GE Energy Consulting

Experts in systems integration

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GEEnergyConsulting.com

Every electric grid has 3 requirements ...

Stable

Keep the circuit safe
voltage and frequency requirements

Reliable

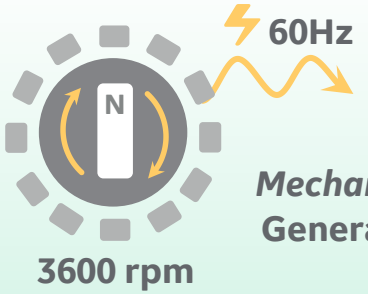
Keep the lights on
enough buffer room for uncertainties

Economic

Suppliers and consumers happy
rational investments, reasonable costs

Today's grid favors **synchronous machines**

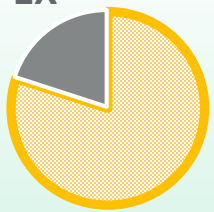
NEW RENEWABLE TECHNOLOGIES NEED NEW RULES



Mechanical Generator

Constant max power

CAPEX



OPEX

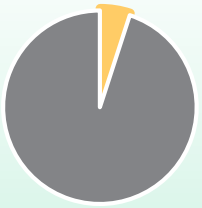
Costs *vary* W/fuel

SYNCHRONOUS MACHINES

Electronic Generator

Variable and uncertain max power

OPEX



CAPEX

Costs *fixed* W/free fuel

POWER ELECTRONIC MACHINES

Stable

Mechanical-based circuits disrupted by electronic equipment

Reliable

Load is usually variable and uncertain, generation isn't

Economic

Fuel-centric energy markets disrupted by free-fuel techs

GE Energy Consulting has been solving tough renewables problems >15 years

SIMULATION + INVENTION TO DIAGNOSE & REMOVE OBSTACLES

Stably connect large renewable plants

Colorado GE's 1st >100MW wind

Invented wind voltage controls

Invented wind inertia & frequency regulation

China grid code dev't

California 1st blackstart battery

Australia fast frequency response

Texas >2GW/yr transient studies

100%

New Mexico Wind + HVDC

Ireland GE's 1st offshore

Brazil '09 -'11 auctions

Vietnam grid codes

Stability upgrades -> 100%
60Hz + voltage formation

>30 GE inventions

Power electronic controls stabilize grid

Colorado Springs 33%

Qinjhai, China 35%

Hawaii 40%

Papua New Guinea 70%

New York 5%

PJM 30%

Nova Scotia 40%

New England 30%

California 15%

Ontario 30%

Saskatchewan 33%

West US 30%

Minnesota 30%

Canada 30%

Grand Bahama 30%

Barbados 30%

Texas 20%

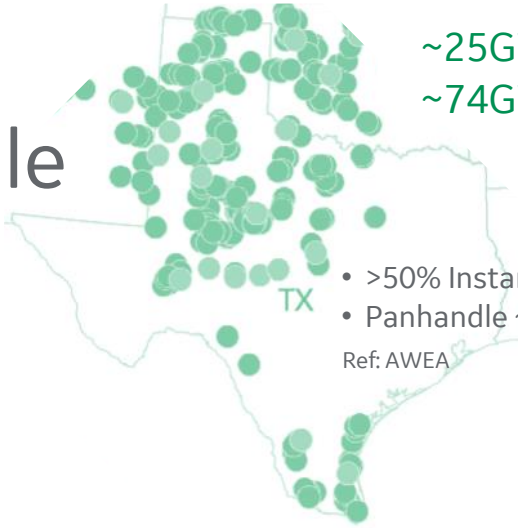
Tune **synchronous machine settings** ↑flexibility

Operational upgrades -> 30%
forecasting + faster mkt

Reliably + economically plan renewables

GE partners w/ERCOT … enabling 100% in TX Panhandle

IMPLEMENTING INTEGRATED APPROACH TO RELIABILITY, STABILITY AND ECONOMICS



GE study '08 + ERCOT update '13
-> new market requirements

RELIABILITY + ECONOMICS

↑ **weather variability** ->
↑ flexibility requirements

How to minimize costs …

1. **Integrate wind forecasts** into operations … ↓ ancillary requirements
2. **New ~4 hr. - ahead commitment** … ↓ error
3. **New 15 min. non-spin service** … ↓ spin requirements

STABILITY

↑ **power elect** ->
weak grid + control interactions

How to enable stability …

1. **Voltage:** new + retro synchronous condensers
2. **Frequency:** Wind governor + inertia
3. **Transient models required:** resonances -> controls interactions -> tripping … converter + controls tuning

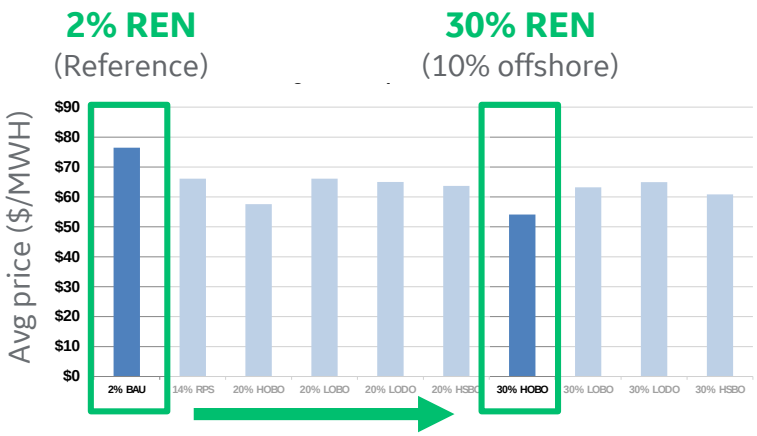
GE + ERCOT transient studies: >2GW/yr.

GE partners w/PJM to plan for 30% renewable

FOCUS ON RELIABILITY + ECONOMICS

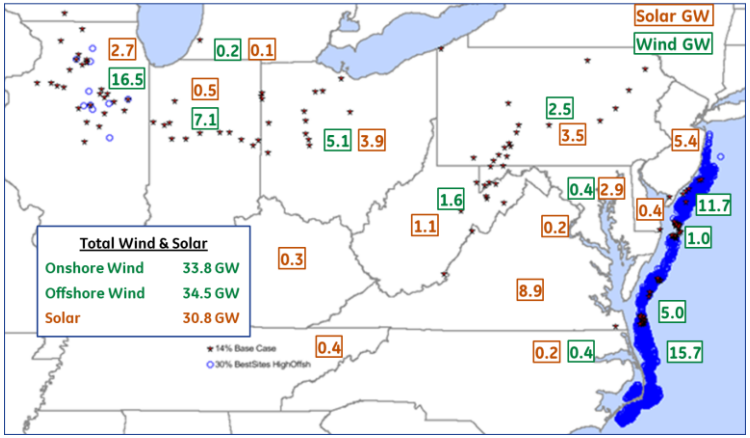
Problem: What are the challenges integrating **30% renewables** into the world's largest energy market?

Simulated future system … identify renewables value + challenges



Average energy price ~$20/MWh lower

Range of scenarios include 35GW **offshore wind**



Key findings:

- New high voltage **transmission** required
- Minimal renewables **curtailment**
- Lower average energy **prices**
- **Capacity *credit*:** offshore (27%) vs. onshore (17%)

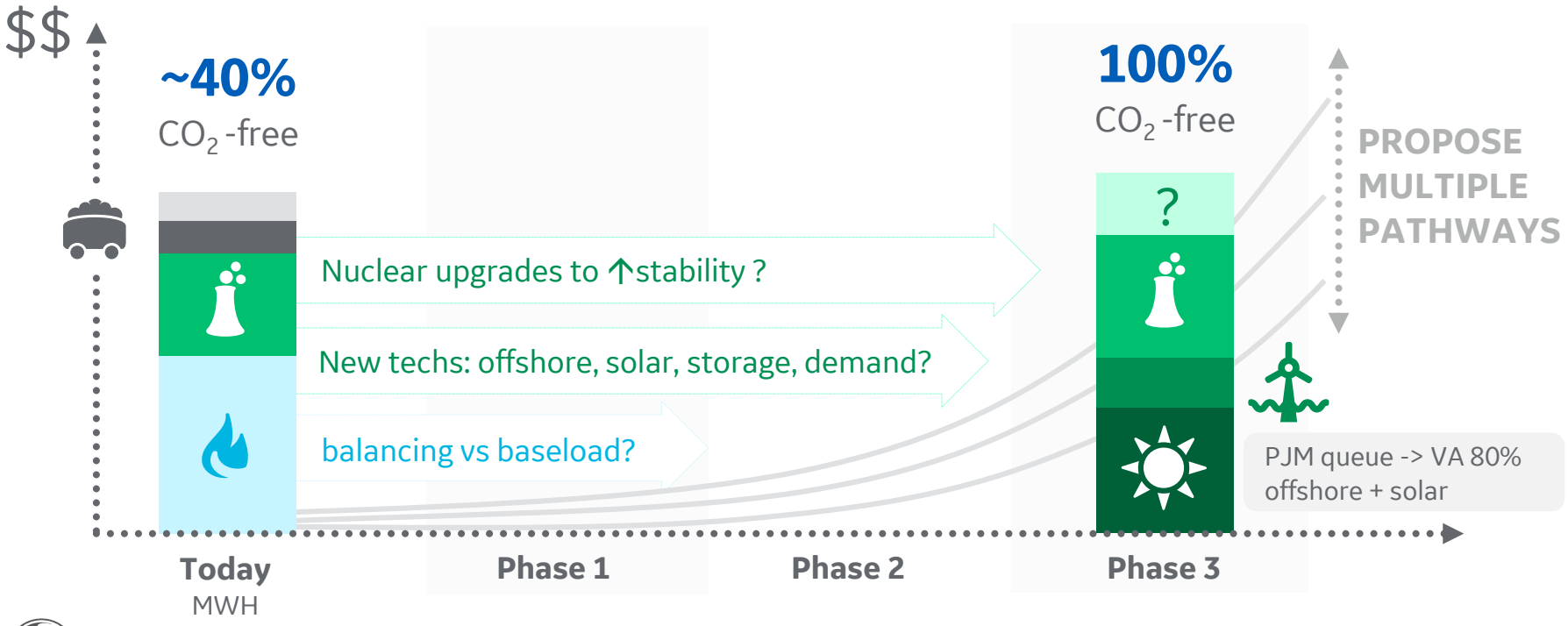
https://www.pjm.com/~/media/committees-groups/subcommittees/irs/postings/pris-executive-summary.ashx

Possible path forward: Virginia partners with tech experts to shape 100% transition strategy

PROACTIVELY SHAPE POLICY … CLEARLY OUTLINE COSTS AND TRADEOFFS

DEVELOP *PHASES* TOWARD 100% CO_2-FREE

- **Define scenarios** for an attainable VA CO_2-free mix
- **Identify enablers**: transmission, reliability, stability, market
- **Optimize:** economic + reliability … how close to 100%?



Ref: PJM interconnection queue

GE Energy Consulting:
Energy industry advisors for >100 years

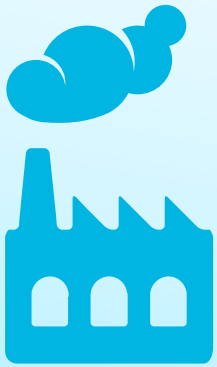
GE's GRID EXPERTS … OEM AGNOSTIC

~130 grid experts
9 countries
>100 patents

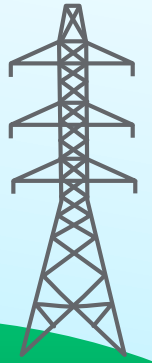
GENERATION INTEGRATION | voltage & frequency performance

GRID STRATEGY | complex plant interconnection

ECONOMIC ANALYSIS | grid value of technology



- Interconnection support
- Grid code testing and compliance
- Equipment tuning



- Stability studies
- Network risk assessment
- Grid reinforcements

- Renewables planning and strategy
- Financial modeling and forecasting

Models

Transients milliseconds

Planning years

Software

Power flow GE PSLF*

Energy GE MAPS*

Capacity GE MARS*

GE technology

1/3 earth's power | #1 clean energy fleet

*Trademark of General Electric

Renewable integration study references (page 1 of 2)

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