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Major Power Outages in the US, and around the World

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Abstract
The creation and delivery of power is one basic infrastructure expected by all modern industrial societies. Power distribution basics started in the US in the early 1900s when the first AC grid was established. Since 12 independent power grids were completed in the lower 48 states in the mid-1950s, reliability has been a customer concern. Parts of these earlier grids have been updated, and four of the US grids are tied to similar power grids in Canada. In this context, reliability concerns itself with an understanding of why there are power failures. A power surge in one part of the extended grid may bring down other sections when they are shut down for self-protection. This action is a self-protection mechanism for the grid which preserves the equipment, but extends the outage to more customers. As one grid becomes larger and more interconnected with other grids, higher power demands, and perhaps larger surges, may be expected. Shut down self-protection, intrinsic design margins, and redundant paths become keys to maintaining reliability. Until a smart grid is developed, which would separate and isolate sections of the grid, the whole grid could come crashing down. Maintenance practices, the incidence of extreme weather events, and the loss of transmission lines or power substations may then dominate the causes of power outages in this complex, dynamic system.

Detail
Table I presents a summary of major power outages over the last 45 years [1]. Because this is a time dependent table, one can determine if the power reliability is improving or declining over the years. Because the evolution of the power grid is dynamic, one must be careful when drawing conclusions. The items in the following tables show only the major power outages in the US & Canada, Europe, and the rest of the world (International). These failures are typically known by date, weather conditions, grid conditions, cause or causes, locations of failures, extent of failures in population, and duration of the power outage.

Table I A Summary of Major Grid Failures

Years	US & Canada	Europe	International
1965-1988	3 fails	3 fails	1 fail
1989-1994	2 fails	None	1 fail
1995-1999	8 fails	1 fail	7 fails
2000-2005	11 fails	7 fails	15 fails
2006-2009	33 fails	16 fails	20 fails
	57 Total	27 Total	44 Total

The definition of a major grid failure is
a) an **unplanned event** (down for maintenance or rotating blackouts don't count) that
b) affects at least **1000 customers** (in this study the number is 30,000 minimum) for
c) a total **downtime** of at least 1,000,000 customer hours.

Few major incidents were reported in the 1960s, 1970s, and early 80s. The last 20 years reflects many more outages, and so was divided into smaller groups. Reporting in developed countries (US & Canada and Europe) could not be responsible for this increase. This increase appears to be real, and probably reflects two factors; increasing load on the grid, and the increased cable miles with higher interconnectedness of the grid. The incident curves for the US and Europe are very similar to each other, but different from the international curve. Perhaps, in some of the international entries the change in reporting methods may have added to the increase in reported incidents over the last 45 years. Twelve power grids exist across the US & Canada, and some parts of Mexico. In Western Europe, one large grid exists, and several smaller grids connect most countries. Most of the rest of the world has small self-contained power grids within their country, and are not connected to other grids. It is less likely that power outages beyond the US & Canada or Europe could meet the three criteria for major outages. In fact, if one counts all outages in the US & Canada, there were 76 events in the 1995 to 1999 years, and 140 from 2000 to 2005 [5]. The general trend of Table I reflects increasing major outages since 1970, as well as all outages.

Table II shows a basic breakdown of the high level causes. In some cases, there could be multiple interacting events. For example, a windstorm may take down one segment of transmission lines, and that leads to a surge elsewhere which takes down a power grid temporarily. This type of event is reflected only as “high winds” in Table II (i.e. greater than 60 MPH). These events most often occur in the Spring and Fall months as weather patterns change. Two events are listed as cyber attack. These reflect the events of January 2005, and Sept 2007 that brought down the power grid in Brazil [2].

The biggest single cause listed in Table II is snow storms (this includes ice storms) in the US & Canada occurring mainly from December to March. The second biggest item is summer storms. The combination of high winds with lightning and heavy rains may cause an outage. Hurricanes are next at eight events, mostly along the Gulf Coast. Six hurricane events occurred in just three years (2003 to 2005), and this group reflects an irregular hurricane cycle for powerful storms. This cycle has multiple nodes with repeat times of 22 years, 35 years, and 50 years [3], [4]. The years from 1970 to 1995 were a period when the annual number of hurricanes was low, and only one caused an outage. One hurricane in 2008 caused a major outage, and the hurricane trend appears to be for fewer and less powerful storms in the near future [4]. The number of hurricanes in years 1965-2002, and 2006-2009 produced only two major power outages in those 41 years.

High winds were next in number. This was important in the US, but not as important in Europe or International regions, though one cause of a power failure in Egypt was listed as “sandstorm”. The “other category” for the US & Canada contains entries such as earthquake, flood, lightning strike, geomagnetic storm (Canada in 1989), and heat wave (high power usage leading to grid failure). This last incident, like the July 2006 New York City outage, and the August 2006 London outage, can be attributed to multiple events. A multi-day heat wave pushed power consumption of the grid to near its limit. A minor incident then brought the high stressed grid down. The total of all the entries in the “other” category is important, but the events themselves are unique. The same is true of the “other” category for Europe and International.

Table II A Breakdown of Major Grid Failures by Cause

Main Causes	US & Canada	Europe	International
Snow Storm	13fails	3 fails	3 fails
Summer Storms	11fails	2 fails	1 fail
Hurricane	8 fails	None	None
High Winds	8 fails	1 fail	3 fails

Unknown	3 fails	8 fails	11fails
Substation	3 fails	2 fails	7 fails
Transmission Line failures	3 fails	2 fails	4 fails
Lightning strike.	2 fails	None	None
Heat Wave	2 fails	2 fails	3 fails
Other	4 fails	7 fails	12 fails
Total	57fails	27fails	44 fails

On the International side, about 1/5 of the power outages (9 of 44) were not given a cause in the reports. A similar problem exists for Europe. Problems at "substations" are the next biggest cause for International regions, while snow storms are a large cause for Europe. "Heat waves" are a common cause (3 incidents each for Europe and International regions) possibly because of the power surge that often accompanies them. Accidents are next in number for International, while transmission line failures are important for both Europe and International. The "other category" is unusually large, and contains entries such as earthquakes, brush fires, floods, lightning strikes, natural gas explosions, incidents of war, terrorist attacks, sandstorms, and cut underseas cables as the detailed causes.

The breakdown by regions of the world can be interesting. Of the 57 outages for the US & Canada, 41 could be identified as primarily the US, 14 as primarily Canada, and two were shared (both caused by large winter storms). The raw numbers would suggest Canada reflects more failures than would have been expected. Based upon population, Canada should have had fewer outages during the period. Summer and winter storms combined with high winds and hurricanes totaled 11 of 14 total Canada entries, while these weather issues totaled 21 of the 42 total US incidents. On the European side, there were 27 outages, with the United Kingdom contributing 14 of these. Because Europe is well electrified, and mostly tied to a common grid, this result is surprising. Asia, which is partially electrified, came in second with 26 outages. Australia was the biggest contributor with eight events, with New Zealand and Malaysia next having three each. South America contributed nine major power outages, with Brazil the biggest contributor at four, followed by Venezuela and Colombia with two each. Central America had only three outages, with Mexico sustaining two. Africa logged four outages reported. This may reflect higher levels of grid development in some countries. A few countries such as Poland, Spain, Italy, Nigeria, Ukraine, China, and Taiwan had only one reported incident each during the last 20 years.

Trends

The information in the two tables suggests the following conclusions may be drawn.

1) Incidents of major power outages have been increasing everywhere, especially over the last 20 years. In the US & Canada, there were about three major outages per five years before 1995, and about 16 after that time. Europe and International region outages more than doubled after 1995.
2) Storms, both summer and winter, seem to be the biggest causes in the US & Canada with 24 by count. In Europe the unknown category dominated with storms second. Internationally the biggest known category was substation failures
3) Hurricanes, and high winds were the third, and fourth biggest causes in the US by count.
4) Problems with substation failures was the fifth biggest stated cause of power grid outages in the US, but none were reported in Canada. Worldwide, transmission line failures were the second largest contributor.
5) Heat wave was low as a cause worldwide at 3 incidents, and in Europe at 2 incidents.
6) Snowstorms was a contributor in Europe at three failures, and International with three.

The tables can't tell us more about the causes behind the stated causes. If we follow the standard approach of asking "why" at least five times deep, we might discover more complexity and underlying factors. For example, with the snowstorm cause, power outages could be due primarily to a combination of high winds, heavy snow, and/or ice. This may be true of the US & Canada, but is not clearly known for the rest of the world. Because the US and Canada are temperate climates with extensive open plains, winter storms may be seen to play a bigger role in causing outages. The same question can be asked with summer storms. These are usually associated with high winds, heavy rain, and lightening. All may combine to cause outages by toppling transmission lines, causing major power surges or taking out sections of the grid through lightning strikes. Total outage costs are estimated at above $75B annually in the US & Canada.

Substation failures, and heat wave outages worldwide need further research before better explanations are available. There doesn't seem to be a trend for substation incidents, with the more fundamental causes including one incident of deliberate vandalism (in the UK), and several unrelated maintenance errors behind the outages. Perhaps those countries with the fastest power demand growth might be operating near the edge of capable supply, so that any fluctuation may lead to a surge that can't be filled, resulting in a major power outage.

Does this information suggest a deteriorating infrastructure situation? One can't tell at this level, as few causes seem to be related to equipment. Weather seems to be the majority of causes. The complexity and interconnectedness of the US & Canada grid has increased since the 1960s with an increasing power demand, but so has the automated self-response capability. All of these issues, combined with parts of the grid near their end of life, poor maintenance, and uncertain and/or slow switching could lead to more major outages. More shut downs may actually reflect a grid that has become "somewhat smarter" as it reflects increased self-protection. A plan now in the works for a real smart grid would add processors at each node of the grid so that each node could be quickly separated into independent, unconnected islands when surges occur [5].

Another contributing item to grid unreliability may be the age of some of the parts of the grid. During the 1960s and 1970s, a large number of nuclear power plants were brought online with their new transmission lines. This greatly added to the existing power grid complexity as these elements were connected. Many of these nuclear plants had projected lives of 30 to 40 years as do substations and transmission lines. Maintenance and upgrades have extended the operating life time for the nuclear plants, but not necessarily for the transmission lines or substations. A lower design margin may now exist for these older lines and substations. Thus, a surge event may lead to an outage. This cause was given as a contributing cause of the great Aug 14, 2003 outage that darkened 55 million customers. We would also expect that older grid components may be more susceptible to high winds, heavy rain, lightning, or snow and ice build up on the power lines.

Now focus upon the big categories. A simple Pareto analysis of identified weather-related causes for the US & Canada actually totals 41 out of the 57 total events. For Europe, the same measures were 16 out of 27 failures, and in the International region, weather-related events totaled only 6 out of 44. Finding a systematic way to reduce these outages would have a big impact. No detailed solution can be suggested here. The second Pareto item is substation-related, and transmission related outages. These are far fewer in number, but may reflect deterioration, aging, or maintenance problems.

Are there differences around the world? It is clear that those portions of the world with the highest levels of power grid maturity also seem to fail most (US, Canada, UK). If one calculates the major outages per million of population, or for miles of high voltage transmission lines, the analysis may change. Table III shows these numbers for select countries for the last 45 years. The reasons may be a little different from the US & Canada. The UK, Australia, and Brazil all have the highest incidents of outages. Japan, on the other hand, with a mature power system, recorded only two major outages in the last 45 years. Countries such as France, Sweden, Greece, Spain , Finland, Poland, and Italy seem to follow this trend as well.

Slow power demand growth, combined with well maintained systems, and low populations may be other reasons so few major outages have been reported in these last countries.

Table III Outages normalized to population, and miles of HV lines

Country	Outages	Pop.	Miles of HV line	Outs/ million	Outs/ Kmile
US	42	300 M	160K	0.13	0.26
Canada	15	27M	40K	0.56	0.38
UK	14	67M	16.5K	0.23	0.85
Australia	8	22M	80K	0.36	0.36
Brazil	4	180M	85K	0.02	0.10
New Zealand	3	4.3M	7.4K	0.41	0.41

Table III suggests that Canada has the most outages per population, followed by Australia. On the other hand, the UK has the most per miles of high voltage transmission lines, followed by New Zealand.

Conclusion

The major power outage data shows major systematic causes are mostly related to weather in the US, Canada, and Europe. Maintenance problems or deteriorating infrastructure are low causes of the outages. From a grid reliability measure, it is the weather that causes unreliability of the US & Canada grid. As we often say “everyone talks about the weather, but no one can do anything about it.” This idea may only be partially true for the US & Canada power grid. It is not presently possible to change the weather, but the grid could be made more robust and smart to prevent surge events or weather events from bringing down the whole grid. Much of the rest of the world is still creating power grids, and they are dominated by substation failures and transmission lines failures, not weather related causes. These causes require further study before systematic solutions may be proposed to enhance the grid reliability in the rest of the world.

References

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Biography

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