What do fault statistics tell us regarding causes resulting in power outages?

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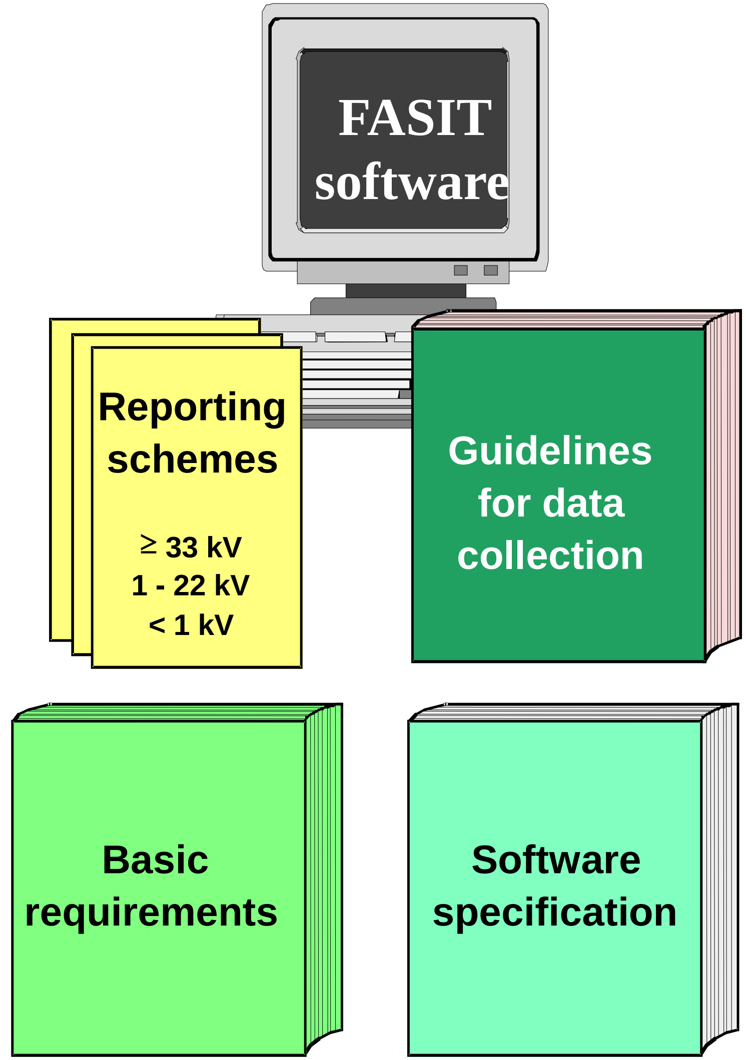
Content of presentation

- FASIT – The Norwegian standard for reliability data collection and reporting
- Faults and interruptions (power outages) – definitions
- Highlights from the fault statistics 1 – 420 kV
  - Number of events and energy not supplied 1989 – 2010
  - Fault causes 2007 – 2010
  - Component faults and fault rates
- Interruptions and cost of energy not supplied (CENS)
- Large disturbances (high impact)
- Brief comparison Nordic countries

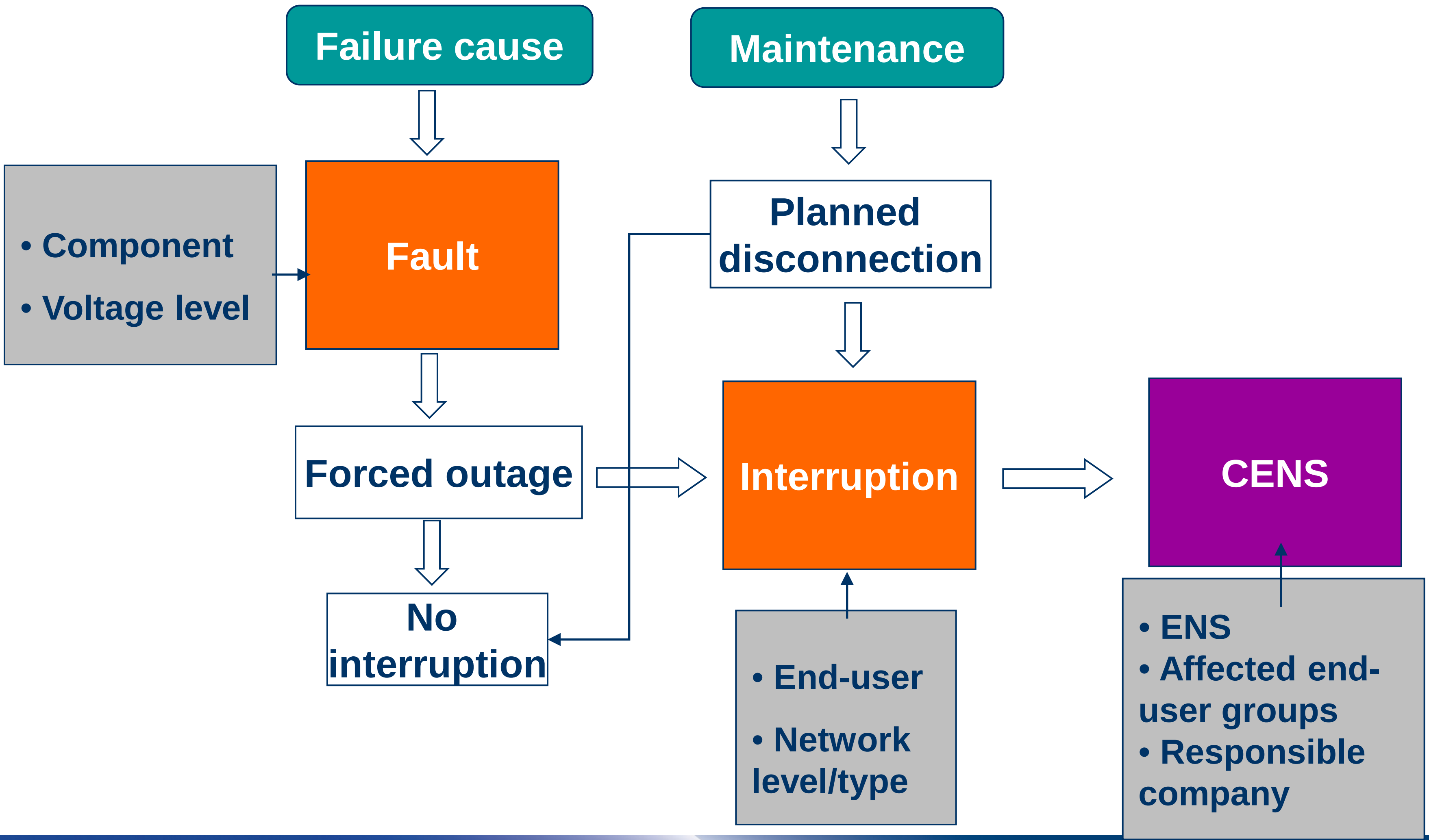
Standard for collection, calculation and reporting – FASIT

- Introduced in 1995
- Used by all network companies in Norway
- 6 software vendors
- Software quality assurance (contracts and acceptance test)

www.fasit.no



FASIT – reliability data classes



Interruption – definition (EN 50160)

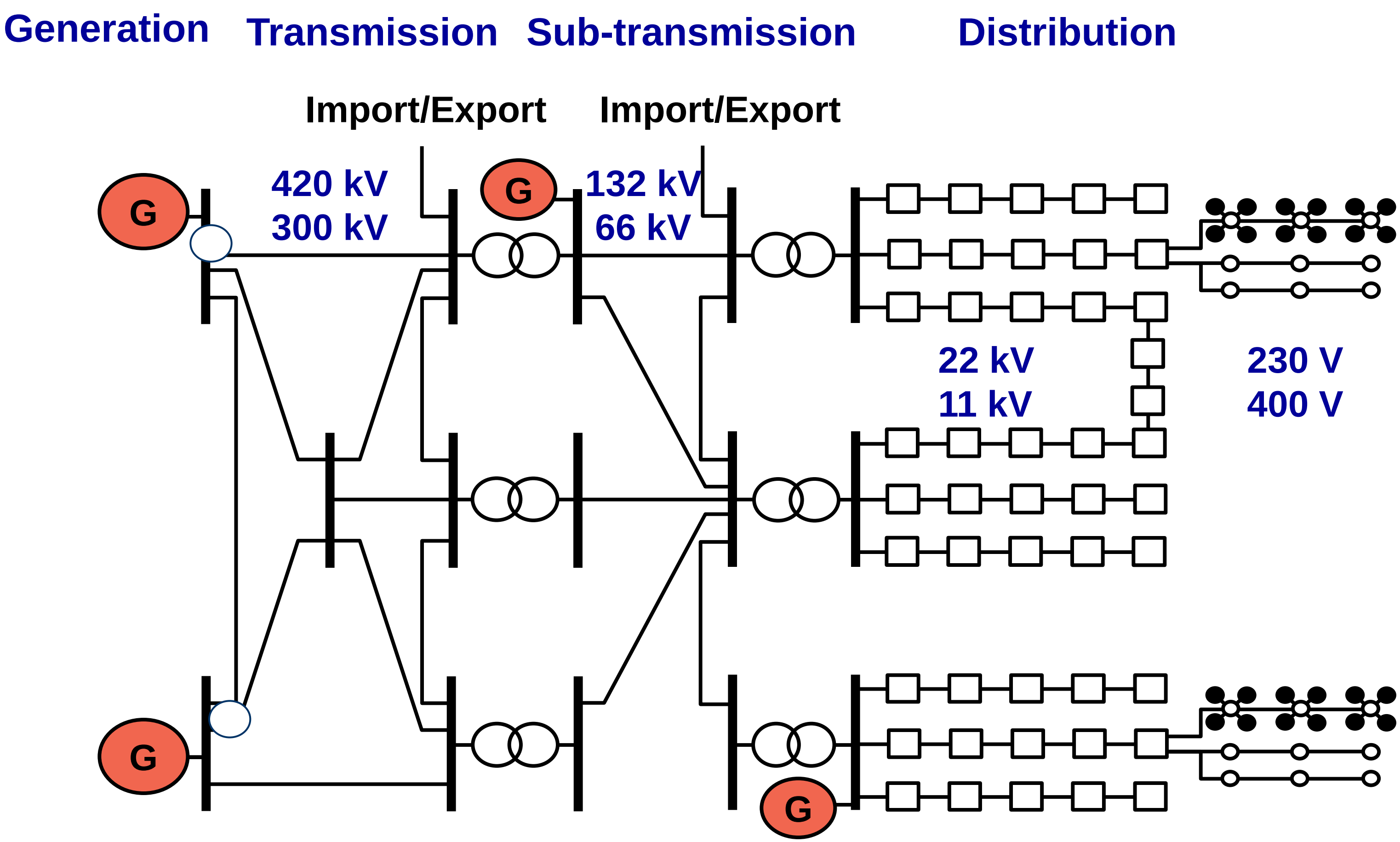
- Condition in which the voltage at the supply terminals is lower than 5 % of the reference voltage.
- A supply interruption can be classified as
  - prearranged, when network users are informed in advance, or
  - accidental, caused by permanent or transient faults, mostly related to external events, equipment failures or interference. An accidental interruption is classified as:
    - a long interruption (longer than 3 min);
    - a short interruption (up to and including 3 min)

Power outage = interruption in this presentation

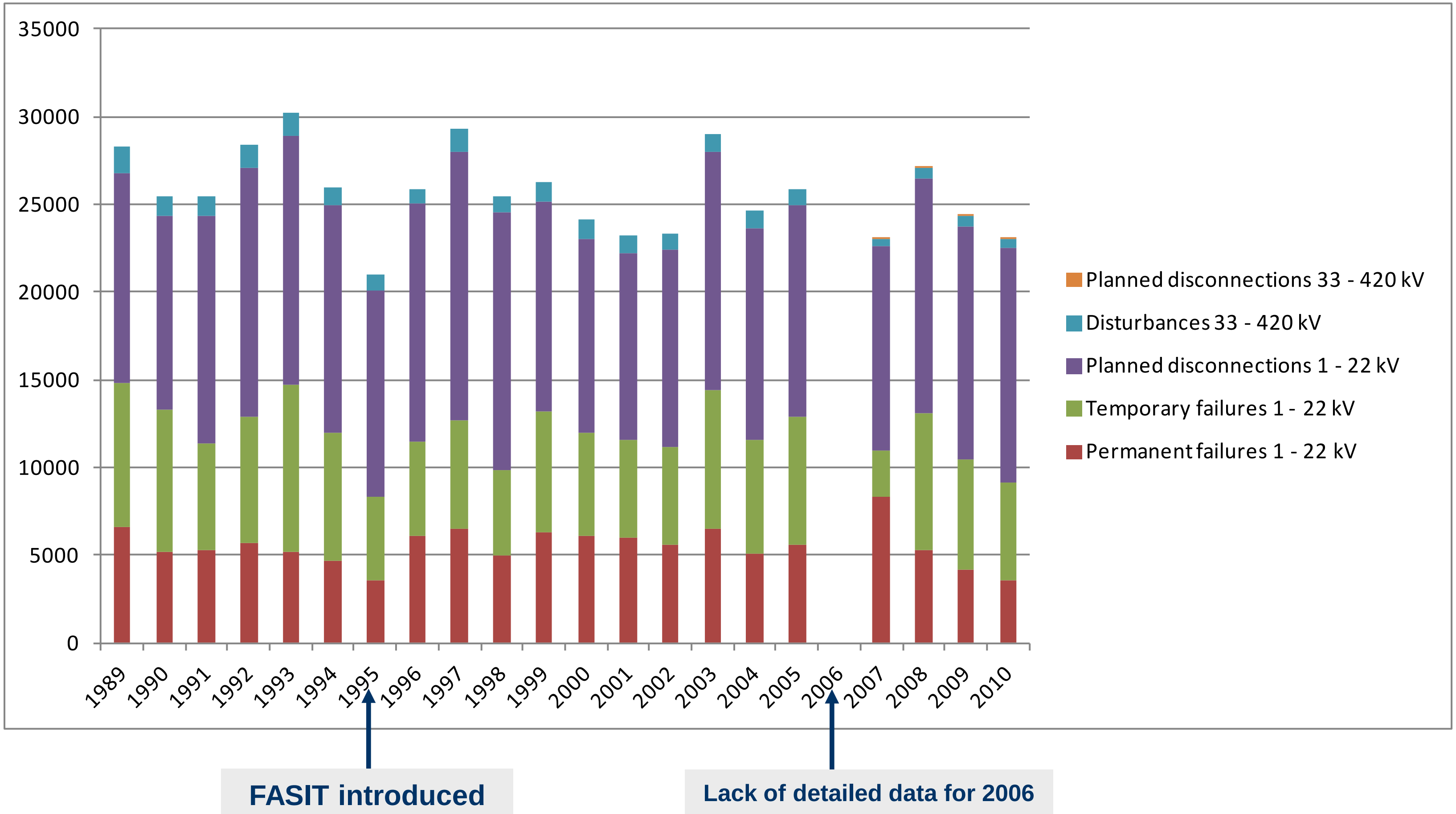
Fault – definition

- Fault is *the state of an item characterized by inability to perform a required function* (IEC)
- Fault causes may be related to construction, production, installation, use or maintenance causing fault on the unit
- Fault causes may be classified in triggering, underlying or contributing causes
- Faults are divided in
  - Permanent (corrective maintenance/repair)
  - Transient/ temporary (no corrective maintenance/repair, reconnection of breaker or replacement of fuse)

Power system levels – Norway

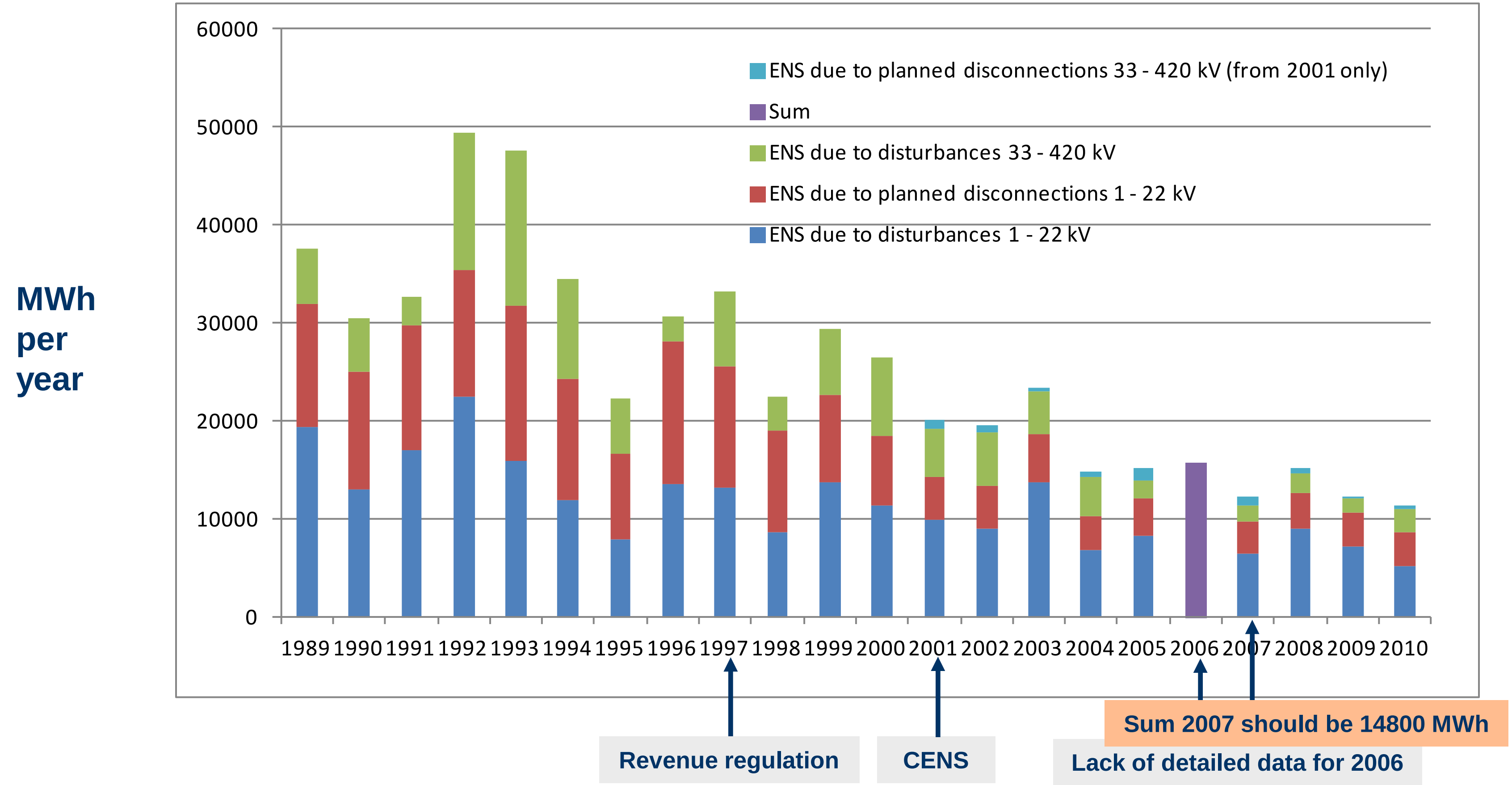


Number of events 1 – 420 kV



About 25000 events per year > 95 % in the distribution network, ~ 50 % disturbances

Energy not supplied 1 – 420 kV

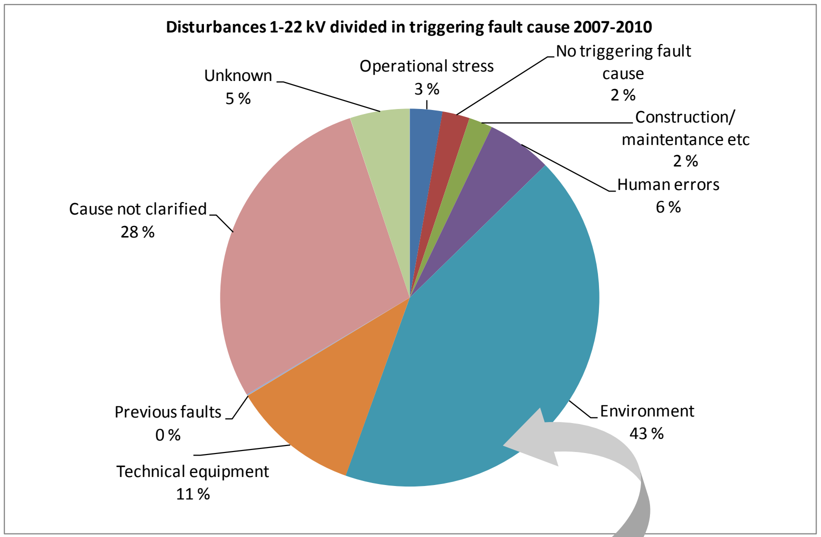


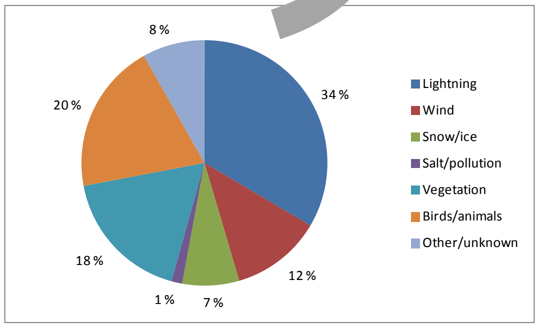
~ 80 % caused by faults in the distribution network

Triggering fault causes 1 – 22 kV 2007 - 2010

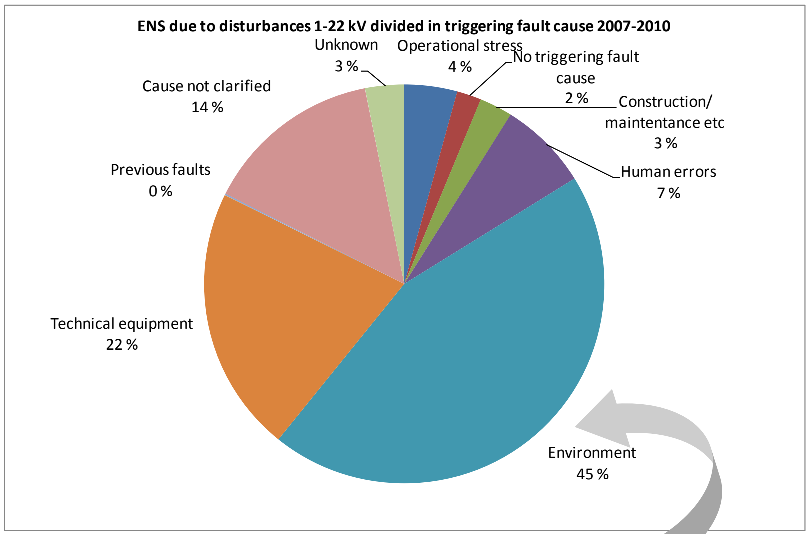
Weather and unknown/not clarified fault causes dominate

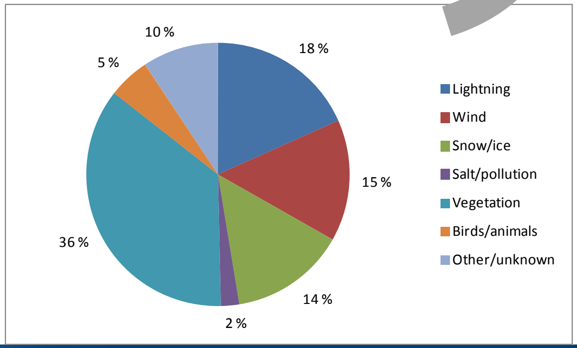
No of disturbances:





Energy not supplied (ENS):

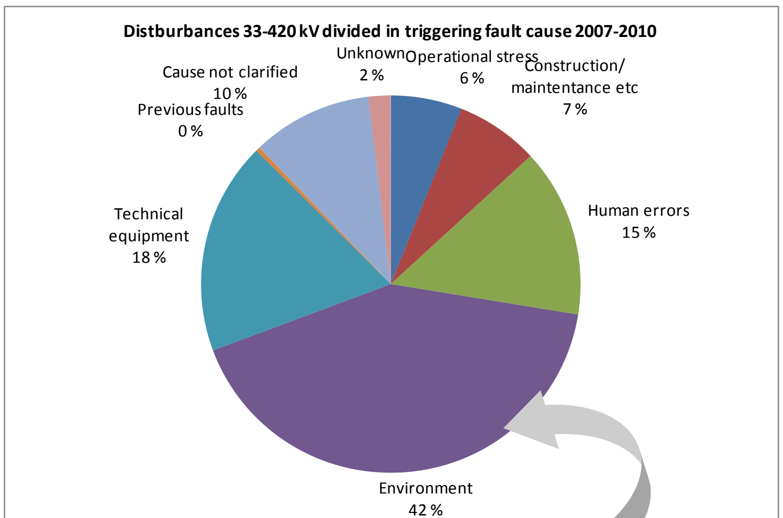


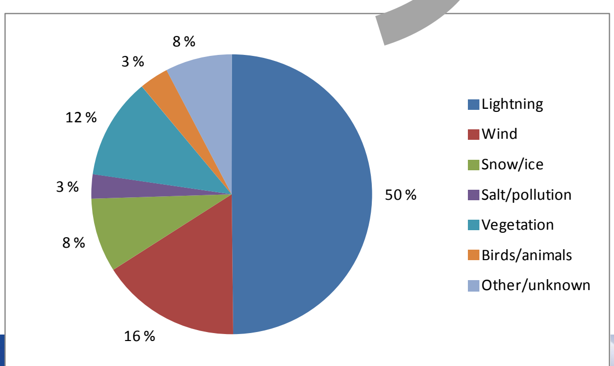


Triggering fault causes 33 – 420 kV 2007 – 2010

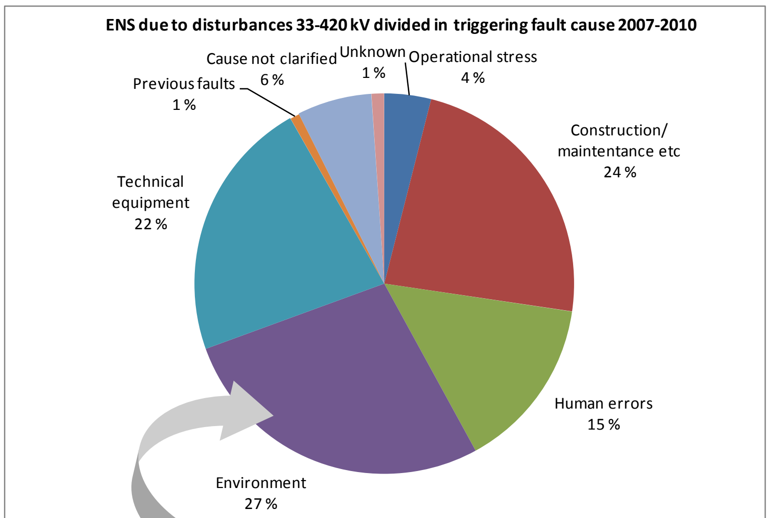
Weather , technical equipment and human errors dominate

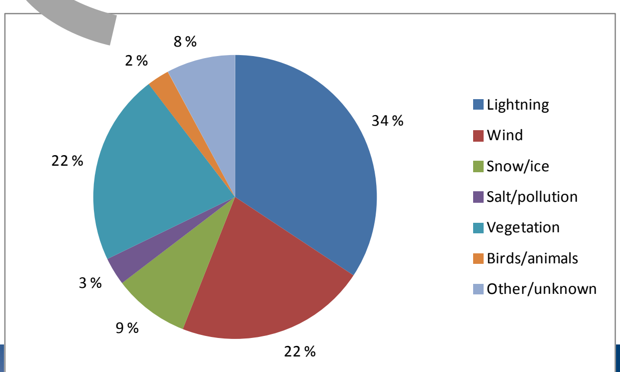
No of disturbances:



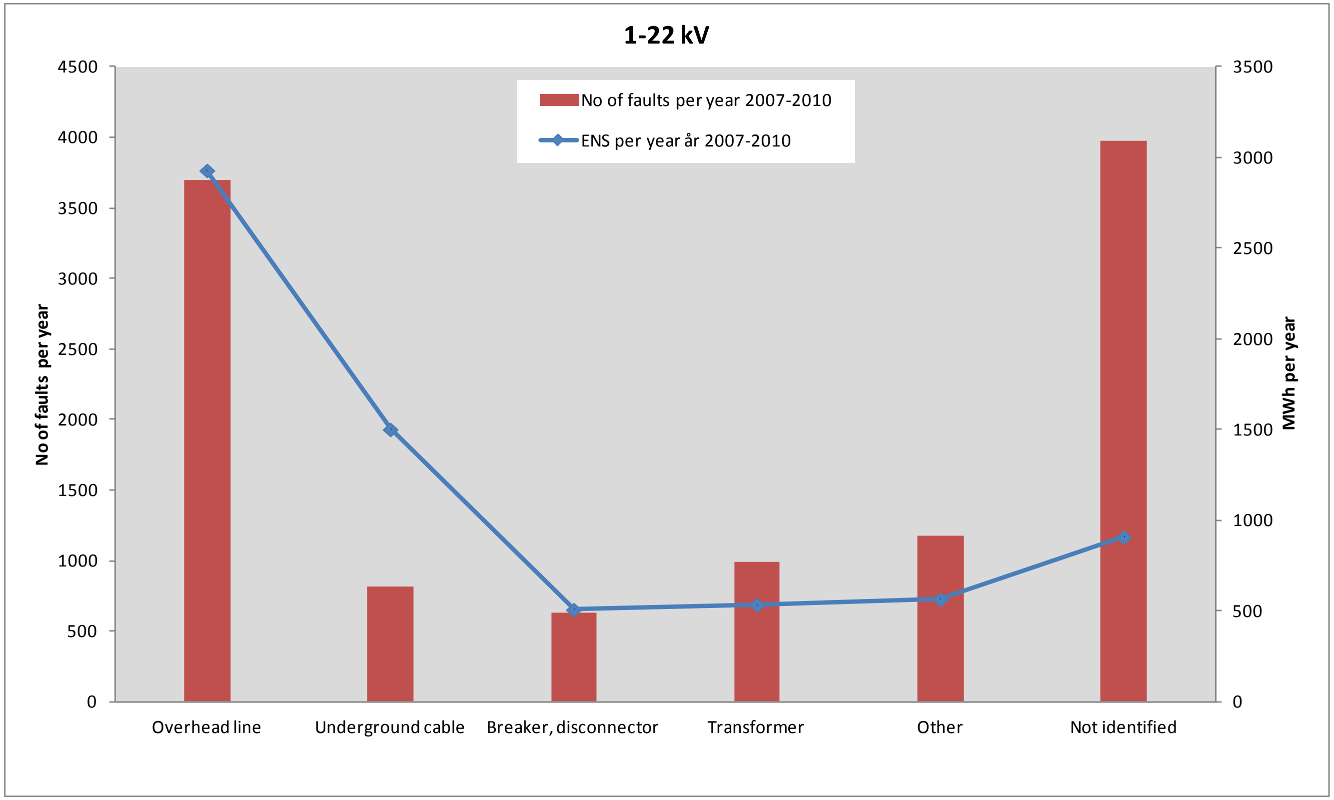


Energy not supplied (ENS):

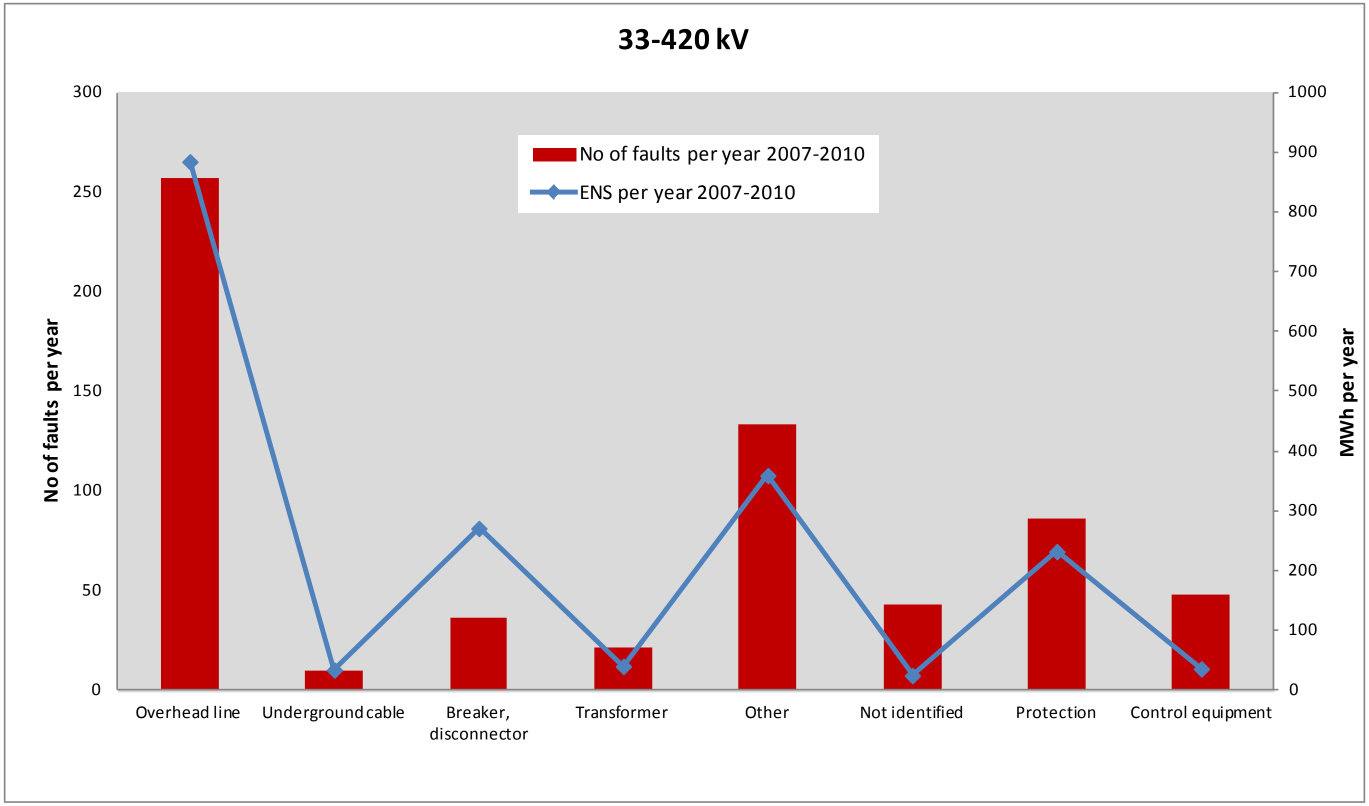




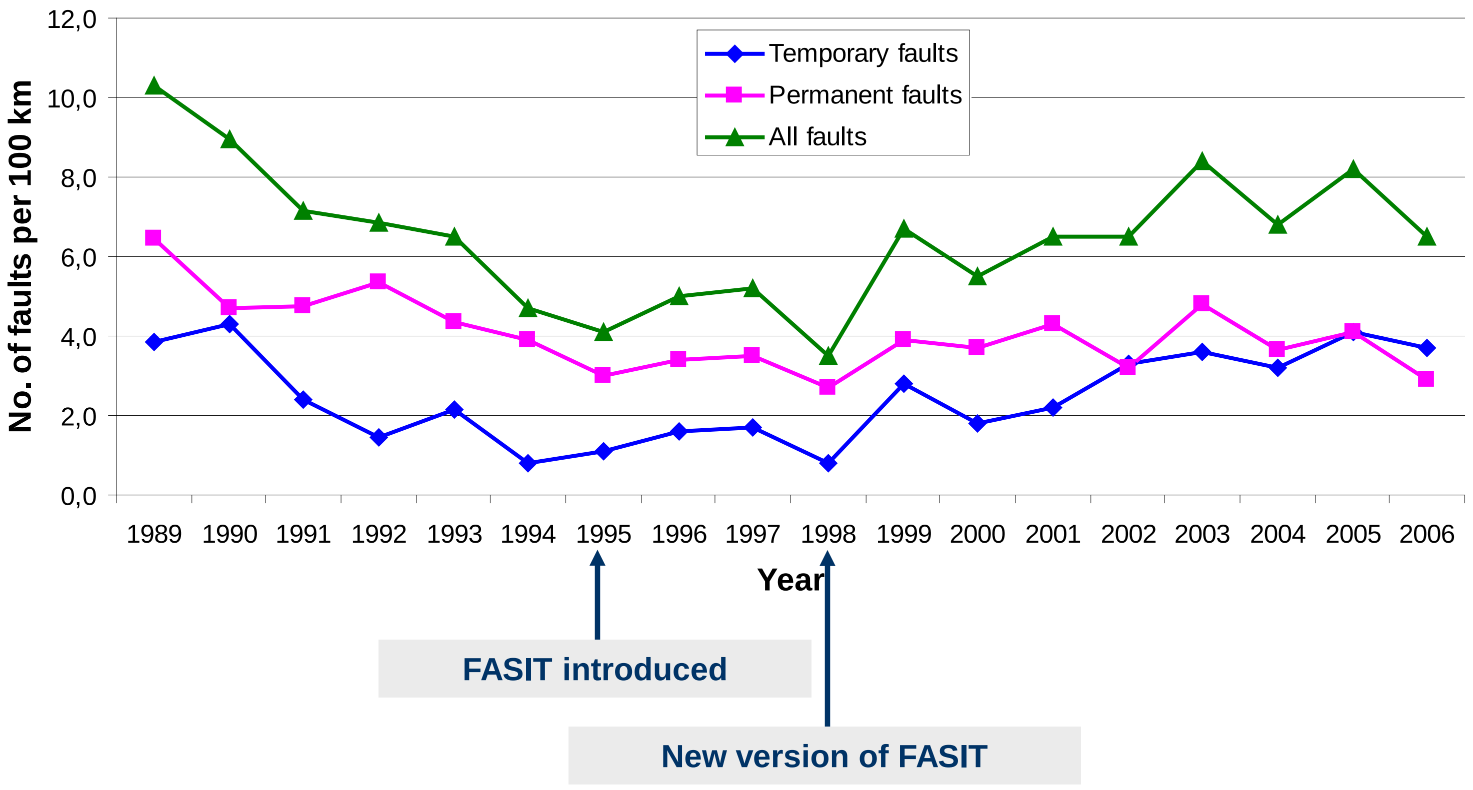
Component faults 1 – 22 kV 2007 – 2010



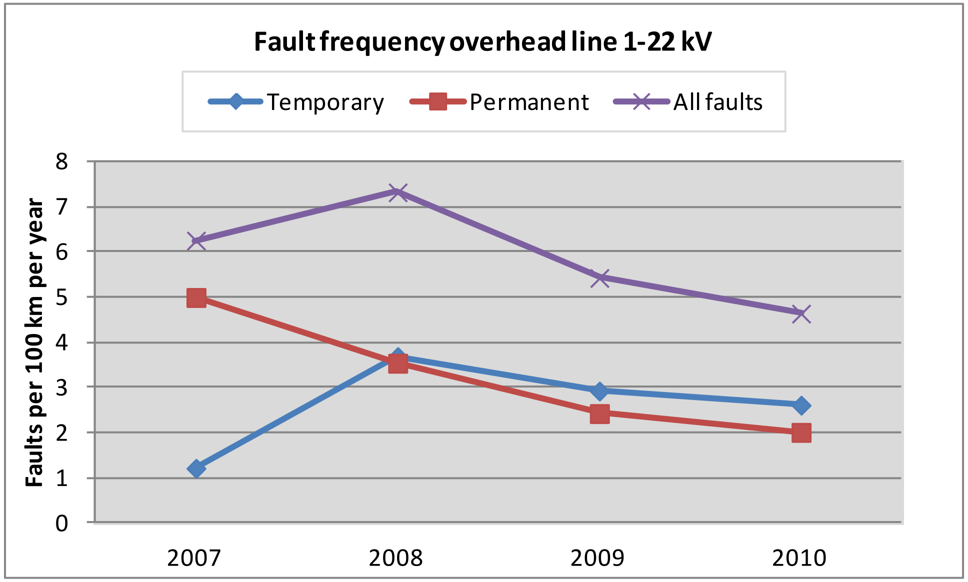
Component faults 33 – 420 kV 2007 – 2010



Fault rate for overhead lines 1 – 22 kV 1989 – 2005

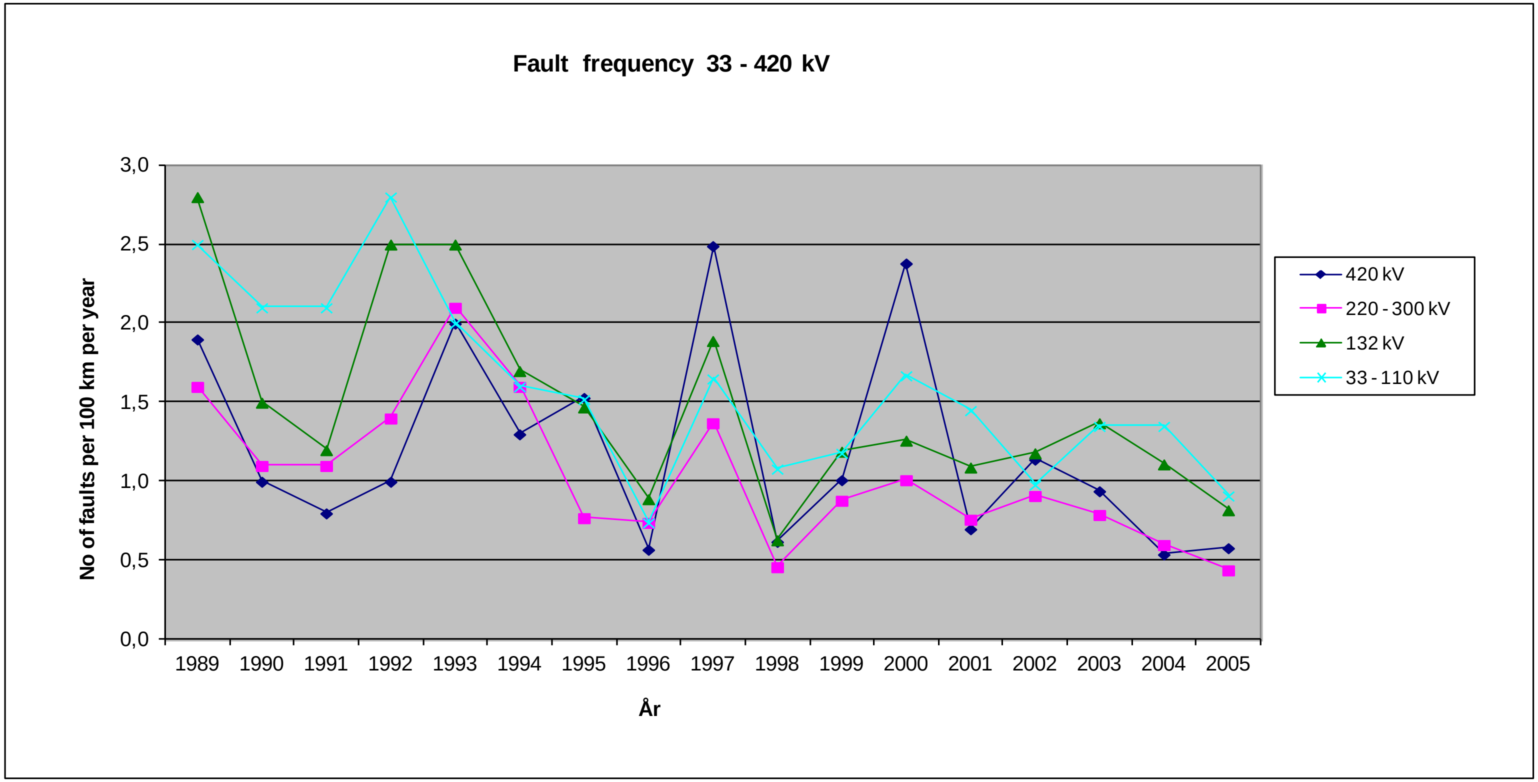


Fault rate overhead lines 1 – 22 kV 2007 – 2010

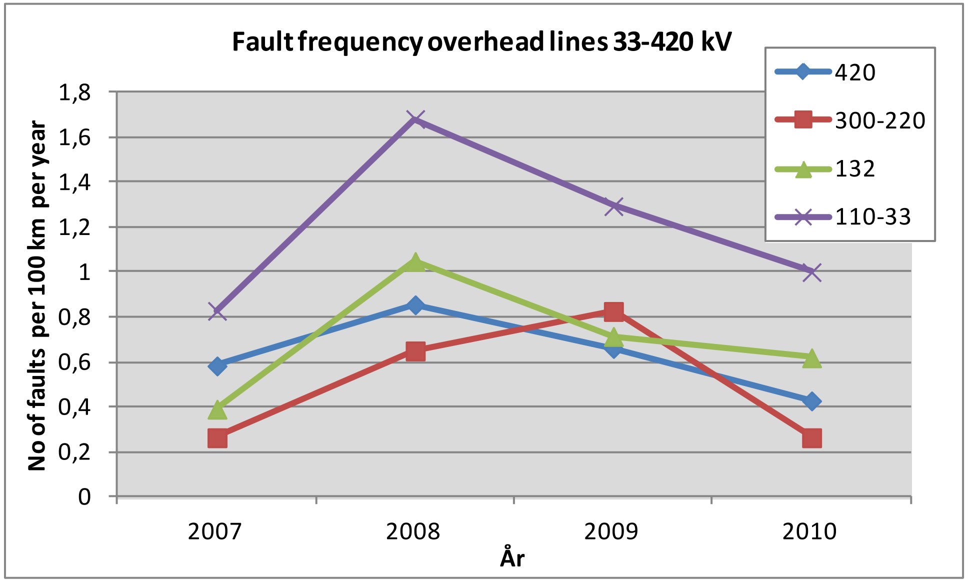


1 – 22kV: 6 – 7 faults per 100 km per year

Fault rate overhead lines 33 – 420 kV 1989 – 2005

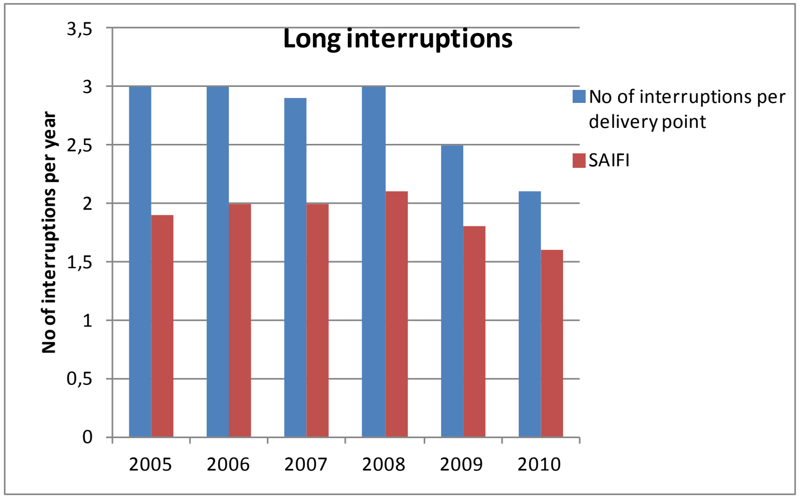


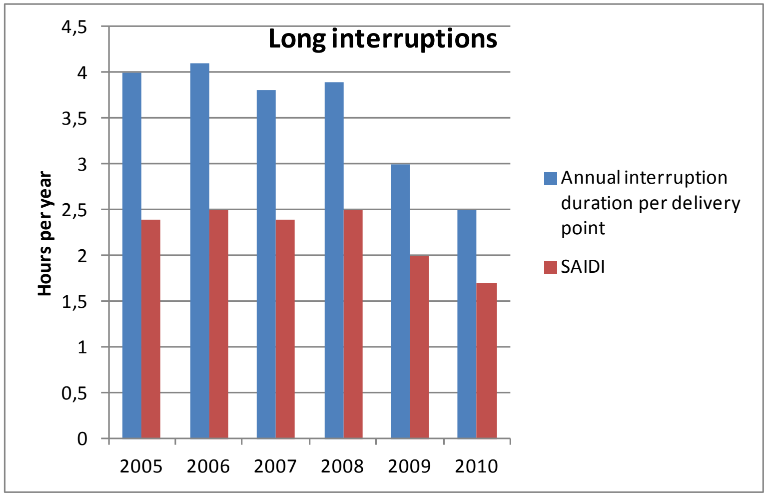
Fault rate overhead lines 33 – 420 kV 2007 – 2010



420kV – 33 kV: ~ 0,5 - 1 faults per 100 km per year

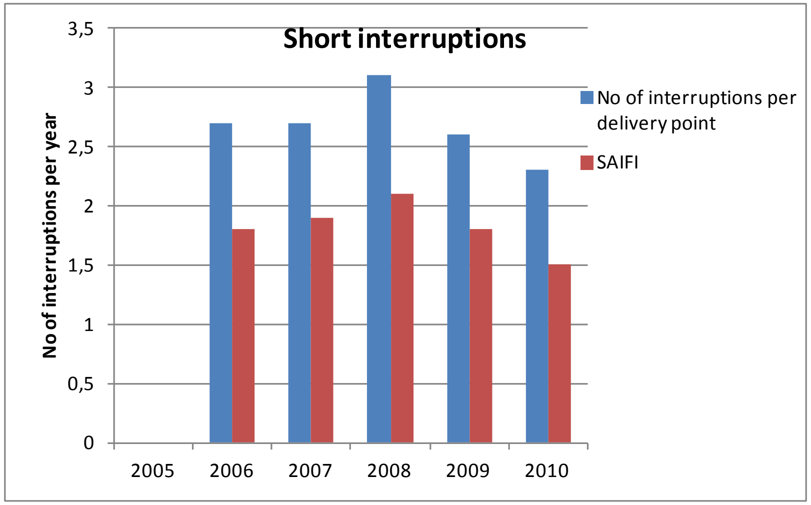
Interruptions 2005 – 2010, long interruptions > 3 minutes

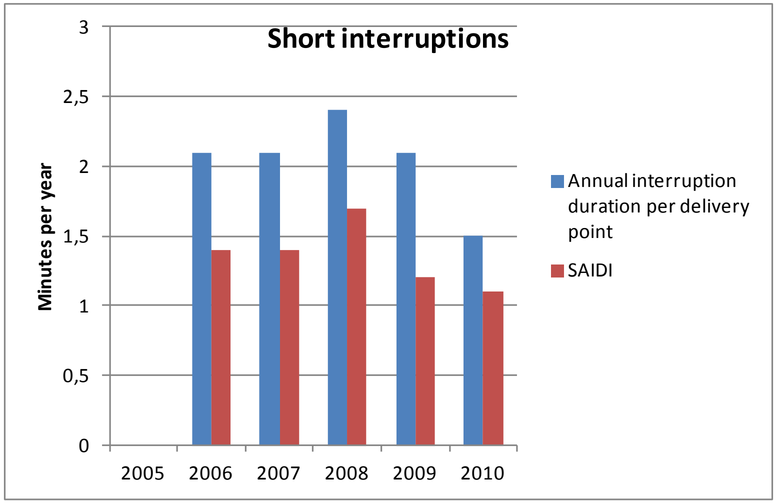




About 3 long interruptions and 3 – 4 hours per year per delivery point

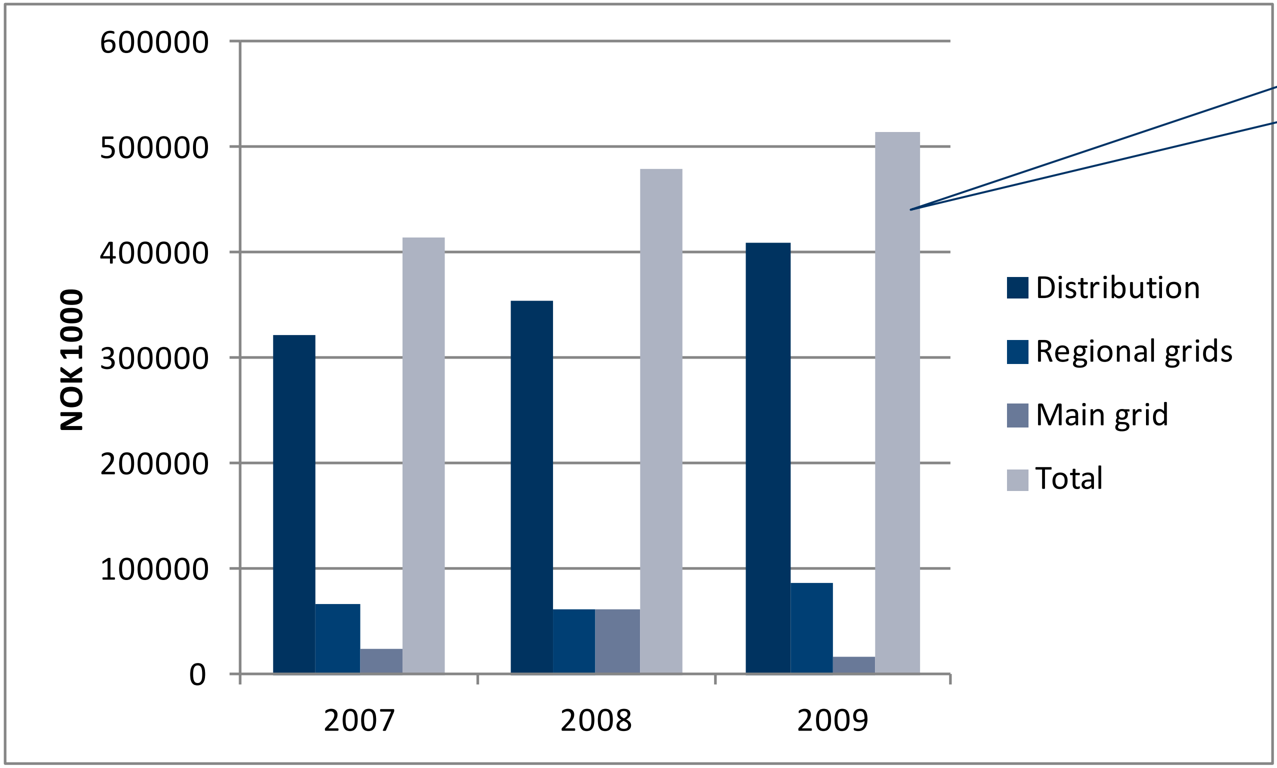
Interruptions 2006 – 2010, short interruptions ≤ 3 minutes





About 2,5 short interruptions and 2 minutes per year per delivery point

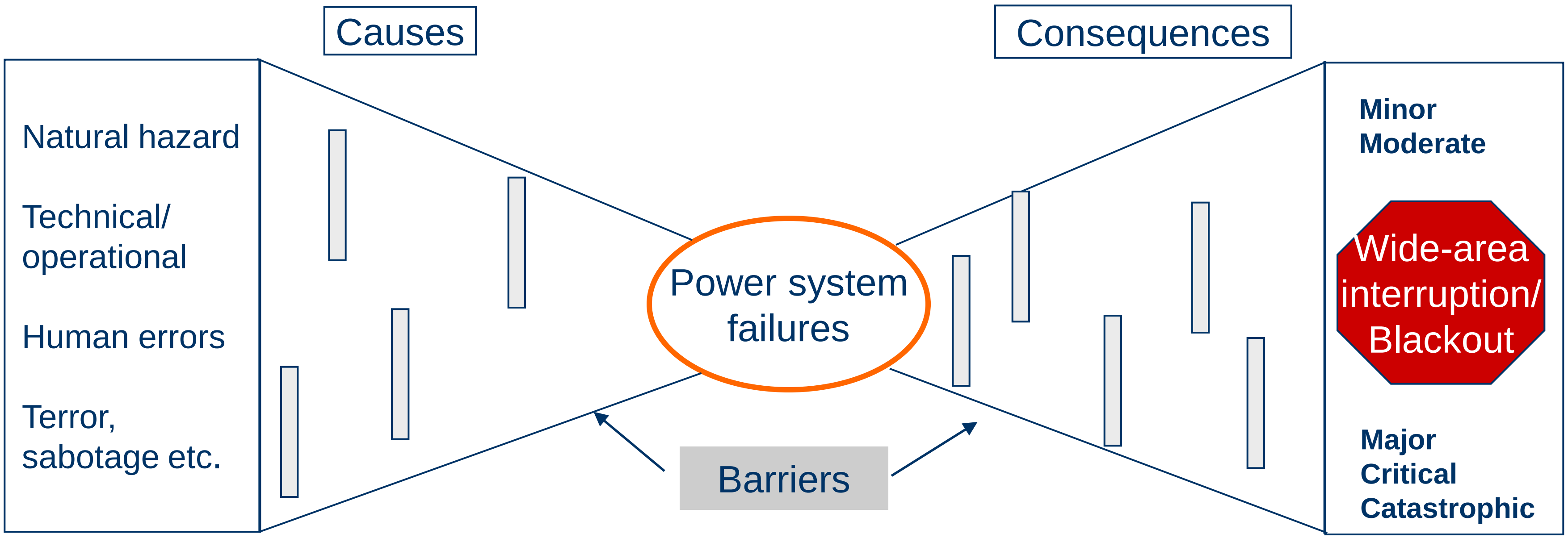
Cost of energy not supplied caused by different system levels



Cost of short interruptions included from 2009

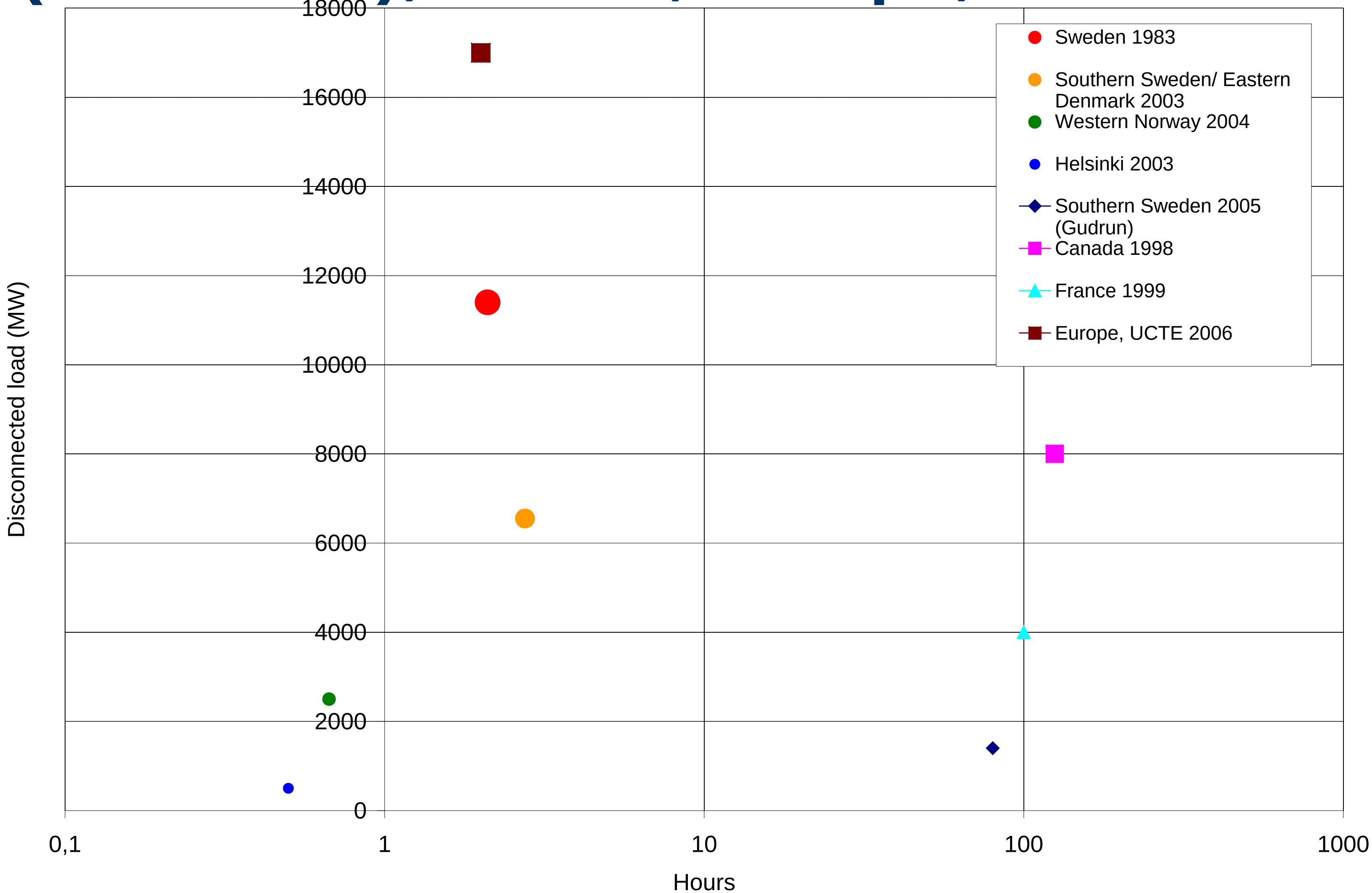
Distribution counts for 78 %

Normal/frequent events vs major events (large disturbances, HILP)

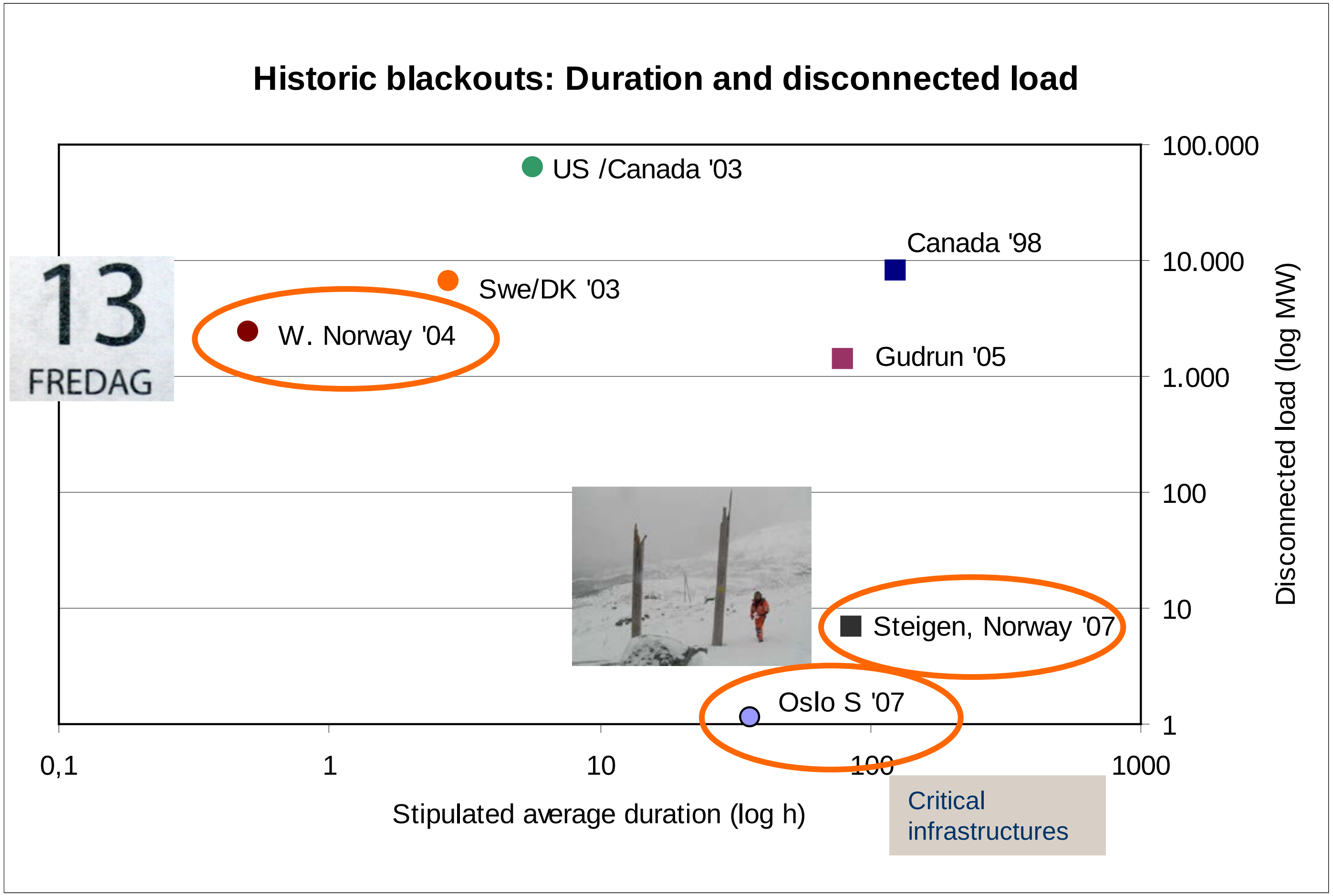


Fault statistics mainly give information about normal/frequent events

Examples of large disturbances (blackouts), Nordic, Europe, Canada



More examples, Norway, US/Canada...



Project Vulnerability and security in a changing power system, Nfr/SINTEF Energi, 2009 - 2012

Fault causes major events - examples

- ”Western Norway”, February 2004, 300 kV
- Breakage of line joint
  - Delayed protection response
- Causes:
  - Construction fault
  - Degradation of components
  - ”Inappropriate” protection

- Steigen, January 2007, 66 kV
- Breakdown of both overhead lines
- Causes :
  - Storm, icing
  - Construction fault
  - Degradation (ageing)

Comparison Nordic countries

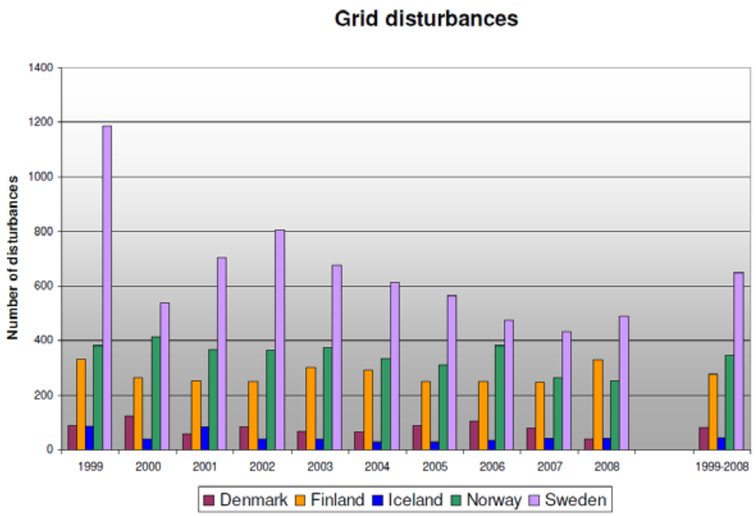


Figure 3.1 Number of grid disturbances in each Nordel country during the period 1999–2008.

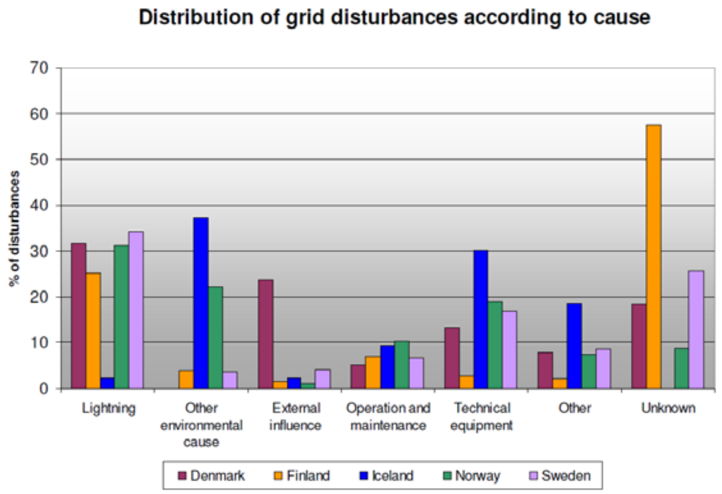


Figure 3.3 Percentage distribution of grid disturbances according to cause in 2008.

ENTSO-E Nordic Grid disturbance and fault statistics 2008

Comparison Nordic countries

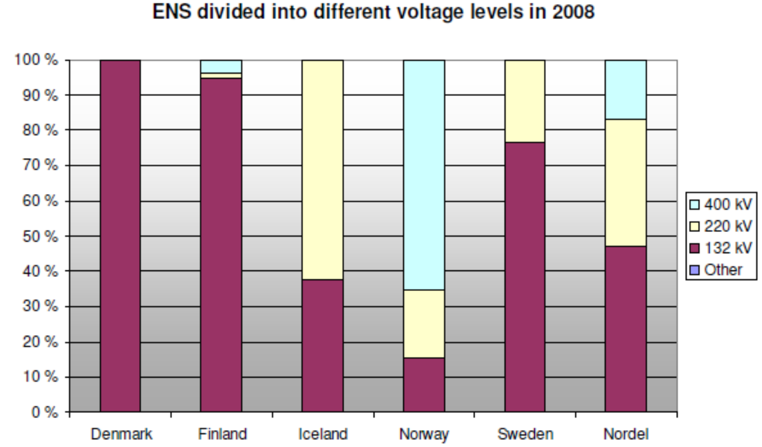


Figure 4.1 Energy not supplied (ENS) in terms of the voltage level of the initiating fault in 2008.

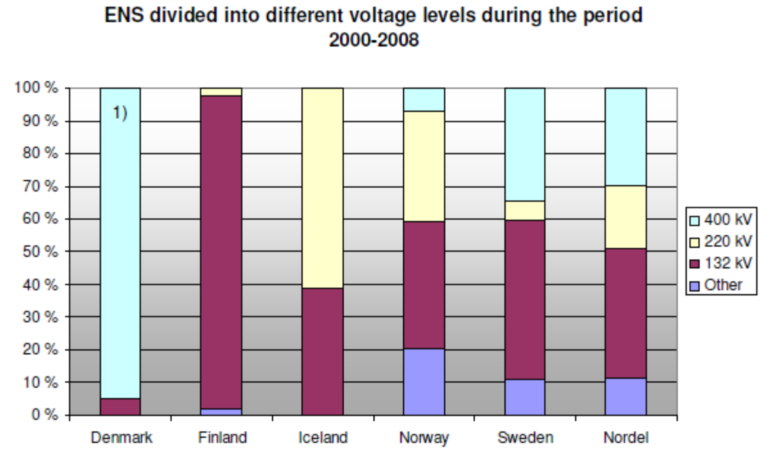


Figure 4.2 Energy not supplied (ENS) in terms of the voltage level of the initiating fault during the period 2000–2008.

ENTSO-E Nordic Grid disturbance and fault statistics 2008

Comparison Nordic countries

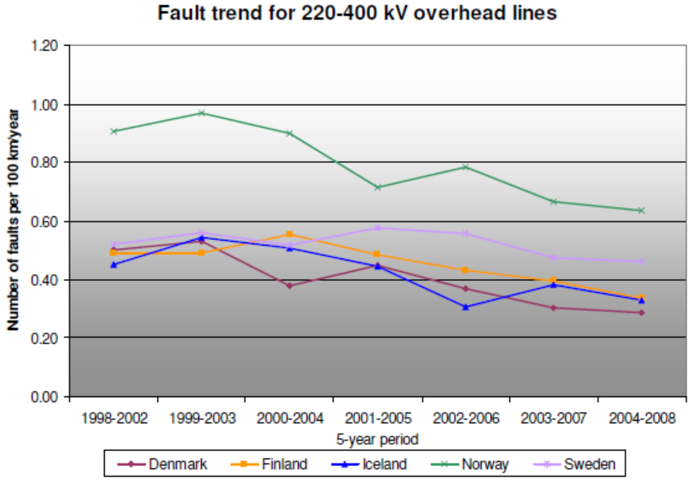


Figure 5.4 Fault trend for overhead lines at voltage level 220–400 kV.

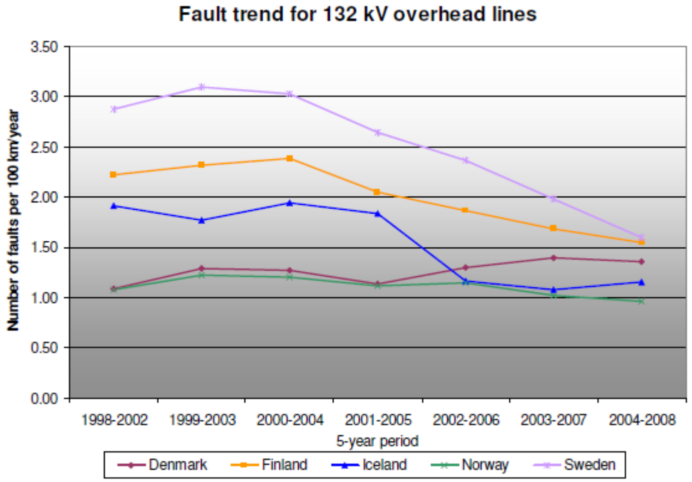
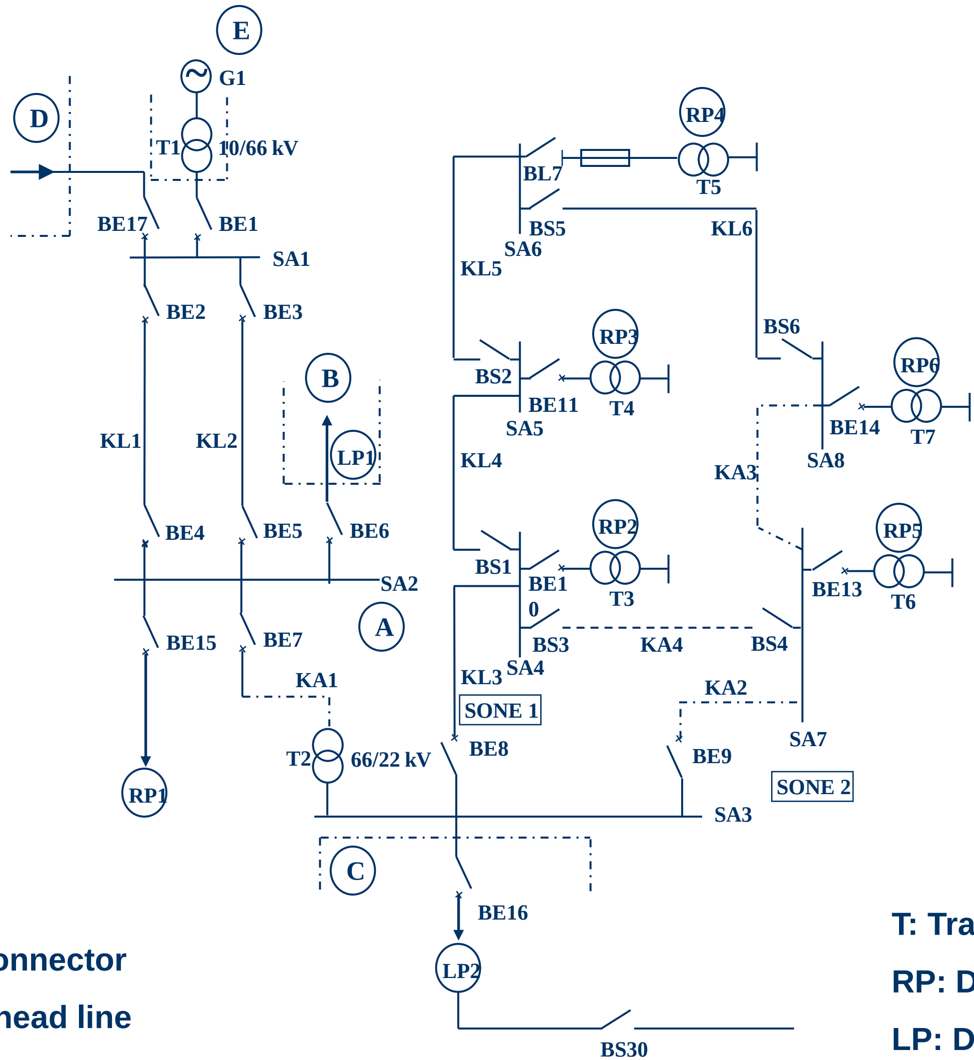


Figure 5.5 Fault trend for overhead lines at voltage level 132 kV.

ENTSO-E Nordic Grid disturbance and fault statistics 2008

Extra slides

Software certification: FASIT test network



G: Generator

SA: Busbar

BE: Circuit breaker

BS: Disconnector

KL: Overhead line

KA: Underground cable

T: Transformer

RP: Delivery (load) point

LP: Delivery point

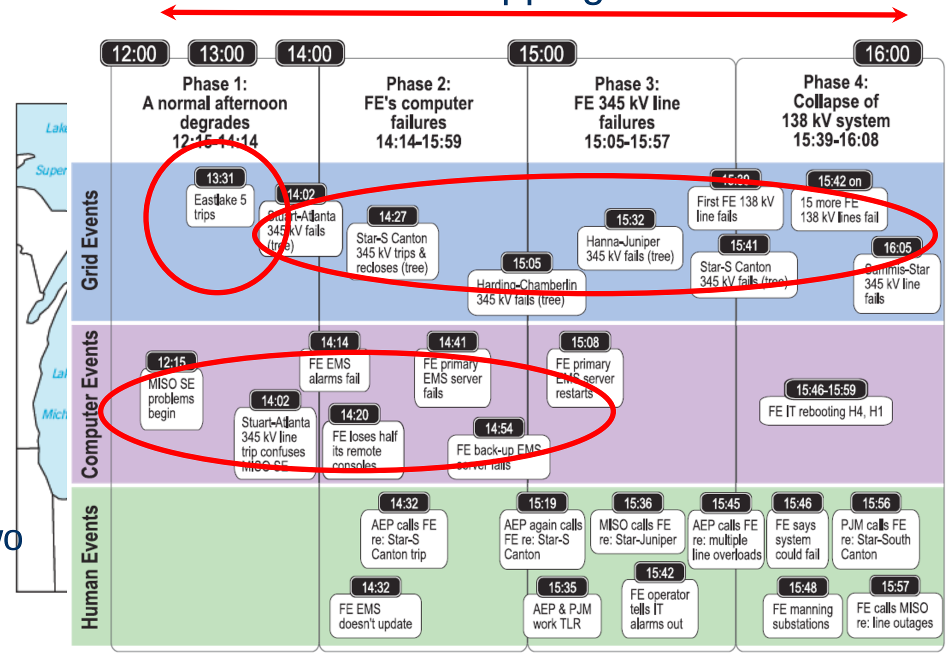
A, B, C, D: Network companies

U.S. and Canada, August 14, 2003

- Simplified description of the event

1. 12.15-14.54:
   Malfunctioning software systems limiting the operators situation awareness and control (State Estimator, SCADA alarm and logging, EMS terminals and server)
2. 13.31:
   Trip of important generation increases loading on lines
3. 14.02-16.05:
   Tripping of highly loaded lines, with premature tripping of many lines due to inadequate vegetation management
4. 16.06-16.11:
   This eventually caused instability, triggering cascaded tripping, separating the Eastern Interconnection into two asynchronous areas
5. 16.11-16.13:
   Large differences between load and generation, led to instability and blackout of the island consisting of parts of Northeastern U.S and Ontario

Time between triggering event and cascaded tripping ~ 4 h



Ref.: Final Report on the 2003 Blackout in the United States and Canada: Causes and Recommendations, U.S.-Canada Power System Outage Task Force

U.S. and Canada, August 14, 2003

- Threats
  - Malfunction of computer systems for system operation
  - Overgrown vegetation
  - Inadequate system understanding, operator training and clarification of responsibility
  - Inadequate protection system/ scheme
- Final consequences for end-users
  - 50 million people affected
  - 61 800 MW lost, 350 000 MWh lost

US / Canada, August 14 2003

Overview of the course of events.1

The map highlights the affected regions.

Aug 14		System in normal state, within prescribed limits. High, but not abnormally high loads
12:15	Failure (info)	Erroneous input data put the Midwest Independent System Operator's state estimator and real time contingency analysis tool out of service
13:31	Failure	Generator at Eastlake power plant trips – loss of important source of reactive power
14:02	Failure	345 kV line trips due to tree contact caused by high temperature and line-sagging
14:14	Failure (info)	Control room operators at First Energy looses the alarm function (with no one in the control room realising this)
15:05 – 15:41	Failures	Three 345 kV lines into the Cleveland-Akron area trips due to tree contact. Loads on other lines increase
15:42		Operators at First Energy begin to realise that their computer system is out of order and that the network is in serious jeopardy.
	Failures	Decreased voltage and increased loading of the underlying 138 kV system, causes 16 lines to fail in rapid order
16:06	Failure	Loss of the 345 kV Sammis-Star line between eastern and northern Ohio due to overload. Triggers the cascade
	Cascade	Uncontrolled power surges and overload causes relays to trip lines and generators. Northeastern US and Ontario form a large electrical island, which quickly becomes unstable due to lack of generation capacity to meet the demand. Further tripping of lines and generators breaks the area into several electric islands, and most of these black out completely. Some smaller islands with sufficient generation manage to stabilize.
16:13		Cascade over. 50 million people deprived of power
Aug 15	Restoration	Approx 80 % of the energy restored
Aug 22		Restoration completed

Ref.: Final Report on the 2003 Blackout in the United States and Canada: Caus

U.S. and Canada, August 14, 2003

- Vulnerabilities
  - Lack of sufficient tools, competence and standards, leading to:
  - Inadequate situational awareness
  - Insufficient diagnostic support from the interconnected grid's reliability coordinator (MISO)
- Barriers to prevent component failure
  - Vegetation management
  - Monitoring of lines and operation to prevent overload.
- Barriers to prevent power system failure
  - Situation awareness and response of TSOs, operator training
  - Computer tools for monitoring, and back-up systems for these
  - Reliability standards and clear areas of responsibility; ensure operation within secure limits
  - Information sharing between TSOs

Ref.: Final Report on the 2003 Blackout in the United States and Canada: Causes and Recommendations, U.S.-Canada Power System Outage Task Force