ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Operation, Monitoring and Control Technology of Power Systems

Course 227-0528-00

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Course Outline

1. Introduction
2. Monitoring and Control Technology
3. Operation Principles
4. Algorithms and Computations

Contents

- Operation Philosophy
- Operation
- Day-ahead Planning
- Long-term Planning

Important Terms

- Stability:
  - continuance of intact operation following a disturbance. It depends on the operating condition and the nature of the physical disturbance.
- Security:
  - degree of risk in power system ability to survive imminent disturbances (contingencies) without interruption of customer service. It relates to robustness of the system to imminent disturbances and, hence, depends on the system operating condition as well as the contingent probability of disturbances.

Important Terms

- Reliability:
  - probability of power system satisfactory operation over the long run. It denotes the ability to supply adequate electric service on a nearly continuous basis, with few interruptions over an extended time period.

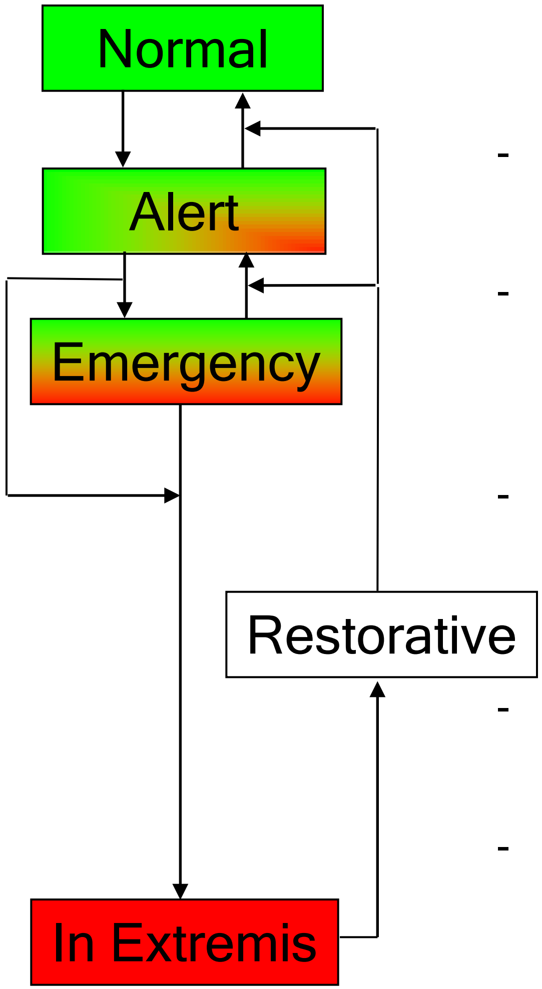
Threats of Power Systems Security

- Frequency instability
  - is inability of a power system to maintain steady frequency within the operating limits
  - it is in its nature rather a tracking than truly a stability control problem
- Voltage instability
  - the inability of a power system to maintain steady acceptable voltages at all buses
  - system enters a state of voltage instability when a disturbance, increase in load demand, or change in system conditions causes a progressive and uncontrollable drop in voltage

Threats of Power Systems Security

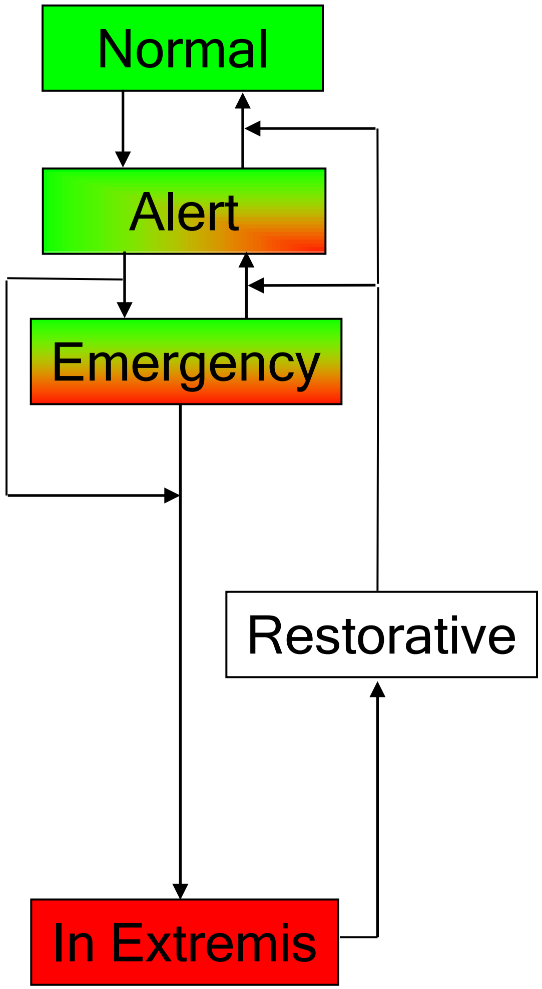
- Transient angular instability
  - inability of the power system to maintain synchronism when subjected to a severe transient disturbance
- Small-signal angular instability
  - inability of the power system to maintain synchronism under small disturbances
  - modes:
    - local
    - Inter-area
- Cascading spreading of components overloads and outages

Operation States



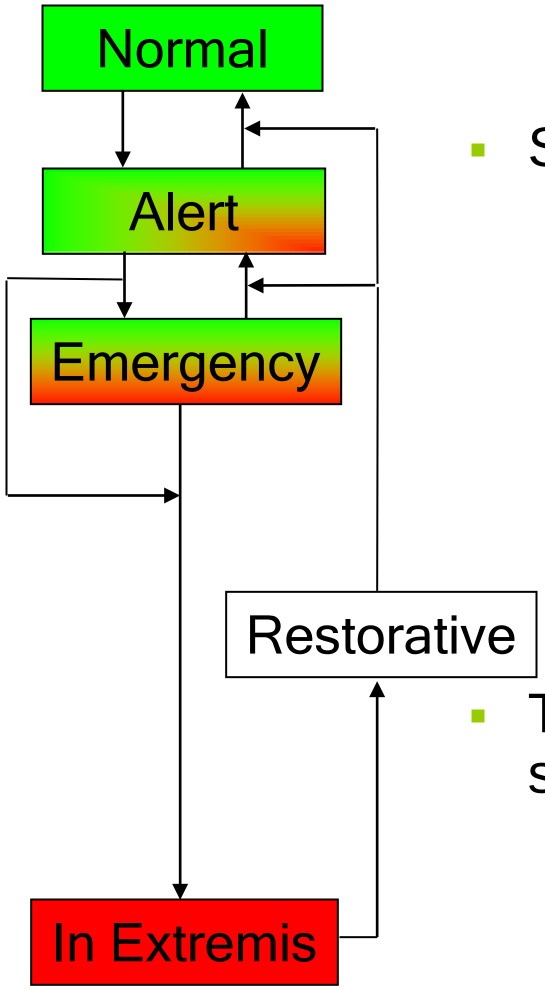
- Normal – no equipment overloaded. The system can withstand any contingency without violating any of constraints.
- Alert – no equipment overloaded yet. The system is weakened - a contingency may cause an overloading of equipment, resulting in emergency state.
- Emergency – Some equipment overloaded. If no control action executed, system progresses into In Extremis.
- In Extremis – Cascading spreading of system components outages resulting in partial or system-wide blackout.
- Restoration – Energizing of the system or its parts and reconnection and resynchronization of system parts.

Operation States



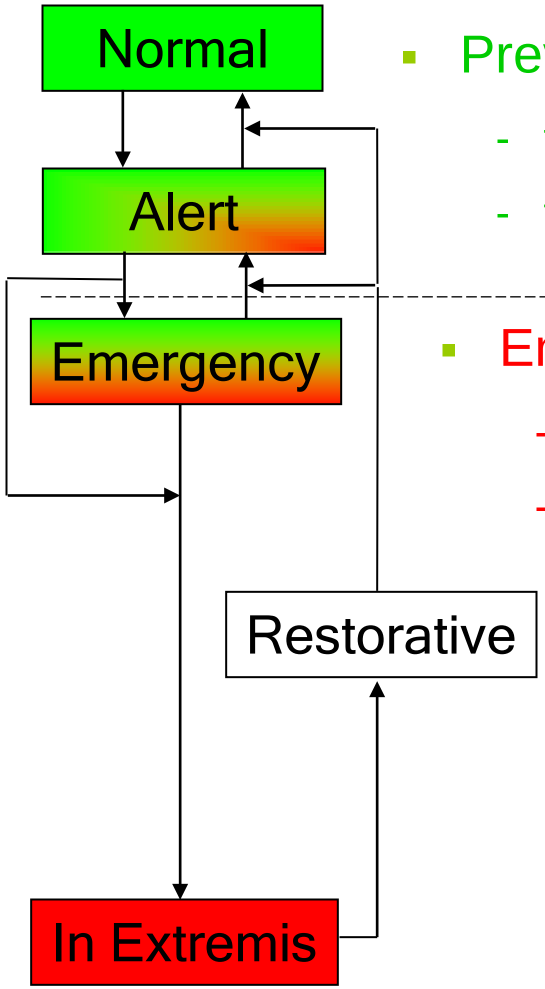
Operation State	Energy balance	Tech. and Econ. Requirements	N - 1 criteria
Normal	fulfilled	fulfilled	fulfilled
Alert	fulfilled	fulfilled	not fulfilled
Emergency	fulfilled	not fulfilled	not fulfilled
In Extremis	not fulfilled	not fulfilled	not fulfilled
Restorative	not fulfilled	fulfilled	not fulfilled

Security



- Security:
  - "degree of risk in power system ability to survive imminent disturbances (contingencies) without interruption of customer service. It relates to robustness of the system to imminent disturbances and, hence, depends on the system operating condition as well as the contingent probability of disturbances."
  - Normal state is secure
  - All other states are insecure
- The transition/border between Normal and Alert state is expressed by N – 1 criterion:
  - Outage of a single component can not lead to violation of operation limits of any other component.

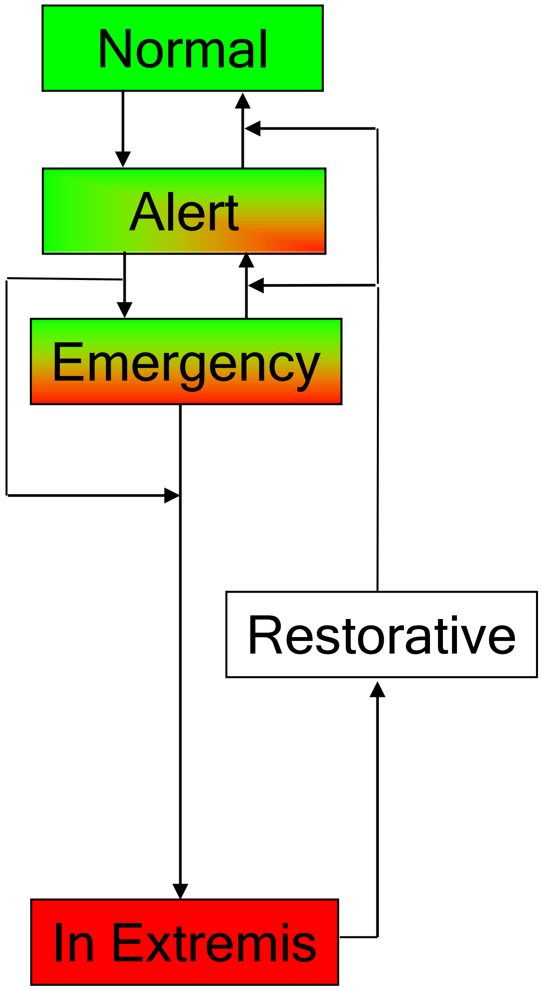
Defense Strategies



- Preventive Control:
  - to keep the system in Normal state
  - to bring the system back into Normal state

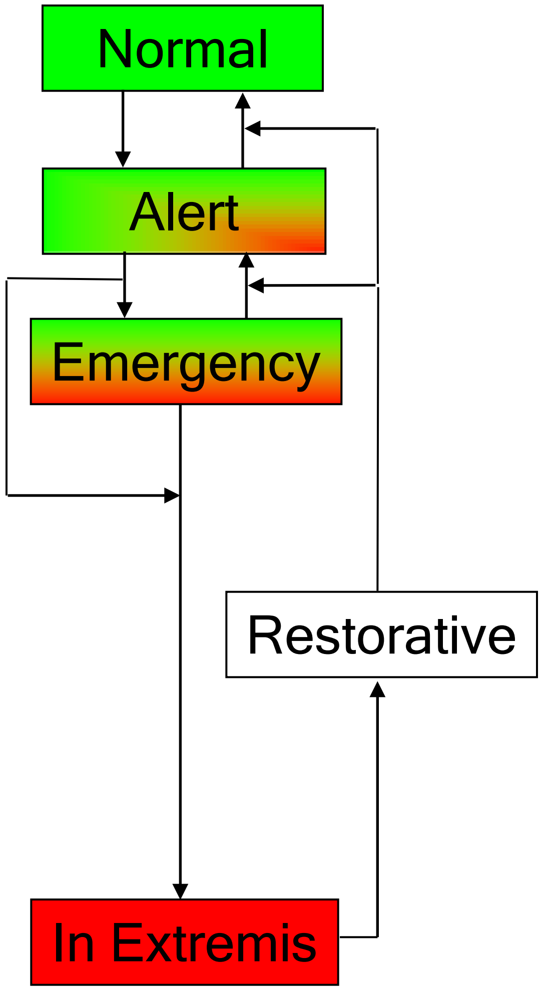
- Emergency control:
  - to stop the further system degradation and failure propagation
  - to bring the system back into Alert state

Preventive Control



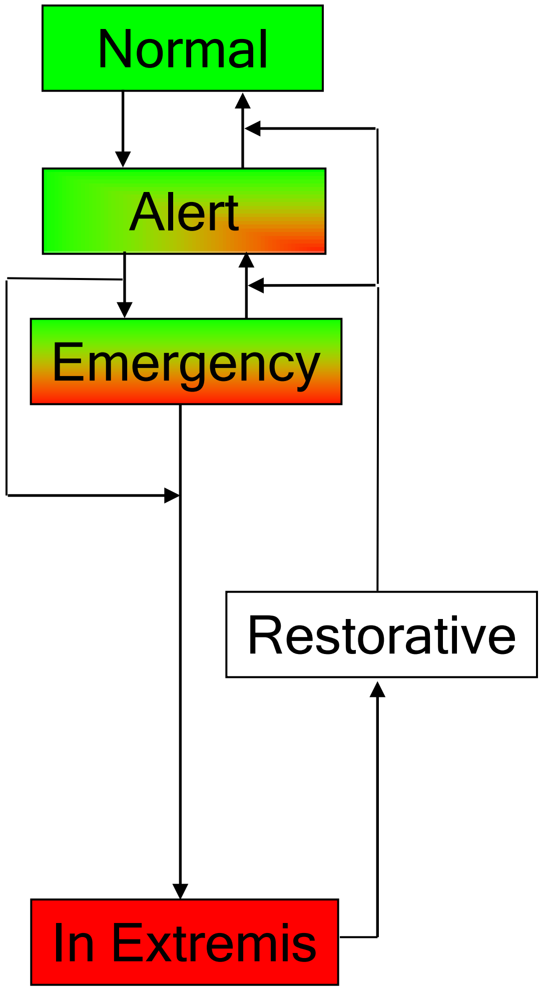
- Preventive Control:
  - to keep the system in Normal state
  - to bring the system back into Normal state
  - Hierarchical automatic control:
    - Frequency control
    - Voltage control
  - Centralized manual control:
    - Decision support tools
    - Operator judgment

Preventive Control



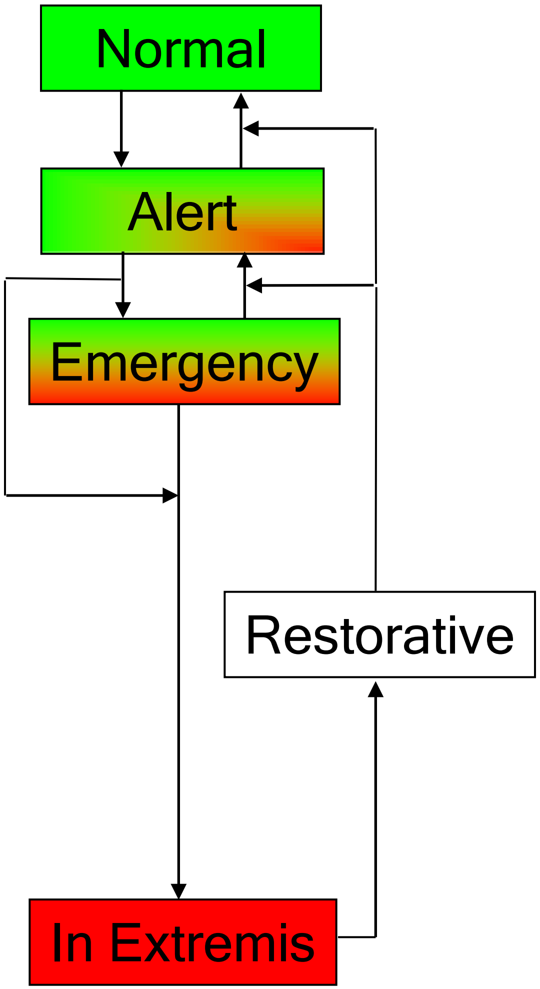
- Preventive control measures:
  - Generation redispatch (change of active power production of generators)
  - Change of reference points of controllable devices (e.g. FACTS, phase-shifting transformers)
  - Start-up of generation units
  - Change of voltage reference points of generators and voltage control devices (e.g. Static Var Compensator)
  - Switching of shunt elements (e.g. reactors, capacitors)
  - Change of substation configuration (e.g. busbars splitting)

Emergency Control



- Emergency control:
  - to stop the further system degradation and failure propagation
  - to bring the system back into Alert state
  - Protection based systems
    - Under frequency load shedding (UFLS) schemes
    - Under voltage load shedding (UVLS) schemes
    - System Protection Schemes (SPS)
  - Damping control

Emergency Control



- Emergency control measures:
  - Tripping of generators
  - Fast generation reduction through fast-valving or water diversion
  - Fast HVDC power transfer control
  - Load shedding
  - Controlled opening of interconnection to neighboring systems to prevent spreading of frequency problems
  - Controlled islanding of local system into separate areas with generation-load balance
  - Blocking of tap changer of transformers
  - Insertion of a breaking resistor

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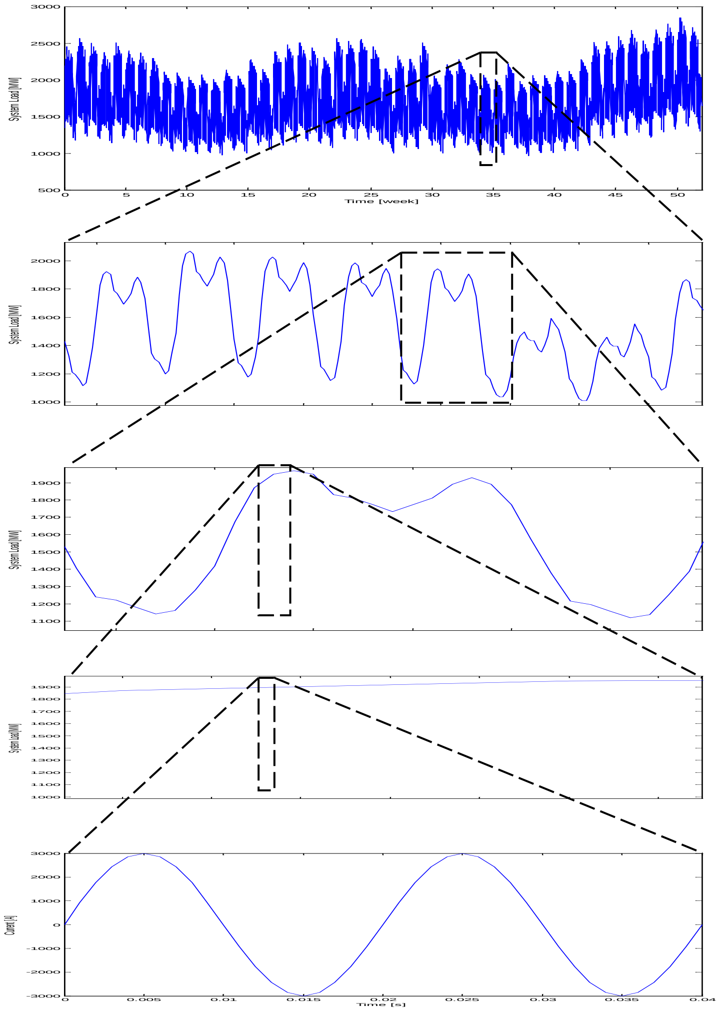
Time Scale Decomposition of TSO Activities



- Years - Planning
- Week – Operation planning
- Day – Day-Ahead Operation Planning
- Hour - Operation
- Milliseconds - Planning

Day Ahead Operation Planning

- Construction of the base case plan (i.e. loading and generation) for the coming day (0:00 – 24:00, basic unit is 1 hour):
  - Expected loads' values
  - Scheduled generators' production
  - Limitations of the transmission system are not considered yet !

Day Ahead Operation Planning

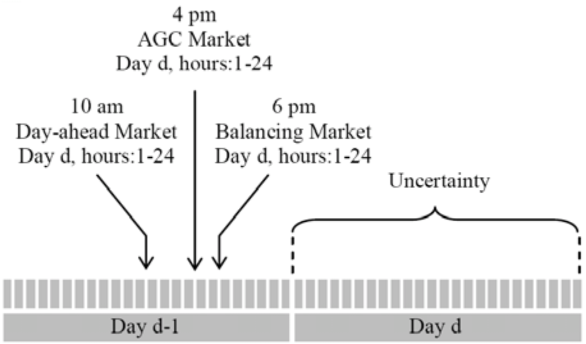
- Security considerations and possible adjustments of the base case plan
  - Scheduled outages (i.e. expected topology)
  - Security Assessment of the base case plan, i.e. compliance with N-1
  - Modifications of the base case plan, if needed:
    - Generation redispatch
    - Topology changes (including maintenance disapprovals)

Regulated markets => vertically integrated utility

- Construction of the Base Case Plan
  - Load forecast
  - Generation dispatch (including basic generation, AGC participation and reserves allocation)
- Security Considerations
  - Security Assessment of the base case plan, i.e. compliance with N-1 Criterion
  - If the base plan violates security constraints => Security constrained OPF (Optimal Power Flow)

Deregulated markets => TSO/ISO

- Construction of the Base Case Plan
  - Collection of long-term bilateral agreements
  - Clearance of day-ahead, AGC and balancing markets
  - Scheduling of AGC areas interchanges
  - Allocation of transmission capacity between systems
- Security Considerations
  - Security Assessment of the base case plan, i.e. compliance with N-1 Criterion
  - If the base plan violates security constraints => Congestion Management



Source of the example: Prof. Antonio Conejo

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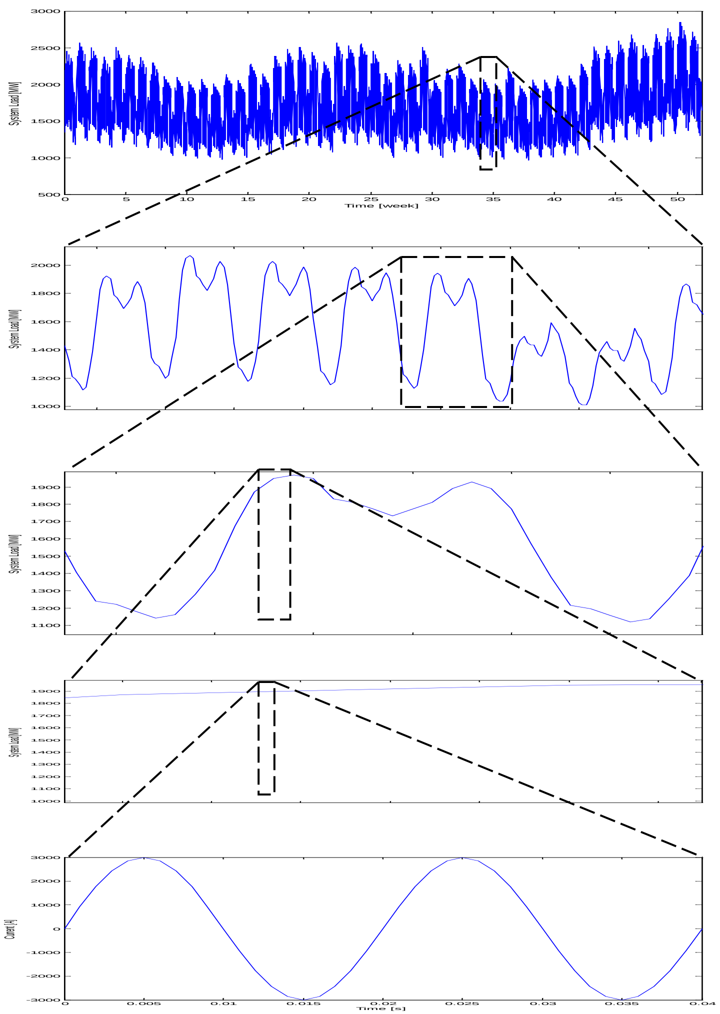
Time Scale Decomposition of TSO Activities



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On-line Operation

- On-line system state differs from the day-ahead forecast because:
  - Day-ahead plan unit is one hour
  - Load values vary
  - Contingencies:
    - Transmission components
    - Generators
- Operator observes:
  - if the day-ahead plan is followed
  - System security:
    - Operator‘s judgment
    - On-line security assessment (either regular time intervals or ‚on demand‘)

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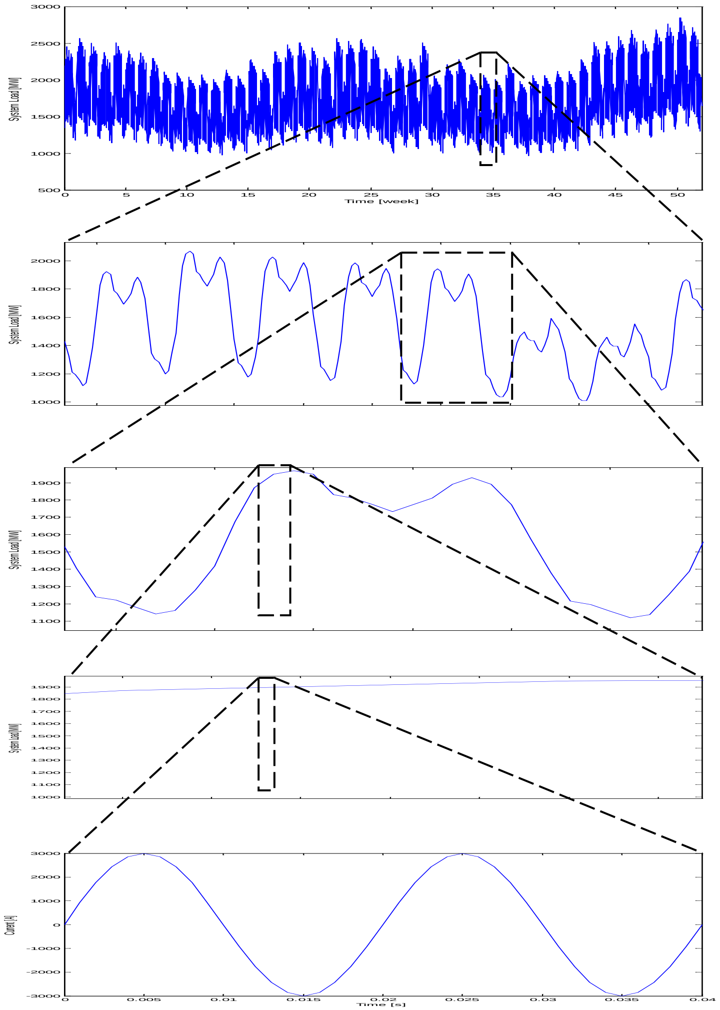

- Years - Planning
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Long-term Planning

- Planning focuses on the adequate performance of a power system over a long run
- All aspects to be considered from a long-term perspective:
  - Security
  - Reliability
  - Stability
  - Economy

Long-term Planning

- Tasks of System Planning:
  - Computations and Analysis

  - Preparation of Operation Procedures
  - Power System Development
  - Determination of Transmission System Operation Rules

  - Power System Maintenance

  - Experimental Tasks

Computations and Analysis

- Activities:
  - Load forecast
  - Adequacy assessment
  - Security assessment
  - Short-circuit studies
  - Operation limits computation

Adequacy Assessment

- Adequacy measures capability of power system to supply load in all steady states under all normal conditions and situations, which may occur

  - Transmission system adequacy

  - Generation adequacy focuses on the capability to meet the peak demand, considering possible generation units outages

Preparation of Operation Procedures

- Emergency Scenarios:
  - Recognition signs of a dangerous situation
  - Employment of necessary controls

- System Restoration

Power System Development – Asset Management

- Process for acquisition and use of a operation component for a maximal economical profit and management of risks and cost during the entire component lifetime
- Asset Management has to do with:
    - Strategy / Policy definition (maintenance, investment)
    - Real Time Control (fault management)
    - Asset History (condition, faults, maintenance)
    - Asset Location (geographic position)
    - Asset Value (purchase price, depreciation, replacement costs)
    - Planning Tools (system capacity, security, losses)
    - Risk Management (system security and asset criticality)
    - System Performance (reliability, availability)
    - Health & Safety (policies, codes of practice)
    - Customer Information (who, where, when, history, …)
    - Financial Performance (return on investment)

Determination of Transmission System Operation Rules

- Operation limitations:
  - Internal
  - External = Transmission Capacity

- Transmission pricing.
  - Covering of the network use cost (short-term objective)
  - Incentive for the power system development – placing of new generation, load (long-term objective)

- Ancillary services

Transmission System Operation Rules – Trans. Capacity

- Definitions by ETSO:
  - TTC (Total Transmission Capacity) – maximum exchange program between two areas compatible with operational security standards applicable at each system if future network conditions, generation and load patterns were perfectly known in advance
  - TRM (Transmission Reliability Margin) – a security margin that copes with uncertainties on the computed TTC values arising from:
    - Unintended deviations of physical flows during operation due to the physical functioning of load-frequency regulation
    - Emergency exchanges between TSOs to cope with unexpected unbalanced situations in real time
    - Inaccuracies, e.g. in data collection and measurements

Transmission System Operation Rules – Trans. Capacity

- Definitions by ETSO:
  - NTC (Net Transfer capacity) – the maximum exchange program between two areas compatible with security standards applicable in both areas and taking into account technical uncertainties on future network conditions
    - NTC = TTC – TRM
  - AAC (Already Allocated Capacity) – total amount of allocated transmission rights, whether they are capacity or exchange programs depending on the allocation method
  - ATC (Available Transmission Capacity) – the part of NTC that remains available, after each phase of the allocation procedure, for further commercial activity
    - ATC = NTC - AAC

Transmission System Operation Rules – Trans. Capacity

- Important remarks:
  - There are two phases of activities related to trans. capacities:
    - planning phase – computation of NTC etc.
    - allocation phase – market mechanism
  - NTC does not consider transient stability dependent on clearing time !
  - NTC considers all other stability and components overloads limits under N-1 criteria assumption
  - NTC is time dependent
  - NTC refers to an interface between two systems (i.e. may be several tie-lines)
  - NTC is theoretical value (parallel flows etc.)

Power System Maintenance

- Hardware assets maintenance:
  - Check of impact of aging on equipment
  - Regular equipment performance tests (CTs, PTs, transformers etc.)
- Outage Scheduling:
  - In secure conditions (e.g. light loading)
  - Coordinated with all involved parties (neighboring TSOs)
  - Announced sufficiently in advance
  - Modified operation rules (e.g. NTC reduced etc.)
- Software related issues:
  - SCADA databases updates
  - Simulation software databases updates

Experimental Tasks

- Testing of new technologies, tools and procedures before applying them in operation

- Field measurements:
  - Tests of power plants for dynamic modeling in simulations
  - Line Thermal monitoring