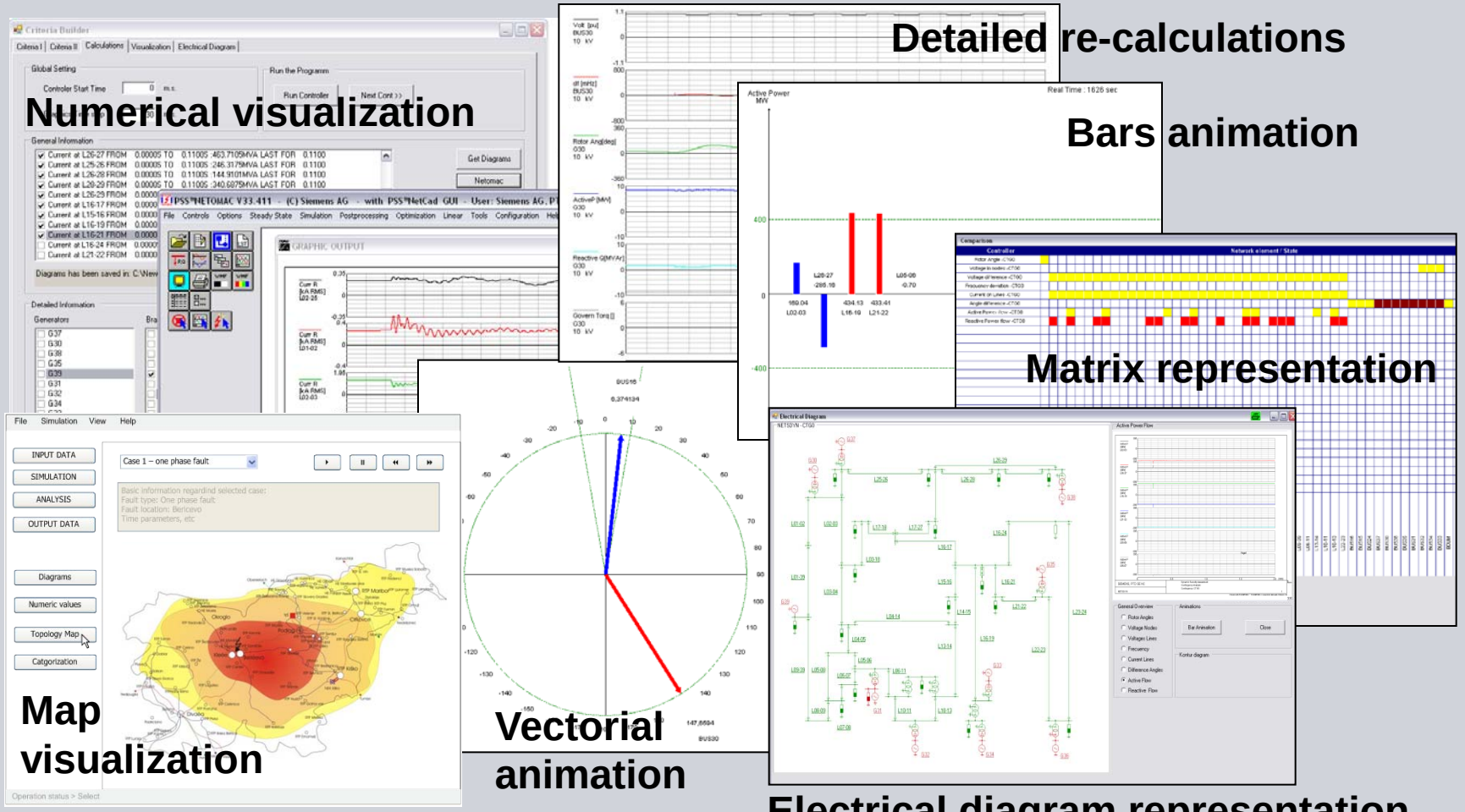

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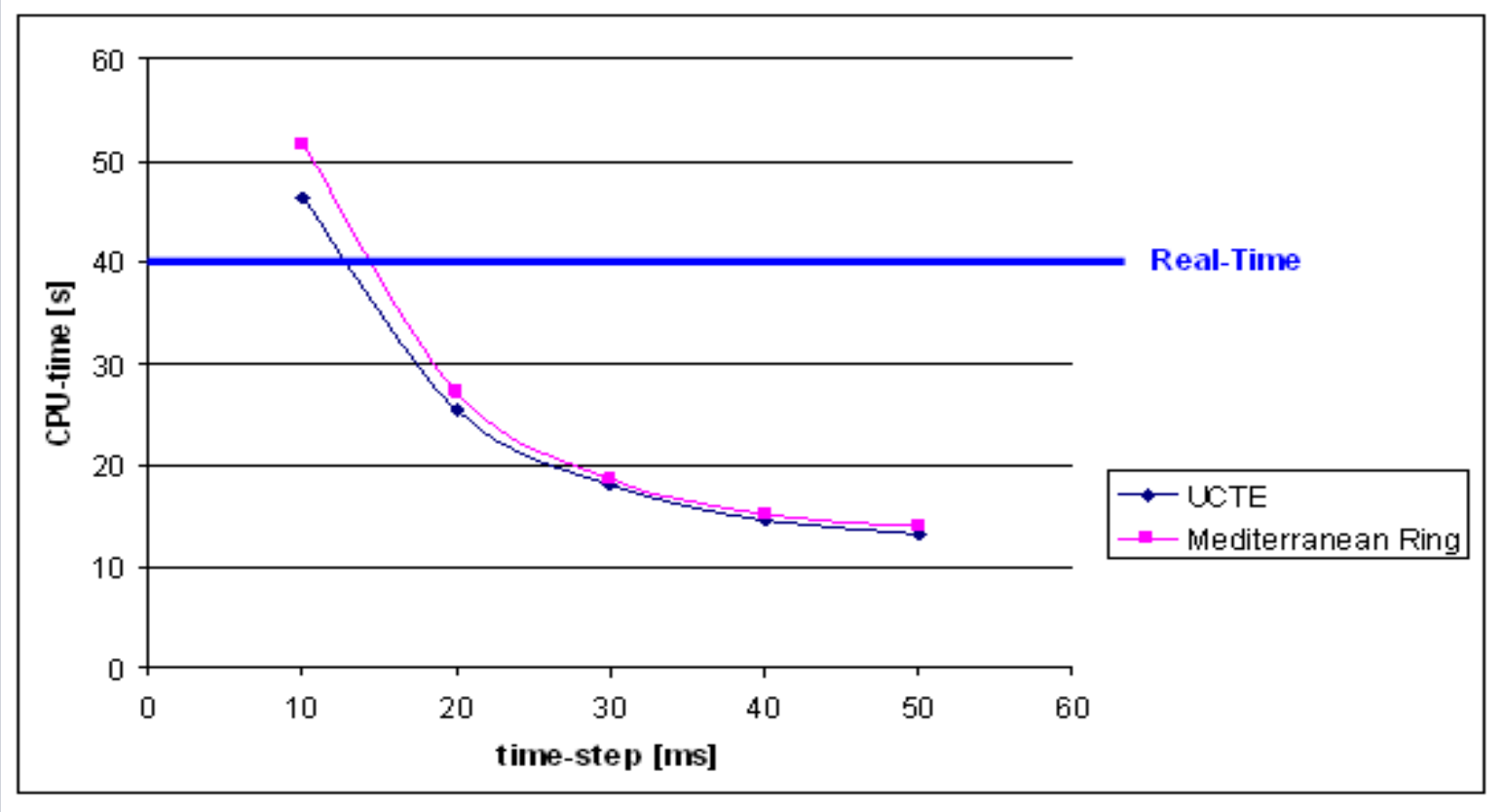
Simulation results and computation time using one CPU



Grid 1: UCTE		Grid 2: Mediterranean Ring	
610	Generator	712	Generator
4.400	Nodes	7.600	Nodes
21.000	Branches	31.200	Branches
1.050	Controller	1.300	Controller

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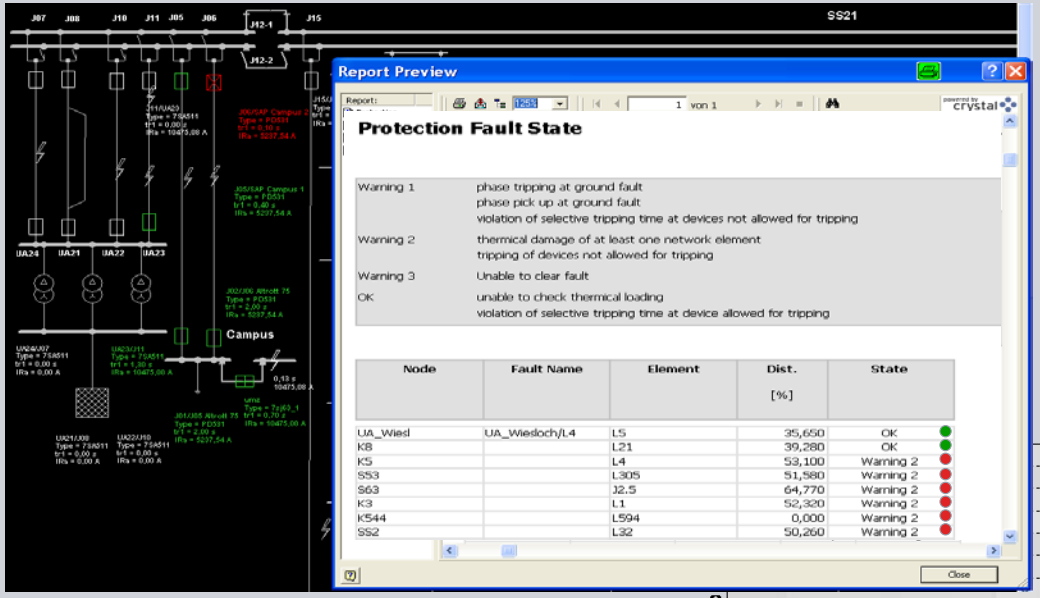
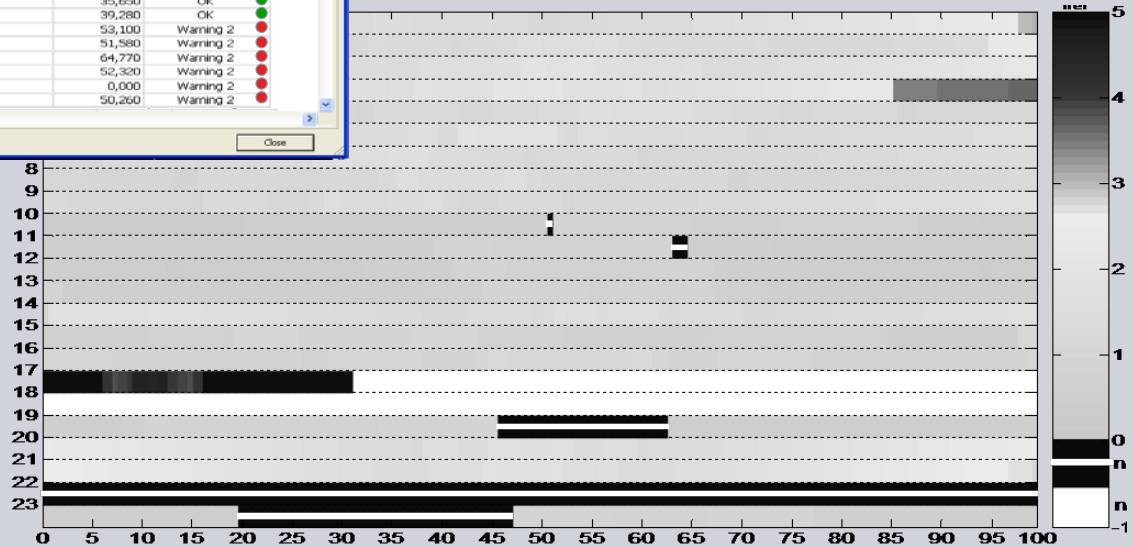
Protection Security Assessment – PSA (1)

- Actual switching and load state
- Data base of installed relays, relay functions, characteristic and settings
- Stepped event simulation (at busbars and along lines)
- Check of relay pick ups and selectivity
- Check of fault clearing time
- Breaker failure and relay failure are simulated and analysed
- Results displayed in tabular and graphical form

Protection Security Assessment – PSA (2)



Results and documentation of PSA with PSS™SINCAL graphical selectivity presentation and selectivity evaluation



Results and documentation of PSA for localisation of unselectivities

Horizontal axis: fault at line length 0% ... 100%
Vertical axis: line number
Grey scales: fault clearing time
White: no protection trip
Black-white: non selective trip

Morocco Project
(FAT February / March 2009)

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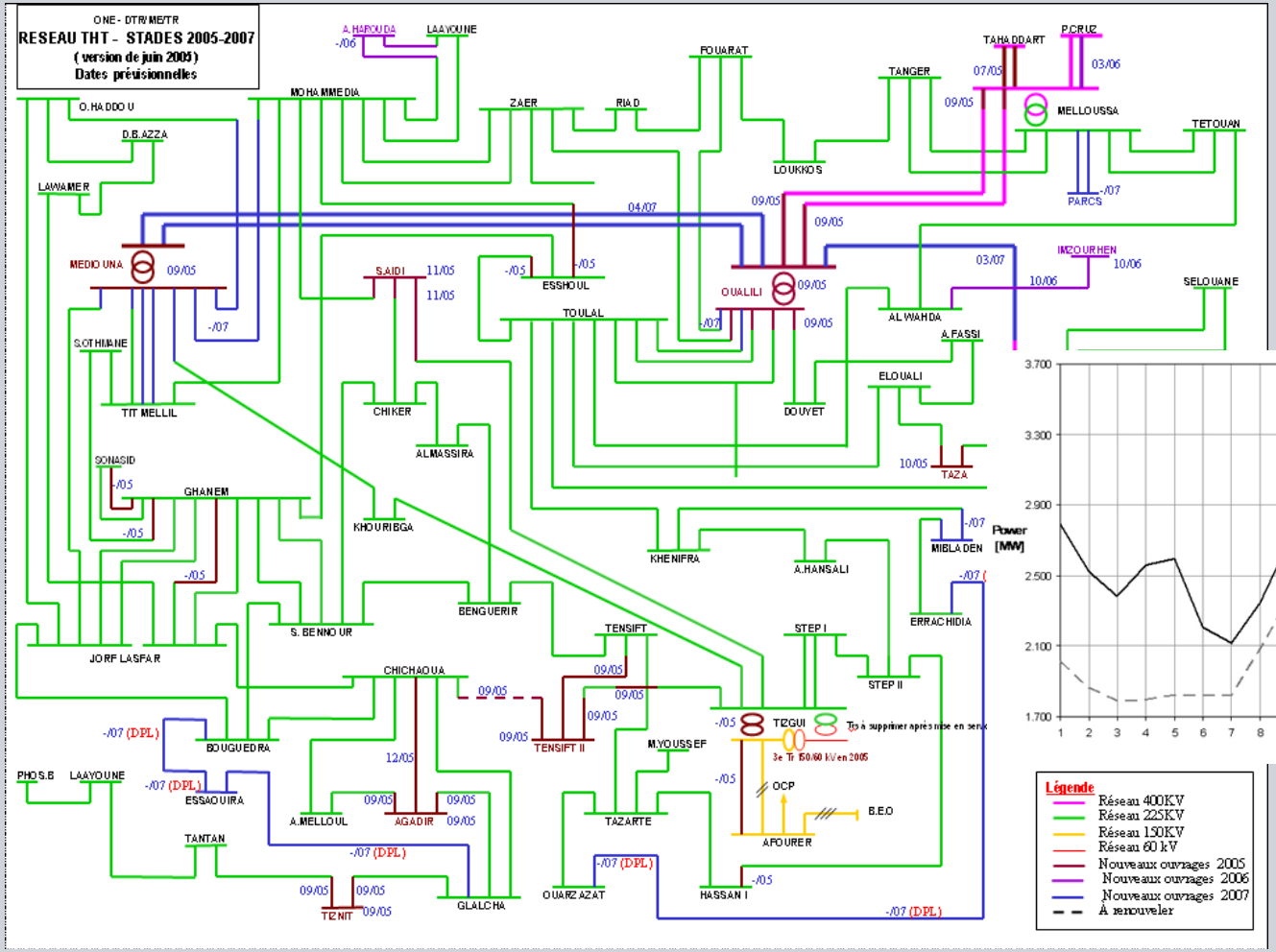

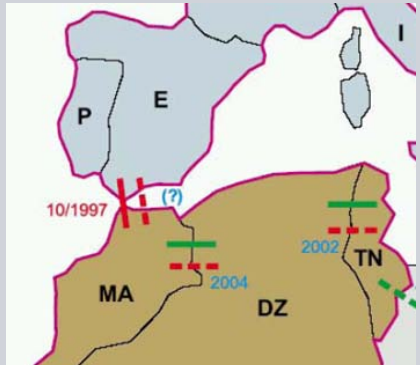

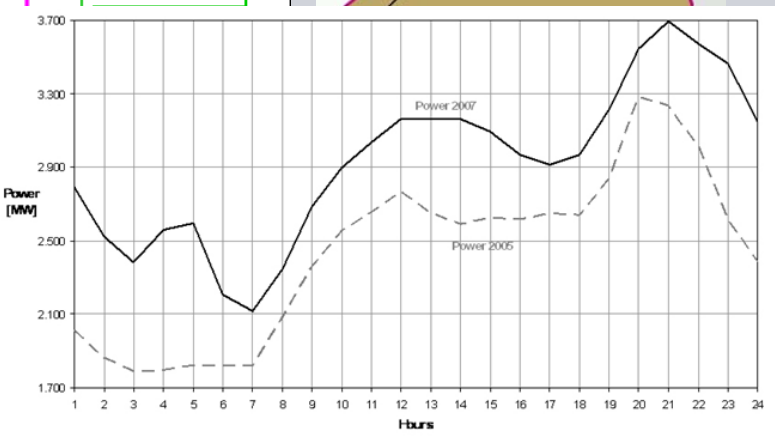

~ 700 buses
~ 70 plants
~ typical load: 3000 MW

DSA System Structure
Implementation in the SINAUT Spectrum System

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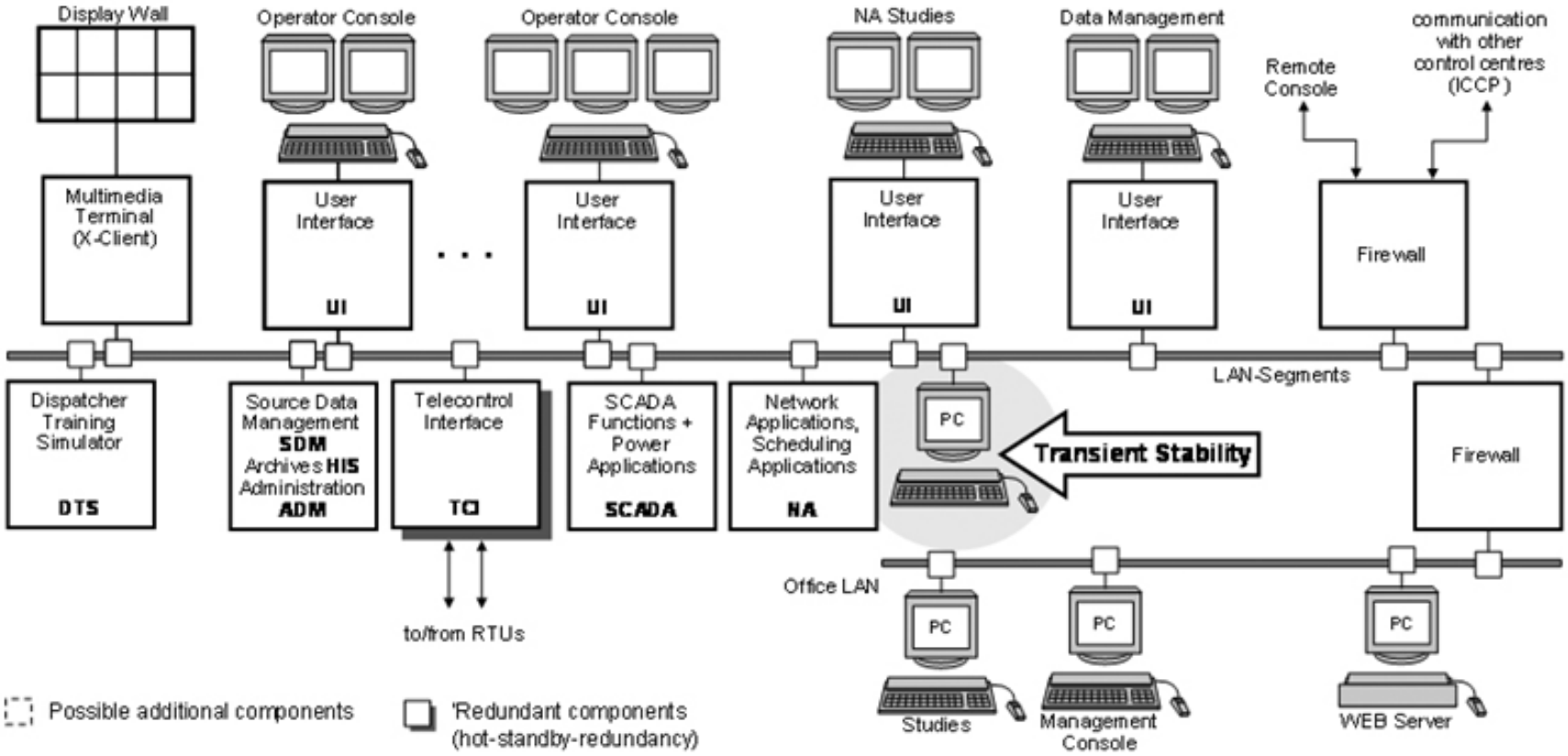

DSA System Structure
Principle Data Flow DSA - NA

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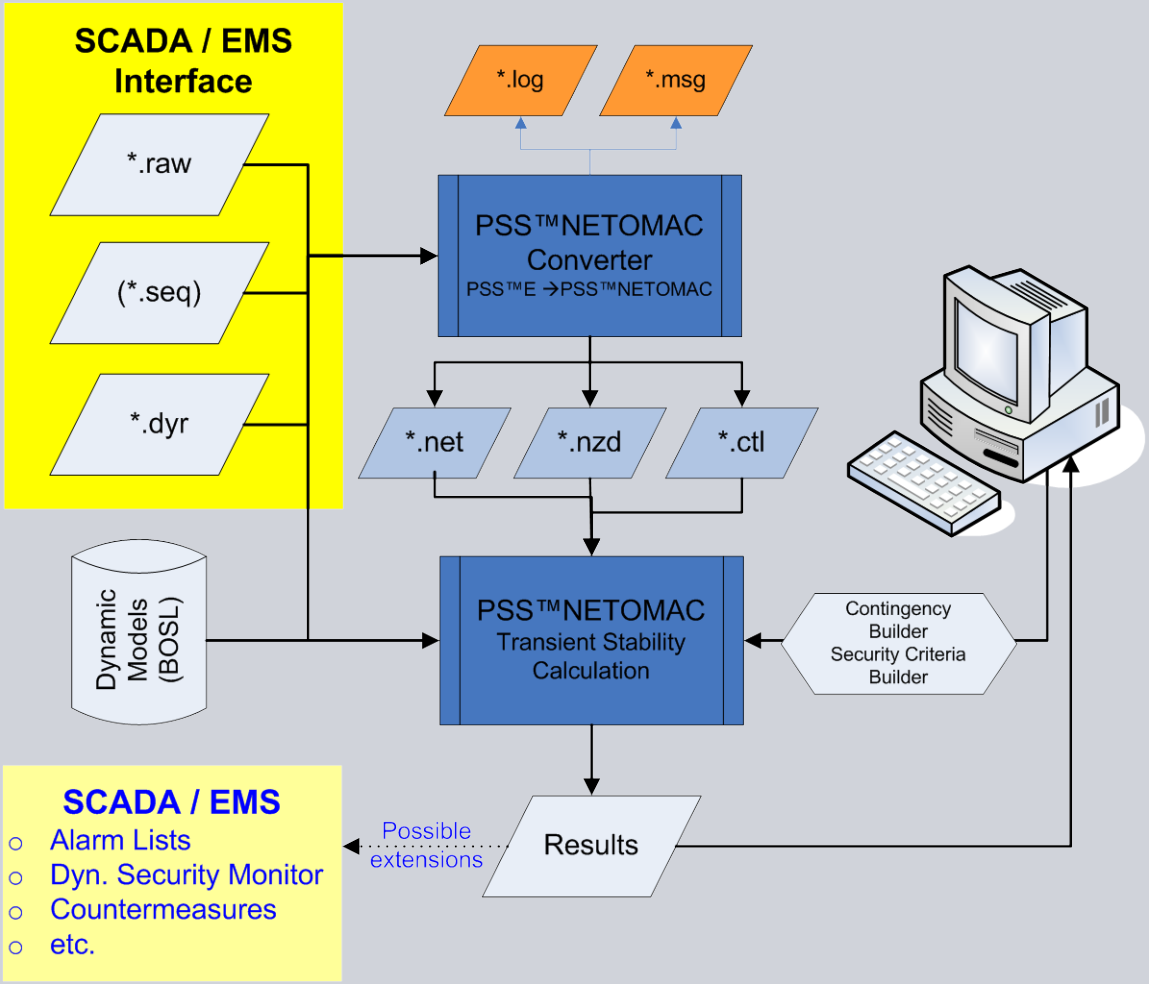

Morocco Project
15-minutes cyclic cuts from EMS

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081127_0015_RealTime.raw	27.11.2008 01:15
081127_0030_RealTime.raw	27.11.2008 01:30
081127_0045_RealTime.raw	27.11.2008 01:45
081127_0100_RealTime.raw	27.11.2008 02:00
081127_0115_RealTime.raw	27.11.2008 02:15
081127_0130_RealTime.raw	27.11.2008 02:30
081127_0145_RealTime.raw	27.11.2008 02:45
081127_0200_RealTime.raw	27.11.2008 03:00
081127_0215_RealTime.raw	27.11.2008 03:15
081127_0230_RealTime.raw	27.11.2008 03:30
081127_0245_RealTime.raw	27.11.2008 03:45
081127_0300_RealTime.raw	27.11.2008 04:00
081127_0315_RealTime.raw	27.11.2008 04:15
081127_0330_RealTime.raw	27.11.2008 04:30
081127_0345_RealTime.raw	27.11.2008 04:45
081127_0400_RealTime.raw	27.11.2008 05:00
081127_0415_RealTime.raw	27.11.2008 05:15
081127_0430_RealTime.raw	27.11.2008 05:30
081127_0445_RealTime.raw	27.11.2008 05:45
081127_0500_RealTime.raw	27.11.2008 06:00
081127_0515_RealTime.raw	27.11.2008 06:15
081127_0530_RealTime.raw	27.11.2008 06:30
081127_0545_RealTime.raw	27.11.2008 06:45
081127_0600_RealTime.raw	27.11.2008 07:00

```
0,  100.0
27.11.08 03:00:0     Results of  SE     Start:  cyclic    00
PSS/E version 30     P/Q_load:   1701.80 MW     367.941 Mvar
    1,'IMF60S      ',60.0000,1,        0,        0, 1, 1,1.0648,-5.2773,1
    2,'Hans25S1    ',225.000,1,        0,        0, 1, 1,1.0230,-18.975,1
    3,'ElOu25S1    ',225.000,1,        0,        0, 1, 1,1.0455,-11.429,1
    4,'ElO60I1     ',60.0000,1,        0,        0, 1, 1,1.0995,-13.347,1
    5,'ElOVS_T1    ',60.0000,1,        0,        0, 1, 1,1.0982,-13.495,1
    6,'ElOVS_T2    ',60.0000,1,        0,        0, 1, 1,1.1002,-13.448,1
    7,'Fes60S1     ',60.0000,1,        0,        0, 1, 1,1.0811,-13.876,1
    8,'SKHIR60S1   ',60.0000,1,        0,        0, 1, 1,1.0597,-14.384,1
    9,'SEH25S      ',225.000,1,        0,        0, 1, 1,1.0422,-10.967,1
   10,'SEH25I      ',225.000,1,        0,        0, 1, 1,1.0422,-10.967,1
   11,'SEH60S      ',60.0000,1,        0,        0, 1, 1,1.0424,-11.547,1
   12,'SEHVST1     ',60.0000,1,        0,        0, 1, 1,1.0424,-11.593,1
   13,'O_H25S1     ',225.000,1,        0,        0, 1, 1,1.0257,-9.5718,1
   14,'jb NOUACEUR ',60.0000,2,        0,        0, 1, 4,1.1021,-13.077,1
   15,'CTM25I23    ',225.000,1,        0,        0, 1, 1,1.0390,-11.153,1
   16,'CTM25S1     ',225.000,1,        0,        0, 1, 1,1.0390,-11.153,1
```

- CTL
- DIS
- NEX
- PLOT
- RESULT
- 081127_0000_REALTIME.net
- 081127_1200_REALTIME.net
- 081127_2000_REALTIME.net
- 081128_0800_REALTIME.net
- 081128_1200_REALTIME.net
- 081128_1600_REALTIME.net

Conversions from PSS®E to PSS®NETOMAC

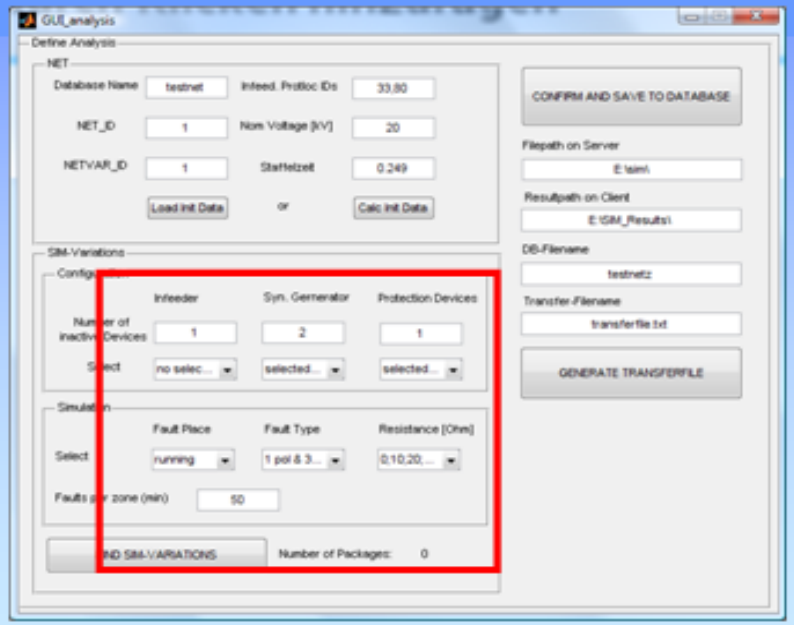
[N]279 [LaW25S1 225.00]	0.9661	-16.773
[N]283 [SiO25S1 225.00]	1.0111	-17.174
[N]287 [TIT25S1 225.00]	1.0127	-17.245
[N]294 [SiBo25S1 225.00]	1.0404	-16.633
[N]164 [LaaLy25I 225.00]	1.0176	-17.680
[N]163 [LaaLy25S 225.00]	1.0180	-17.549
[N]162 [LSahVSS_ 225.00]	1.0217	-45.254
[N]3 [ElOu25S1 225.00]	1.0345	-17.712

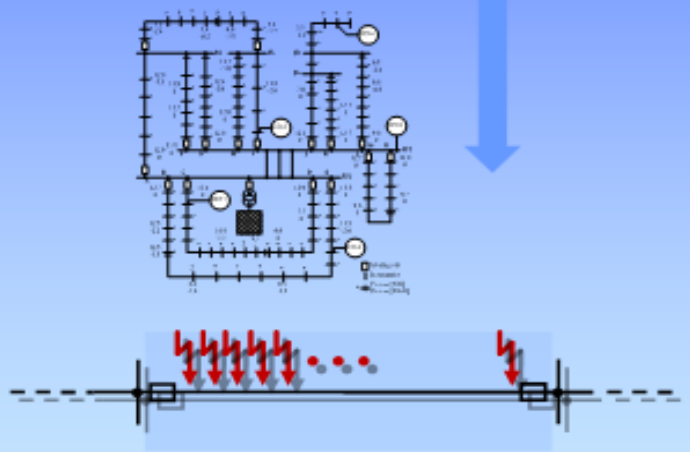
Scenario Configuration

Network configuration
- Infeed condition
- DG conditions

Protection configuration
- type of protection
- back-up protection
- protection failure

Fault conditions
- Type of fault (1p, 3p)
- Fault impedance
- Fault location
- Number of faults



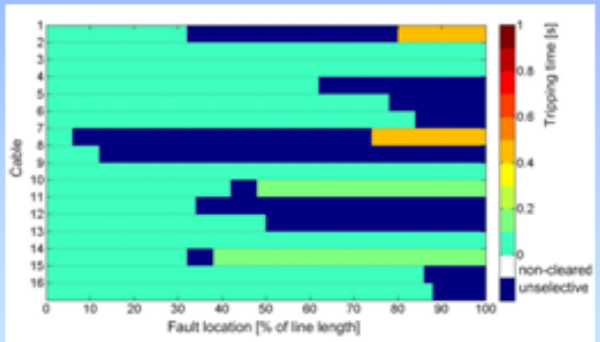


„Running fault method“

Evaluation of Simulation Results

Network and Protection Simulation
Protection Reliability – Dependability and Security

Fault Pattern Analysis "Finger-Prints"



Economic Impact Assessment