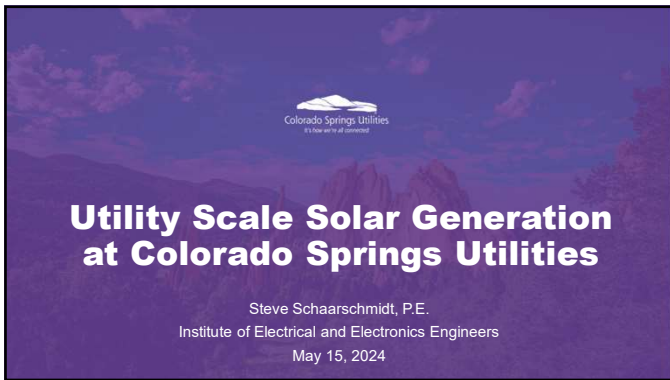
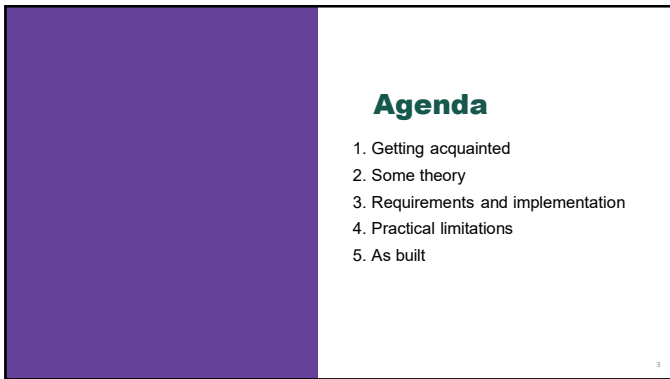




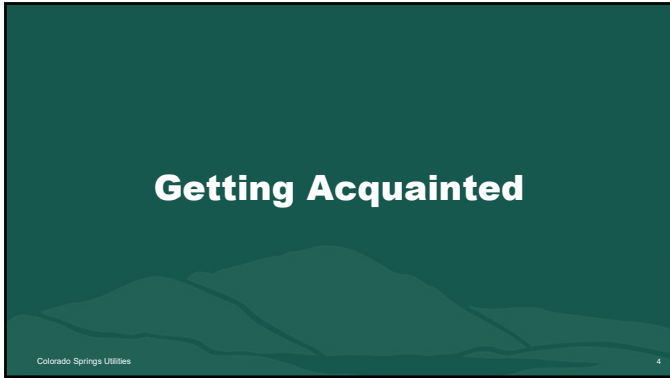
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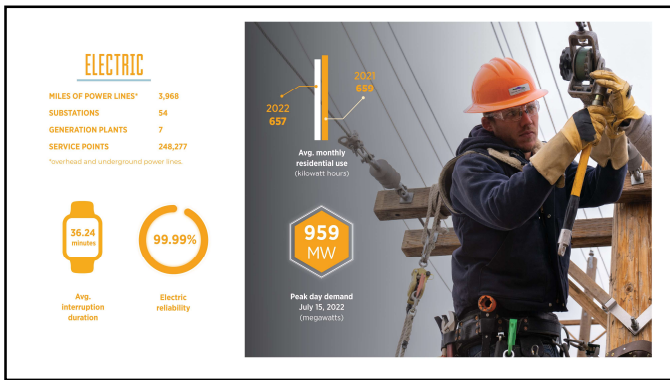
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Colorado Springs Utilities

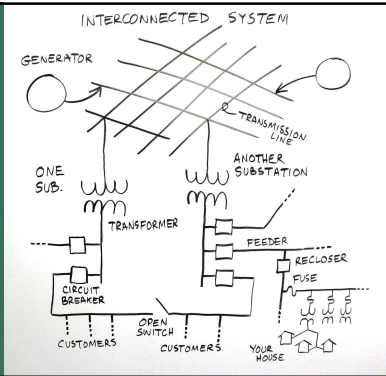
<p>System size</p> <ul style="list-style-type: none"> • Peak Demand ~900 MW • Western Interconnection that we belong to ~180,000 MW • Electrically ~0.5% of the western United States 	<p>Resource mix</p> <ul style="list-style-type: none"> • Coal • Natural Gas • Hydroelectric • Solar PV (by contract) • Wind (by contract)
---	---

Colorado Springs Utilities 4

6

Interconnected electric transmission system

- “The grid”
- Actually a collection of utility systems that have been knitted together over 100+ years



7

Pike Solar

- 414,072 modules at 540 W each
- 40 power stations at 4.36 MVA, each with two inverters at 2.18 MVA
- Grid following philosophy

(from Brandon Aho of juwi)

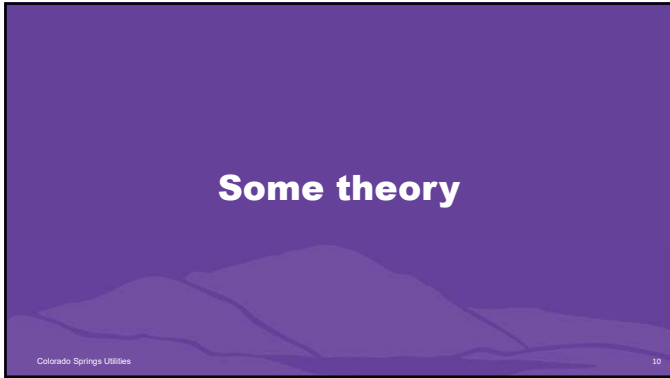
Colorado Springs Utilities

8

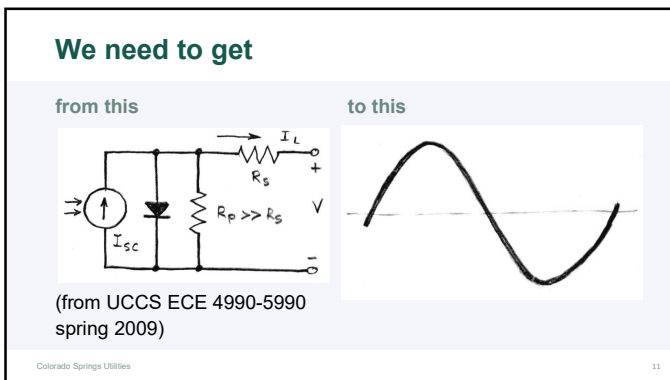
How do we...

- ...integrate large sources of solar generation?
- ...make them work with other resources?
- ...continue to operate the system SAFELY and effectively?

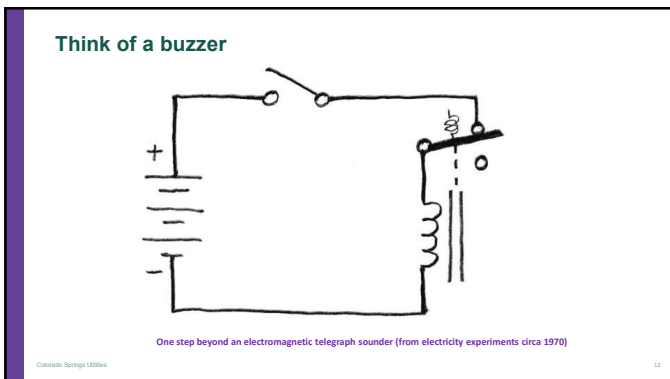
9



10



11



12

Take advantage of the switch

(from exploration of the tube-type AM radio in a 1955 Chevrolet circa 1980)

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13

Replace with electronics

Drive the transistor with a symmetrical square wave

(from UCB EE 362 Spring 1983)

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A more modern version

(from UCCS circa 2020)

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15

A solar array with one inverter serving an isolated load

- “Island” or “grid forming”

16

Conventional generator serving an isolated load

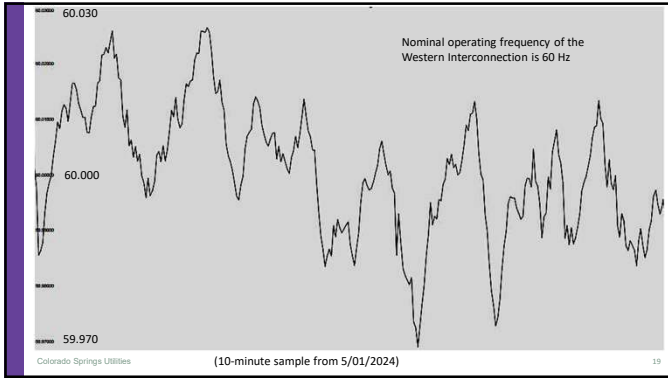
FIG. 9.9 Isochronous governor.

Colorado Springs Utilities from Power Generation, Operation, and Control 2/e by Wood and Wollenberg 1996

17

Requirements and implementation

18

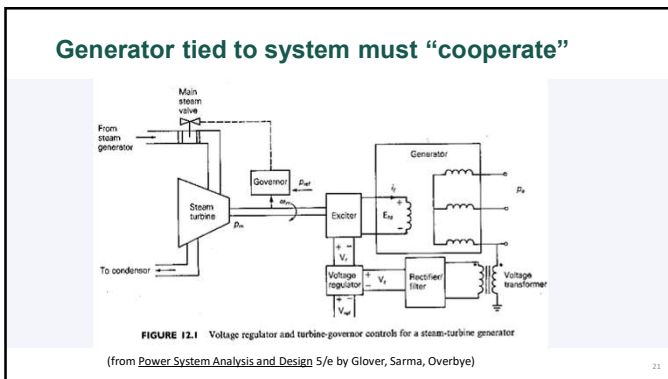


19

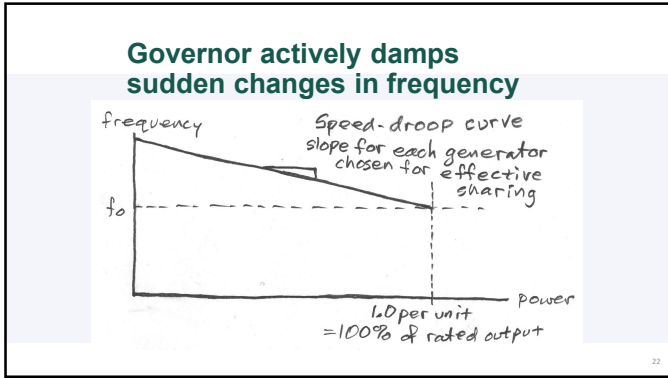
Before connecting generator to system

- Voltage at the generator matches system voltage
- Frequency at generator matches system frequency
- Voltage at generator is in phase with system voltage

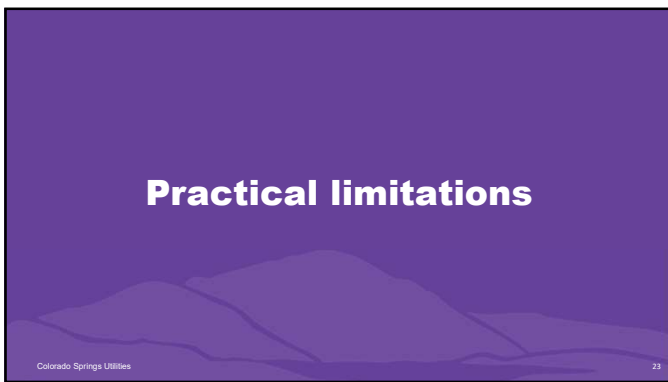
20



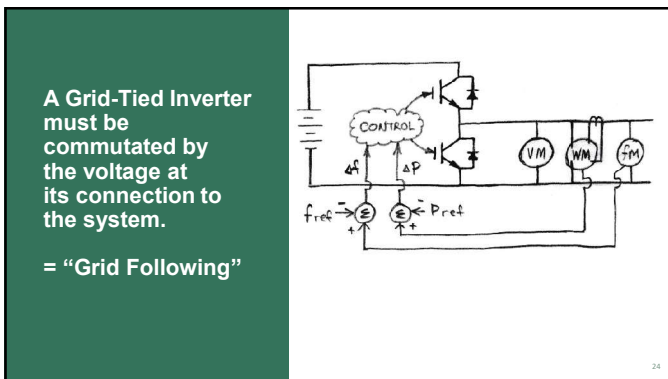
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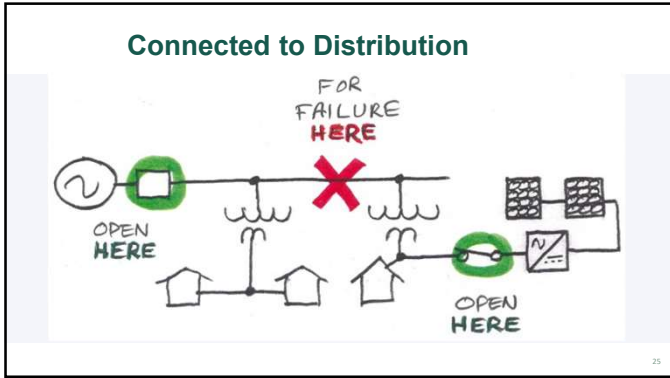
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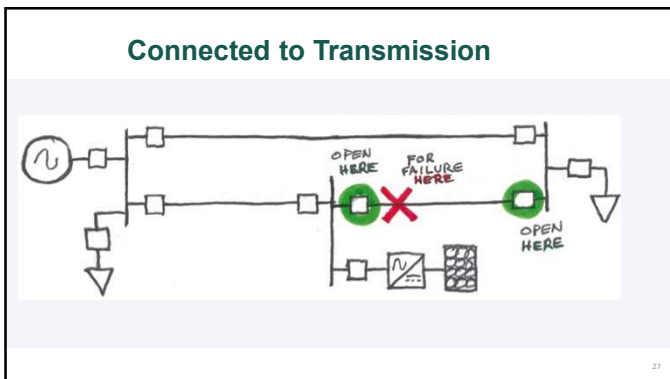


25

Safe and successful restoration

- Qualified lineworkers
- Removal of all energy sources
 - Momentary cessation
- "Not tested, not dead"

26



27

Continuity of service

- Proper sectionalizing
- Voltage ride-through
 - Opposite of momentary cessation
- Stability of the Interconnection

28

28

As built

Colorado Springs Utilities

29

29

From panels to transmission

600V

34.500kV

230kV

M

30

30

Lessons learned

Improvements in weather forecasting

Need for effective communication

Control of inverters

Operation with conventional machines

31

31

Future considerations

• Battery Energy Storage Systems

• Grid-Forming Capabilities

• Interface with a power pool

• Hail

32

32

Thank you for being here!



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33
