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2138-10

Joint ICTP-IAEA Workshop on Vulnerability of Energy Systems to Climate Change and Extreme Events

19 - 23 April 2010

Vulnerability of Electricity Grid Systems to Climate Change & Extreme Weather Events

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International Workshop on 'Vulnerability of Energy Systems to Climate Change and Extreme Events'

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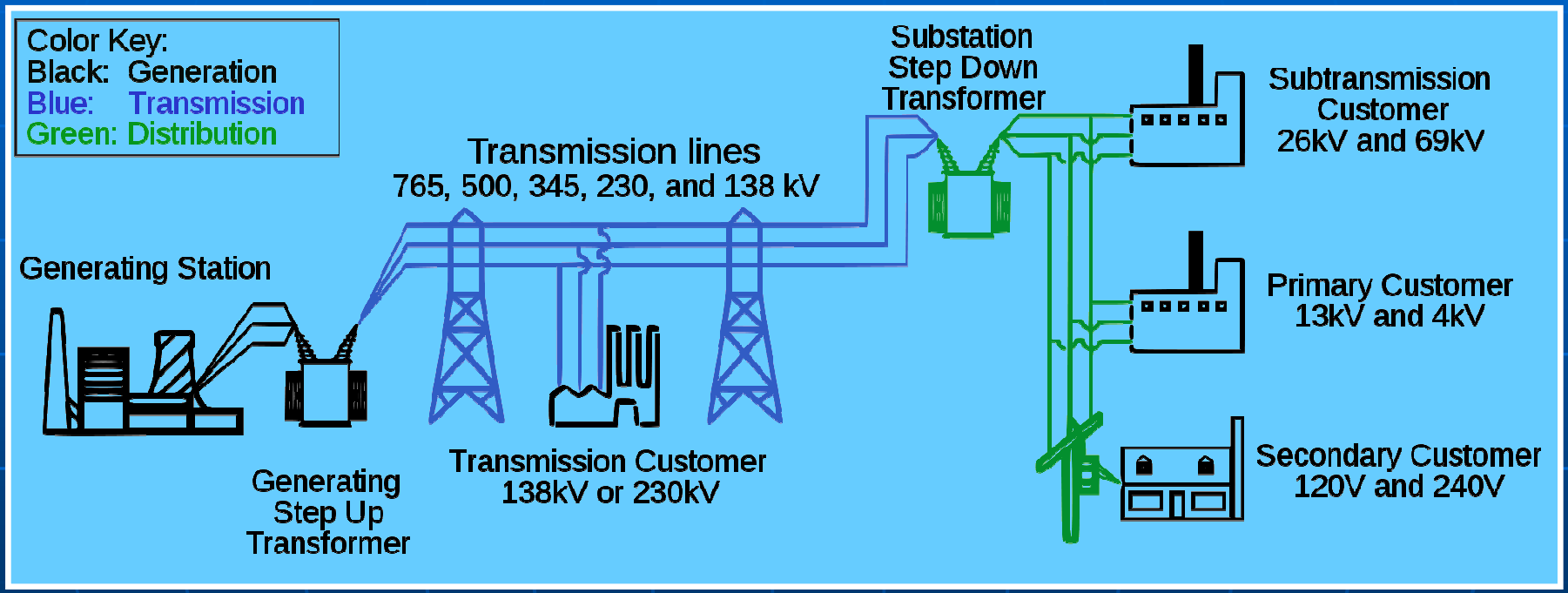
Electricity Grid System



Source: Wikipedia Commons / US DOE /
Final Report of the US-Canada Task Force, 2004

Reliable grid?

- Loss of supply to customers is rare
- System collapse/blackout very rare
- Voltage well controlled (+/- 5%)
- Frequency well controlled (+/- 1%)
- Abnormal voltage or frequency is rare

Components of a Grid System

- Overhead lines
- Underground cables
- Substations (switchyards)
- Transformers
- Control centres
- Communications systems
- People to operate and maintain it

Transmission Network

- Very high voltages (>100kV)
- Transmits high power long distances
- One circuit supplies many customers
- >95% Overhead lines
- Uses tall steel towers

Source: Author's own photo - 400kV line near Bristol, UK

Transmission Substation

Source: British Energy photo - Heysham 400kV substation

Distribution Network

- Operates at medium/low voltage (<<100kV)
- Transmits medium/low power short distances
- Each circuit supplies a few customers
- 25%-95% overhead lines
- Typically uses wooden poles

Source: Author's own photo - 11kV/400V transformer and lines

Distribution Substation

Source: Author's own photo - Almondsbury 33kV/11kV substation

Reliability Standards

- UCTE / ENTSO-E (Western Europe)
  http://www.entsoe.eu/
- NERC (USA & Canada)
  http://www.nerc.com/
- National Grid (Great Britain)
  http://www.nationalgrid.com/
- Nordel (Scandinavia)
  http://www.entsoe.eu/

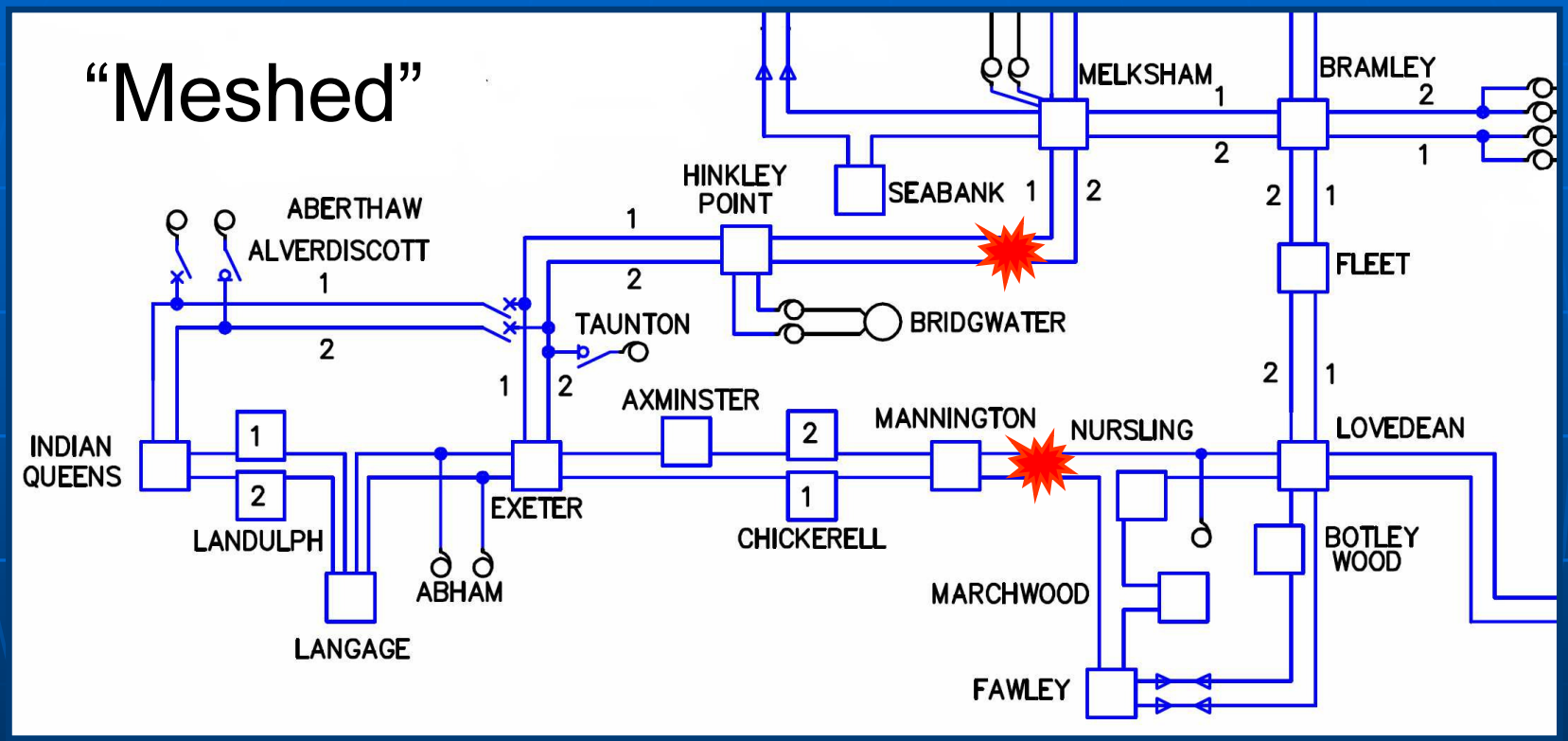
Unplanned trip of:

- Generating unit
- Overhead line
- Underground cable
- Transformer
- Busbar in substation

Should not cause:

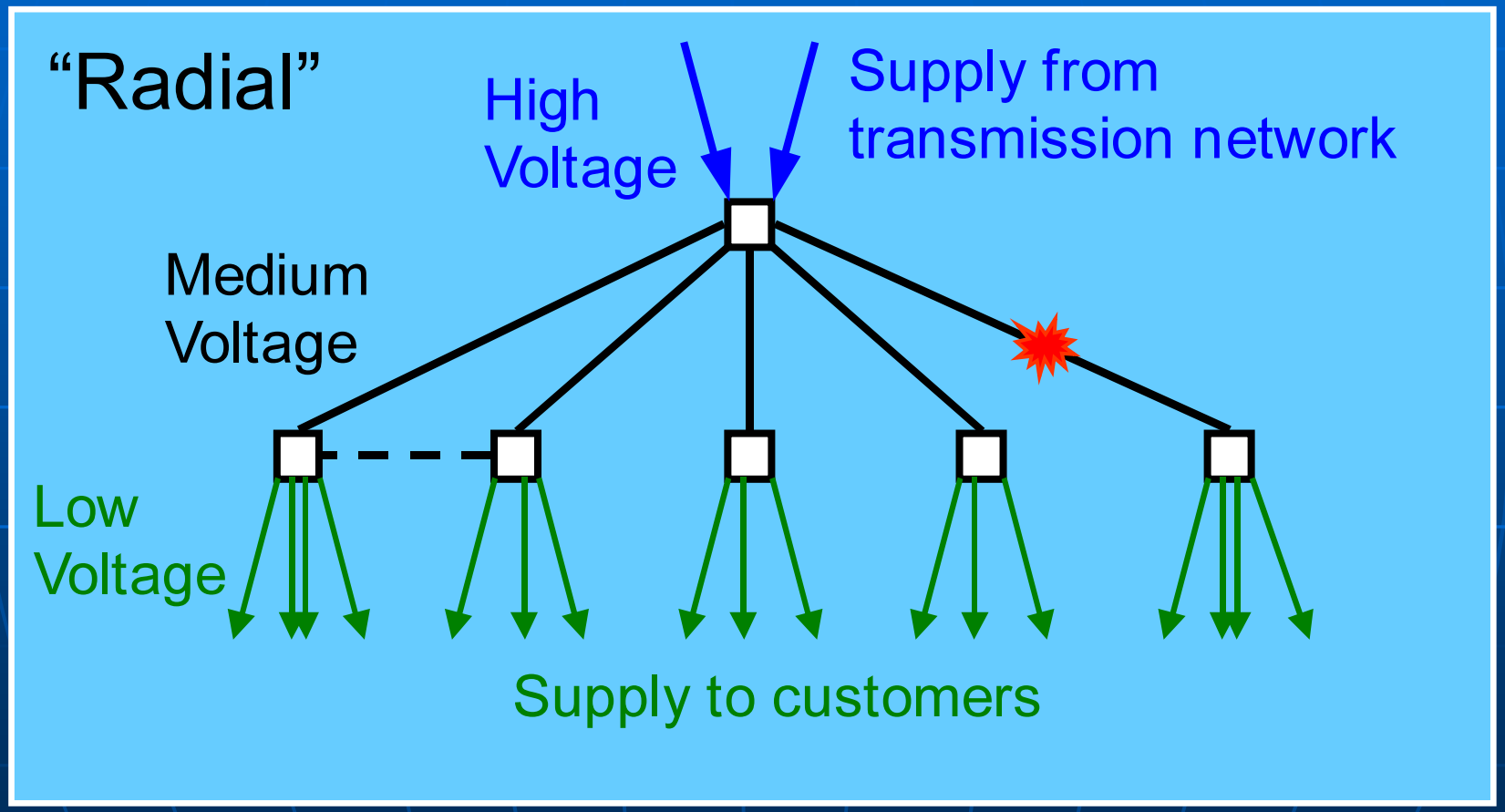
- Disconnection of customers
- Unacceptable voltages
- Unacceptable frequency
- Circuit overload
- Loss of synchronism (pole slip)
- Cascade tripping

Transmission Network



Source: National Grid Seven Year Statement

Distribution Network



Source: Author's own drawing

Grid System Faults

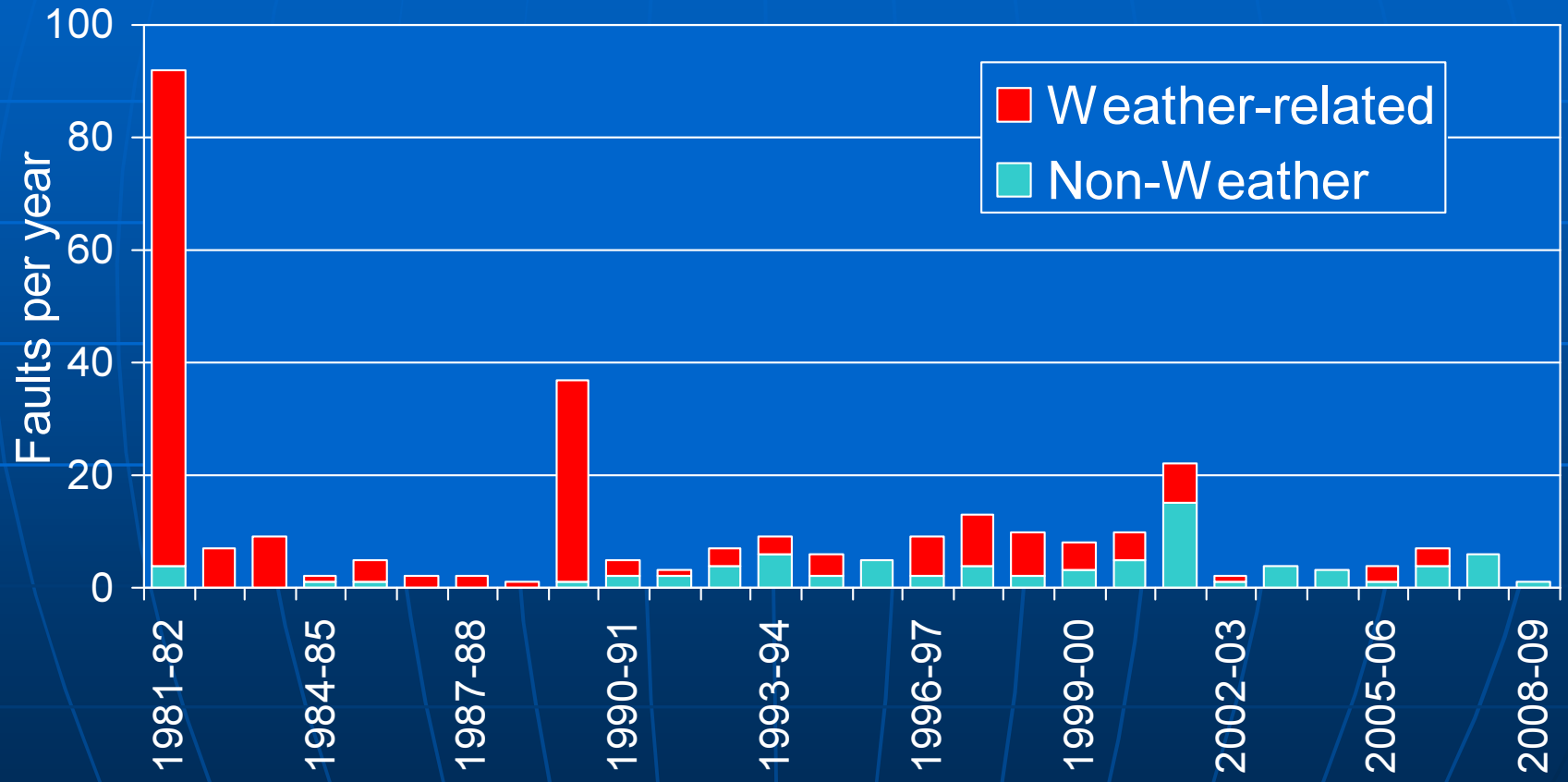
- Weather-related
  - Lightning, wind, rain, snow
- Environmental
  - Trees, birds, vermin, air pollution, earthquakes, geomagnetic storms
- Equipment failure
- Human error
- Malicious damage

Weather and Grid Systems

- Normal Weather
  - Occasional grid faults
- Adverse Weather
  - Multiple grid faults, but little damage
- Extreme Weather
  - Multiple grid faults
  - Widespread damage

Transmission Faults

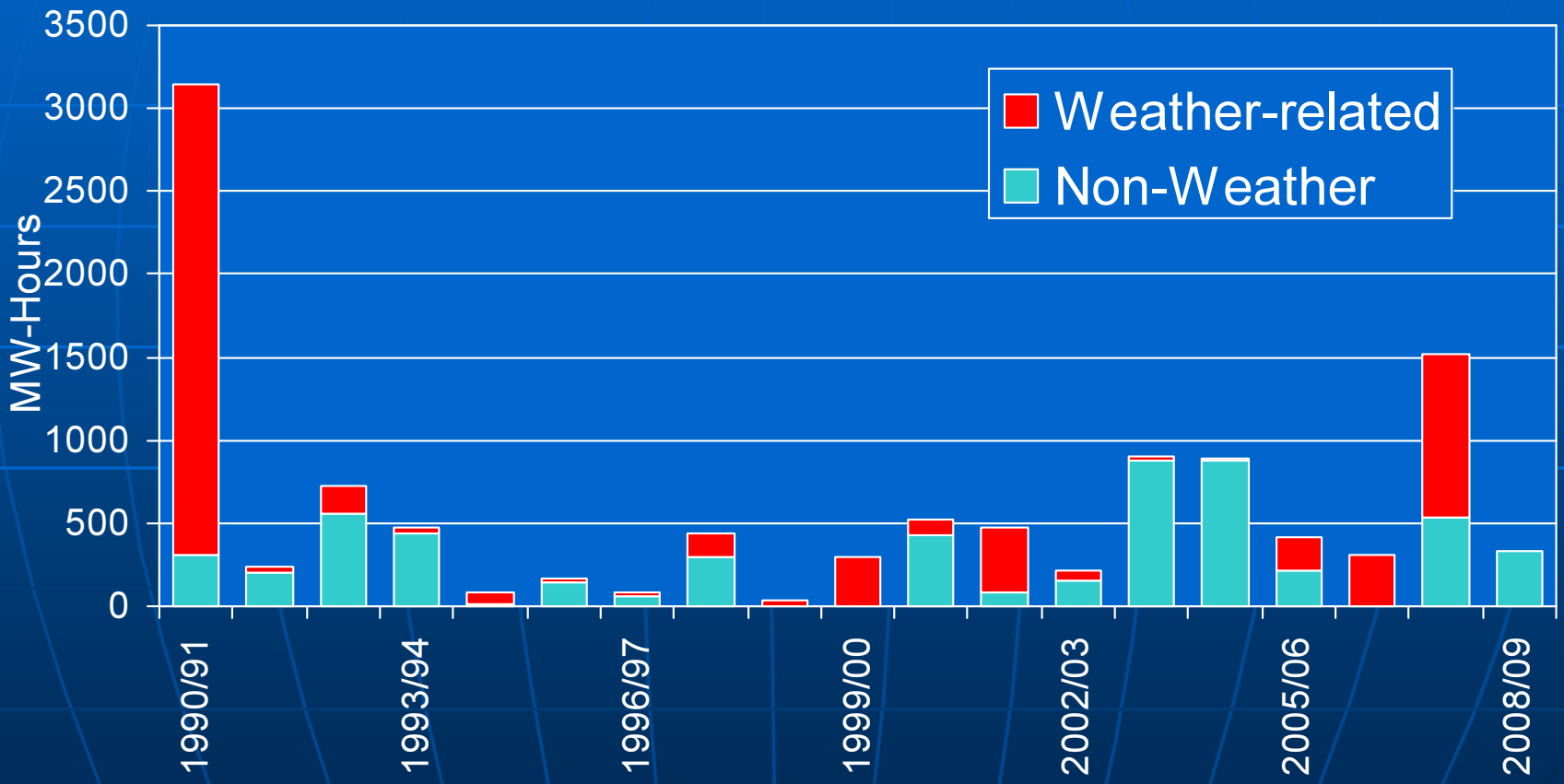
(One region of GB - 741 circuit km of overhead lines)



Source: Prepared by author from National Grid data

Energy Not Supplied

(All of England and Wales - transmission faults only)



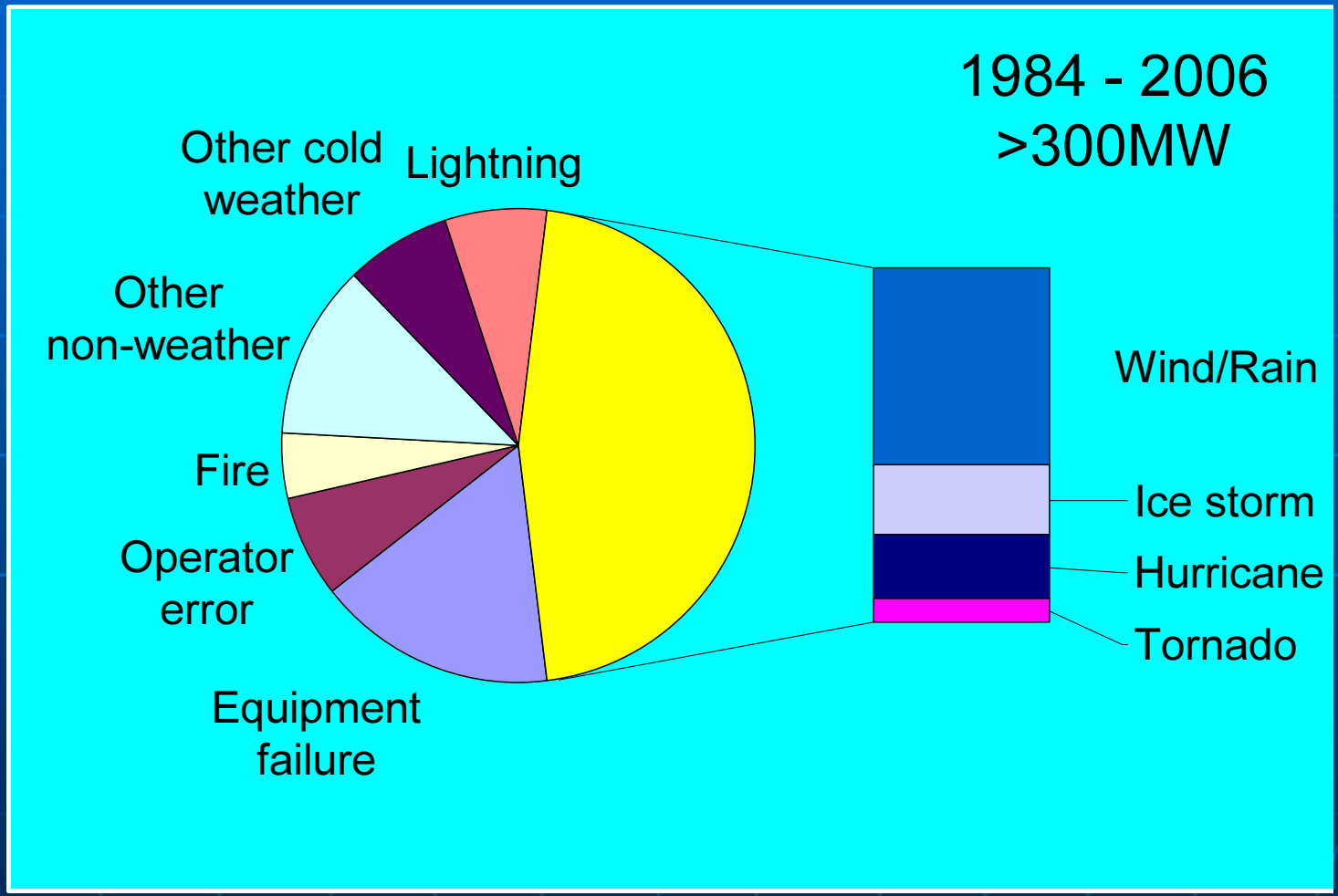
Source: Prepared by author from published National Grid data

Blackouts in 2003

- Flashover to trees; poor control & communications
  - USA/Canada (14 August)
  - Italy (28 September)
- Unusual equipment faults
  - Sweden/Denmark (23 September)
- Human error (incorrect protection)
  - London (28 August)

Source: Various published reports

Causes of Major US Events



Source: Prepared by author from data in Hines et al (2009)

High winds

- Most customer interruptions due to damage to distribution network
- >50% damage due to trees
- Damage related to square of maximum (gust) wind speed
- Only in most severe storms is transmission network damaged

Source: Davidson et al (2003), Winkler et al (2010), Reed (2008)

England - October 2002

- Wind speed up to 45m/s
- 2 million customers lost supplies for 18 hours up to 10 days
- Damage to distribution networks
- “Nearly all damage caused by falling trees”
- One very minor interruption do to fault on transmission network

Source: House of Commons report (2004)

England - October 1987

- Worst storm in UK for 300 years.
- Wind speed 50 m/s
- 15,000,000 trees blown over
- 17,000 houses damaged

Source: House of Commons (2004). Photos: BBC Website

England October 1987

- 1.5 million customers lost supply, some for up to 3 weeks
- Distribution network severely damaged, mostly by falling trees
- Parts of transmission network out of service for up to 12 hours
  - Wind blown debris, salt pollution
  - No structural failure

Source: Various published reports

France - December 1999

Storms “Lothar” and “Martin”

- Most severe storm ever in France
- Wind speed up to 60m/s
- 3.5million customers lost supply
- 90% of damage to distribution network due to falling trees
- Severe damage to transmission network - 120 towers collapsed.

Source: Various published reports

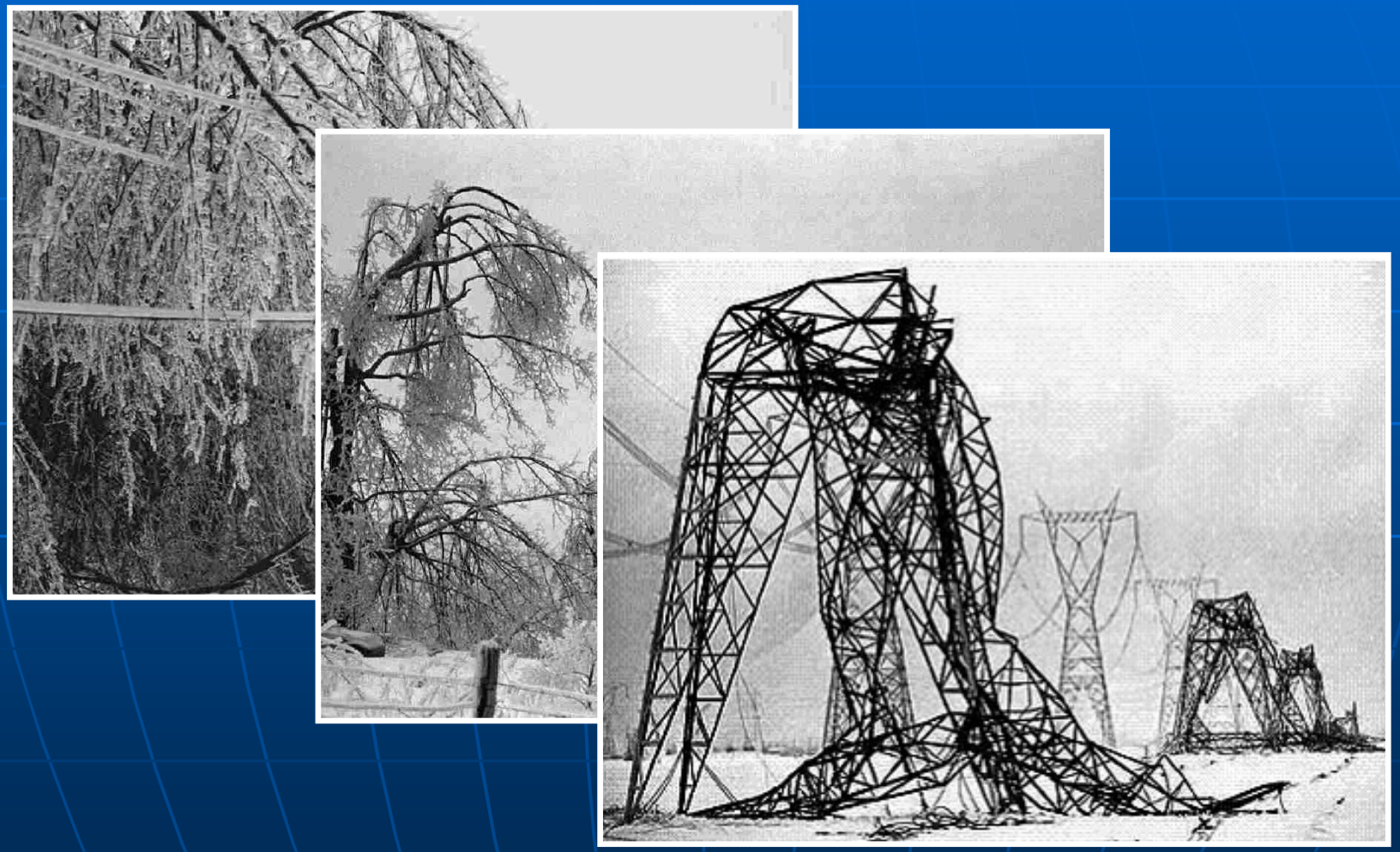
Wind - Remedial Measures

- Higher design standards for poles and towers
- Change routes of overhead lines
  - Along roads, away from trees
- Rigorous management of trees
- Use covered/insulated conductors
- Use more underground cables
  - Particularly in wooded areas

Snow and Ice

- Weight of snow & ice, plus wind may cause failures
  - Direct failure of overhead lines
  - Failure due to falling trees
  - Conductor “galloping”
- Extreme form is the “ice storm”
  - Super-cooled rain causes rapid build-up of ice

Ice Storm - January 1998

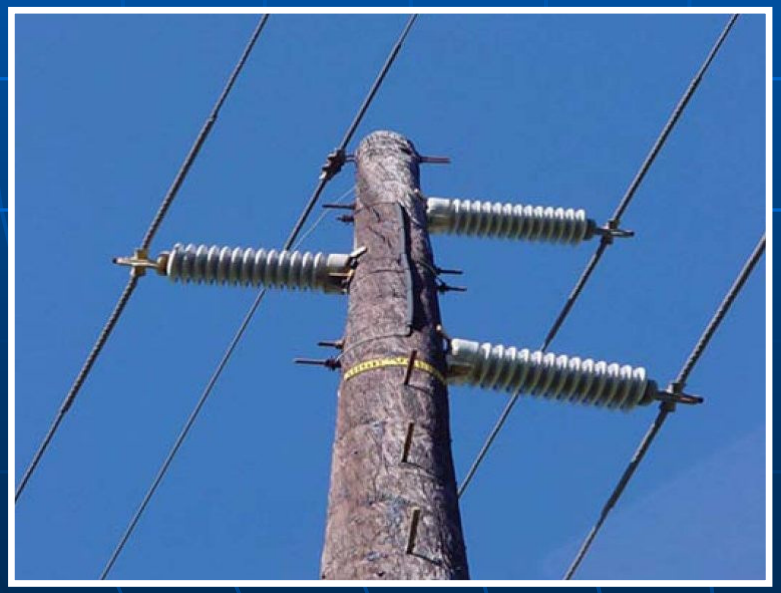


Source: Ontario Hydro centenary booklet & IAEA report

Lightning Strikes

- Common on transmission network
  - Protected by earth wires, spark gaps etc.
- Less common on distribution networks
  - Not usually protected by earth wires, spark gaps etc.

Source: Photo from Wikipedia commons - Lyoha123



Lightning Risk

If lightning gets worse…

- More damage to equipment
- Justifies more money for lightning protection

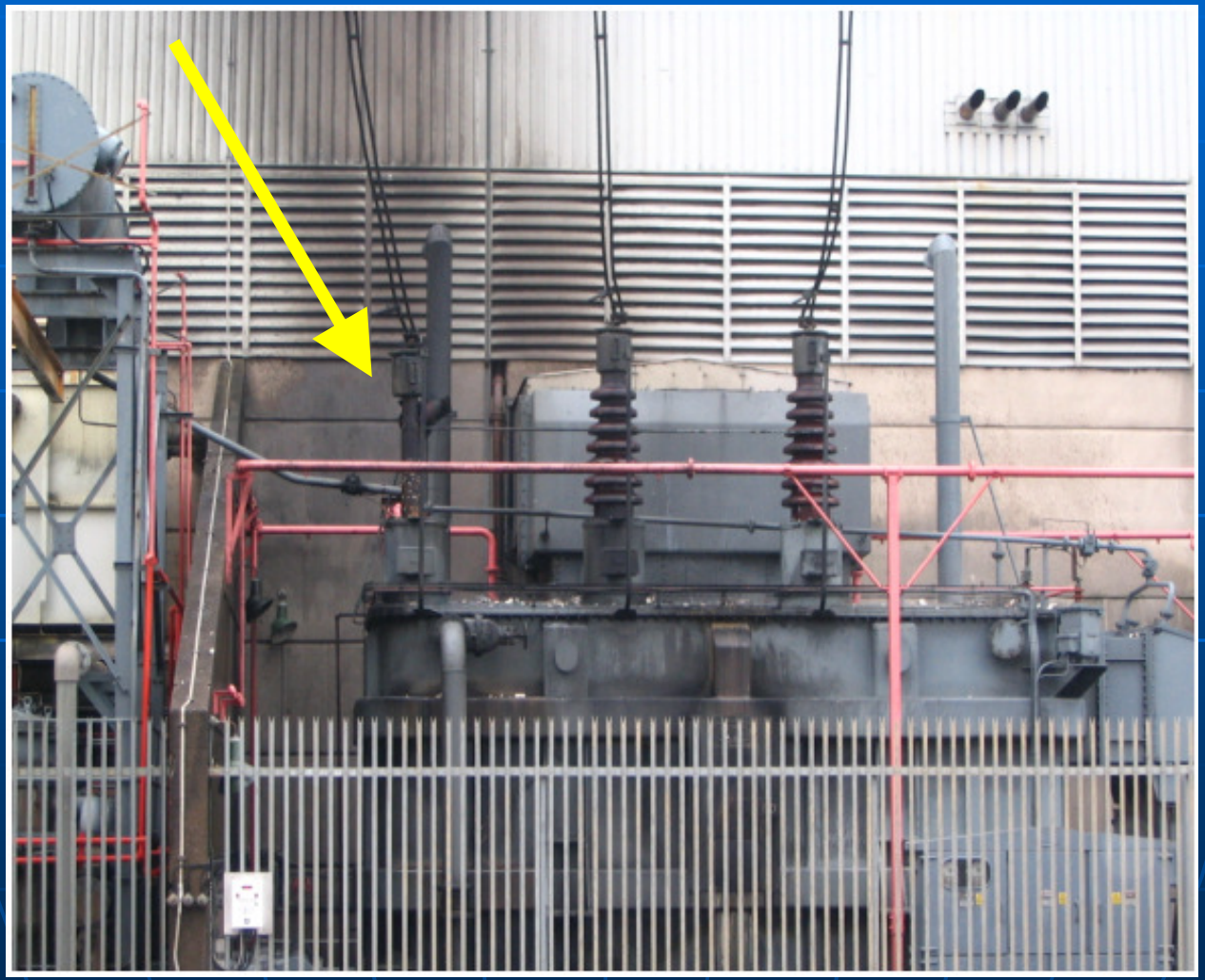
Source: Photos from public domain EPRI reports

Rain

- Heavy rain by itself not usually a major problem
- Sometimes causes flashover faults
- Sometimes leaks into equipment

Source: Photo from public domain EPRI report

Water Ingress - Failure



Source: Magnox photo

Climate and Floods

- Very heavy rain, so rivers flood surrounding area
- Very high winds damage flood defences (e.g. Hurricane Katrina)
- Sea level rise from global warming

Flood

- Not an issue for transmission circuits
- Not an issue for distribution circuits, unless very deep
- Serious issue for equipment mounted at ground level in substations

Source: Author's own photos

Flood

Source: Photo courtesy of British Energy

High Temperature

Limits the power rating of

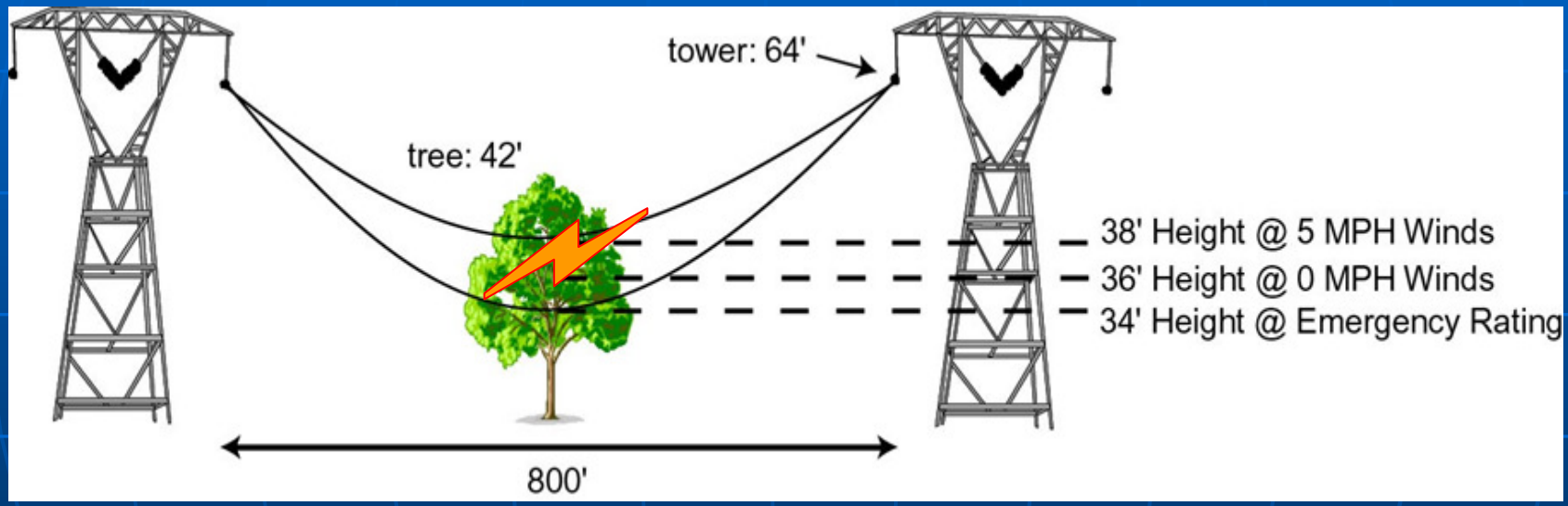
- Overhead lines
- Underground cables
- Transformers

Does not cause immediate faults of

- Underground cables
- Transformers

High temperature flashover

Flashover to trees



Source: US DOE / Final Report of the US-Canada Task Force, 2004

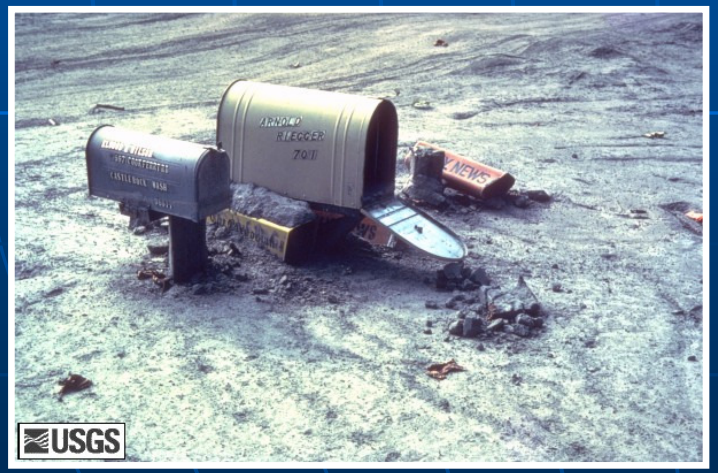
Drought

- Not major problem for grid systems (water not used for cooling)
- If soil dries out - can reduce thermal rating of underground cables
- Main problem is increased risk from brush fires or forest fires.

Fires after drought

Source: Internet photo and US Bureau of Land Management

Avalanches and Landslides

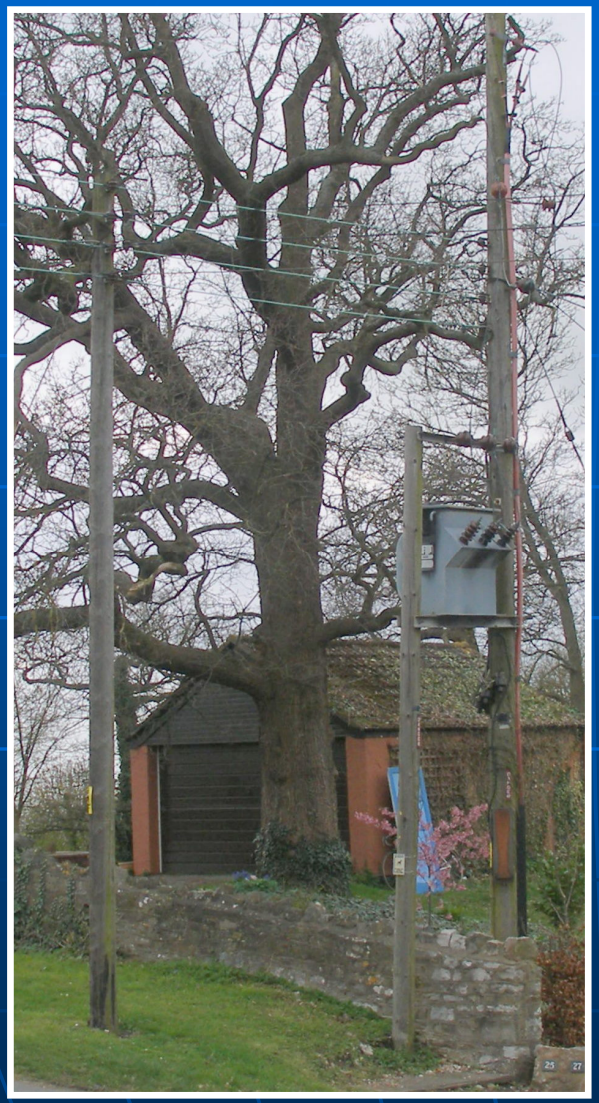


- Result of very heavy rain or snow
- May damage a few towers or poles
- Limited effect on transmission or distribution
- Could damage substations

Source: Photos from Wikipedia Commons (US Federal Government)

Discussion

- Grid equipment has a life of 30 to 50 years.
- It can gradually be replaced with equipment of higher standard
- Transmission and Distribution networks are different
- Control of trees is a major issue.



Thank you for your attention

Source: Author's own photo