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

- Component
- Voltage level

Failure cause:
- Fault

Maintenance:
- Planned disconnection

Forced outage:
- No interruption

Interruption:
- End-user
- Network level/type

CENS:
- ENS
- Affected end-user groups
- Responsible company
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

- **Generation**
- **Transmission**
- **Sub-transmission**
- **Distribution**

- **Import/Export**
- **420 kV**
- **300 kV**
- **132 kV**
- **66 kV**
- **22 kV**
- **11 kV**
- **230 V**
- **400 V**
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

No of disturbances:

Energy not supplied (ENS):

Weather and unknown/not clarified fault causes dominate

Disturbances 1-22 kV divided in triggering fault cause 2007-2010

No triggering fault cause

Construction/maintenance etc

Human errors

Environment

Technical equipment

Previous faults

Unknown

Operational stress

Cause not clarified

28 %

11 %

0 %

11 %

5 %

3 %

1 %

8 %

34 %

20 %

12 %

18 %

1 %

7 %

1 %

Lightning

Wind

Snow/ice

Salt/pollution

Vegetation

Birds/animals

Other/unknown

ENS due to disturbances 1-22 kV divided in triggering fault cause 2007-2010

No triggering fault cause

Construction/maintenance etc

Human errors

Technical equipment

Environment

Previous faults

Unknown

Operational stress

Cause not clarified

14 %

3 %

2 %

45 %

22 %

0 %

14 %

5 %

36 %

18 %

2 %

15 %

8 %

15 %

5 %

10 %

10 %

5 %

Lightning

Wind

Snow/ice

Salt/pollution

Vegetation

Birds/animals

Other/unknown
Triggering fault causes 33 – 420 kV 2007 – 2010

No of disturbances:

Energy not supplied (ENS):

Weather, technical equipment and human errors dominate
Component faults 1 – 22 kV 2007 – 2010
Component faults 33 – 420 kV
2007 – 2010

No of faults per year 2007-2010
ENS per year 2007-2010

Overhead line  Underground cable  Breaker, disconnector  Transformer  Other  Not identified  Protection  Control equipment

MWh per year
Fault rate for overhead lines 1 – 22 kV
1989 – 2005

Year
FASIT introduced
New version of FASIT
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 frequency 33 - 420 kV

No of faults per 100 km per year

- 420 kV
- 220 - 300 kV
- 132 kV
- 33 - 110 kV
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)

Causes
- Natural hazard
- Technical/operational
- Human errors
- Terror, sabotage etc.

Power system failures

Consequences
- Minor
- Moderate
- Critical
- Catastrophic

Barriers

Fault statistics mainly give information about normal/frequent events
Examples of large disturbances (blackouts), Nordic, Europe, Canada

![Graph showing examples of large disturbances](image-url)
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
Software certification: FASIT test network

G: Generator  BS: Disconnector  T: Transformer
SA: Busbar  KL: Overhead line  RP: Delivery (load) point
BE: Circuit breaker  KA: Underground cable  LP: Delivery point
A, B, C, D: Network companies
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.

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

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Overview of the course of events:

- **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 loses 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**
  - Failures
  - Operators at First Energy begin to realise that their computer system is out of order and that the network is in serious jeopardy.

- **16:06**
  - Failure
  - 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.

- **16:13**
  - Cascade over. 50 million people deprived of power

- **Aug 15**
  - Restoration
  - Approx 80% of the energy restored

- **Aug 22**
  - Restoration completed
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