ELEC0047 - Power system dynamics, control and stability

Long-term voltage stability : Simulations of the IEEE Nordic Test System

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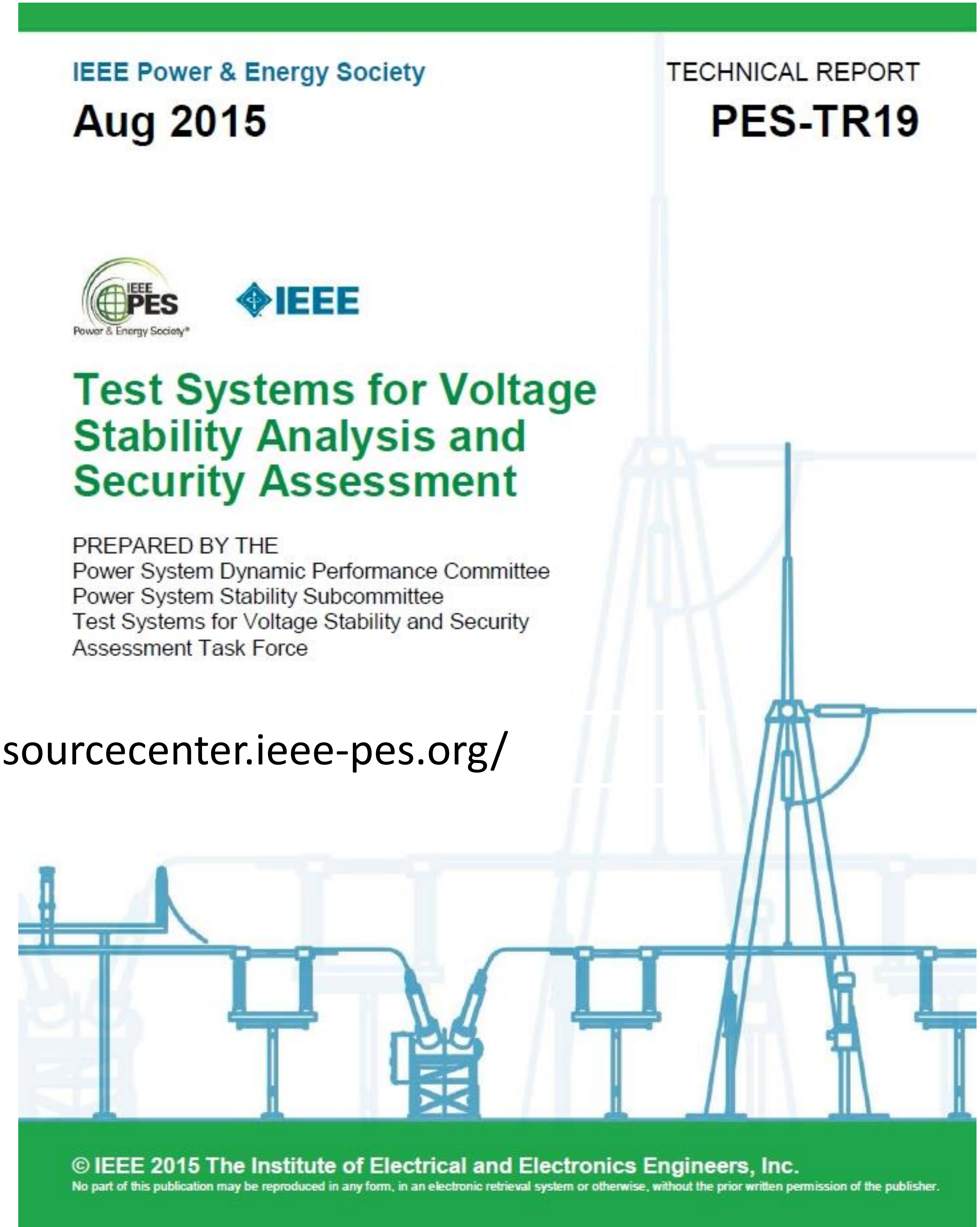

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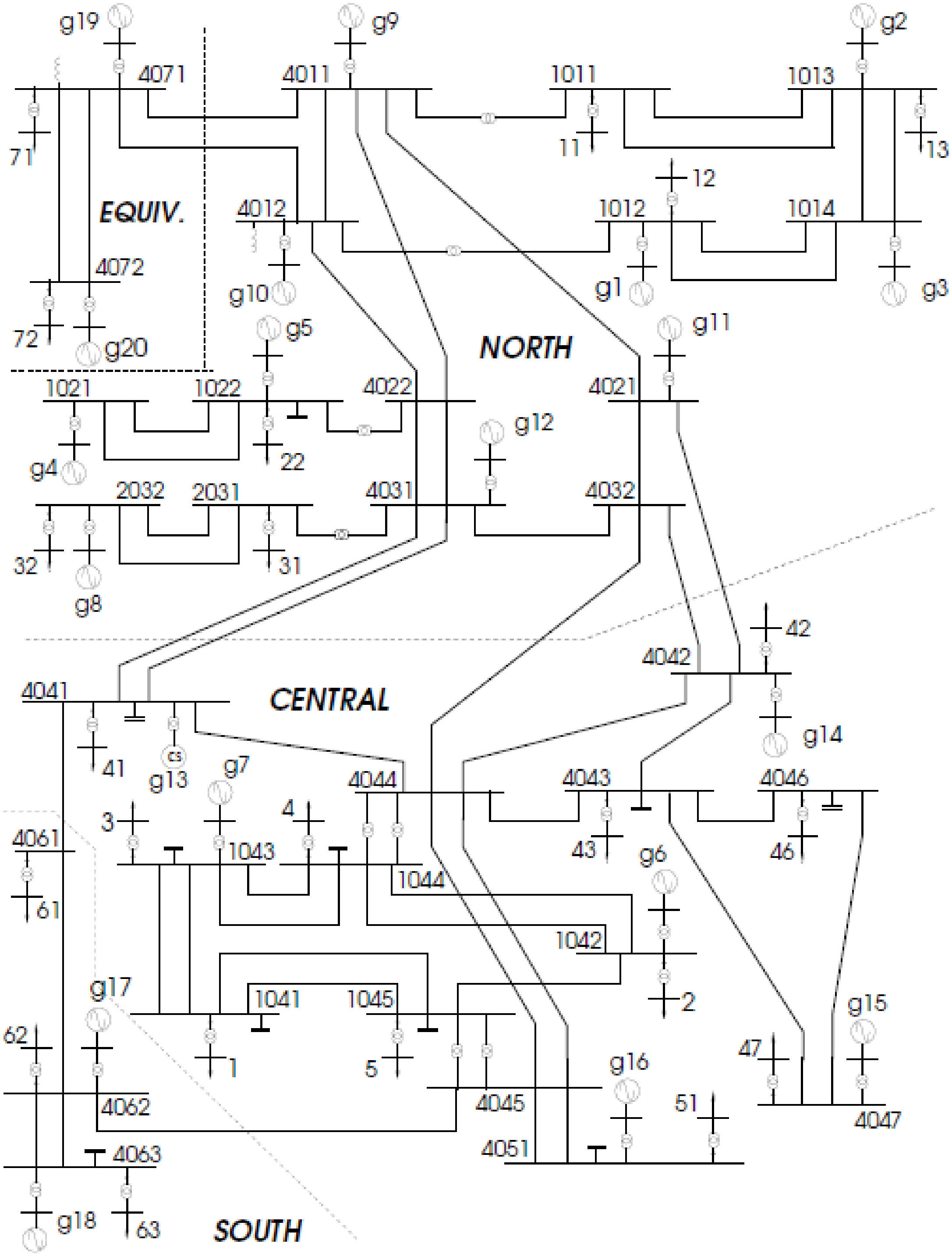
Test Systems for Voltage Stability Analysis and Security Assessment

PREPARED BY THE
Power System Dynamic Performance Committee
Power System Stability Subcommittee
Test Systems for Voltage Stability and Security Assessment Task Force

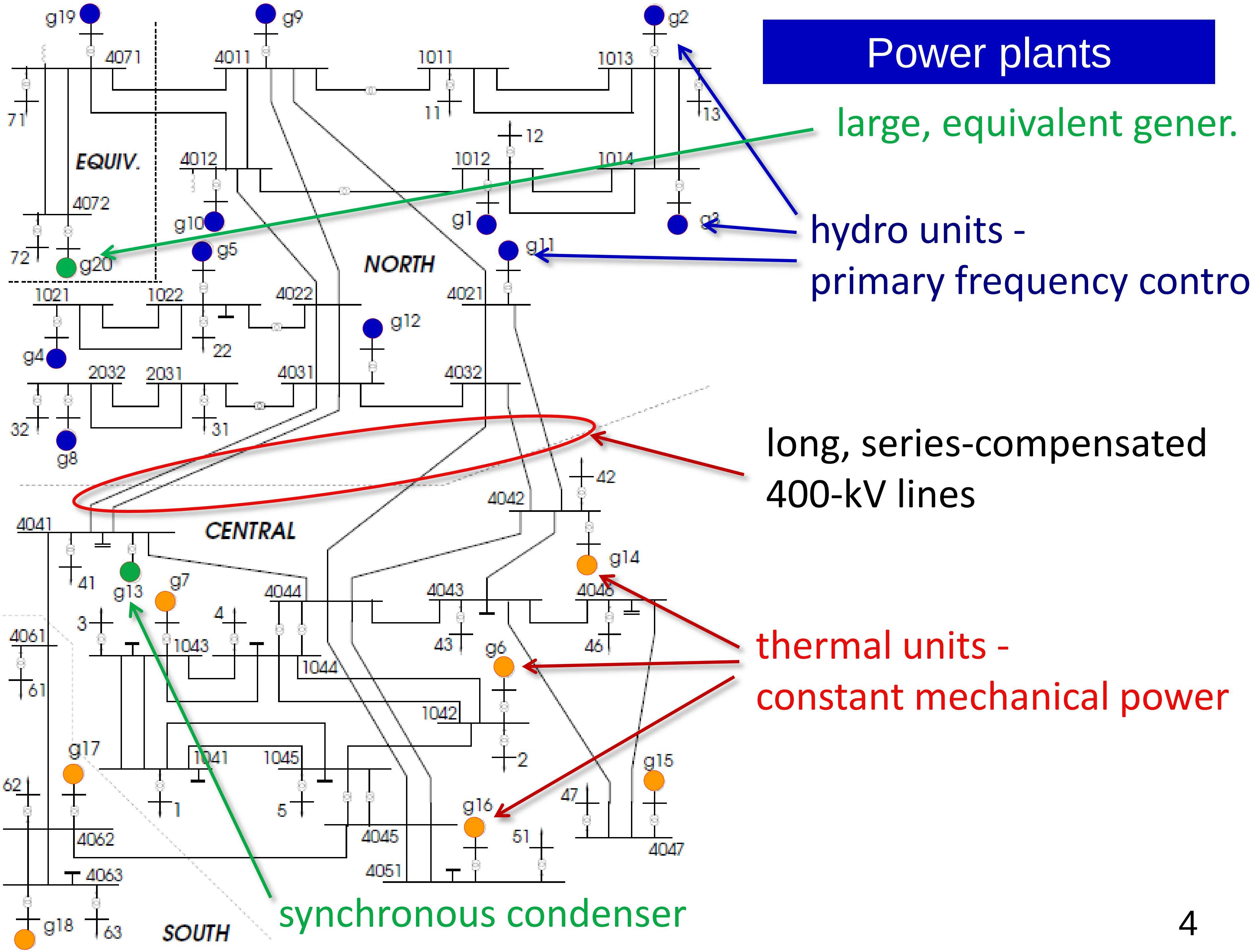
Available at http://resourcecenter.ieee-pes.org/



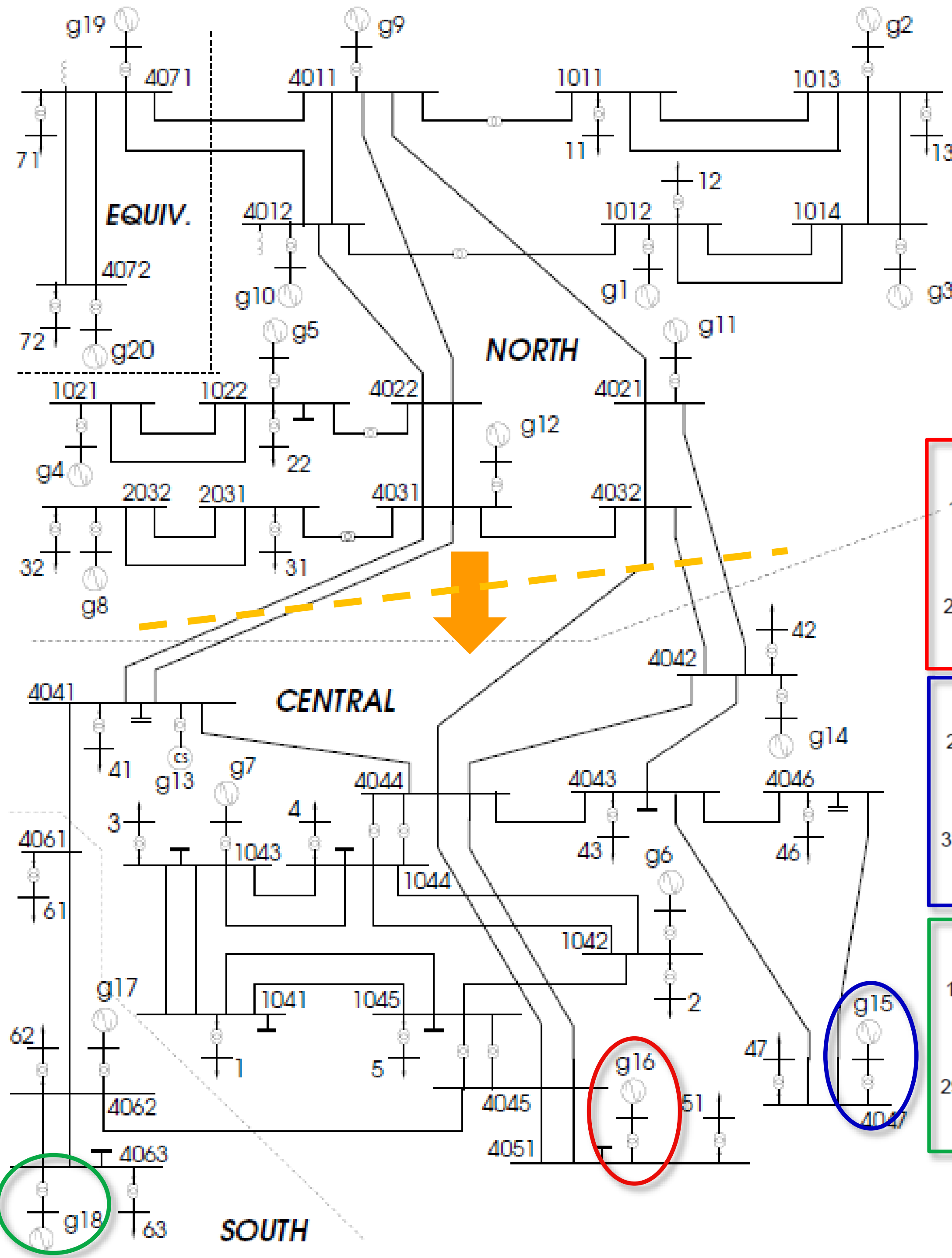
Overall structure

- Transmission : 400 & 220 kV
- sub-transmission : 130 kV
- 50 Hz system
- 74 buses
- 20 generators
- 102 branches, including
  - 20 step-up transformers
  - 22 distribution transformers

Power plants

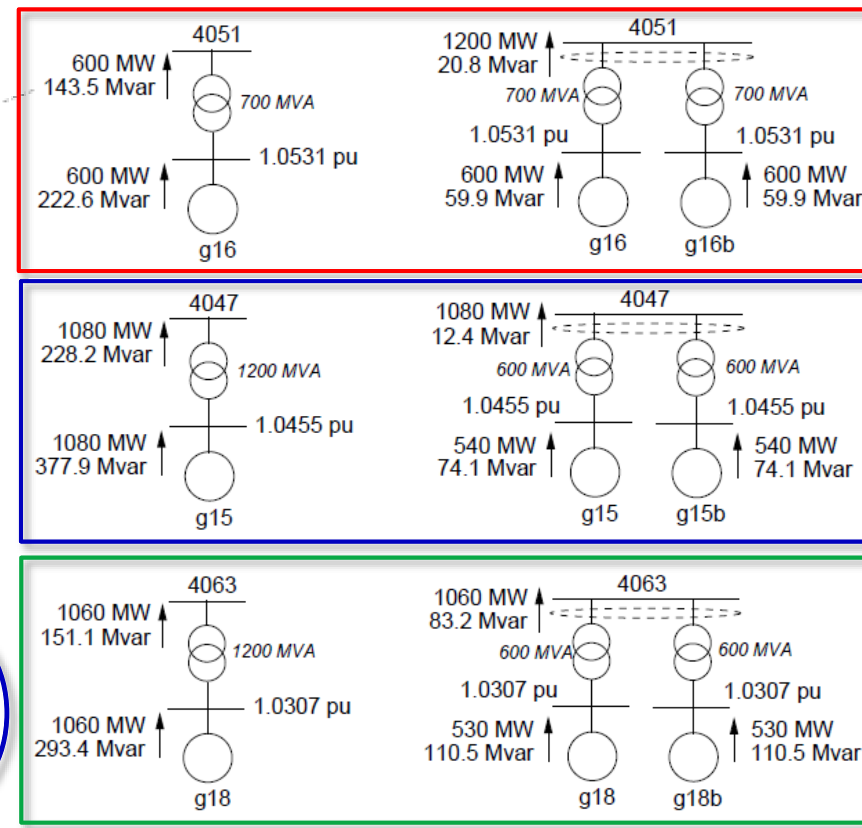


Operating points

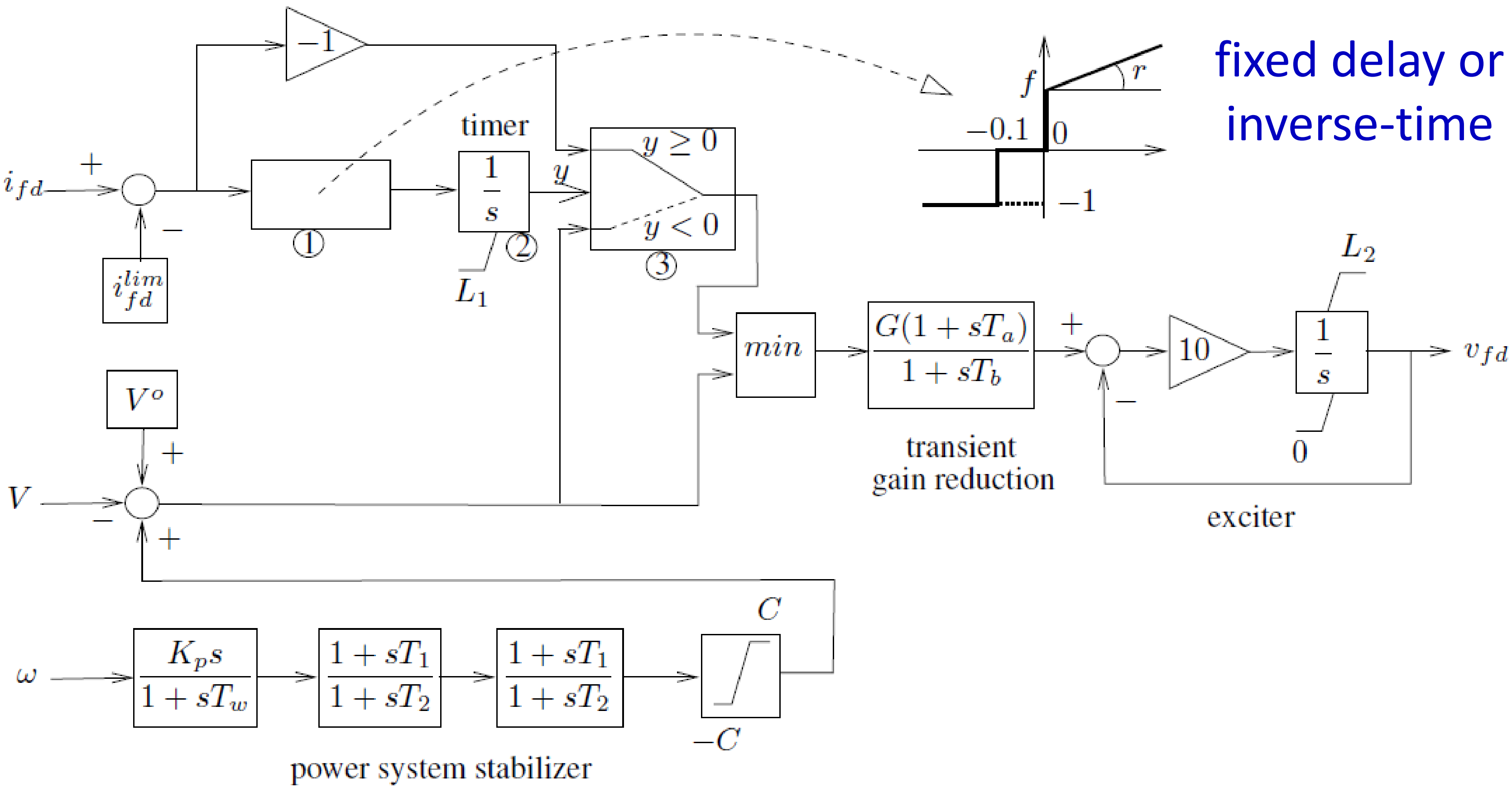


oper. point A

oper. point B

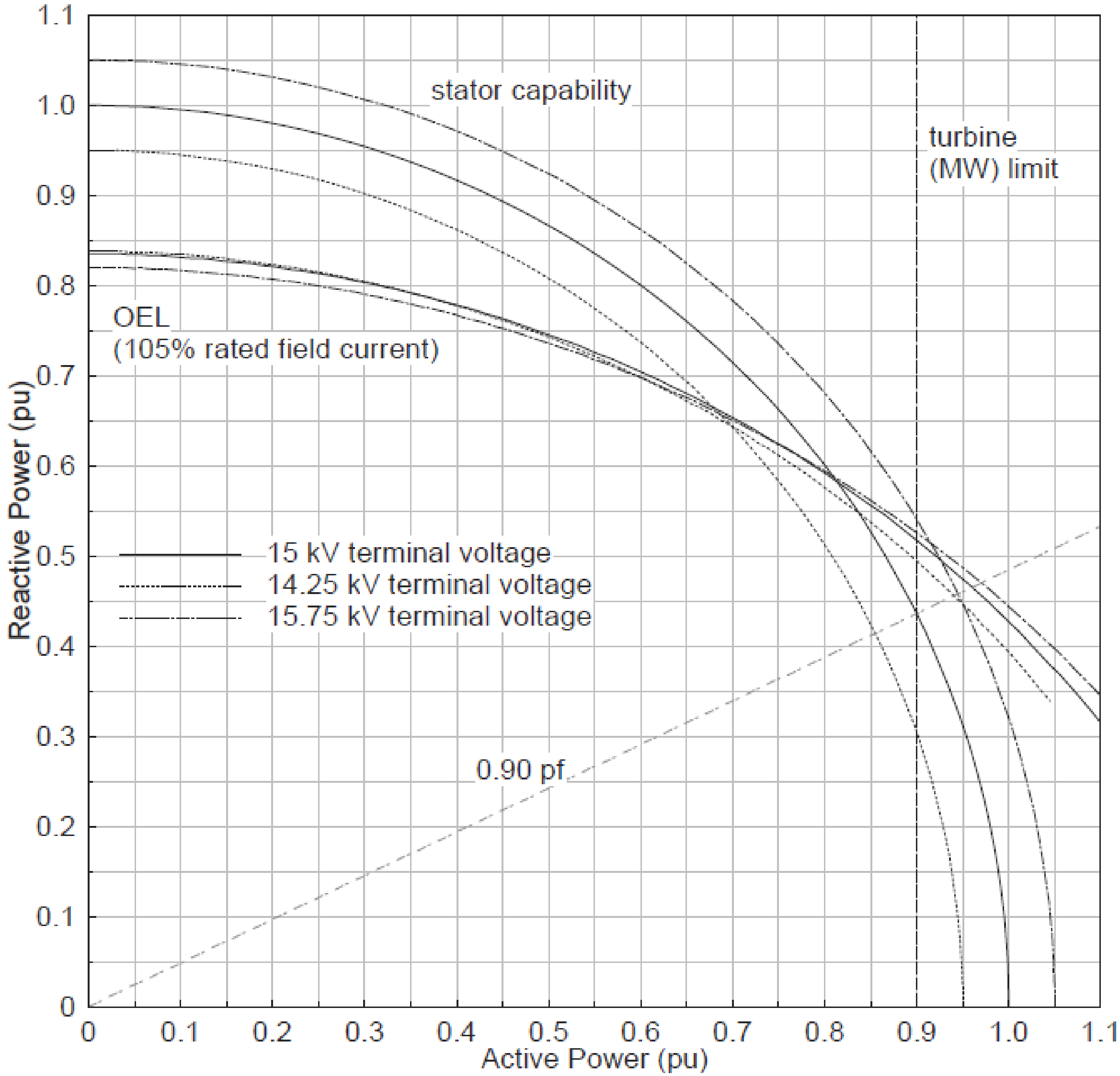


Exciter, AVR, PSS and OverExcitation Limiter (OEL)

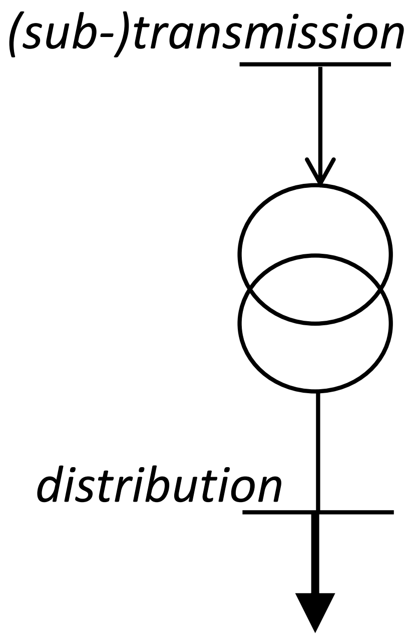


fixed delay or inverse-time

Capability curves of round-rotor generators for various terminal voltages



Load model



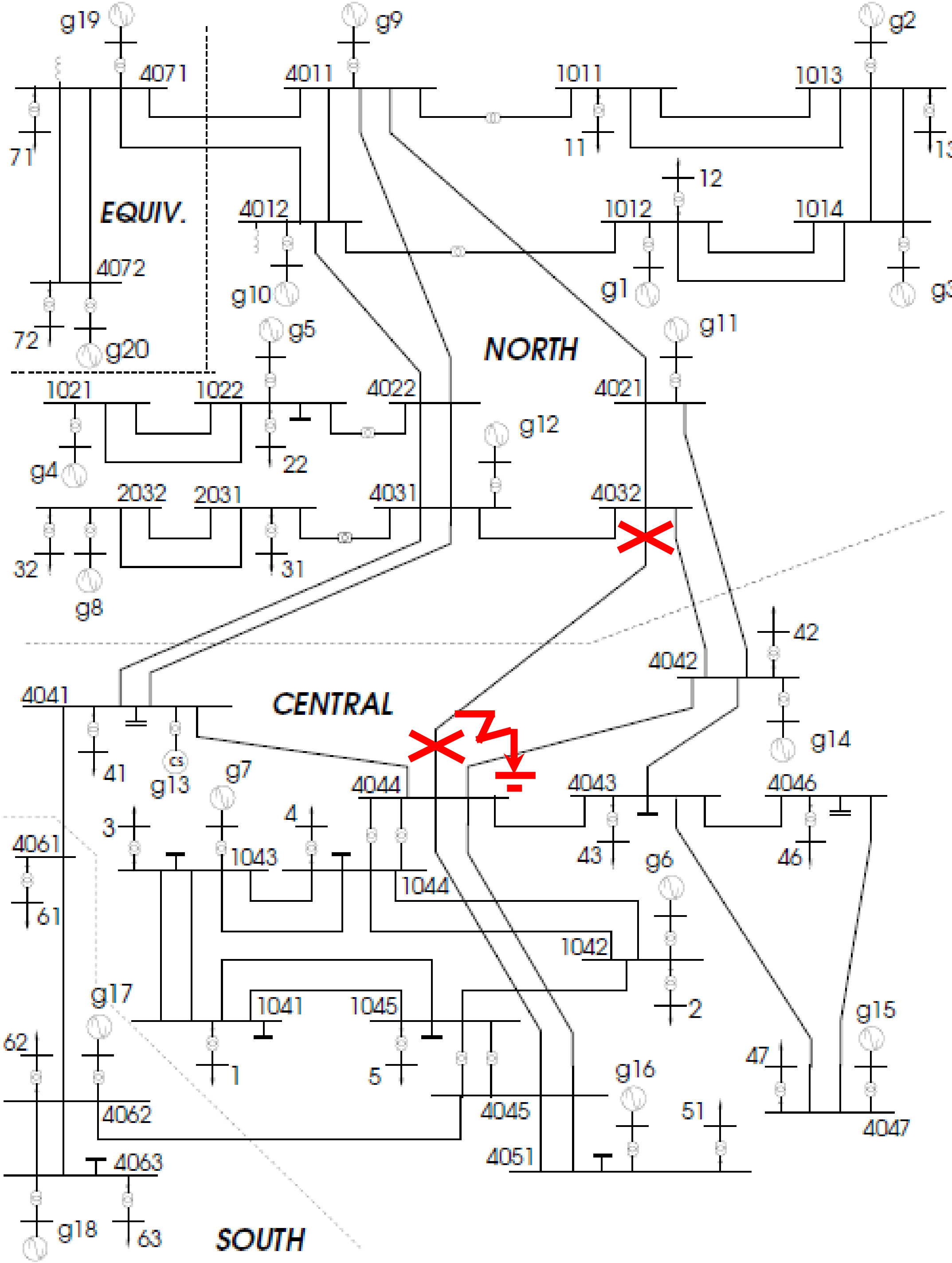
Load Tap Changers (LTC):

- voltage deadband : ± 0.01 pu
- range of transformer ratio : [0.80   1.12] pu/pu
- 33 tap positions
- various tapping delays

$$P = P_o(\frac{V}{V_o})^{\alpha} \qquad Q = Q_o(\frac{V}{V_o})^{\beta}$$

transformer	delays	
	τ_1 (s)	τ_2 (s)
11-1011	30	8
12-1012	30	9
13-1013	30	10
22-1022	30	11
1-1041	29	12
2-1042	29	8
3-1043	29	9
4-1044	29	10
5-1045	29	11
31-2031	29	12
32-2032	31	8
41-4041	31	9
42-4042	31	10
43-4043	31	11
46-4046	31	12
47-4047	30	8
51-4051	30	9
61-4061	30	10
62-4062	30	11
63-4063	30	12
71-4071	31	9
72-4072	31	11

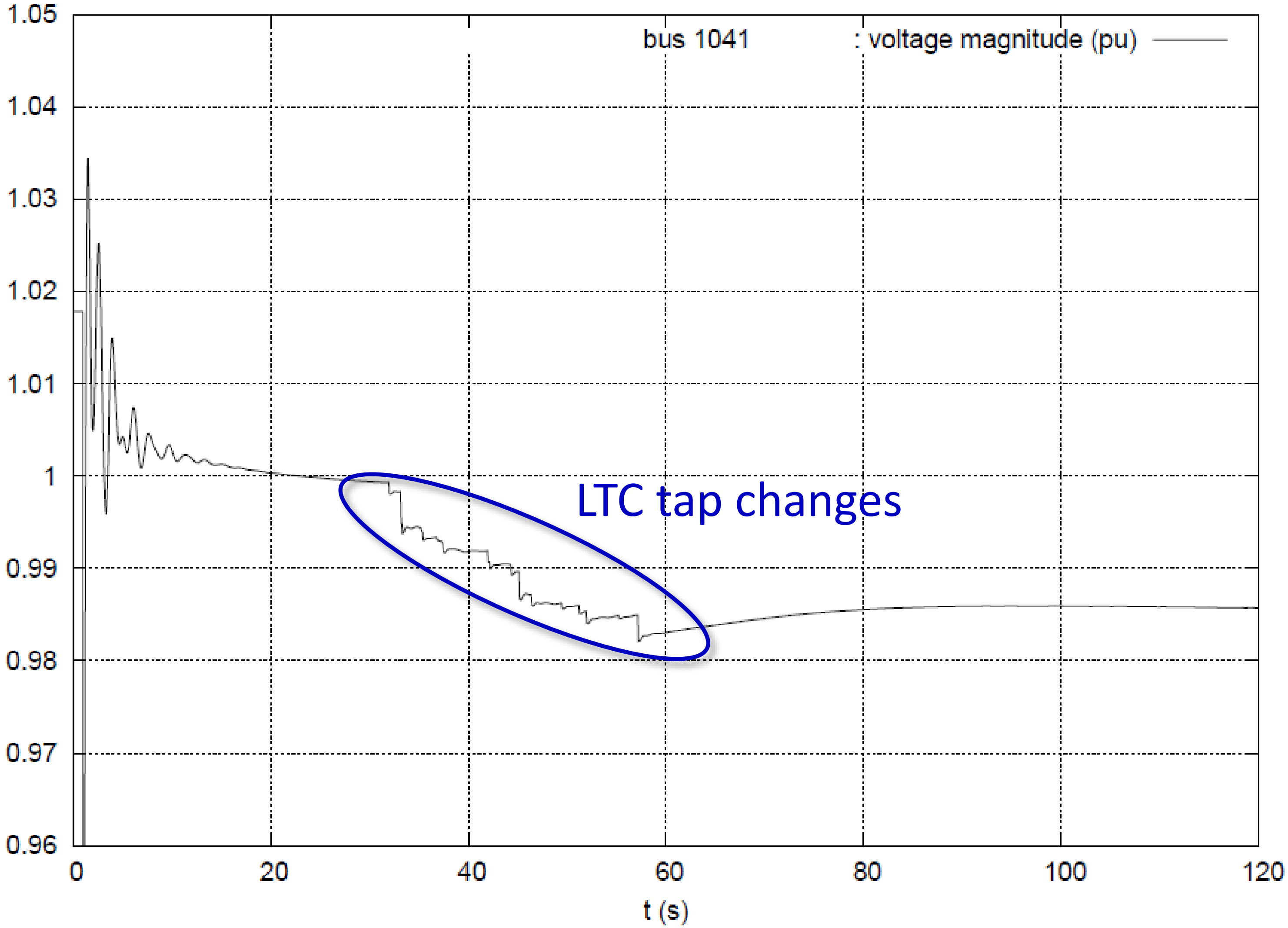
Disturbance



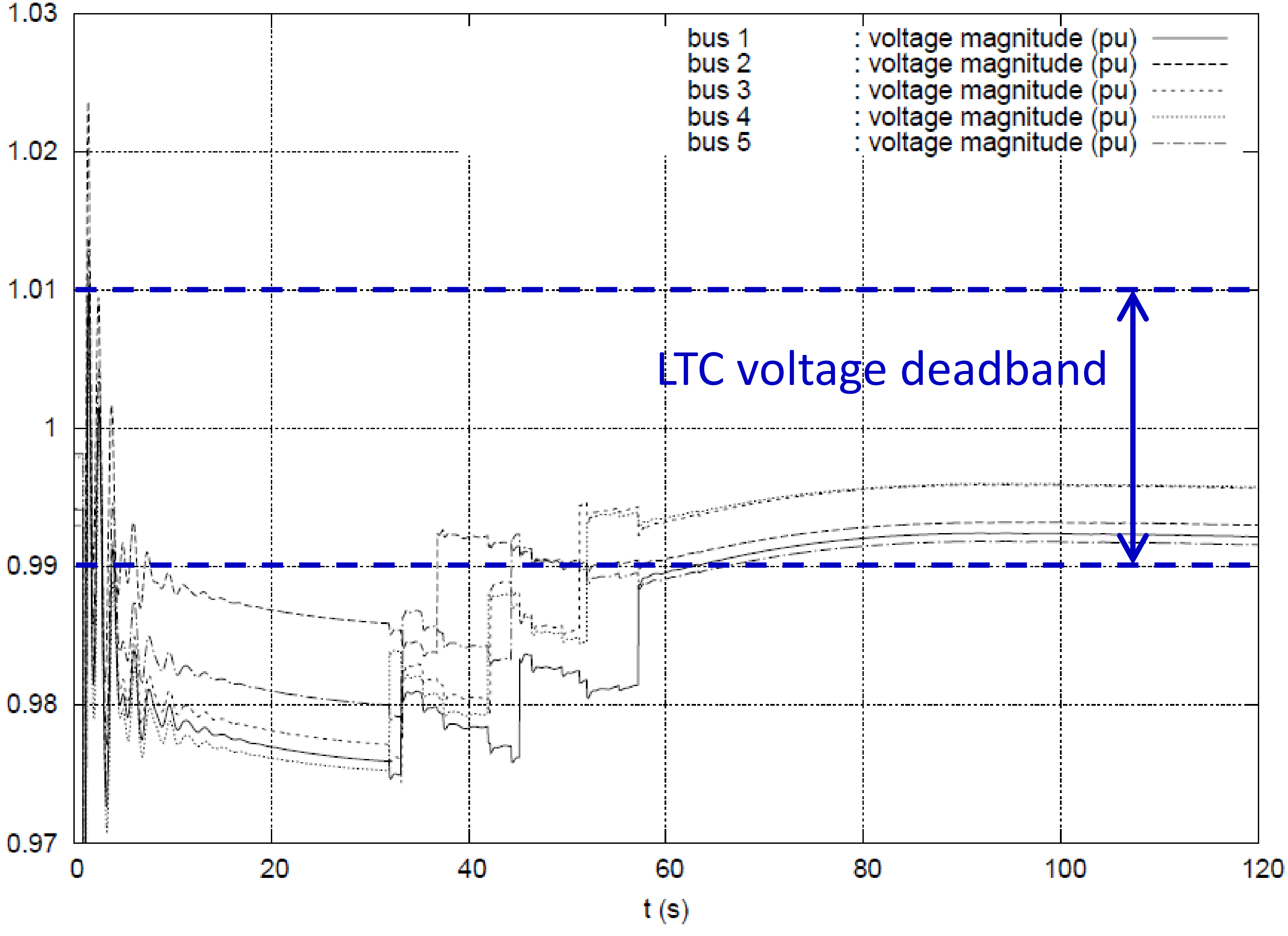
3-phase 5-cycle (0.1 s) fault

cleared by opening the line, which remains opened

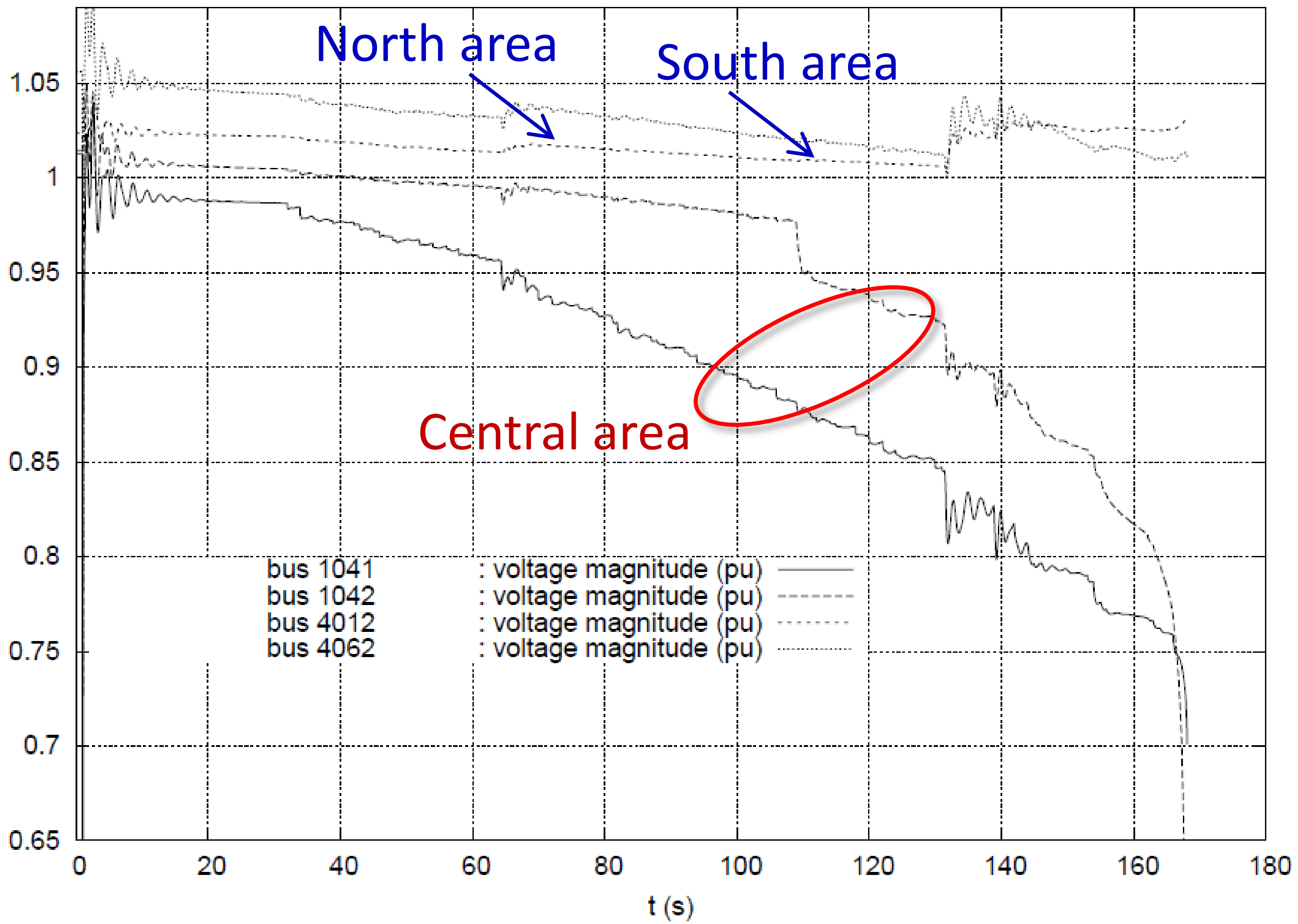
Evolution of a transmission voltage – initial operating point B



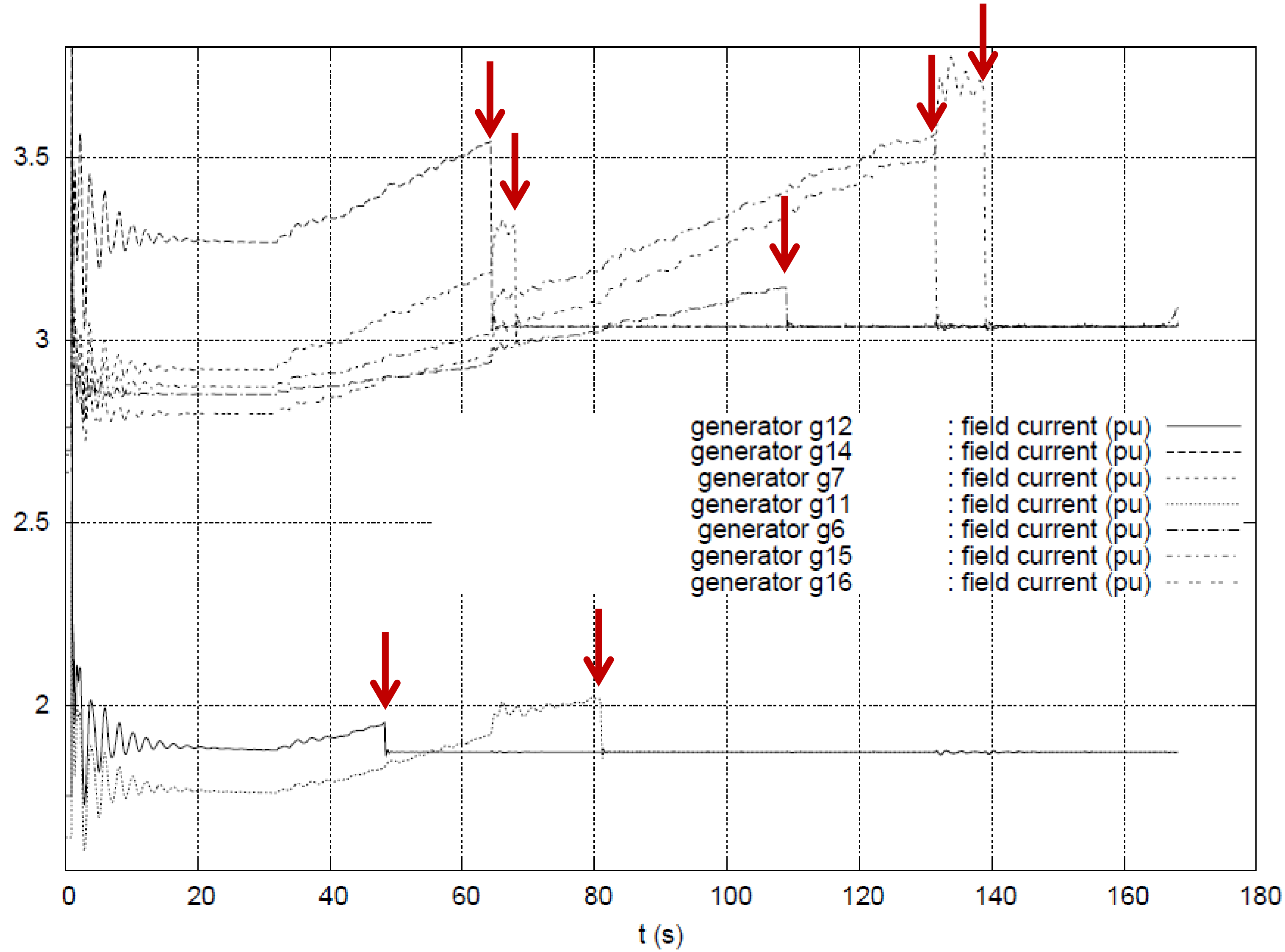
Evolution of voltages at LTC-controlled distribution buses - initial operating point B



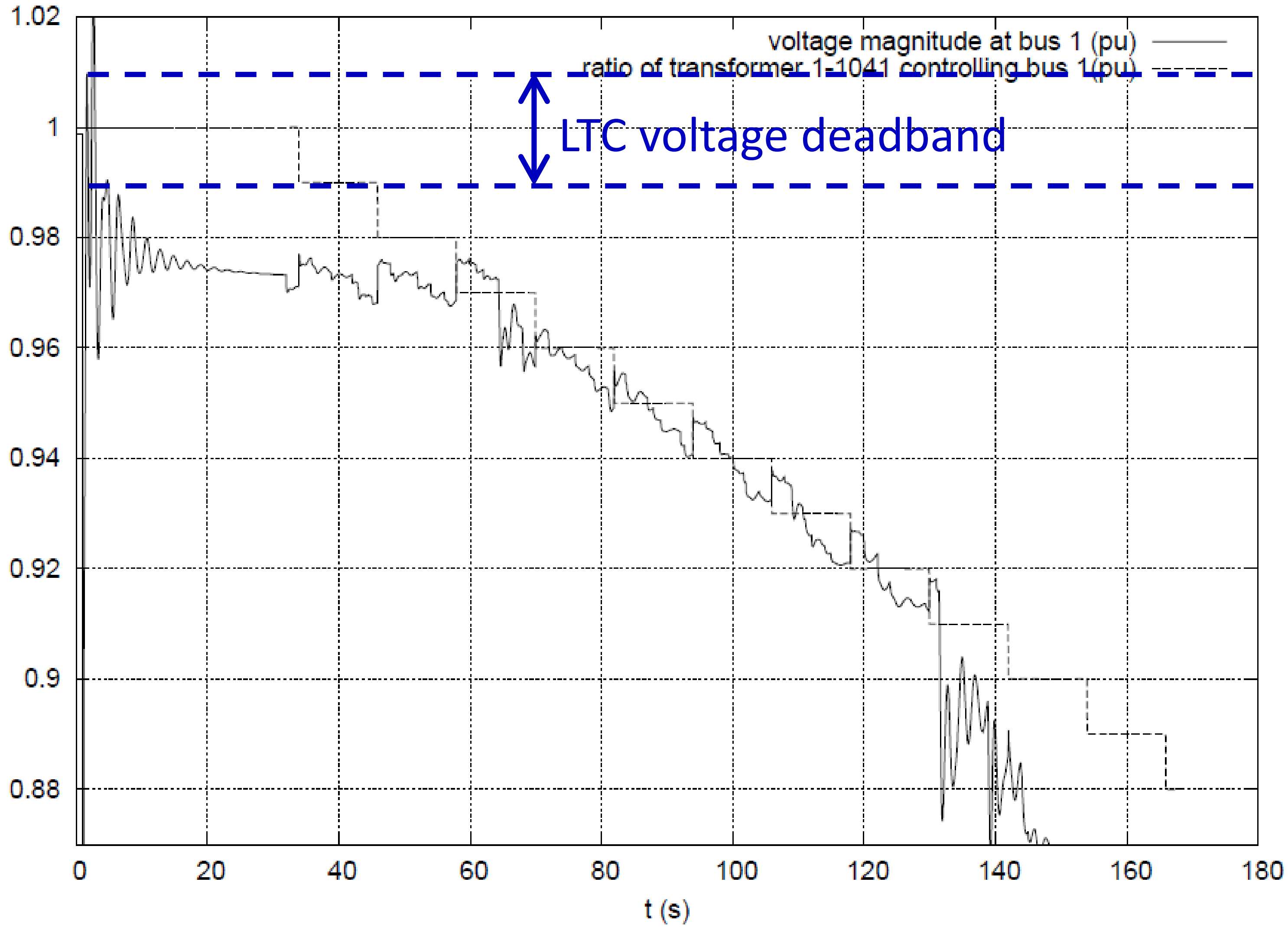
Evolution of transmission voltages – initial operating point A



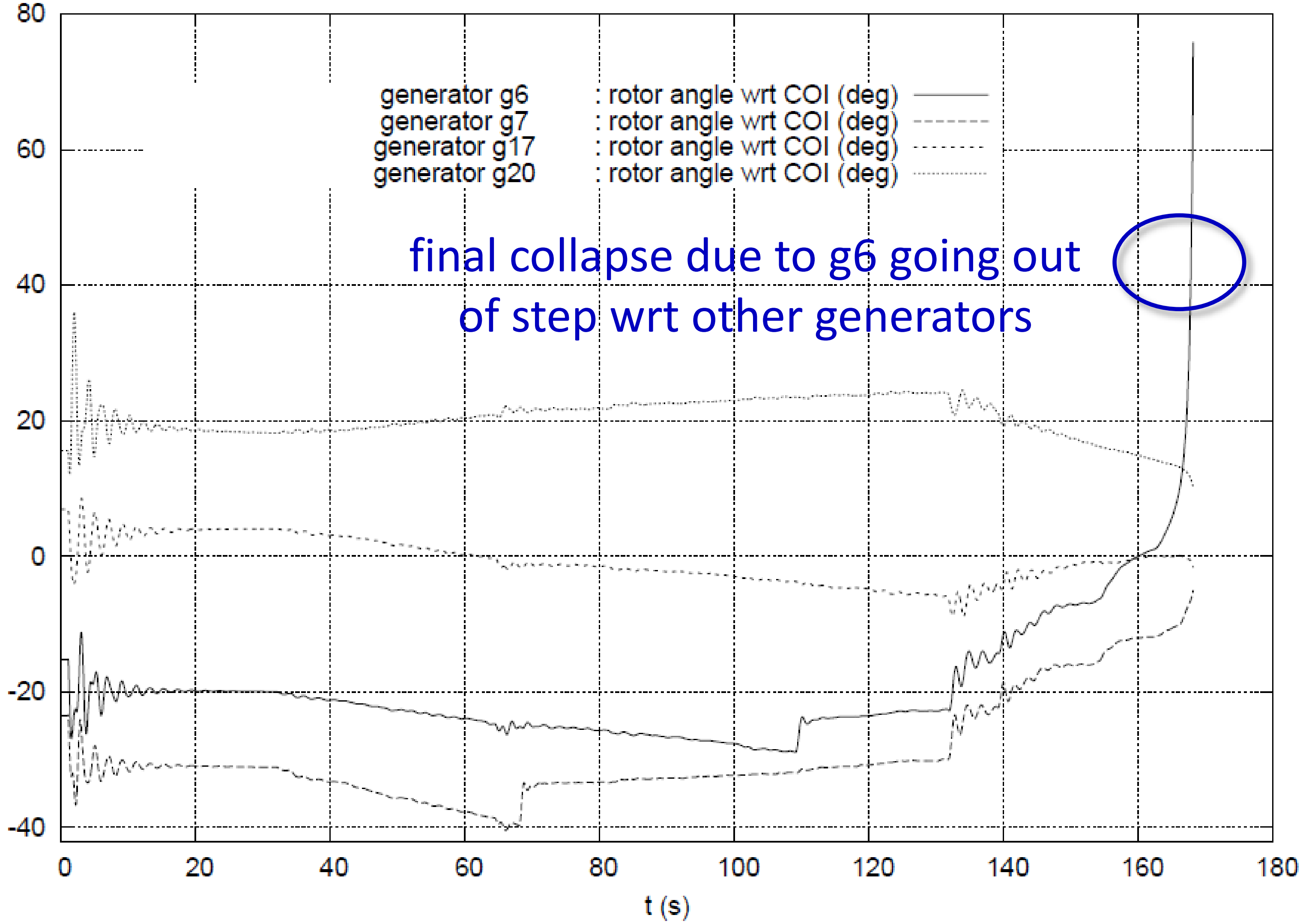
Evolution of generator field currents – initial operating point A



Evolution of voltages at LTC-controlled distribution buses - initial operating point A



Evolution of generator rotor angles (wrt center of inertia) - initial operating point B

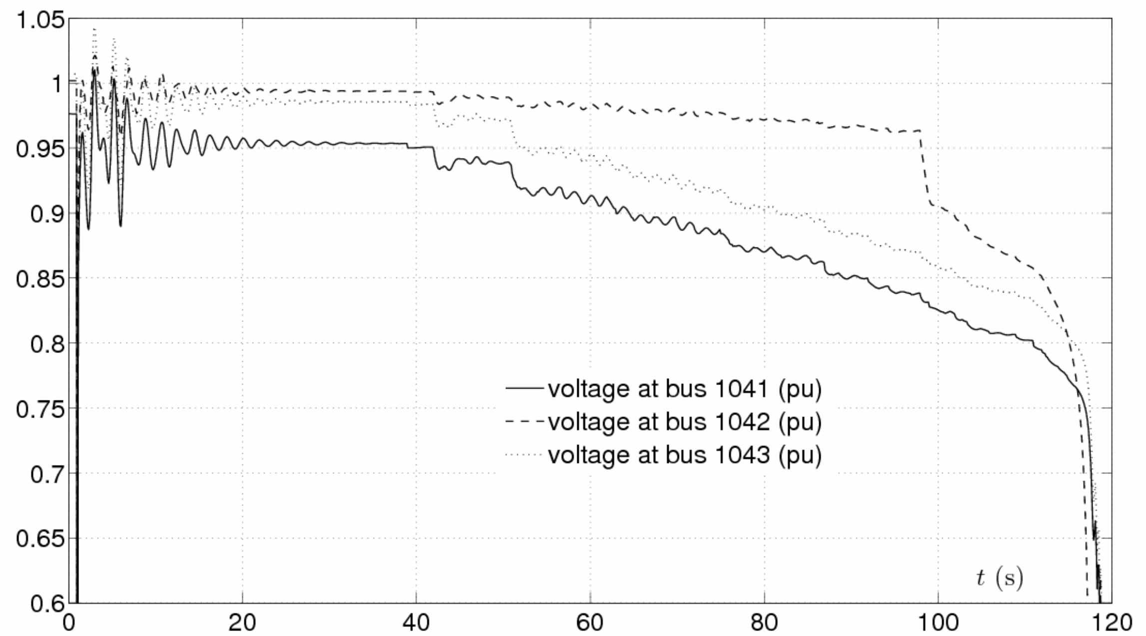


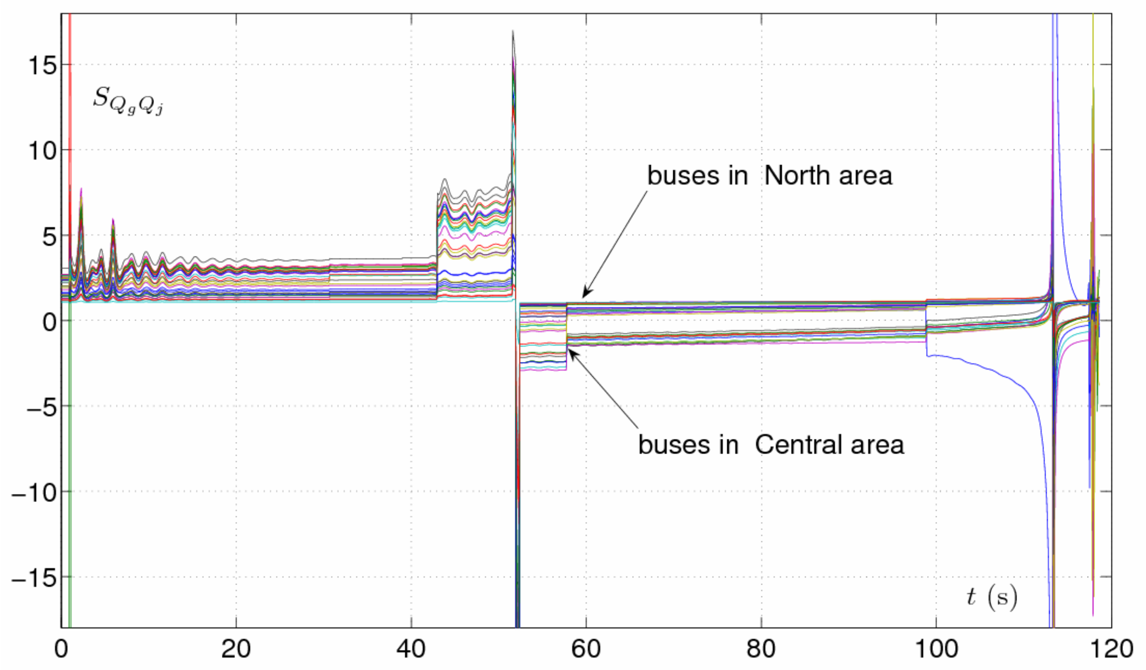
Sensitivity analysis

Load power passing through a maximum gives an indication of the impending instability.

This can be identified through a change of sign of sensitivities.

In this example sensitivities of total reactive power generation to various load reactive powers are considered.

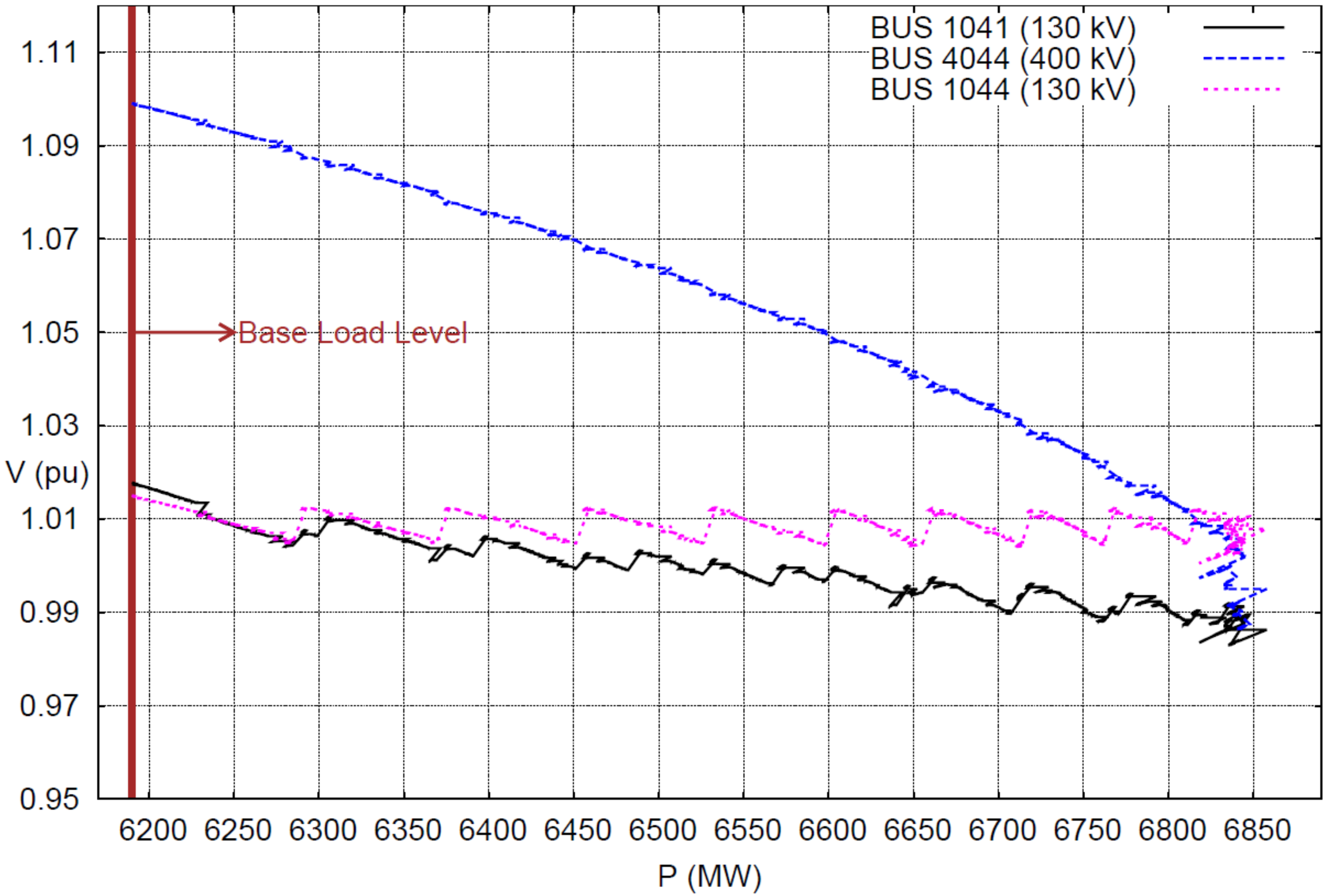




Example of PV curves

- Most often obtained from (repeated or continuation) power flow computations
  - here with dynamic simulation
- a slow load increase in the Central area is simulated :
  - the P_o and Q_o coefficients of loads are increased linearly with time
  - since the load increase is slow, the operator reaction is simulated : the ratios of the transformers 4044-1044 and 4045-1045 are adjusted to control the voltages at buses 1044 and 1045 in a dead-band
- the system dynamic response is obtained
- at selected transmission buses, the voltage is plotted as a function of the total load power $\sum_i P_{oi} \left(\frac{V_i}{V_{oi}}\right)^{\alpha_i}$ in the Central area

Example of PV curves

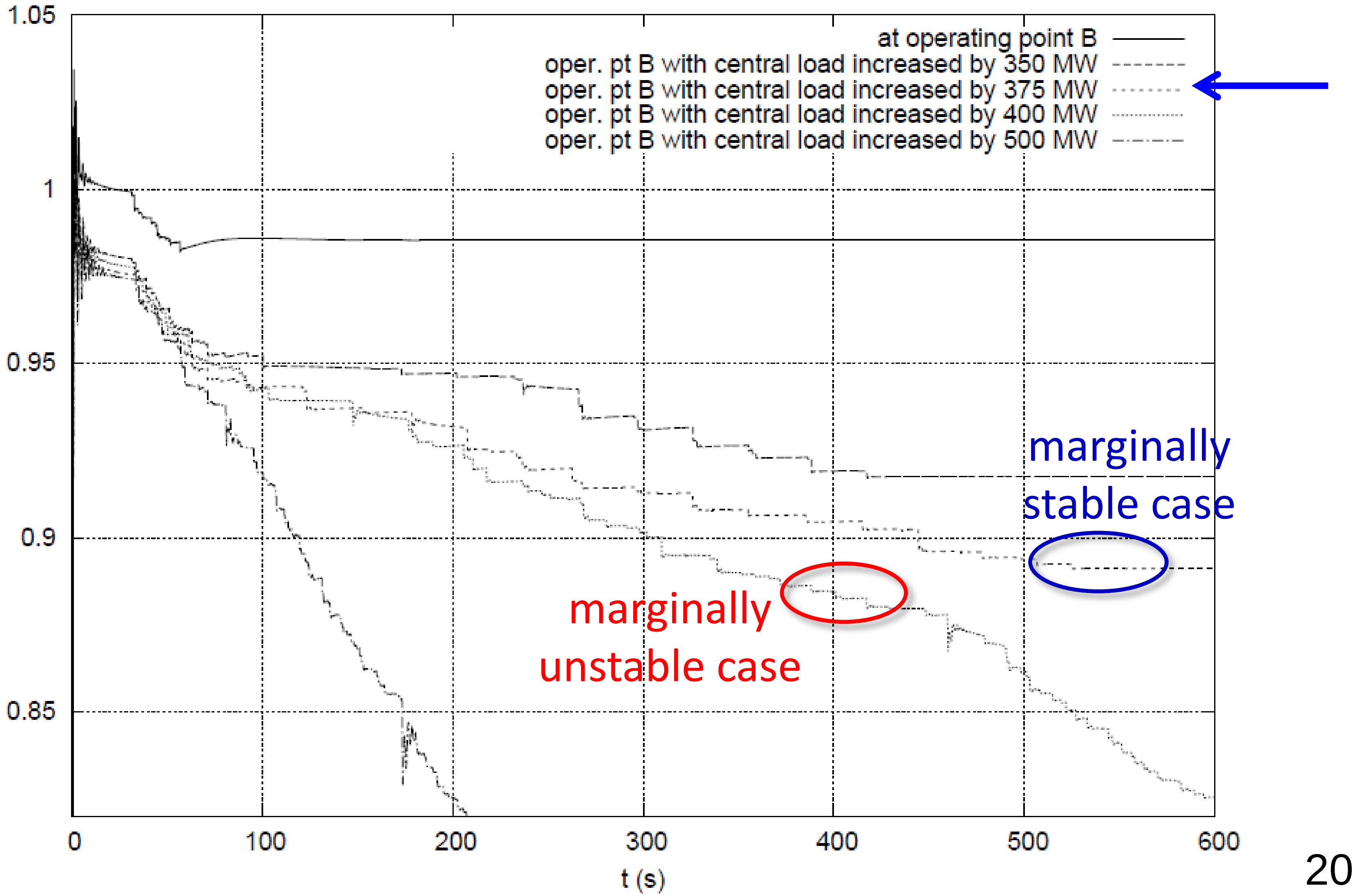


Secure operation limit

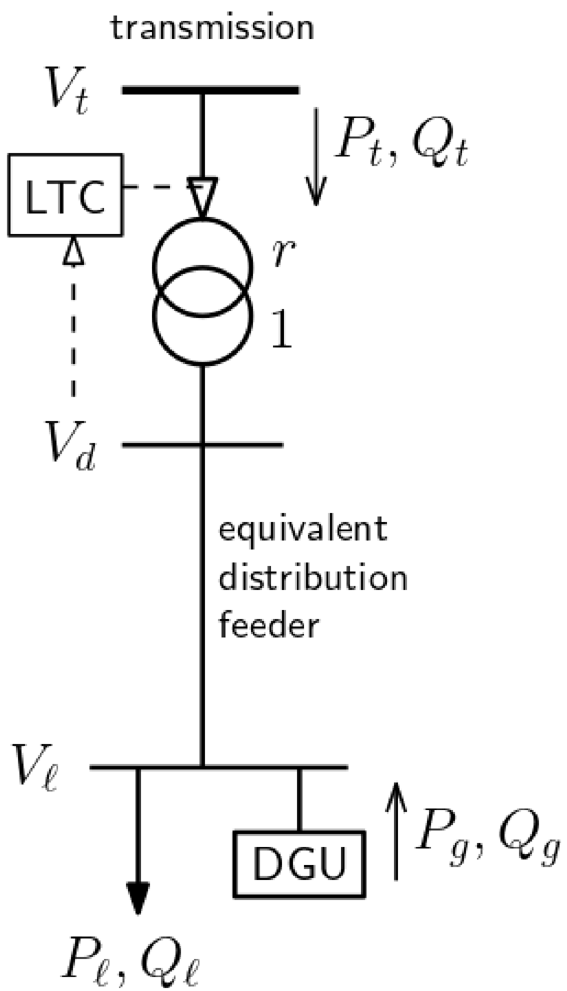
- To assess security margins with respect to contingencies
- which maximum « stress » can be accepted *in the pre-contingency configuration* such that the system responds in a stable way to each of the specified contingencies ?
- procedure :
  - power flow computations to determine the system operating points at various levels of stress
    - taking into account operator reactions in pre-contingency situations
  - starting from those initial operating points, long-term dynamic simulations to assess the system response to each contingency
    - taking into account automatic controls reacting to the contingency

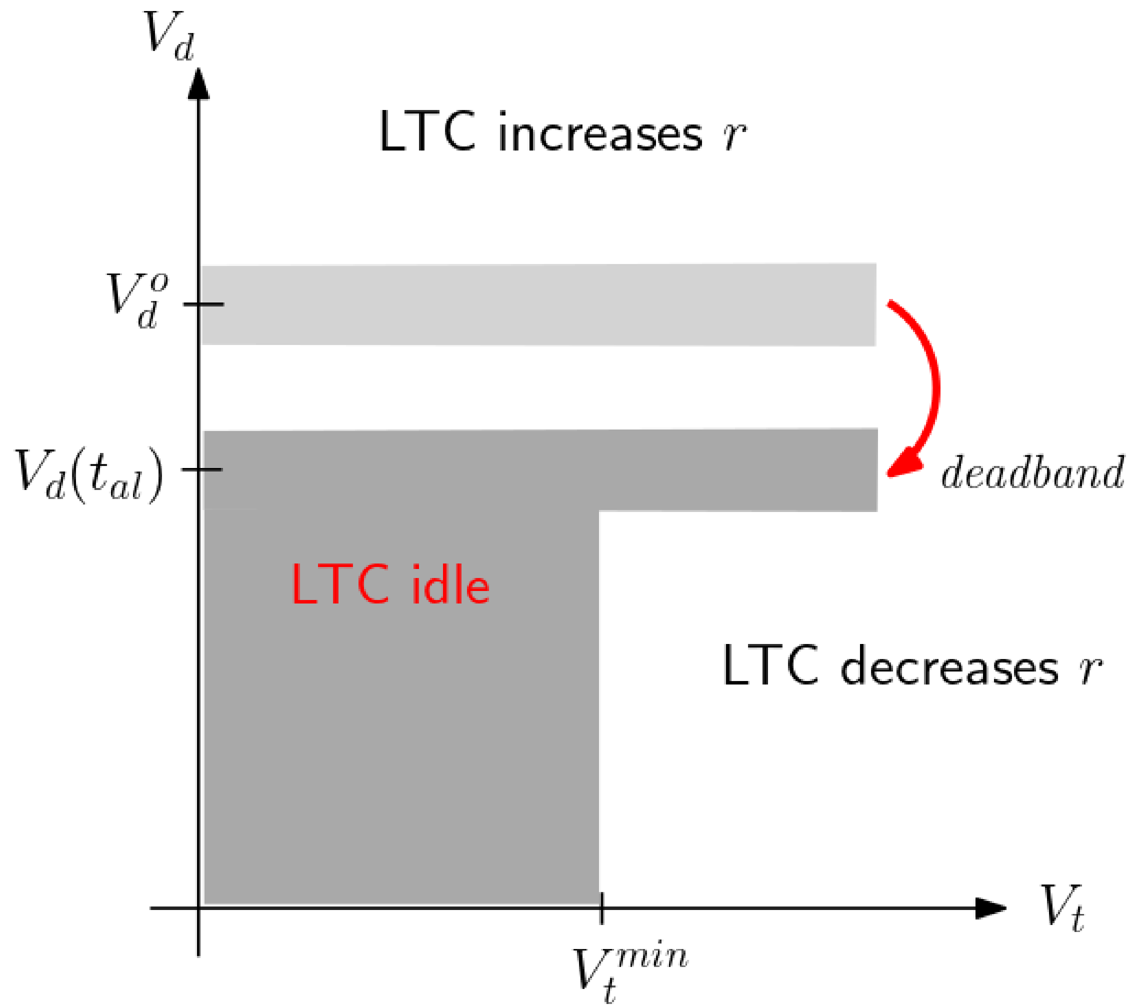
Example of determination of a secure operation limit

stress = loading of Central area disturbance as in previous slides

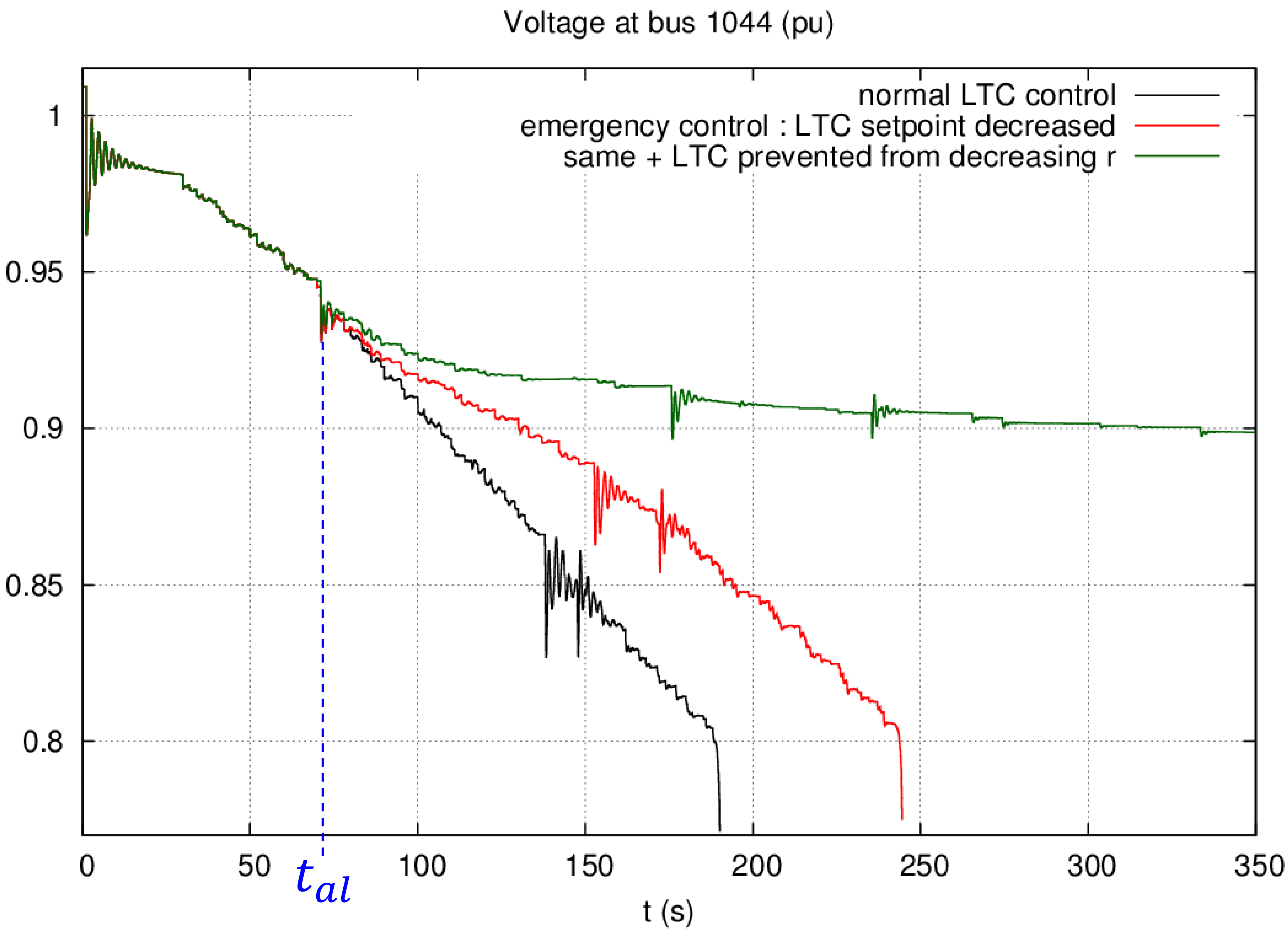


Emergency control of Load Tap Changers (LTCs)





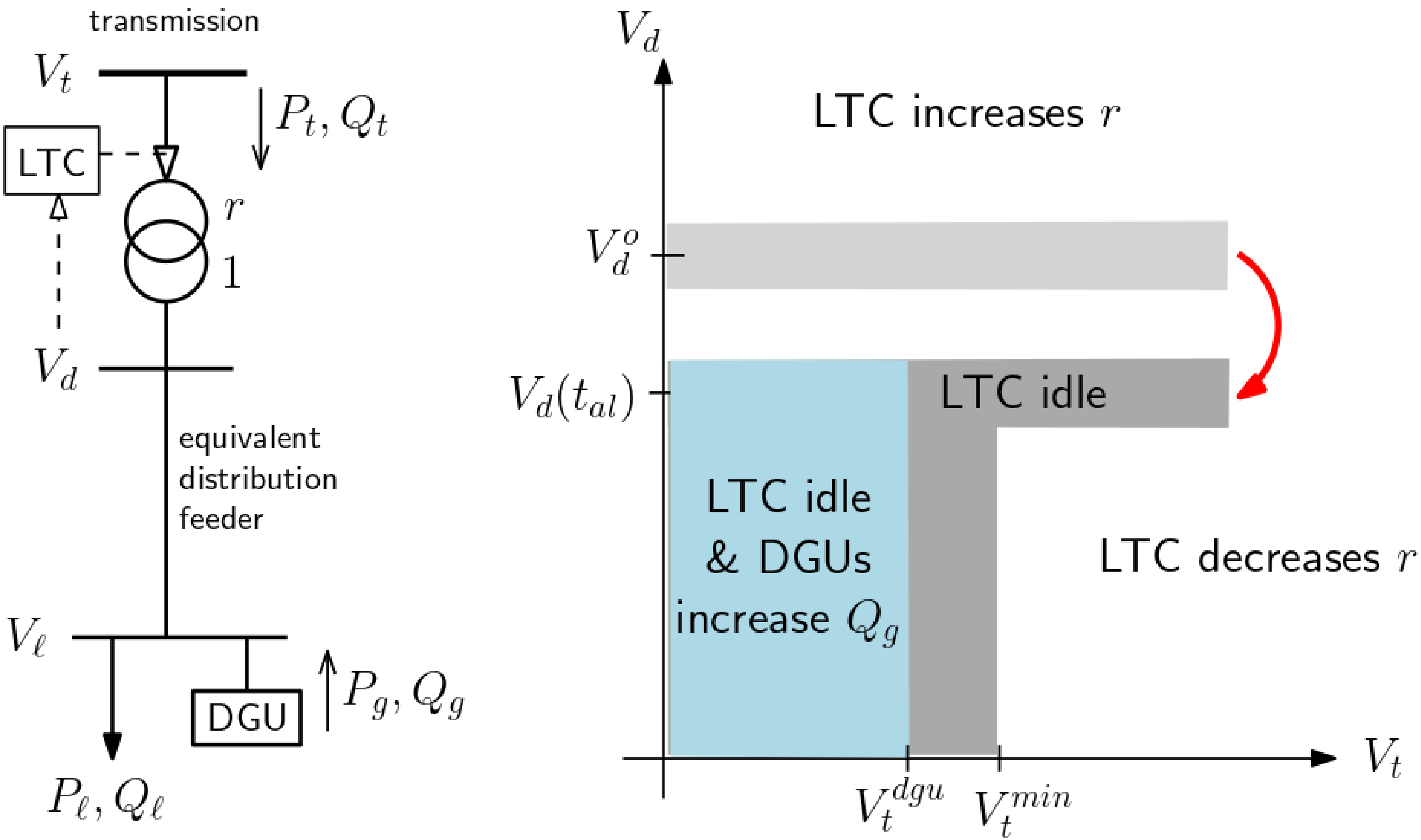
- emergency detected when V_t has stayed below V_t^{min} for τ seconds
- LTC voltage setpoint decreased to $V_d(t_{al})$, where t_{al} = time of alarm
- LTC prevented from decreasing r as long as $V_t < V_t^{min}$



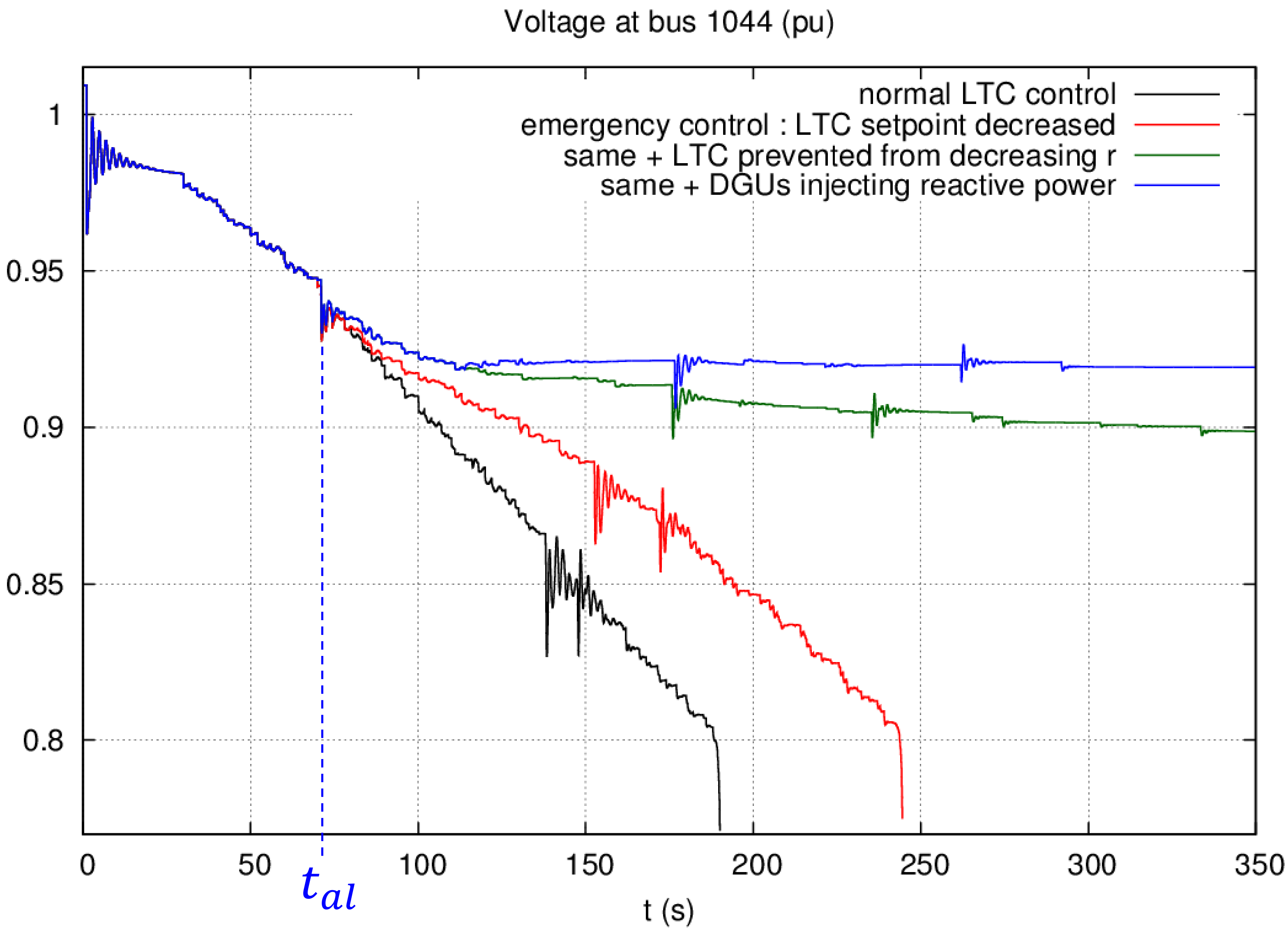
Emergency control of LTCs in Central region

$V_t^{min} = 0.94$ pu $\tau = 3$ s

Emergency control of LTCs & Dispersed Generation Units (DGUs)

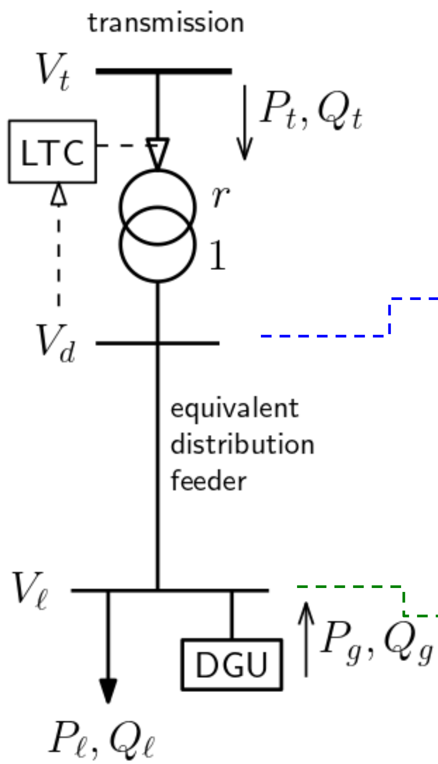


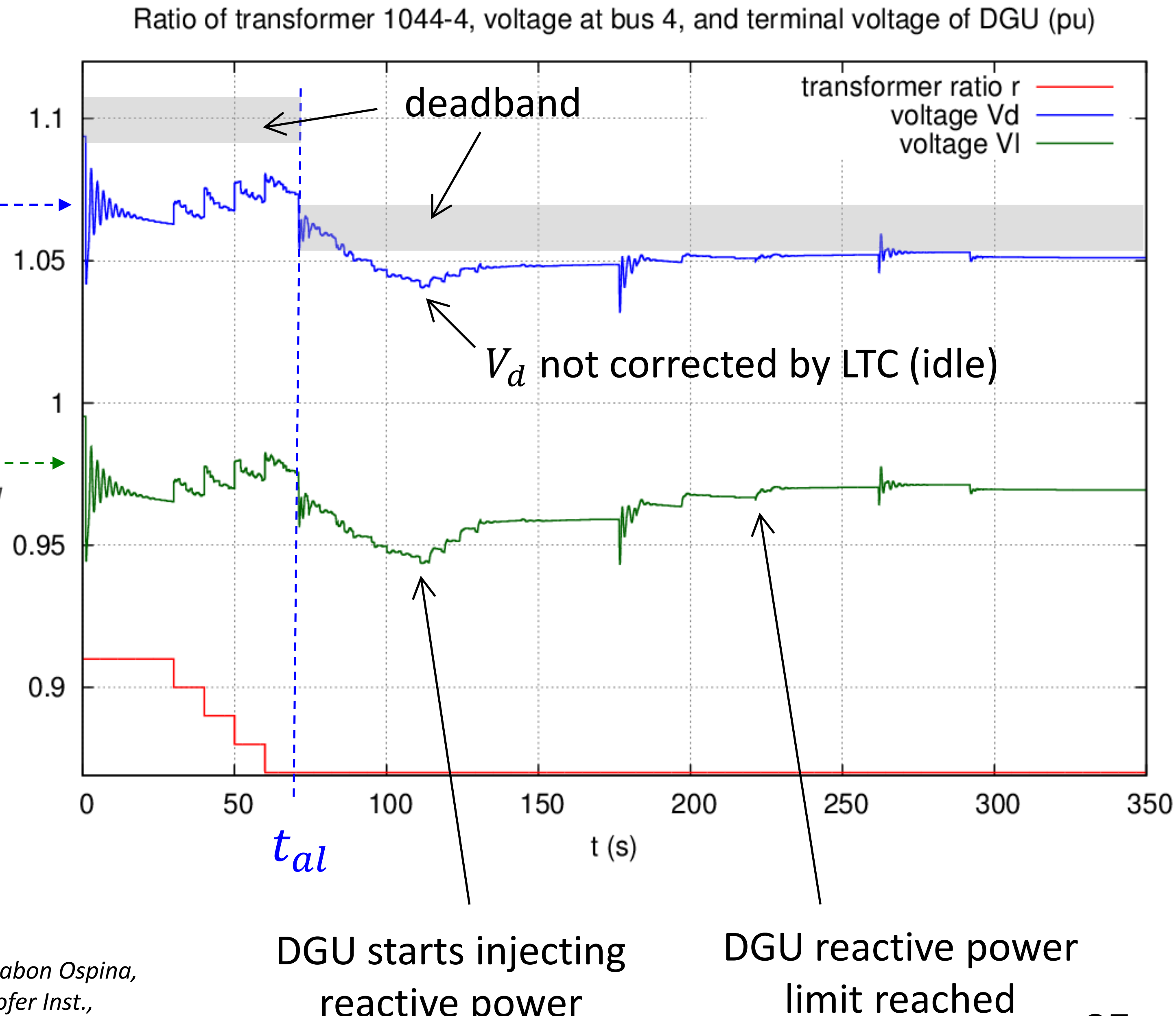
- The DGUs start increasing Q_g when $V_t < V_t^{dgu}$ for τ seconds
- and keep doing so until $V_t > V_t^{dgu}$ or V_d above its deadband



Emergency control of LTCs and DGUs in Central region

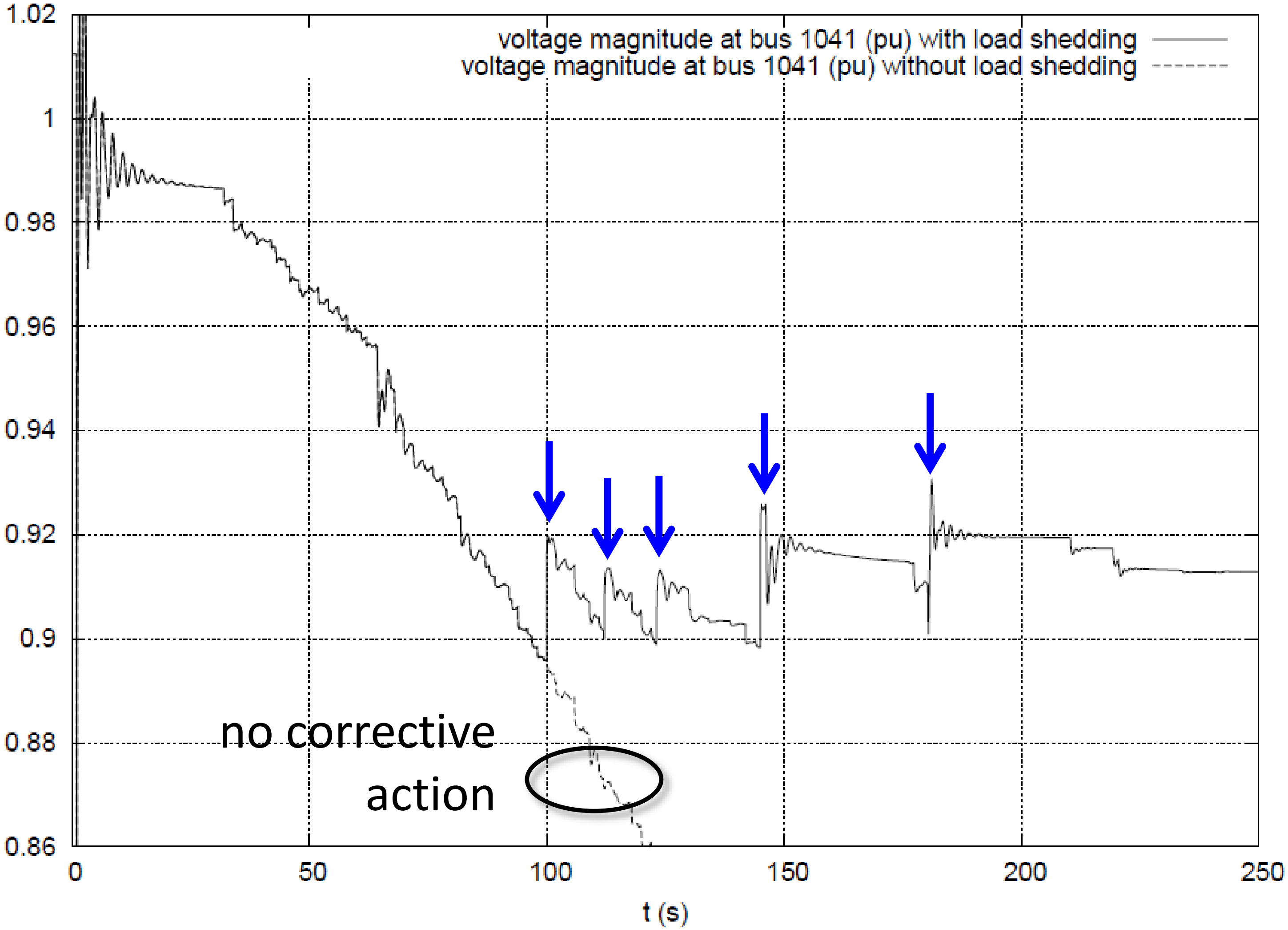
$V_t^{dgu} = 0.92$ pu $V_t^{min} = 0.94$ pu $\tau = 3$ s





Work in collaboration with Luis Pabon Ospina, visiting PhD student, Fraunhofer Inst., Kassel, Germany, 2018-2019

Undervoltage load shedding



300 MW of load shed by distributed controllers,

each controller sheds 50 MW every 3 s until $V_t > 0.90$ pu