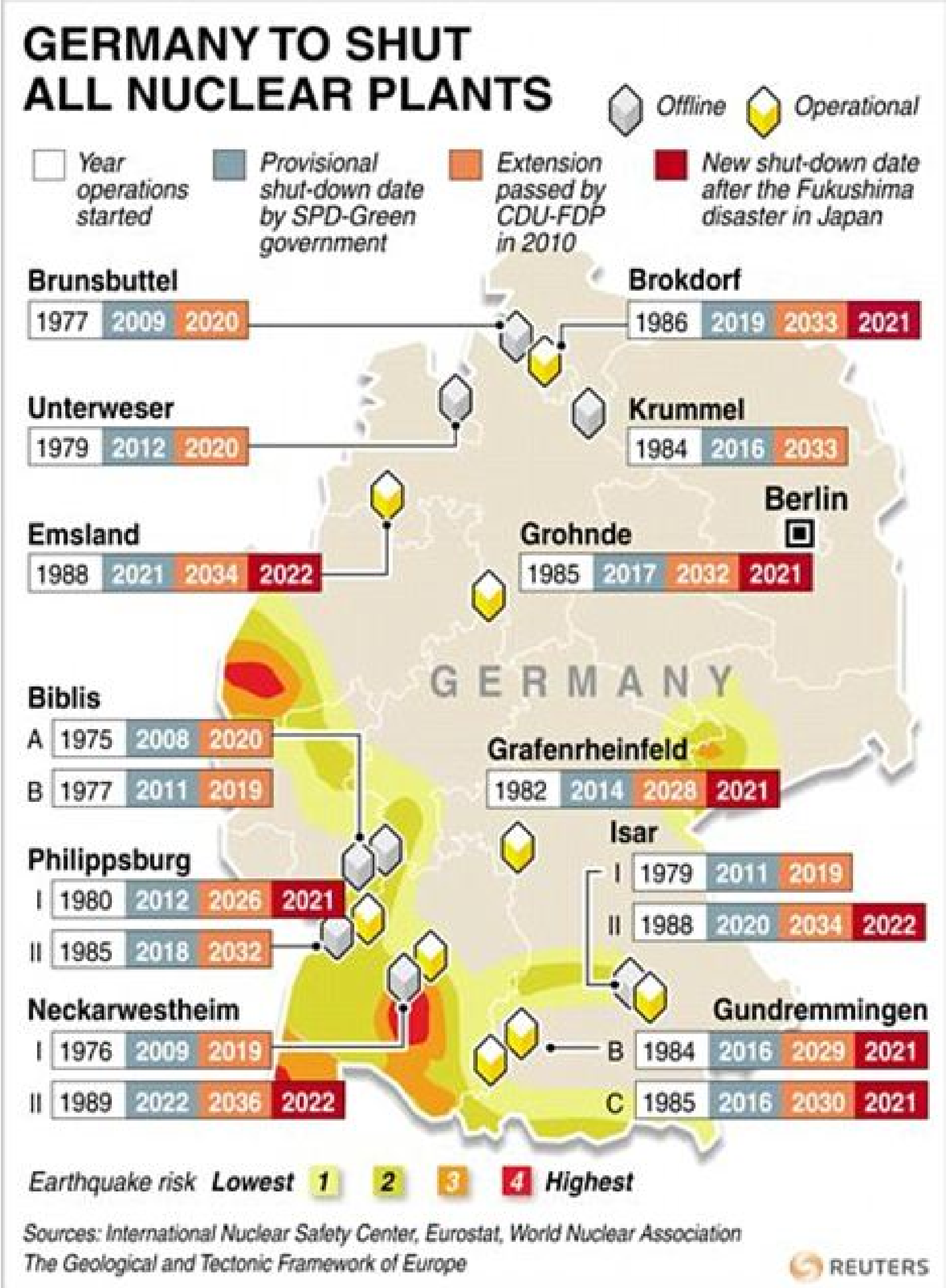
Operational Experience with Synchrophasors at a National Transmission Operations Center

Stefan Steger, TenneT TSO, Germany
Markus Wache, Siemens, Germany
Roy Moxley, Siemens, USA

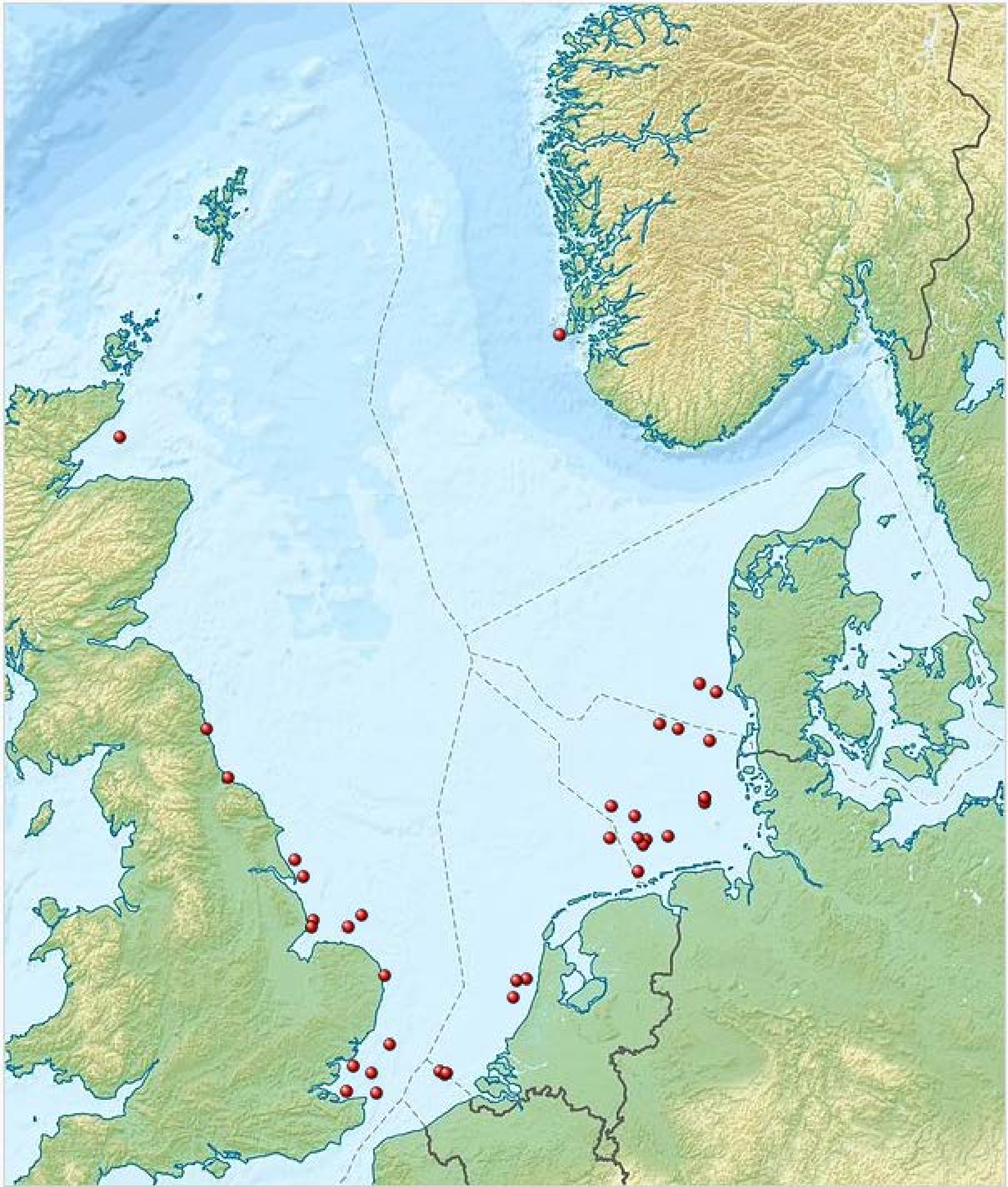
Headlines Impact System Stability

Note the Concentration of Nuclear Plants along the West Edge and the SouthWest



Massive Wind Farms Installed and Planned for the North Sea

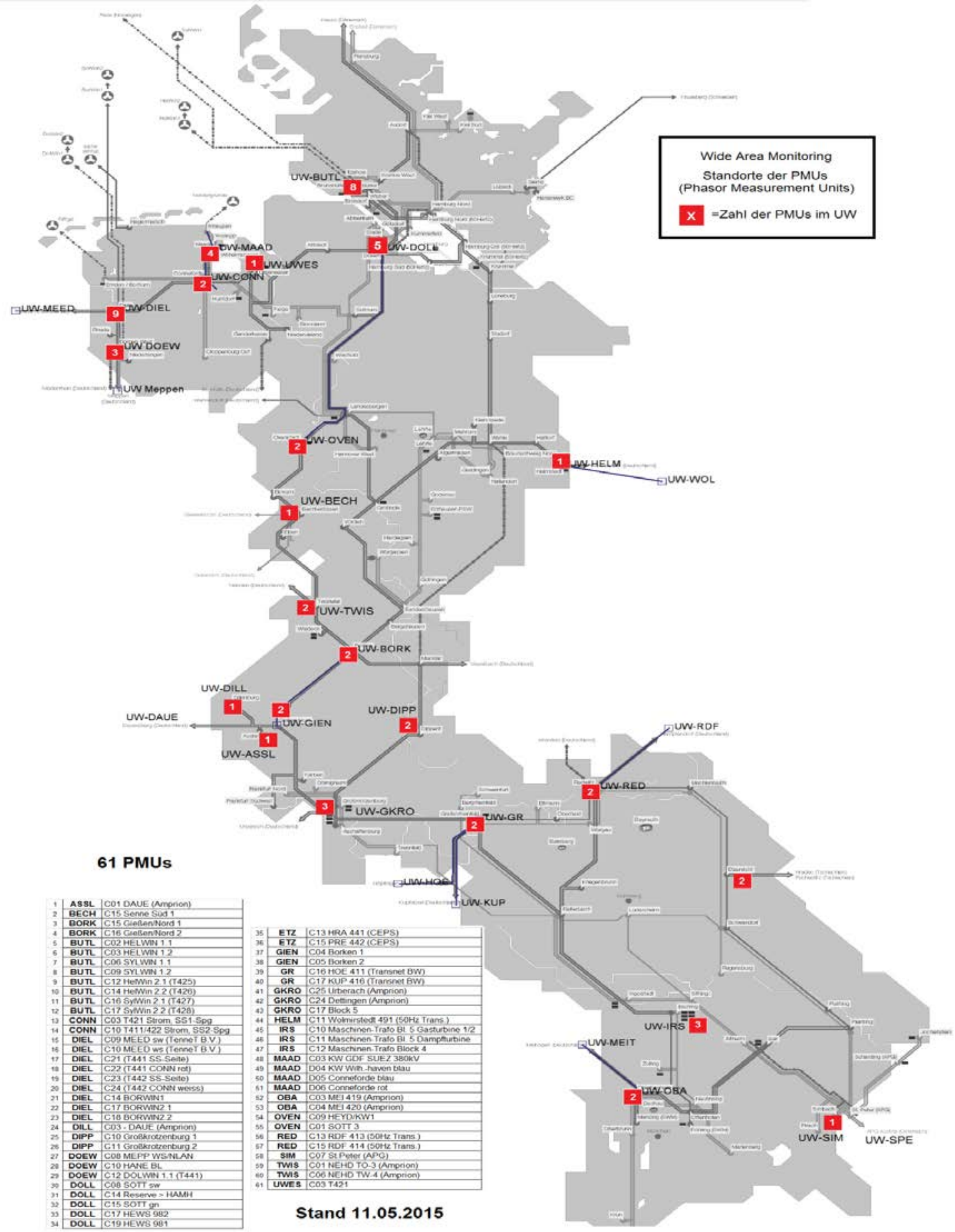
8 GW Installed and 2.9 Awaiting Installation



TenneT Service Area

Based in the Netherlands and South along Germany's Western Edge

- 21,000 km 400 and 110 kV lines
- 403 Substations
- 67 GW installed Generation
- 182,000 km^2 supplied area



61 PMUs

1	**ASSL**	C01 DAUE (Amprion)
2	**BECH**	C15 Senne Süd 1
3	**BORK**	C15 Gießen/Nord 1
4	**BORK**	C16 Gießen/Nord 2
5	**BUTL**	C02 HELWIN 1.1
6	**BUTL**	C03 HELWIN 1.2
7	**BUTL**	C06 SYLWIN 1.1
8	**BUTL**	C09 SYLWIN 1.2
9	**BUTL**	C12 HelWin 2.1 (T425)
10	**BUTL**	C14 HelWin 2.2 (T426)
11	**BUTL**	C16 SylWin 2.1 (T427)
12	**BUTL**	C17 SylWin 2.2 (T428)
13	**CONN**	C03 T421 Strom, SS1-Spg
14	**CONN**	C10 T411/422 Strom, SS2-Spg
15	**DIEL**	C09 MEED sw (TenneT B.V.)
16	**DIEL**	C10 MEED ws (TenneT B.V.)
17	**DIEL**	C21 (T441 SS-Seite)
18	**DIEL**	C22 (T441 CONN rot)
19	**DIEL**	C23 (T442 SS-Seite)
20	**DIEL**	C24 (T442 CONN weiss)
21	**DIEL**	C14 BORWIN1
22	**DIEL**	C17 BORWIN2.1
23	**DIEL**	C18 BORWIN2.2
24	**DILL**	C03 - DAUE (Amprion)
25	**DIPP**	C10 Großkrotzenburg 1
26	**DIPP**	C11 Großkrotzenburg 2
27	**DOEW**	C08 MEPP WS/NLAN
28	**DOEW**	C10 HANE BL
29	**DOEW**	C12 DOLWIN 1.1 (T441)
30	**DOLL**	C08 SOTT sw
31	**DOLL**	C14 Reserve > HAMH
32	**DOLL**	C15 SOTT gn
33	**DOLL**	C17 HEWS 982
34	**DOLL**	C19 HEWS 981

35	**ETZ**	C13 HRA 441 (CEPS)
36	**ETZ**	C15 PRE 442 (CEPS)
37	**GIEN**	C04 Borken 1
38	**GIEN**	C05 Borken 2
39	**GR**	C16 HOE 411 (Transnet BW)
40	**GR**	C17 KUP 416 (Transnet BW)
41	**GKRO**	C25 Urberach (Amprion)
42	**GKRO**	C24 Dettingen (Amprion)
43	**GKRO**	C17 Block 5
44	**HELM**	C11 Wolmirstedt 491 (50Hz Trans.)
45	**IRS**	C10 Maschinen-Trafo Bl. 5 Gasturbine 1/2
46	**IRS**	C11 Maschinen-Trafo Bl. 5 Dampfturbine
47	**IRS**	C12 Maschinen-Trafo Block 4
48	**MAAD**	C03 KW GDF SUEZ 380kV
49	**MAAD**	D04 KW Wilh.-haven blau
50	**MAAD**	D05 Conneforde blau
51	**MAAD**	D06 Conneforde rot
52	**OBA**	C03 MEI 419 (Amprion)
53	**OBA**	C04 MEI 420 (Amprion)
54	**OVEN**	C09 HEYD/KW1
55	**OVEN**	C01 SOTT 3
56	**RED**	C13 RDF 413 (50Hz Trans.)
57	**RED**	C15 RDF 414 (50Hz Trans.)
58	**SIM**	C07 St Peter (APG)
59	**TWIS**	C01 NEHD TO-3 (Amprion)
60	**TWIS**	C06 NEHD TW-4 (Amprion)
61	**UWES**	C03 T421

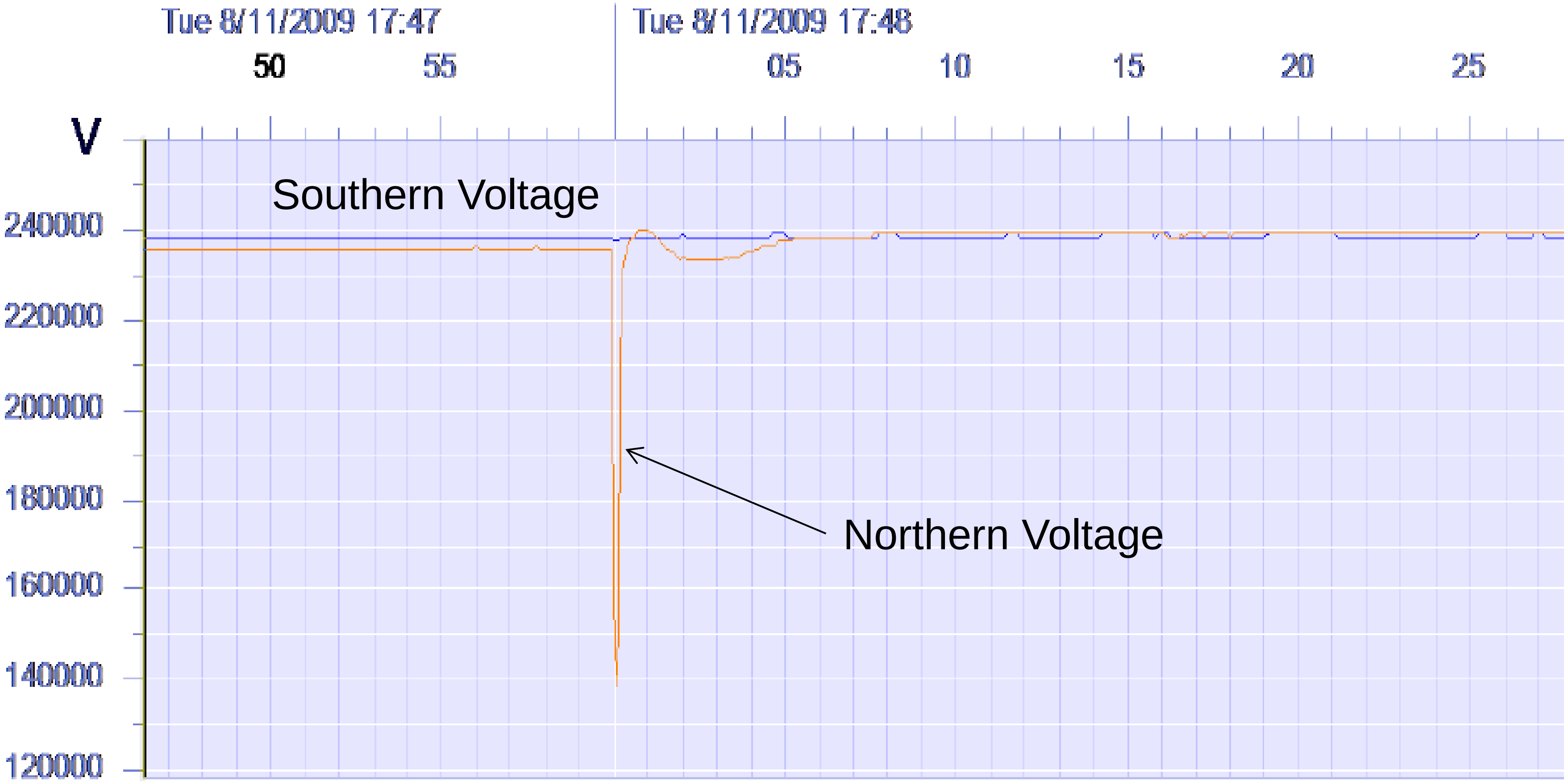
Stand 11.05.2015

Replacing Nuclear with Wind

High Availability
High Inertia
Dynamic Voltage Support

Non-Dispatchable
Low Inertia
No Dynamic Voltage Support

Loss of Northern Power Plant



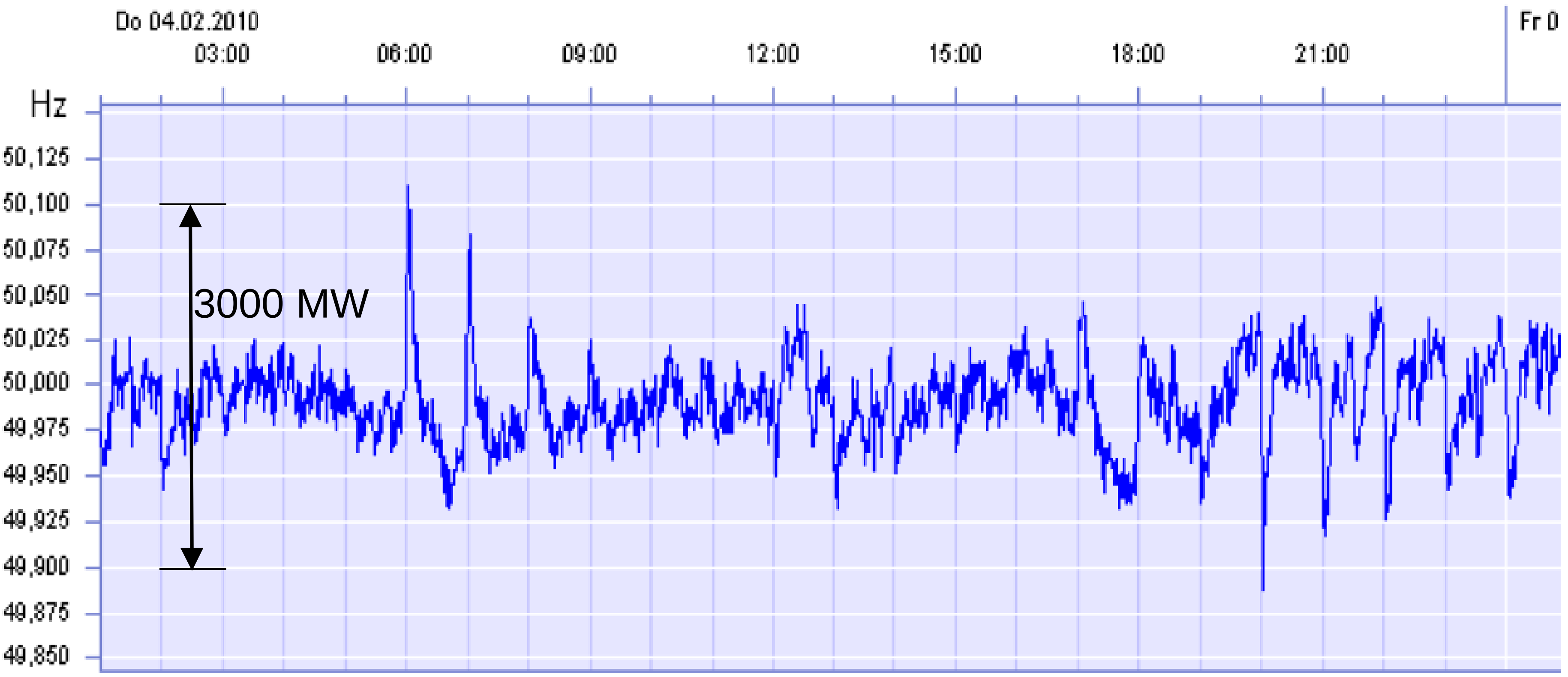
Loss of Northern Power Plant

$$P=V_1V_2\sin\Theta/X$$

Loss of Northern Power Plant

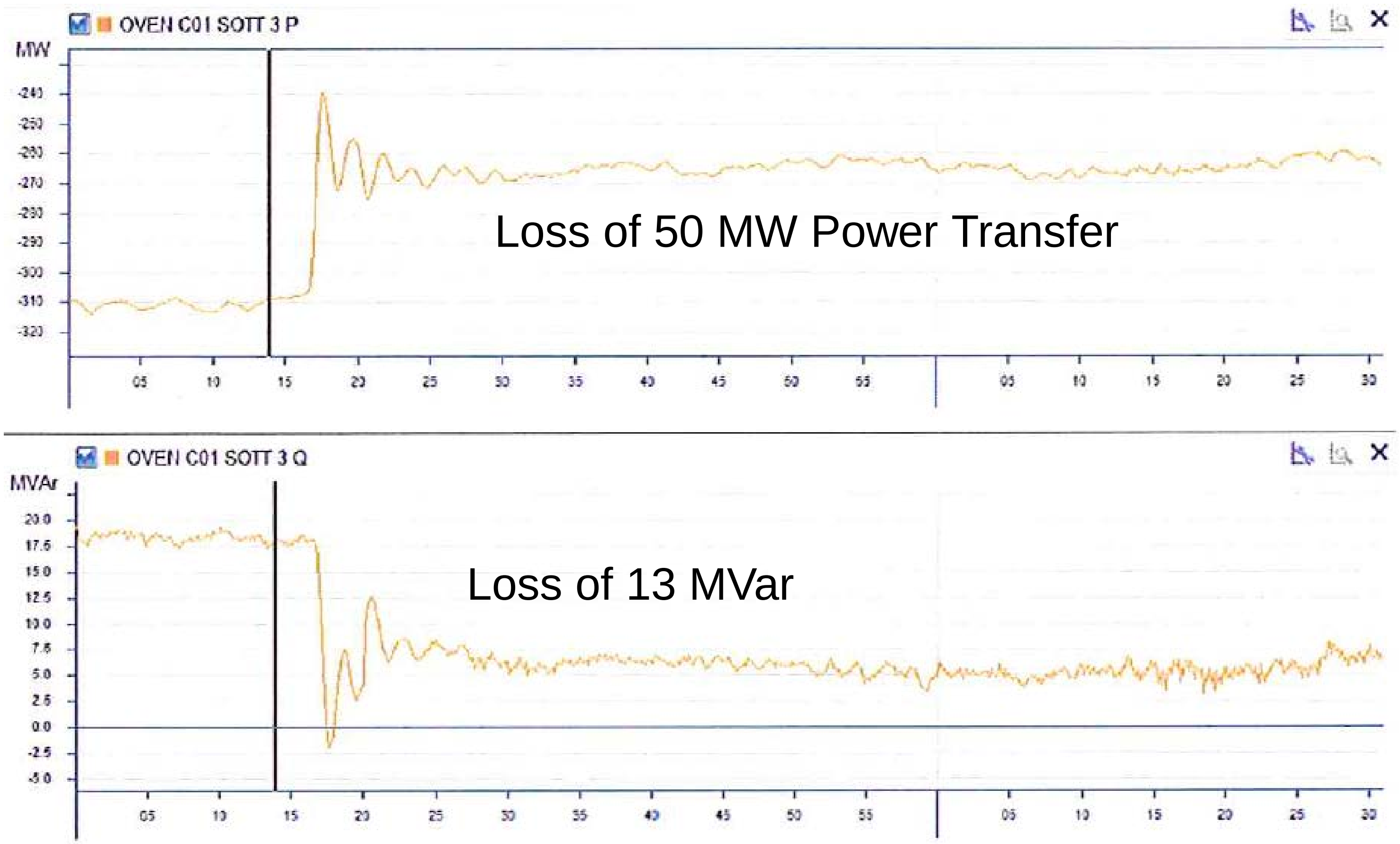
$$P=V_1V_2\sin\Theta/X$$

Frequency Change with Hourly Scheduled Plant Startup - Shutdown

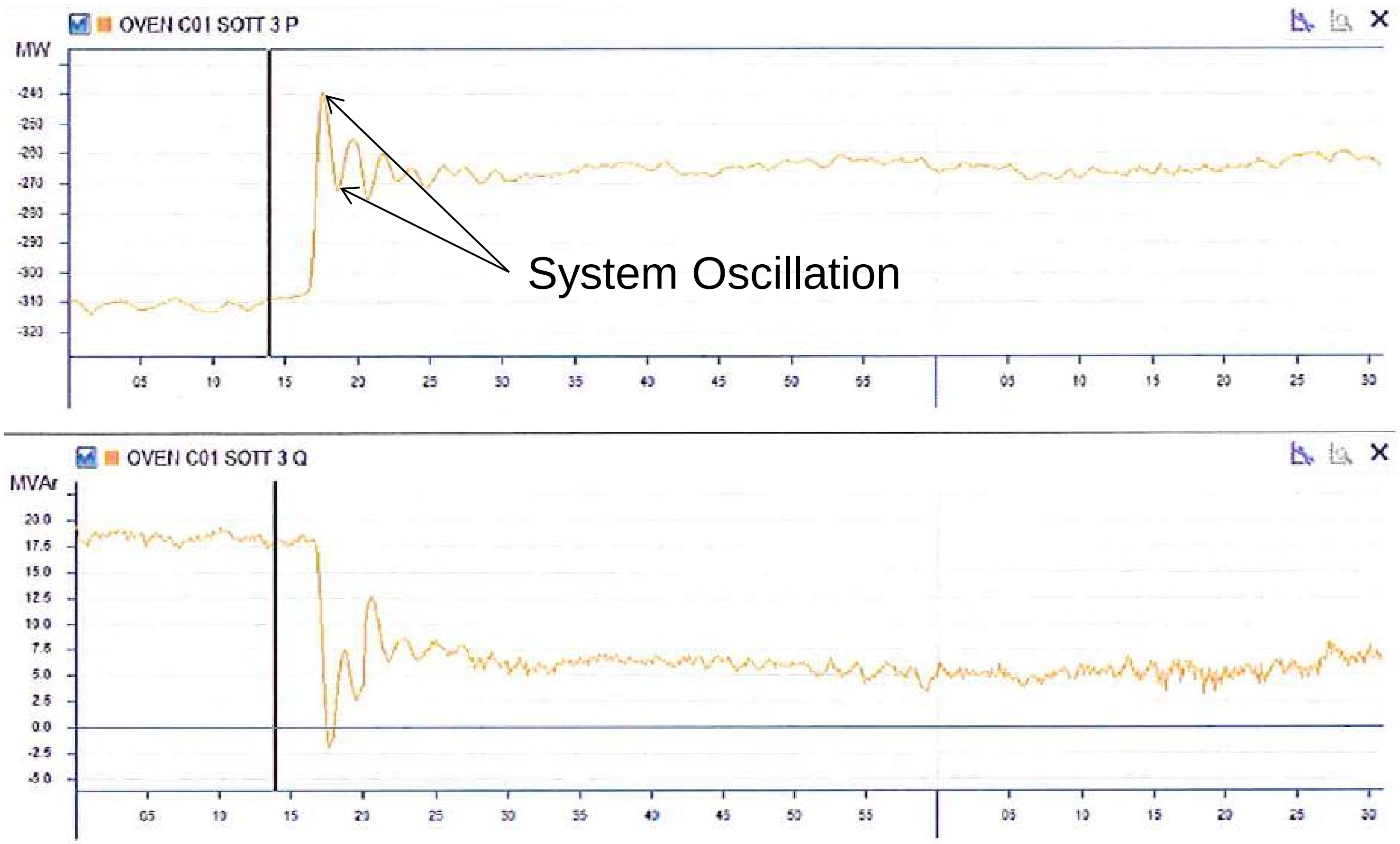


Model Validation, Scheduling Confirmation

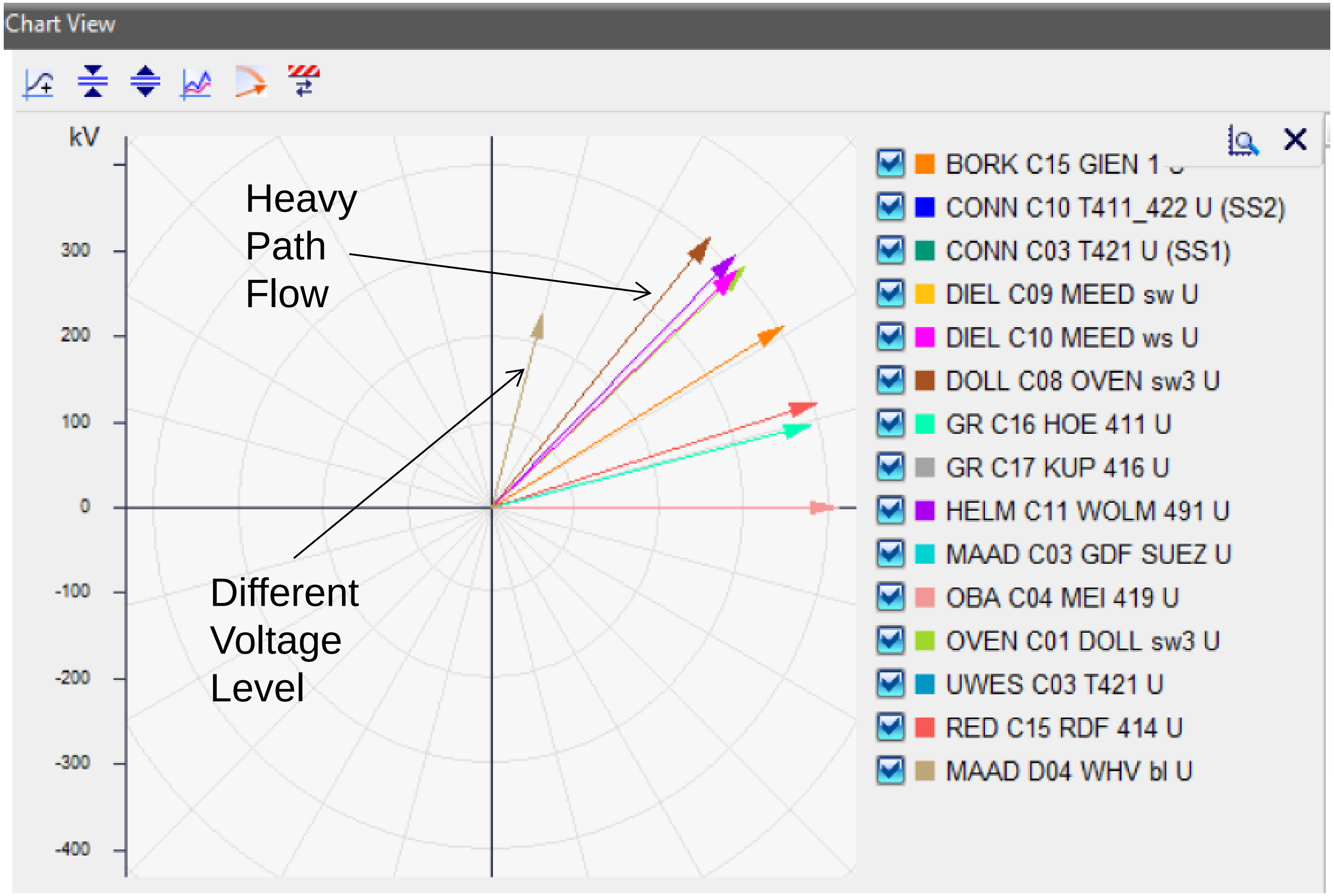
System Impact of a Line Trip



System Impact of a Line Trip

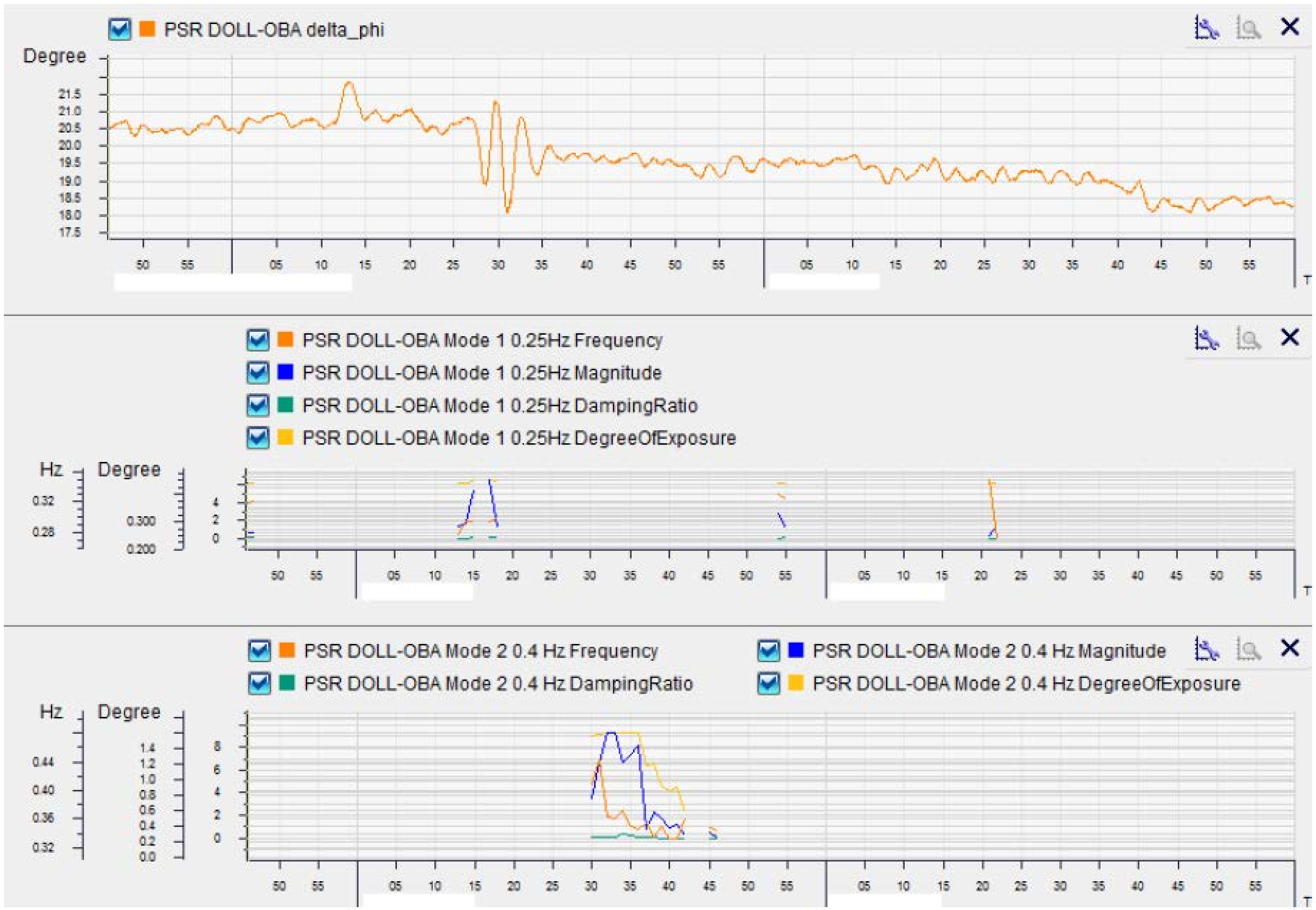


Phasor View in High Load Situation

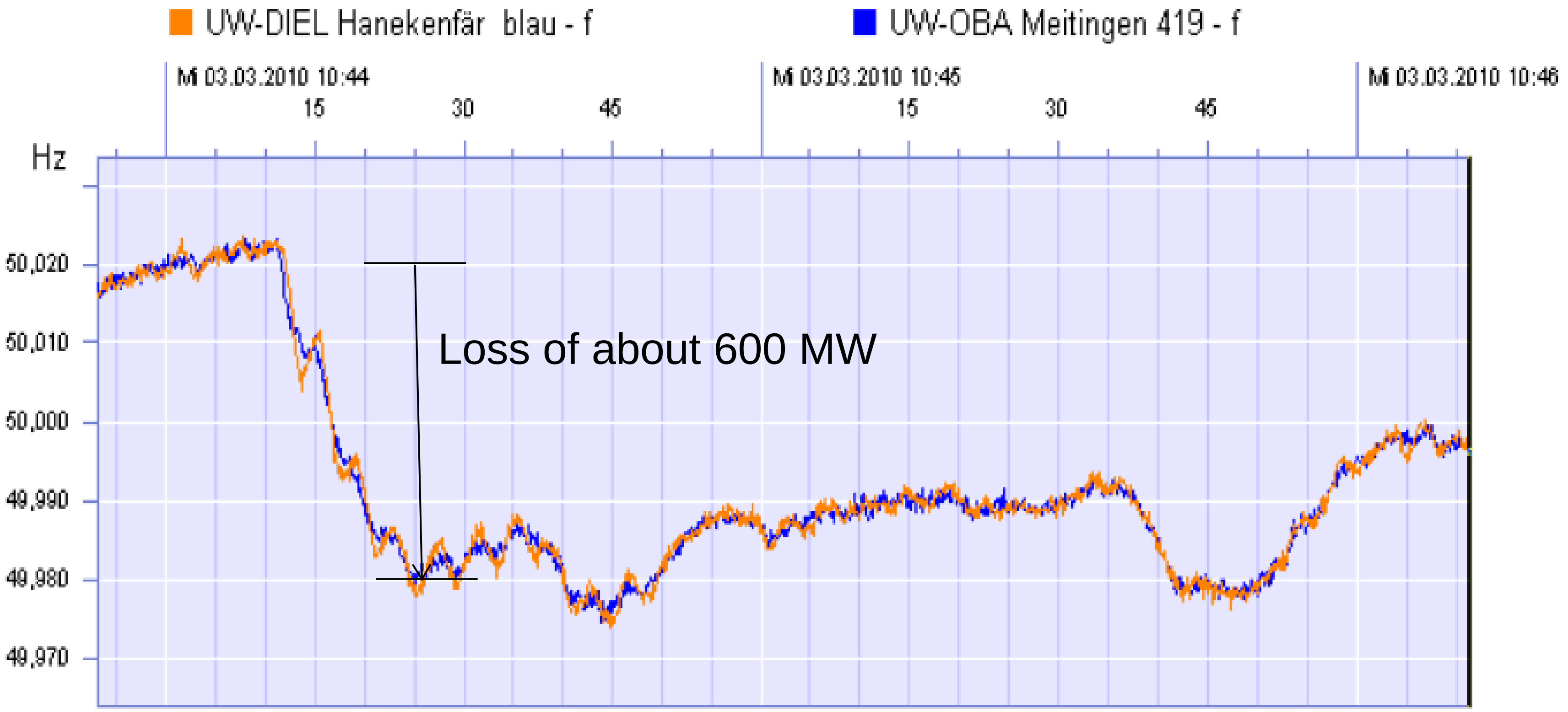


Parallel Paths Included, Summing Paths not Necessary

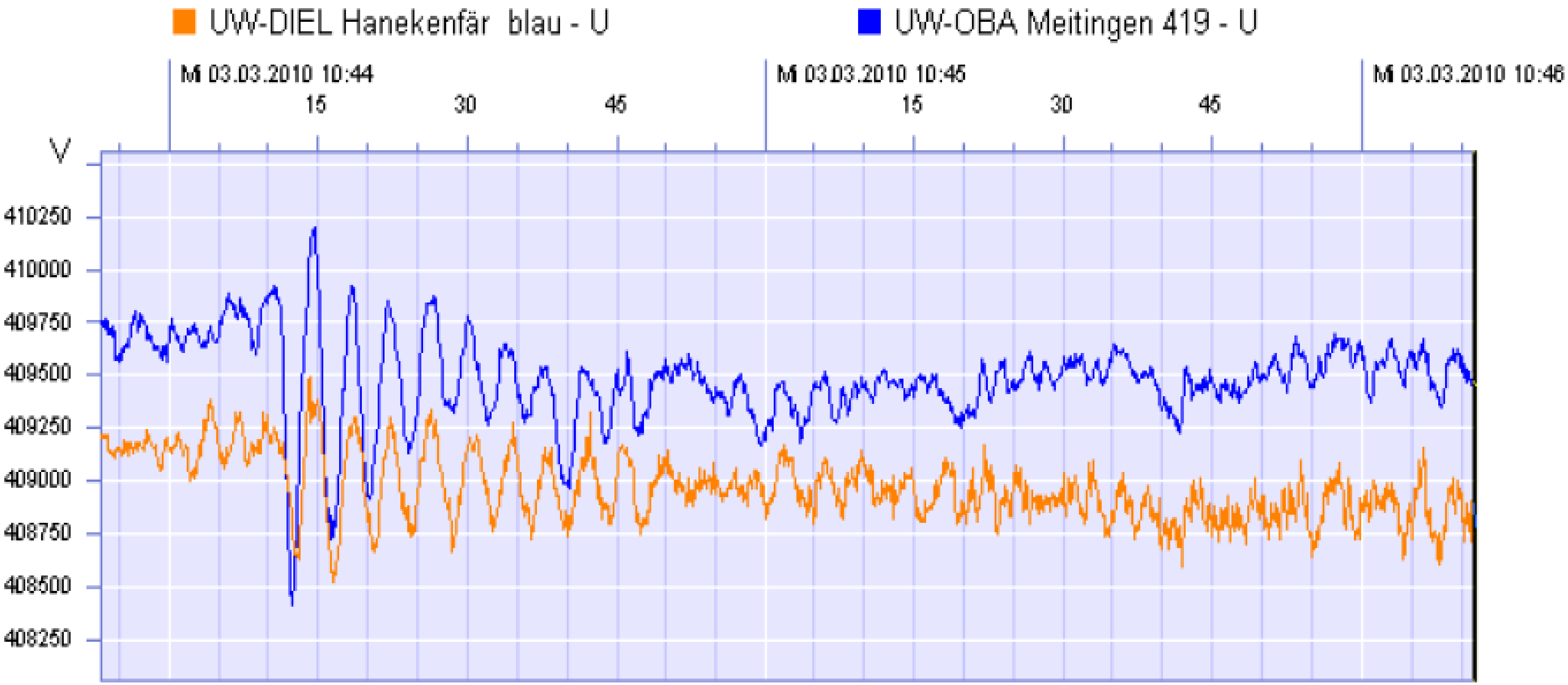
Power Swing Recognition, Alarm and Analysis



Power Plant Trip in Southern Area

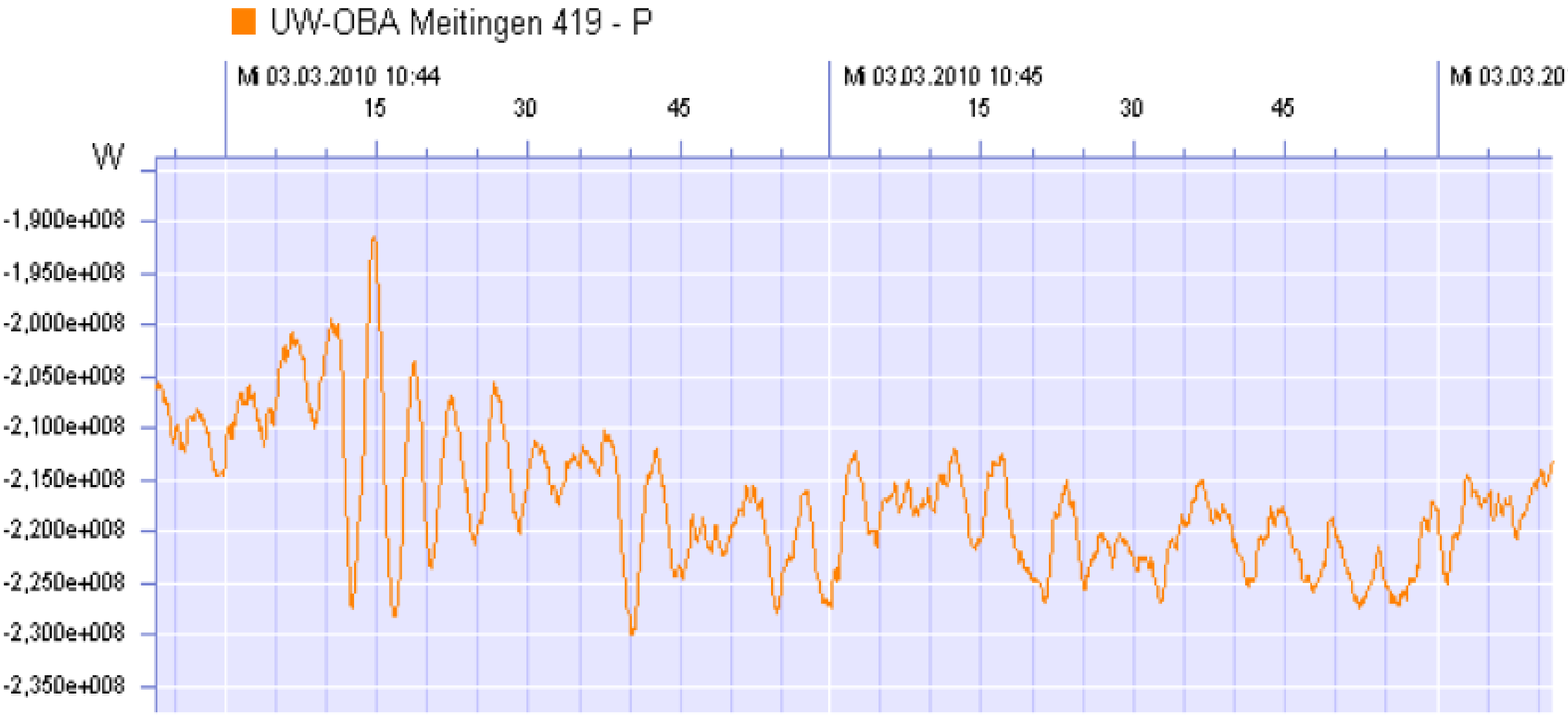


Voltage Oscillations

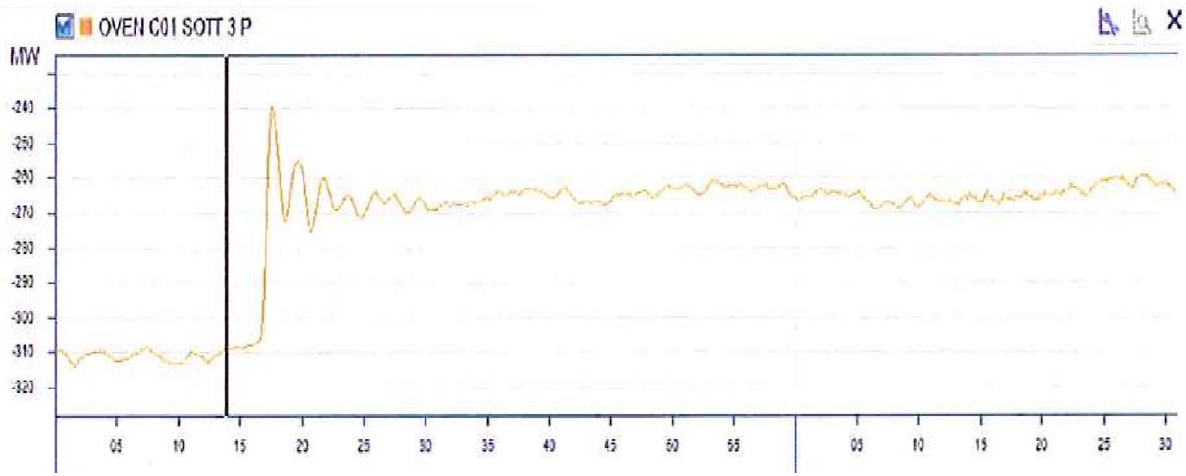


Magnitude not Bad but Poor Damping

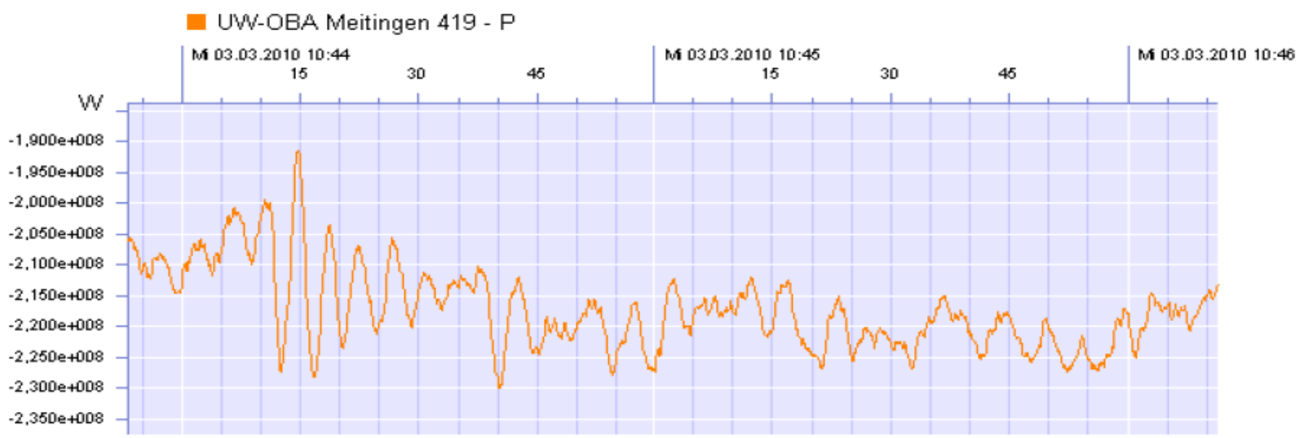
Power Oscillations



Compare Line Trip and Generation Trip



Line Trip



Southern
Generator Trip

SIEMENS

Conclusions and Future Developments

- Synchrophasors Provide Improved Visualization to Operators of the Severity of System Events
- Different Synchrophasor Views Show Events Better – There is no Single Best Viewer
- Synchrophasors can Reduce the Number of Screens Viewed

- Lower System Intertia Means Faster Event Evolution
- Automatic Action to Mitigate Events Will Be Required