Northwest **Power** and **Conservation** Council

February 7, 2017

MEMORANDUM

TO: **Council members**

FROM: **Mike Starrett**

SUBJECT: **Primer on the Physics of the Power System**

BACKGROUND:

Presenter: Mike Starrett and John Ollis

Summary: This presentation will be a primer on the operation of the bulk power system with a focus on generating resources, transmission and distribution power flow, and reliability.

Relevance: The regional power system has incorporated a significant amount of renewable resource capacity while simultaneously retiring or planning for the retirement of many large traditional generating stations. The evolving resource mix presents both opportunities and challenges to system operators tasked with ensuring robust and reliable power delivery. This presentation describes power delivery from a physical perspective as a lead in to a discussion of how inertia and voltage support have affected the power system in the past and how that may be changing in the future.

Workplan: C.4.1 Prepare for 8th Plan, Generating Resources

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Physics of The Power System

Northwest Power and Conservation Council

Power Committee Meeting

February 14, 2017

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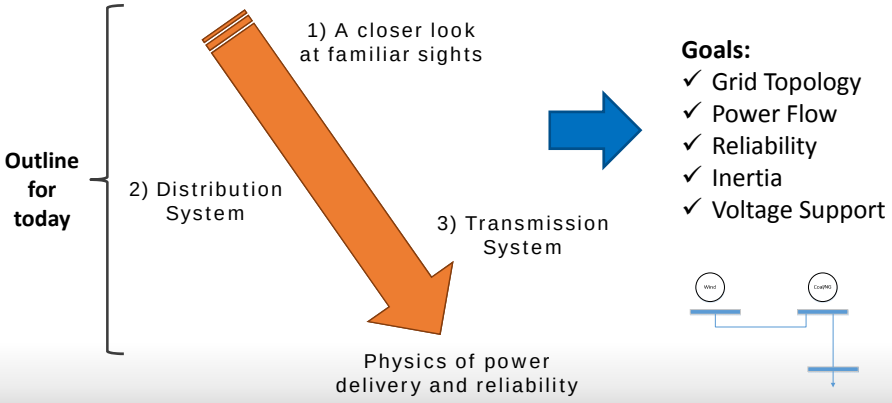
Outline

In the next 30 minutes,



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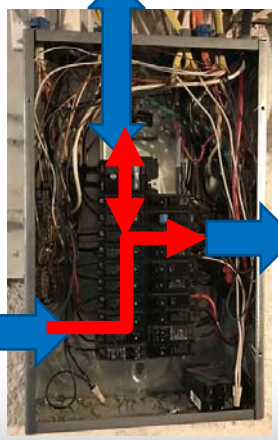
Residential Power



To/From Grid

To outlet, light switch, *etc.*

From generator, battery, solar inverter, *etc.*

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Distribution System

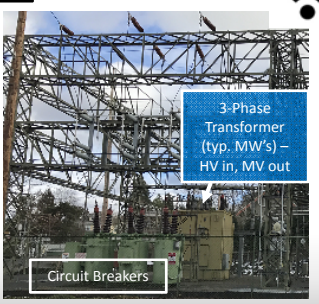
Customer Owned

Utility Owned

Distribution Line (commonly 12.47 kV)

T-connection

Fuse



3-Phase Transformer (typ. MW's) – HV in, MV out

Circuit Breakers

Single phase transformer (typ. 200kW max)

Triplex Service Wires to homes (120/240V)

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Transmission System

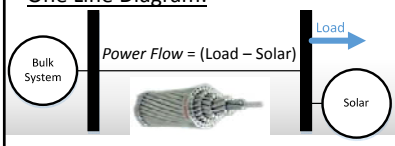
Hydro Powerhouse

Step-up Transformer in switchyard next to Powerhouse

High voltage line for efficient transmission

Substation to step down to distribution voltage

One Line Diagram:



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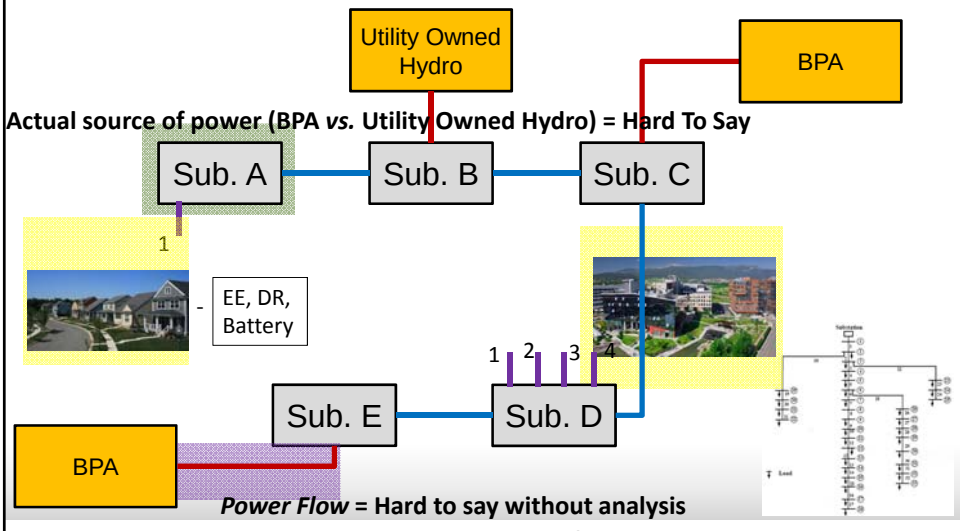
Overall System



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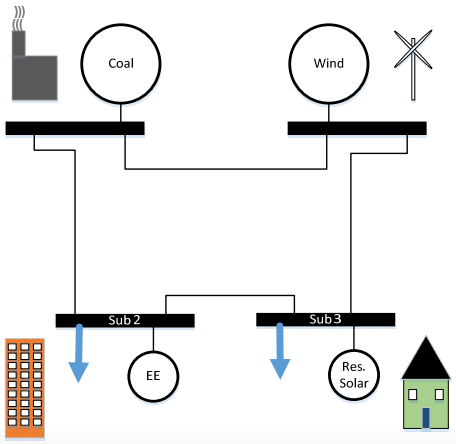
Overall System



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Reliability

- In addition to sufficient transmission,

Must Have	Risk	Mitigation
Sufficient Generation	Frequency Collapse, Load Shedding, Cascading Outage	Inertia, Primary Frequency Response, Reserves
Voltage Support	Voltage Collapse, poor Power Quality	Reactive Power Devices/ Generators

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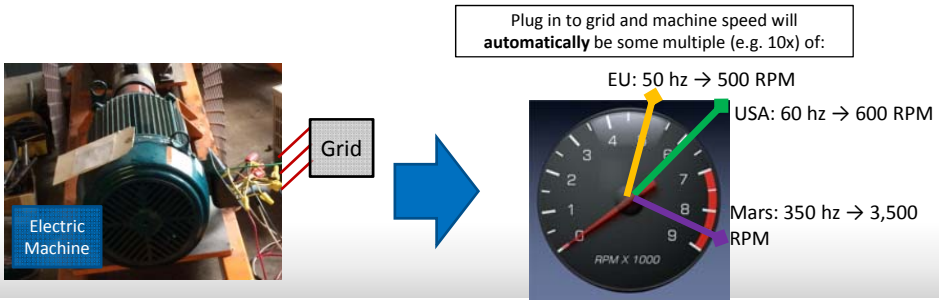
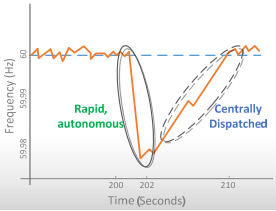
Sufficient Generation - Inertia

- Speed of generator is directly tied to frequency of grid
  - "The grid sets the speed"
- **Inertia:** Big, heavy, grid-connected generators are slow to change speed
  - Can ease frequency drop just long enough for system recovery



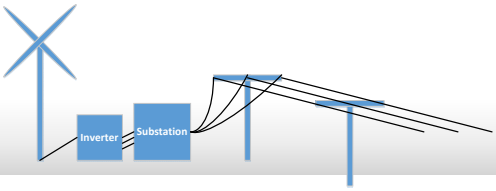
Sufficient Generation - Inertia

- Example:
  - Grid fault causes loss of 300 MW generation
    - Frequency is tied to generation, so frequency starts to drop
  - Since generator speed is directly tied to grid frequency, generators also start slowing down
  - But traditional generators are heavy and resist changing speed, thereby slowing the speed of frequency drop– this is **inertia**



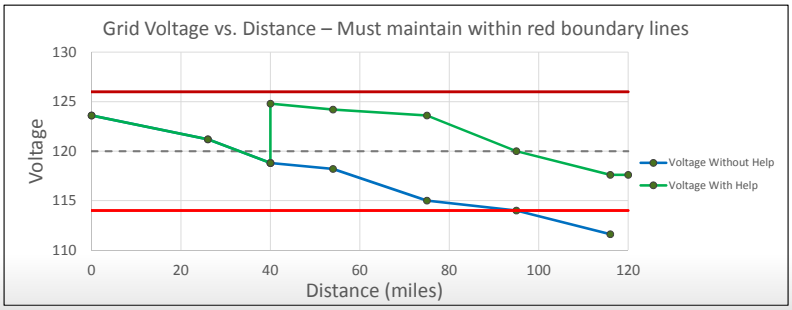
Synthetic Inertia

- Wind turbines are connected to grid through inverter
  - De-couples speed of big turbine motor from grid frequency
  - Makes sense: Sometimes wind is fast, sometimes its slow
- Recall: Grid frequency falls when generation is insufficient
- Some new inverters can act quickly to ***increase generation*** to stabilize frequency - This is called **"Synthetic Inertia"**
- Study from CPUC: Synthetic inertia from solar had similar reliability benefit to traditional resources
  - CPUC will test with wind next



Voltage Support

- Voltage is a key metric of power quality, must maintain ±5%
- Some loads (*e.g.* air conditioners) decrease system voltage by their fundamental operation
- Long distances also decrease system voltage



Voltage Support

- Long-standing need with many solutions:
  - Can use distributed devices to boost voltage locally:

Traditional

3x Single Phase Voltage Regulators

Pole-Mounted Switched Capacitor

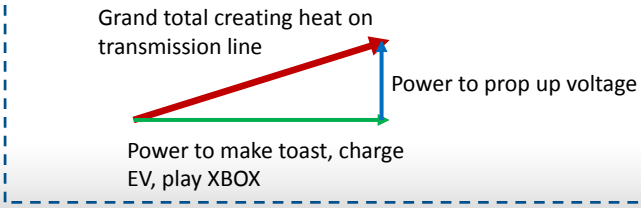
Emerging

Solar, wind, and energy storage connected to grid through smart inverter
- Solar and wind can provide voltage boost even on quiet, windless night

Voltage Support

- Long-standing need with many solutions:
  - Can also have distant generator create voltage-boosting reactive power and send it through transmission system
  - This reduces the capacity for the transmission line to carry the real power that makes breakfast toast, charges cell phones, and pays the bills

Transmission Line Loading



Summary

- Generators within transmission system are very interconnected
- Power finally reaching home could originate from many sources
- Reliable operation is much more complex than producing and selling power