Summary: This week discussion was how the data can be interpreted differently for different purposes. How the probability theory is used in power system context. And useful probability distributions for reliability modelling were discussed.

Probability theory is used to model the reliability of systems. It talks about how likely an event can happen. In other words, Probability is a measure of the likeliness that an event will occur. Quantification of probability can be done by assigning numerical values based on the likelihood of the event as shown in below figure 1.

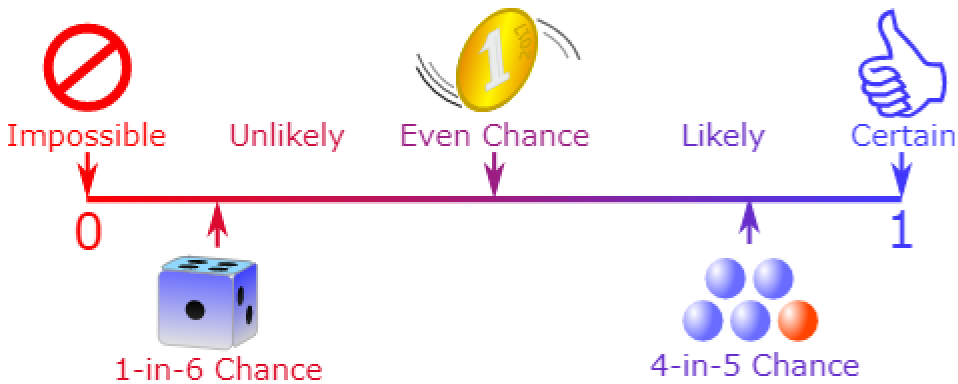


Figure 1

The probability density function of a continuous random provides information on the likelihood of random events. For example, a transformer failure rate with respect to the years. There are different types of probability distributions. These distributions are mainly categorized as continuous probability distributions and discrete probability distributions. Figure 2 a show the histogram of transformer failures. X axis shows the years and y axis shows number of equipment failed in each year. This histogram can be changed into pdf (figure 2 b) by normalizing the equipment failure numbers.

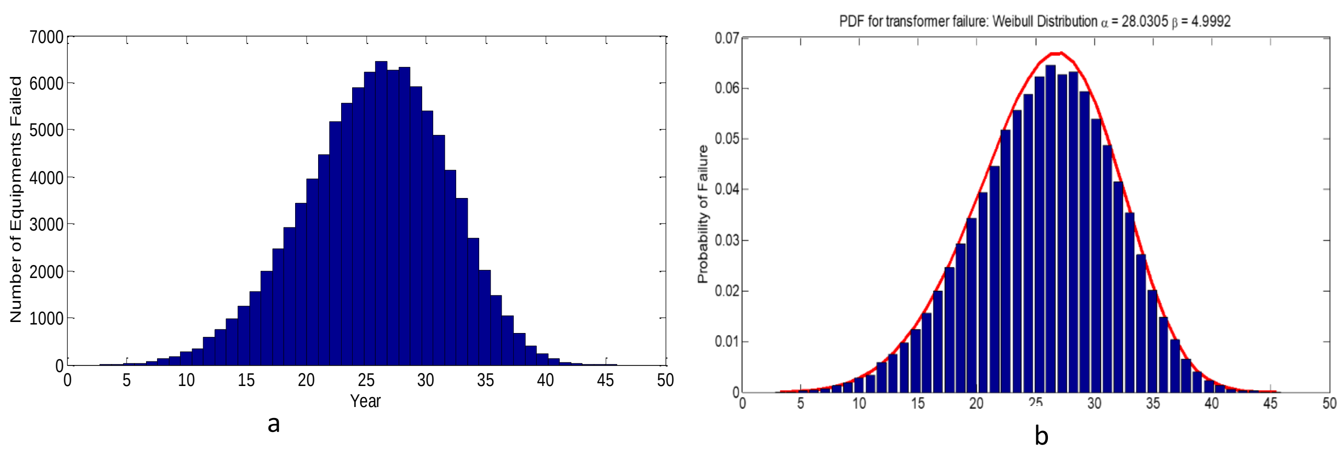
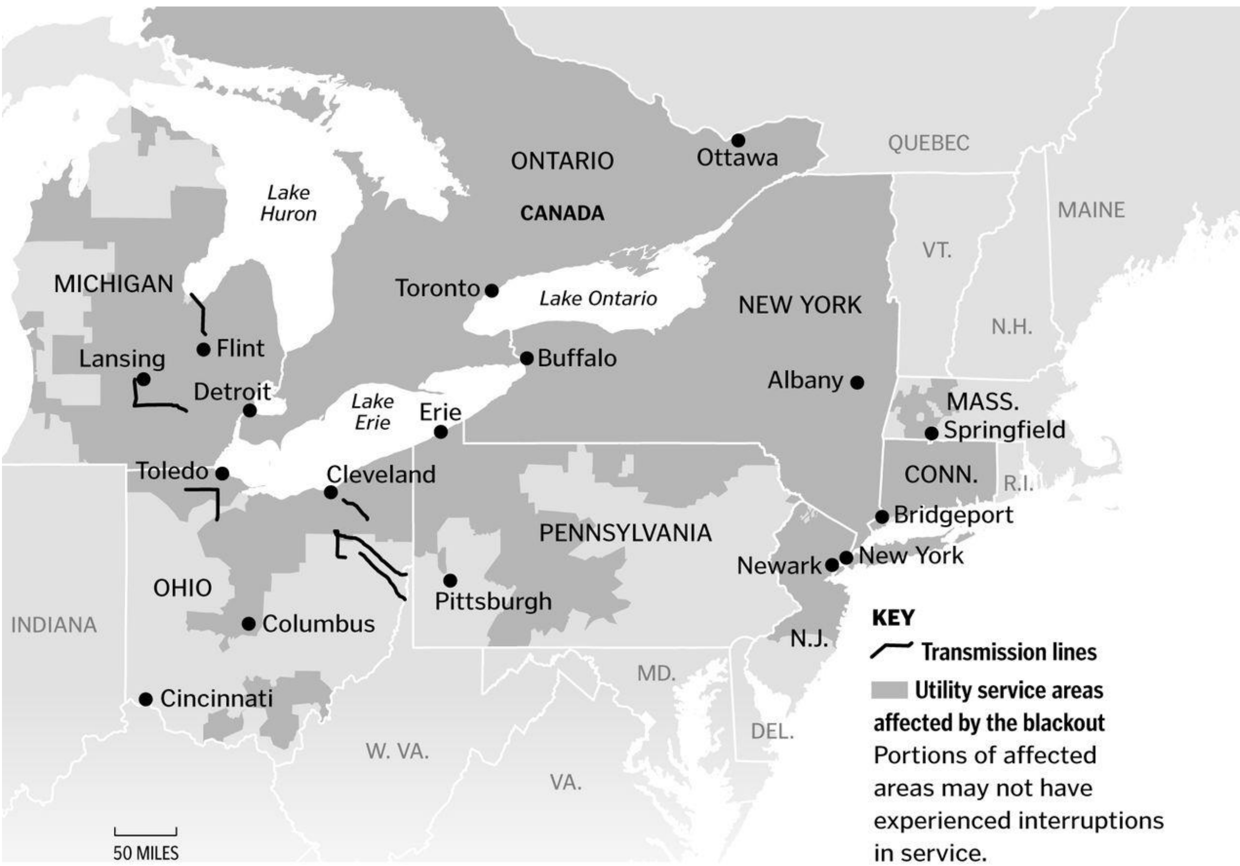


Figure 2

Overview, Introduction to the event: date, location, what happened, event timeline.

Eastern United States and part of Canada experienced a major blackout on August 14, 2003. This is the largest blackout in United States history. The event started at 4:00 pm and 50 million people lost their power within next 3 minutes. Power to some areas were restored in short time (within 2 hours). But some other areas experienced outage up to 4 days. 61,800 megawatts (MW) of electric load were not supplied. 21 power plants shutdown and following areas got affected: New York, Cleveland and Detroit, as well as Toronto and Ottawa, Canada. Figure 1 shows the blackout areas.

The total economic loss caused by this blackout was estimated to be between \$4-\$10 billions. 18.9 million human working hours were lost.



Causes of the failure.

The event was the accumulated result of long-term bad system practices. The operator could not properly manage the voltage and frequency due to poor management practices. U.S.-Canada Power System Outage Task Force has identified four main causes for the blackout. Those causes include the following:

1. FirstEnergy and ECAR did not follow the standard operational procedures. They failed to do proper contingency analysis.
    a. FE didn't conduct enough long-term contingency analysis.
    b. Proper voltage analysis was not done for Ohio control area.
    c. FE's reliability council failed to conduct independent reviews on system adequacy.

2. FirstEnergy didn't evaluate the security of the system in timely manner.
    a. Regular contingency analysis for transmission lines was not conducted by FE.
    b. FE didn't verify the suitability of important monitoring tools.
    c. Their monitoring system was not up to date.

3. Grid maintenance by FE was not sufficient.
    a. Tree growth interfered with transmission system.
    b. Three FE 345 kV transmission lines and a 138 kV line experienced outage due to tree growth.

4. Regional reliability organizations didn't effectively perform their tasks.
    a. MISO could not provide diagnostic assistance to FE. Because it didn't have real time data of certain part of the power system.
    b. MISO used nonreal time data for real time monitoring.
    c. MISO and PJM didn't have plan for coordinating during the contingency events.

Actions, recommendations by the taskforce to operators.

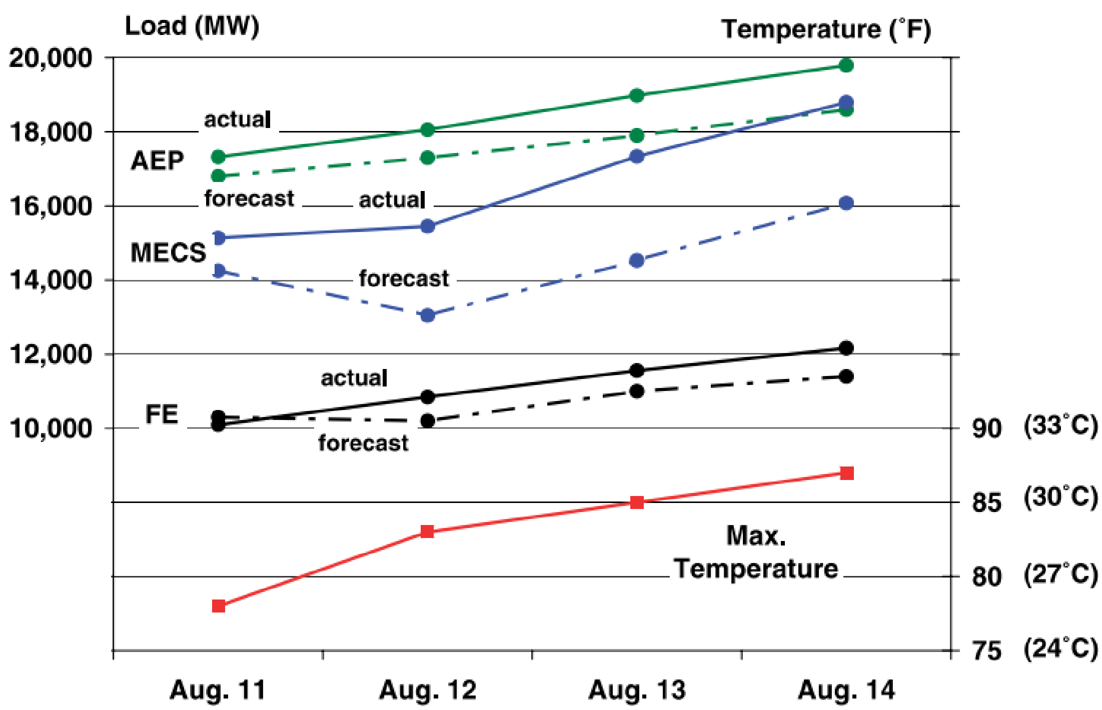
The task force identified that the blackout event would not have happened if proper attention was paid in planning and operational stage of the grid. Following recommendations were given by the task force:

1. Utilities and reliability coordination organizations should strictly follow the standards.
2. Proper and effective procedures should be followed in power system planning and operation.
3. Enough attention should be given in reliability related research studies.
4. Institutional framework should be enhanced to provide improved reliability.
5. Up to date real time monitoring tools should be used to monitor the grid.
6. Adequate system protection measures should be taken.
7. Clear procedures and definition should be established to differentiate different states of the power system.
8. Power quality standards should be strictly adhered.
9. Proper communication procedure protocols should be in place.
10. Should develop IT management tools.
11. Physical and cyber security should be enhanced.

Conditions of the grid before, during and after the event.

Analyzing the pre-event condition of the grid is useful to find the root cause of the failure. The task force identified that following events happened on the day of the event before the event starts

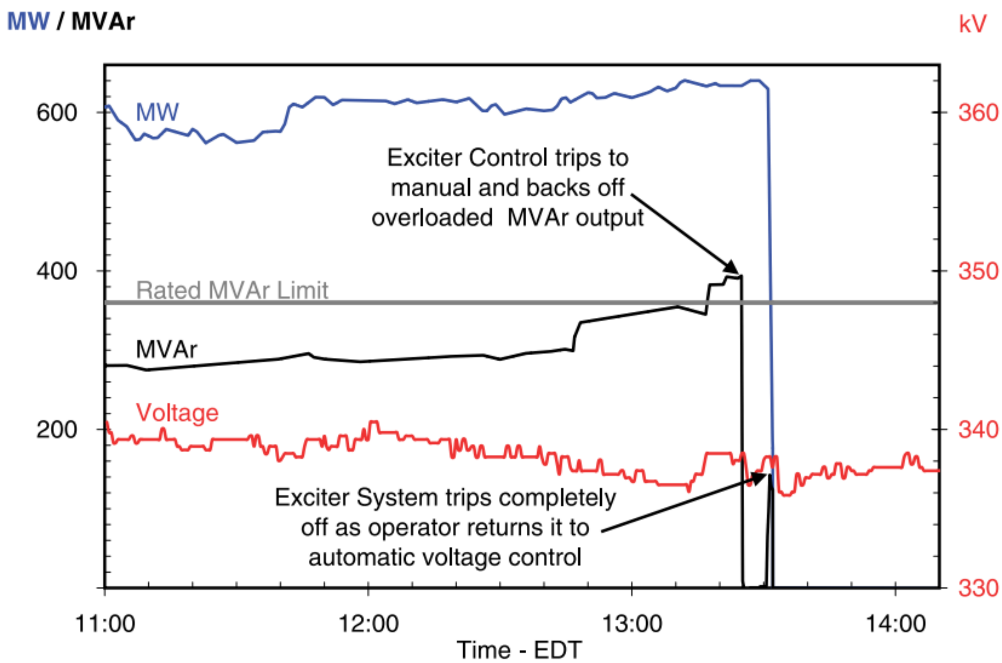
Electricity demands were high since the temperature was high on the day. FirstEnergy experienced 20% load increase. However, the load was not a historic peak. Figure 1 shows that the load forecast also was below actual.



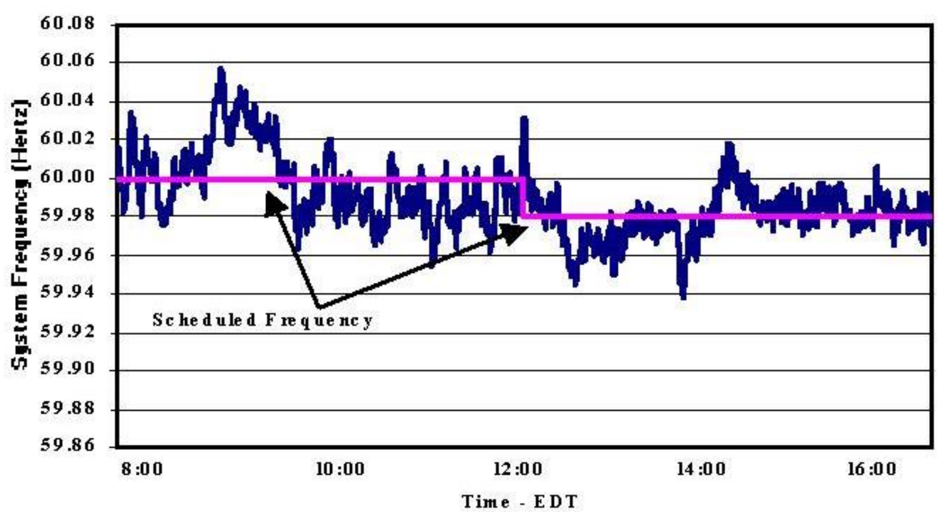
Some generation facilities were unavailable due to planned outage and other reasons. Below table summarizes the generators not available and the reasons. There were 3 unplanned generation outage and several transmission line outages happened on the event day.

Generator	Rating	Reason
Davis-Besse Nuclear Unit	883 MW	Prolonged NRC-ordered outage beginning on 3/22/02
Sammis Unit 3	180 MW	Forced outage on 8/12/03
Eastlake unit 4	180 MW	Forced outage on 8/13/03
Monroe Unit 1	238 MW	Planned outage, taken out of service on 8/8/03
Cook Nuclear Unit 2	1,060 MW	Outage began on 8/13/03

A main reactive power source experienced outage: as shown in below figure, the generator's MVAr supply exceeded the rated value 13:31 EDT and, shortly after generator tripped. FE had to import power from neighboring areas therefore the grid management was challenge for FE.



Critical voltage of the day was within the limits, necessary actions were taken by the operators to maintain the voltage stability. Frequency of the system prior to the event also followed a typical summer day pattern as shown in below figure.



Changes to the system operation due to this outage

- Congress passed the Energy Policy Act of 2005 and expanded the role of FERC. Now the FERC can solicit, approve and enforce new reliability standards.
- 96 new reliability standards were introduced.
- PMU (Phasor Measurement Unit) was introduced to collect and monitor the data.
- installation of equipment such as synchro phasors to monitor the grid with high accuracy.
- Investment on transmissions has increased to ensure the reliability.

The lessons learned from this outage

1. Following causes are common for all the past blackouts:
    a. No proper transmission line management was in place
    b. Operators failed follow the reliability standards.
    c. Situational awareness was poor.
    d. Sufficient training was not provided to the personnel.
    e. Inadequate coordination among operators.
2. This blackout could be avoided if the operators followed the NERC standards.
3. Other prior conditions of the grid such as outage of other generators and lines created trouble on managing the grid.

References

[1] "Final report on the August 14, 2003 blackout in the United ... - energy." [Online]. Available: https://www.energy.gov/sites/default/files/oeprod/DocumentsandMedia/BlackoutFinal-Web.pdf. [Accessed: 19-Sep-2022].

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The figures in this note are used from lecture slide and blackout study report.