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Disclaimer and Credits

- All graphics and information used in this presentation are from various reports and presentations given by NERC – all are in the public domain.
- The opinions expressed in this presentation are those of Robert W. Cummings IEEE Life Fellow from 45 years of experience in the electric power industry:
  - 6 years – Central Vermont Public Service (System Planning – Gen. and Transmission)
  - 8 years – Public Service Company of New Mexico (Operations Engineering and Wide Area Planning)
  - 8 years – East Central Area Reliability Coordination Agreement (ECAR – Manager of Transmission Services)
  - 23 years – North American Electric Reliability Corp. (NERC – retired in 2020 as Senior Director of Engineering and Reliability Initiatives)
- Vice Chair of IEEE-2800™-2022 Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems
  - P2800 WG was the recipient of the IEEE PES - 2024 IEEE PES Working Group Award for Outstanding Standard or Guide
- Vice Chair of IEEE 2030.11™-2021 – Guide for Distributed Energy Resources Management Systems (DERMS) Functional Specification
  - P2030.11 WG was the Recipient of 2023 IEEE PES Award for Outstanding Working Group for Outstanding Standard or Guide
- Vice Chair of IEEE P2030.14 Draft Guide for Virtual Power Plant Functional Specification for Alternate and Multi-Source Generation

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Inverter Connected Demand and Resources – Where is the Magic?

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Robert W. Cummings IEEE Life Fellow 30 July 2024

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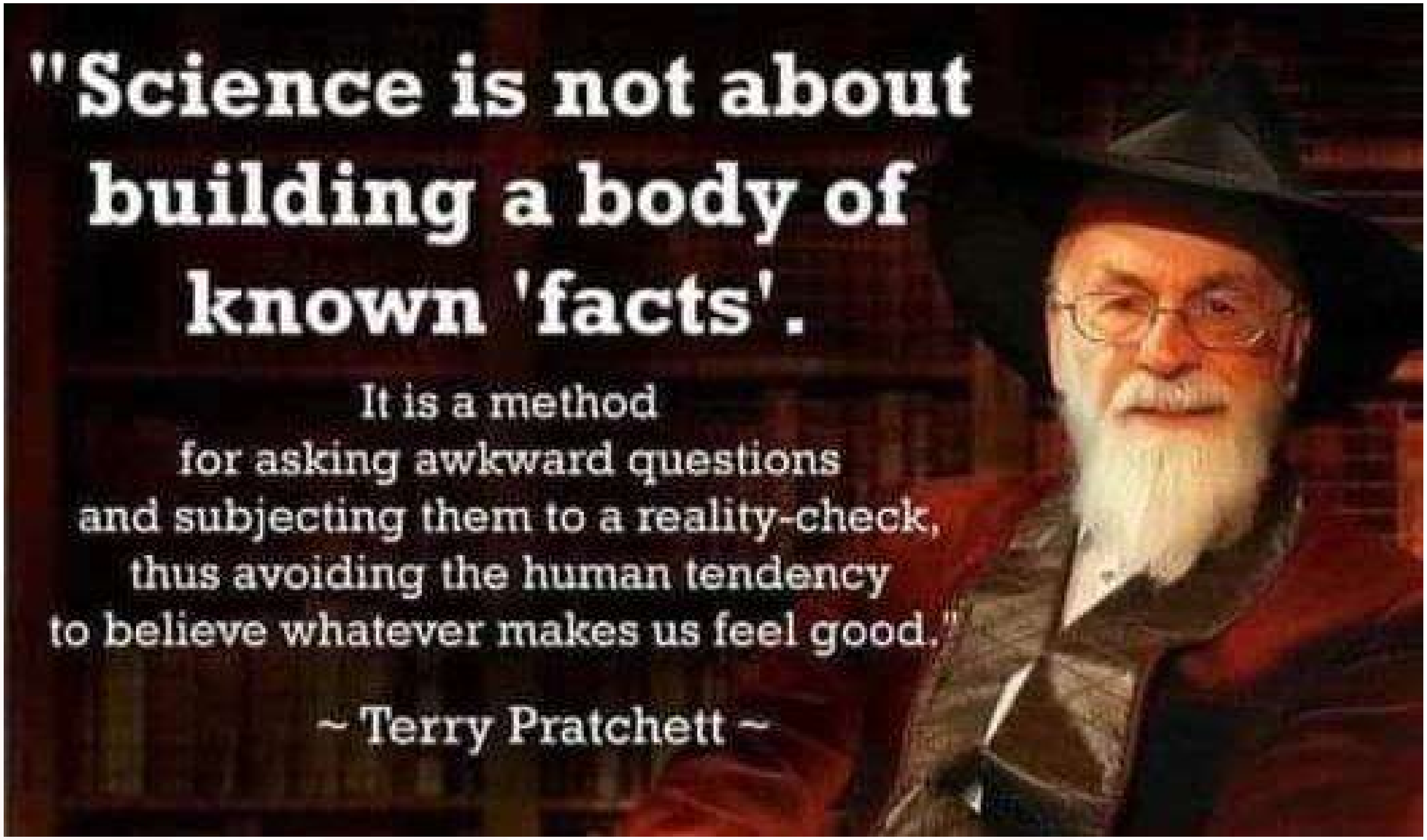
"Science is not about building a body of known 'facts'.
It is a method for asking awkward questions and subjecting them to a reality-check, thus avoiding the human tendency to believe whatever makes us feel good."
~ Terry Pratchett ~

Types of Demand and Resources

- Demand Types
  - Static Load – traditional resistive load, synchronous motor load
  - Controllable Load – inverter-based loads such as variable speed drive motors, controlled LED lighting, etc.
    - *Charging Load – EV charging, BESS charging, advanced pumped storage pumping!*
  - *Quantum increases in power and energy requirements for electrifying everything!!*
- Resource Types
  - Uncontrolled – Uncontrolled rooftop solar – should only be aggregated for providing energy – like run-of-river hydro
  - Controlled DER -- wind, solar, discharging energy storage systems, controllable demand, microgrids, dispatchable fuel cells, small nuclear reactors
  - Traditional dispatchable generation – gas turbines are the new load-following backstop to energy-limited renewables

Resource Adequacy in the New World

Traditional Resources Adequacy

- Known installed and operational capacity compared to load projections
  - Is my operational capacity adequate to support the maximum expected loads
    - Based on relatively few generating resources
    - Predicated on known effective forced outage rates of resources and capacity factors of those generators
    - Predictable load patterns
    - Predictable weather patterns
  - Can be done for peak conditions on a day-ahead basis

New Resource Adequacy Analysis

- Variable operating capacity with heavy links to weather and time of day
  - Virtually unknown (or new) forced outage rates
  - Capacity limitations based on time and previous operating conditions (state of charge of batteries)
  - New, highly influential weather conditions
  - Completely new load characteristics and changing load patterns heavily influenced by vehicle charging and behind-the-meter solar and batteries
- Adequacy analysis must be done for every hour of every day, possibly more often
- Availability of wind, solar, battery charge, and fuel for gas-fired resource backup power MUST be considered for ALL hours – shortages of effective capacity to serve load can happen anytime!

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Some Basic Facts

- There is no magic box!!! You can't create something from nothing!
  - Daily peak load adequacy assessments are no longer valid! The system is at risk at other times of day!
  - Hourly adequacy analyses are necessary (or maybe more frequent than that)!
  - The energy source behind the resources (the sun, water, wind, battery charge, and natural gas supplies, etc.) must be considered in ALL adequacy analyses.
- Battery Energy Storage produces NO energy! Batteries must be charged by something that actually generates power!
  - If solar of wind resources are charging a battery, they are NOT available to serve other loads!
- The math and physics should NOT lie!
- Controls interactions between IBRs and inverter-connected loads presents extensive dynamic interaction and oscillation possibilities!

Renewable Integration Possibilities and The Math Problem

- What is higher penetration?
- The reported penetration MATH is WRONG:
  - The values is stated typically from 1 SCADA scan cycle – 4 seconds!
  - The load value is in the denominator – lower loads make the % higher.
  - You must consider all of the timeframes – on peak, off peak, shoulder hours

- Displacement of fossil resources – synchronous generators
  - Lower operating reserves possible if fast frequency response of IBRs is properly employed
  - Not relying on idling gas turbines to provide primary frequency response
  - Incredible fast frequency response for over and under frequency events
  - Concentrations of server farm loads present a potential for a NEW problem – large blocks of load transferring to backup resources appears as a large loss of load
- Presents challenges to system operators due to variability
  - Extremely high ramp rates
  - Often weather dependent
  - Incredible fast frequency response *possible* of properly applied
- Several mandates for higher penetration

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Resource Capability Comparison

- 500 MW capacity of different resources are NOT equal
- Note: Battery Energy Storage Systems are not included – they do not generate electricity, just storage and must be charged from other resources

Generation Source	Size (MW)	Capacity Factor	Annual MWh
Coal unit	500	87%	3,810,600
Natural Gas	500	95%	4,161,000
Wind Plant	500	32%	1,401,600
Solar Plant	500	28%	1,226,400

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Resource Equal Equality Comparison

- To produce the same amount of annual energy as a coal-fired generator, the other resources would have to have far different capacity ratings (size)

Generation Source	Annual MWh	Size (MW)	Capacity Factor
Coal unit	3,810,600	500	87%
Natural Gas	3,810,600	458	95%
Wind Plant	3,810,600	1,359	32%
Solar Plant	3,810,600	1,554	28%

- Note: Battery Energy Storage Systems are not included – they do not generate electricity, just store energy, and must be charged from other resources

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Local Example of Math Problem

- Replace a 500 MW coal-fired generator (~87% available capacity factor) with:
  - 500 MW solar plant (with ~28% available capacity factor)
  - Supplement with a 300 MW Battery Energy Storage System (4 hours of storage)
    - Must be charged by something that generates power
  - Net replacement = 200 MW of resources (assuming solar charges the BESS), except after 4 hours of BESS discharging
  - Tear down the old coal unit – no recourse for the system operator – eliminate any hope of resilience!
- Assume resources are available from neighboring systems
  - Although all of them are doing the same thing

The Changing Grid

Where we ~~are~~ were

- The electric grid of North America is a system of central generating stations with large rotating machines – we've had over 100 years to learn how the physics works
- Load consisting of synchronous motors, resistive loads, and incandescent lights

Where we are going

- A system of smaller distributed resources, largely connected through inverters (IBRs)
- A large portion of resources are variable (wind and solar) *with much lower capacity factors*
- Energy storage systems will be essential to continuous power availability
- Variable speed drive motors connected by power electronics
- Lighting rapidly moving to LEDs – far less incandescent, CFL, or mercury vapor lights
- Chargers for everything from phones to electric vehicles
- Quantum increases in power and energy requirements for electrifying everything

So…how do we get from here to there without adversely effecting reliability?

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Grid of the Future

Questions

- What will it look like?
- Will we have 100% renewable resources?
- Will all resources be connected through power electronics?
- What will the load look like?
- Will we still have a grid and transmission lines?
- How will microgrids interact?

Transition issues

- Transition to higher penetrations of inverter-coupled renewables may be painful…and not without surprises
- Reductions in inertia and synchronizing torque – a more brittle system
- How to dispatch variable resources with lower capacity factors?
- IBR plant and unit interoperability
- Potential for inverter controls interaction – what kind of oscillations will there be?
- Cyber Security for IBR controls

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New Operational Challenges

- Angular separation problems – moving points of concern for standing angles across open breakers
  - Reclosing across wide angles and high voltage differentials
- New variants on Inter-Area Oscillations
  - New, unstudied frequency oscillation modes and shapes
  - Control system interactions – with other IBRs, DC Ties, SVCs, etc.
  - Potential for control failures with more IBRs
  - Forced oscillations more prevalent
    - How to detect them
    - How to find their sources
    - How to stop them
- Blackstart capabilities are eroding!
  - Anything developed with IBRs MUST have Grid Forming Capabilities!

New Operational Challenges

- Changes to Oscillation Modes and Mode Shapes – new players in the oscillation game
  - Loss of synchronous machines participation
  - New lines (impedance matrix changes) and new injection points change natural oscillation modes
  - Unknown oscillatory behavior of IBRs
    - Not tied to today’s natural mode frequencies – not related to physics of rotating machinery
    - Outside of expected ranges
    - Potential for IBR control interactions

Questions?