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Integration of High Penetration Variable Generation into the Bulk Grid

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Outline

- **Integration into Operations**
  - Variability and uncertainty
  - Integration impacts and cost
  - Are there penetration “limits”?
- **What are we doing to prepare for highier penetration?**
  - Wind as a power plant
  - Interconnection standards
    - Reactive Power
    - Voltage/Frequency Tolerance
- **Q&A**

Hawaii Electric System

- **Transmission and Distribution System**
  - 138 kV transmission
  - 46 kV sub-transmission
  - 25 kV, 12.47 kV, 4.16 kV distribution
  - Transmission and Distribution substations
  - Energy Management System (SCADA, etc)

Managing Frequency in High Penetration Scenarios

- **Schedule units ahead of time to ensure adequate generation capacity + operating reserves are available**
  - Unit commitment process, hours to days ahead
  - Takes into account
    - Load forecast as well as
    - Variable generation forecast—required in high penetration scenarios
    - Generating unit characteristics (cost, minimum loading, start/stop time, min up/down times, up/down ramping capability, availability)
- **Operating reserve: capability above firm demand to cover for regulation, forecast error, forced outages**
  - Spinning: Unloaded synchronized capacity ready to provide regulation and assist with contingency recovery
  - Non-spinning: Capacity not synchronized, but available to assist with contingency recovery within a specified time

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Managing Frequency in High Penetration Scenarios

- **Operate committed generation optimally in real-time**
  - Follow load fluctuations (load following or ramping)
    - Economic dispatch process, minutes to hours time frame
    - Provided by re-dispatching online units or starting pre-committed units, potentially responsive load
  - Help regulate interchange and frequency regulation
    - Provided by spinning units on automatic generation control (AGC)

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Managing Frequency in High Penetration Scenarios

- **Regulation, Load Following and Scheduling**

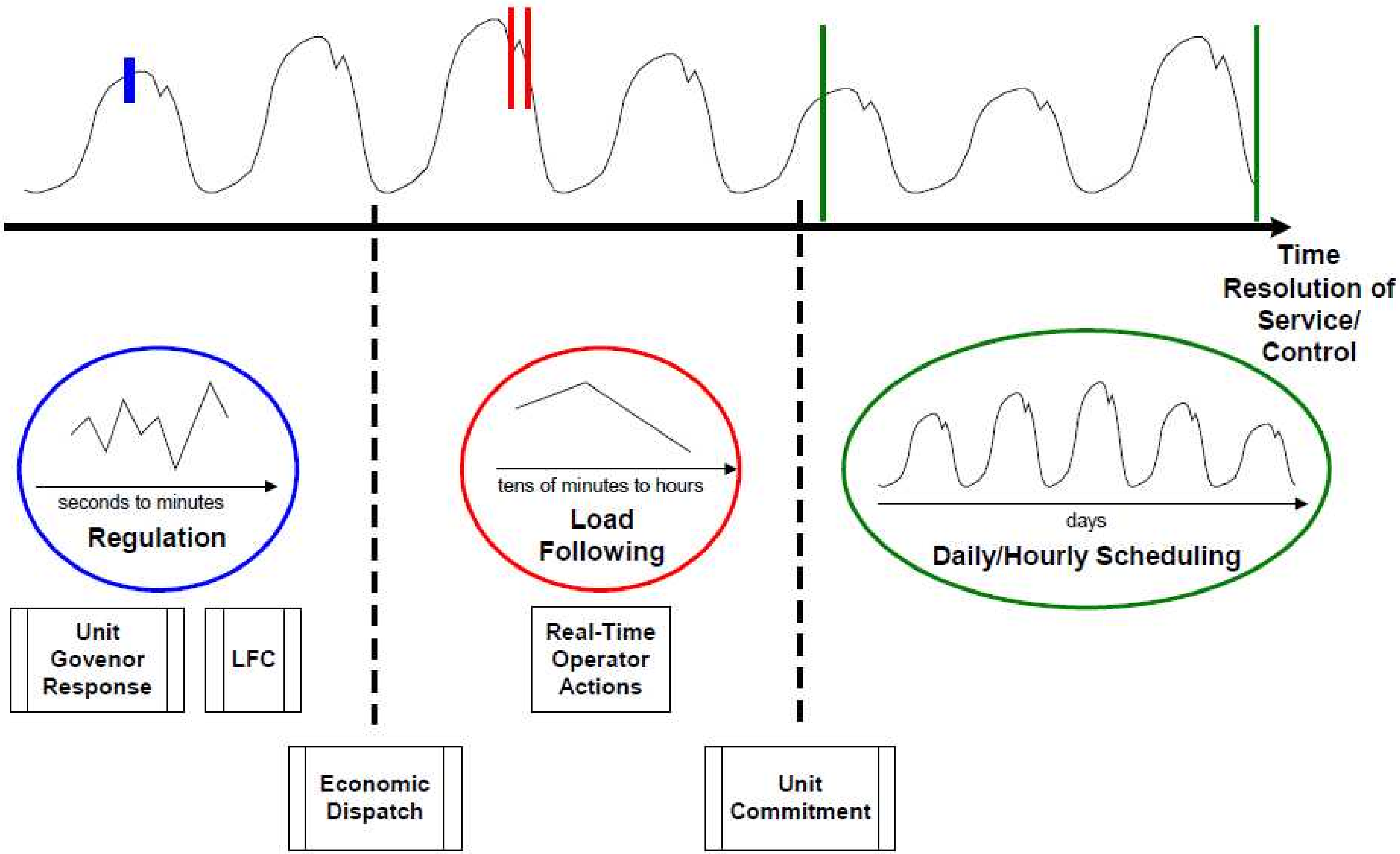


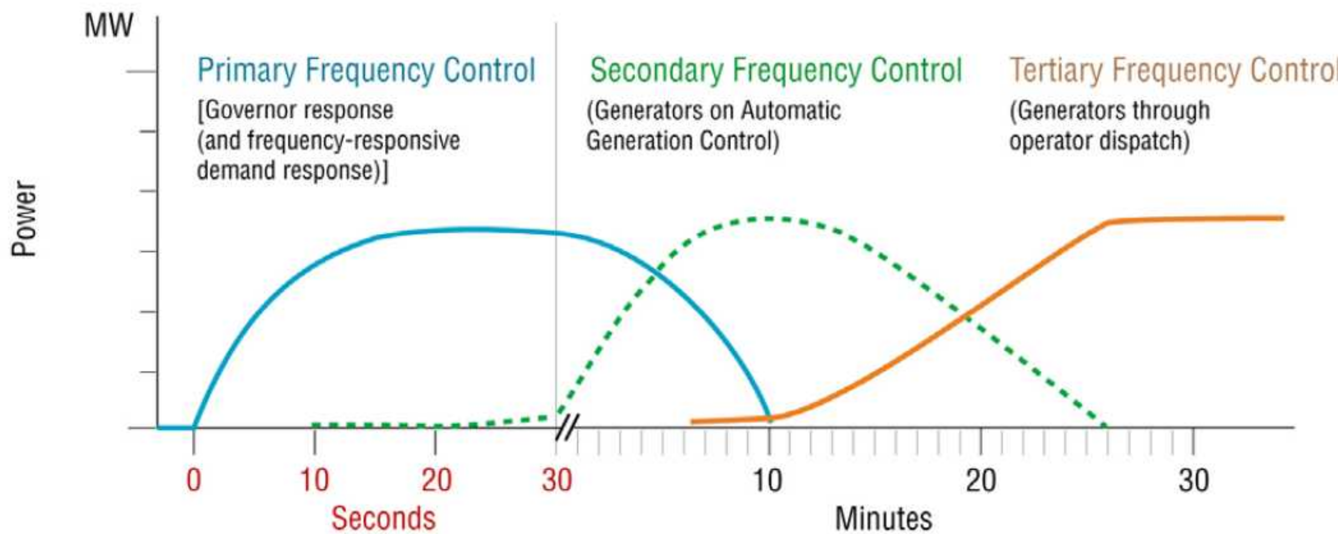
Figure 1-2: Operational Time Frames and Associated Control Mechanisms

Managing Frequency During a System Disturbance

- **Generation too high, frequency above normal**
  - Primary/secondary frequency response
  - Turn down or turn off cycling units
  - Turn down base-load units toward min., leave “must run” units
  - Reduce output of “as available” (variable) generation
  - Turn off “as available” (variable) generation
- **Generation too low, frequency below normal**
  - Primary/secondary frequency response
  - Increase generation of on-line units
  - Turn on quick start or cycling units (e.g., peakers)
  - Turn off non-firm load
  - Under-frequency load shedding
  - Under-frequency generation tripping

Managing Frequency During a System Disturbance

- **Type of Frequency Control**
  - Primary control: Local, automatic, rapid (seconds) coming from generator governor response and possibly demand response
  - Secondary control: External (centralized) and slower (tens of seconds to minutes) coming from generators on AGC
  - Tertiary control: Generation dispatch by operator action



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Managing Frequency in High Penetration Scenarios

	Example	Ramp (%/min)	Min Load	Start time
peakers	GT, diesel	20 - 50	50%	Minutes
intermediate	CCs	5 - 10	40 - 50%	Hours
Base-load	Coal, nuclear	0 - 5	80%	Days

- **Operating generators**
  - Peakers: 1
  - Baseload:
  - Rate may be reduced depending on unit age, fuel, controls, etc
- **Variable generation can have high ramp rates**
  - Dispatchable generators may have difficulty “keeping up” and thus frequency can drift
  - However, ramping should be mitigated at the system level unless local impacts (e.g., voltage) need to be mitigated
    - Mitigating ramps on a project-project basis is inefficient
- **Key concept: Ramp mitigation for frequency management should be done at the system level**

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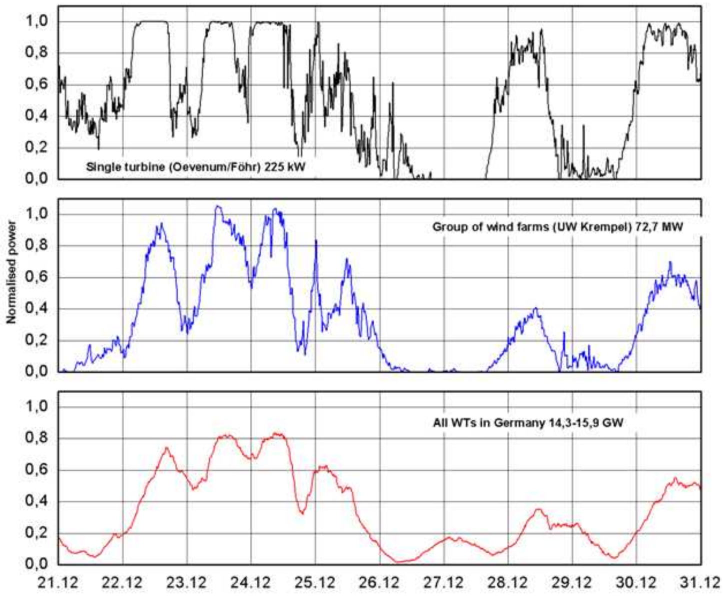
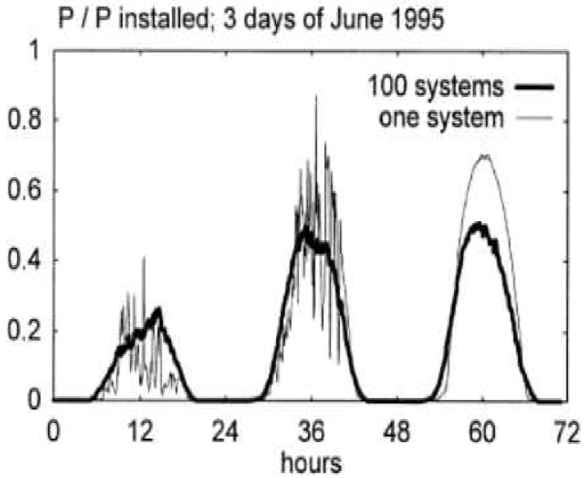
Managing Frequency in High Penetration Scenarios

- **High ramp rates from variable generation**
  - Frequency could be affected if there are insufficient reserves
  - However, geographic diversity virtually eliminates high ramp rates in the short time frames (seconds)
    - No need to mitigate on a project-by-project basis unless local impacts (e.g., voltage) need to be mitigated





Managing Frequency in High Penetration Scenarios

- **Ramp rate mitigation in Hawaii**
  - Several existing large wind & solar plants implement ramp-rate mitigation at the project level using energy storage
  - Similar plans for future large-scale plants

Table 5 Performance Ramp Rate

Generator Size	Performance Ramp Rate
5MW to 25MW	2 MW/min
25MW to 50MW	2 to 3 MW/min
50MW to 100MW	3 to 5 MW/min
100MW to 200MW	5 to 10 MW/min

Source:
Draft RFP for Renewable Energy and Undersea Cable System Projects Delivered to the Island of O'ahu, http://www.heco.com/vcmcontent/GenerationBid/HECO/CompetitiveBid/Books1 and 2 - Draft RFP and Appendices A through Q.pdf

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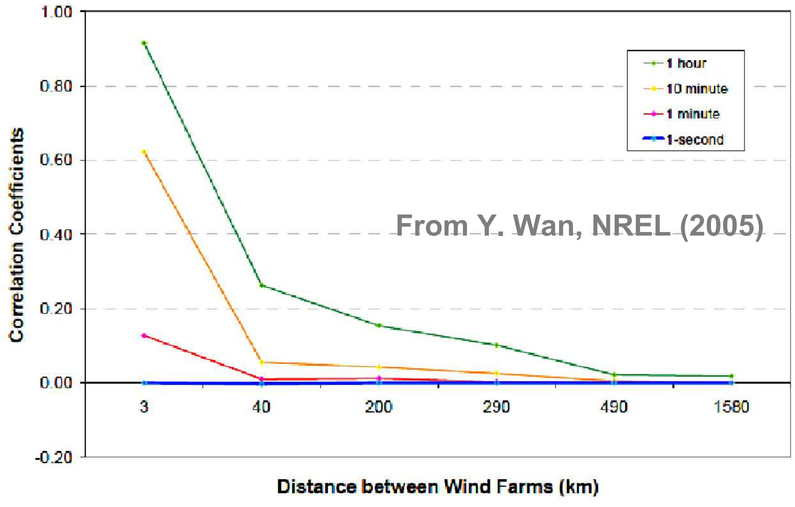
Managing Frequency in High Penetration Scenarios

- **Alternatives to manage ramp rates**
  - Enhance conventional fleet (governor and AGC controls)
    - Effort already underway in Hawaii
  - Plant controls (power limit, up ramp limit, high frequency support)
  - System-level energy storage
  - Frequency-responsive load

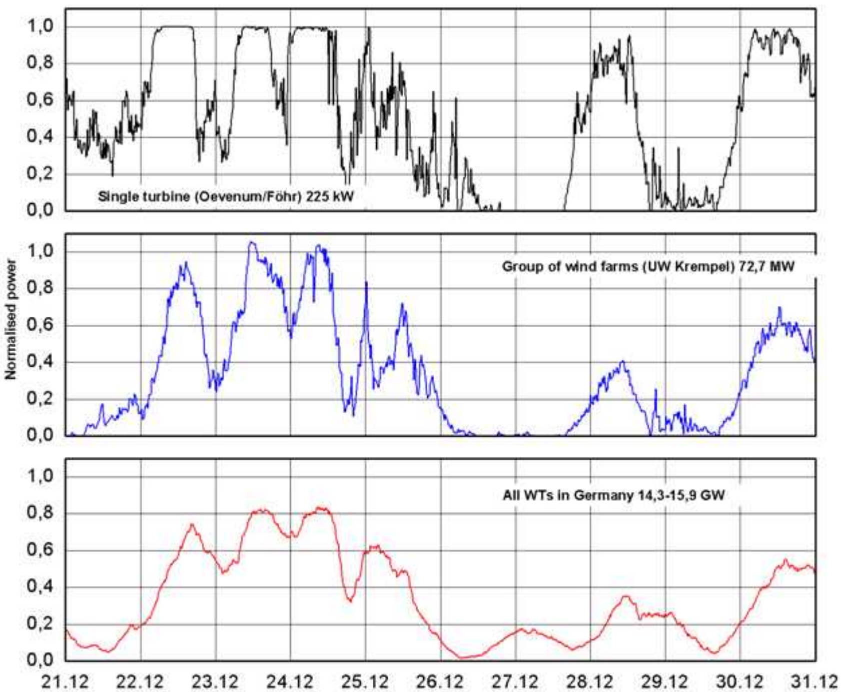
Variability and Uncertainty

- **<u>Variability</u> refers to changes in wind generation output (magnitude and frequency) over time**
  - Diversity reduces variability (smoothing effect)
  - Correlation decreases with distance
  - Smoothing effect is greatest in the short time frames

Wind power correlation as a function of distance



Example for Wind in Germany



Integration Impacts

- **The challenge is to deal with net increase in variability & uncertainty**
  - Local impacts (voltage, etc) are addressed in the interconnection process
- **Key factors**
  - Penetration level
  - System size and flexibility (physical characteristics, operating practices)
  - Transmission service and market flexibility (rules)

"Easy" Week

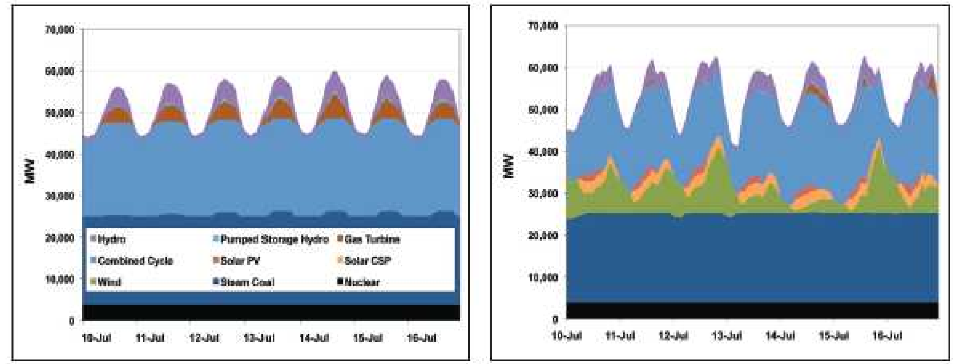


Figure 3 – 35% renewables have a minor impact on other generators during an easy week in July, 2006. WestConnect dispatch - no renewables (left) and 30% case (right)

"Hard" Week

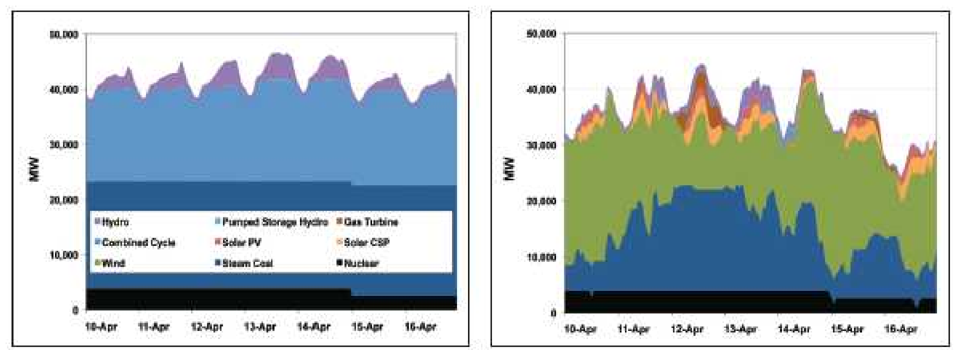


Figure 4 – 35% renewables have a significant impact on other generation during the hardest week of the three years (mid-April 2006). WestConnect dispatch - no renewables (left) and 30% case (right)

Figures from Western Wind and Solar Integration Study, 2010

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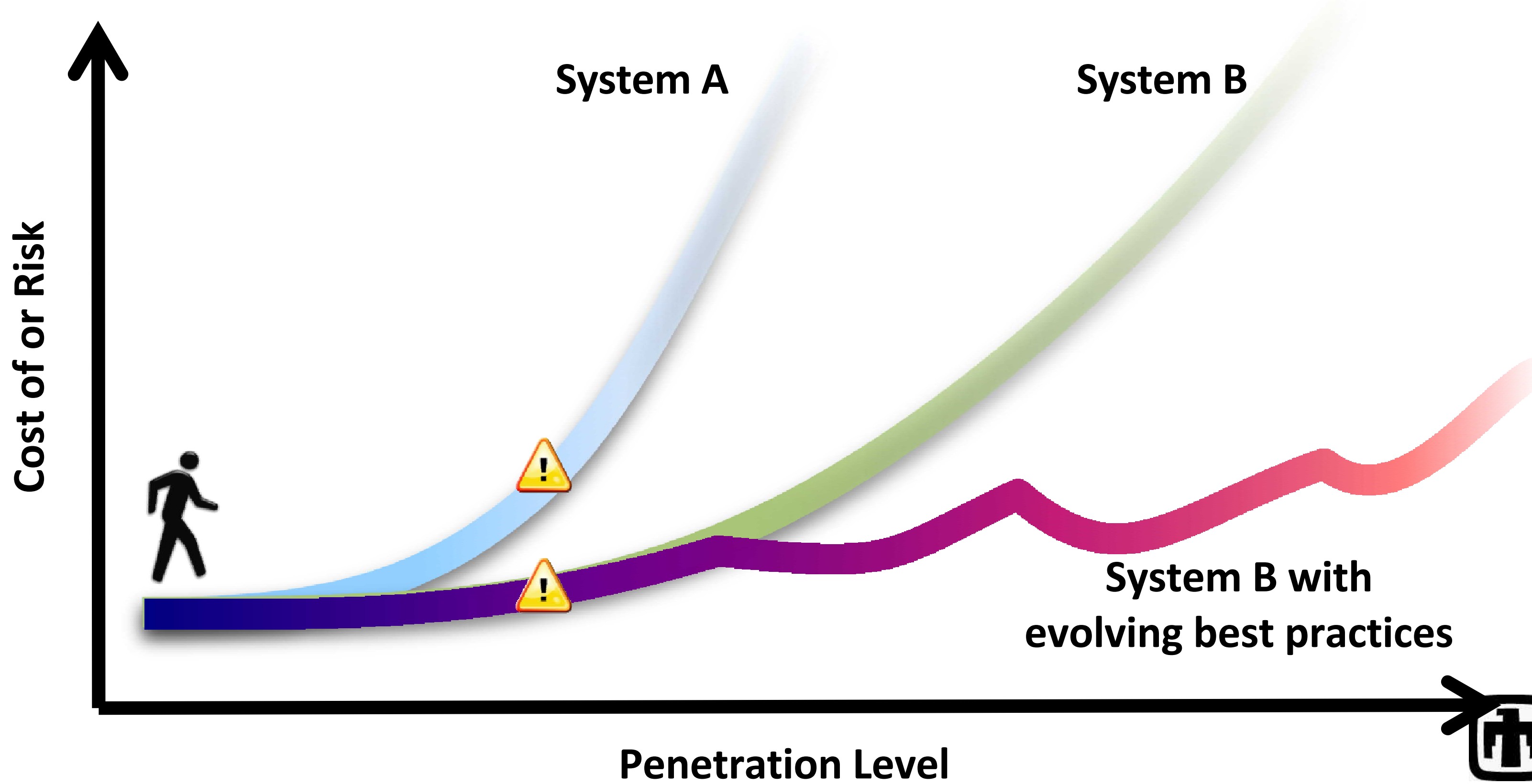
Are There Penetration Limits?

- **There are no <u>absolute</u> technical limits to integration of variable generation**
  - It all boils down to cost, and the impact is system-specific
  - Transmission access is the most challenging issue



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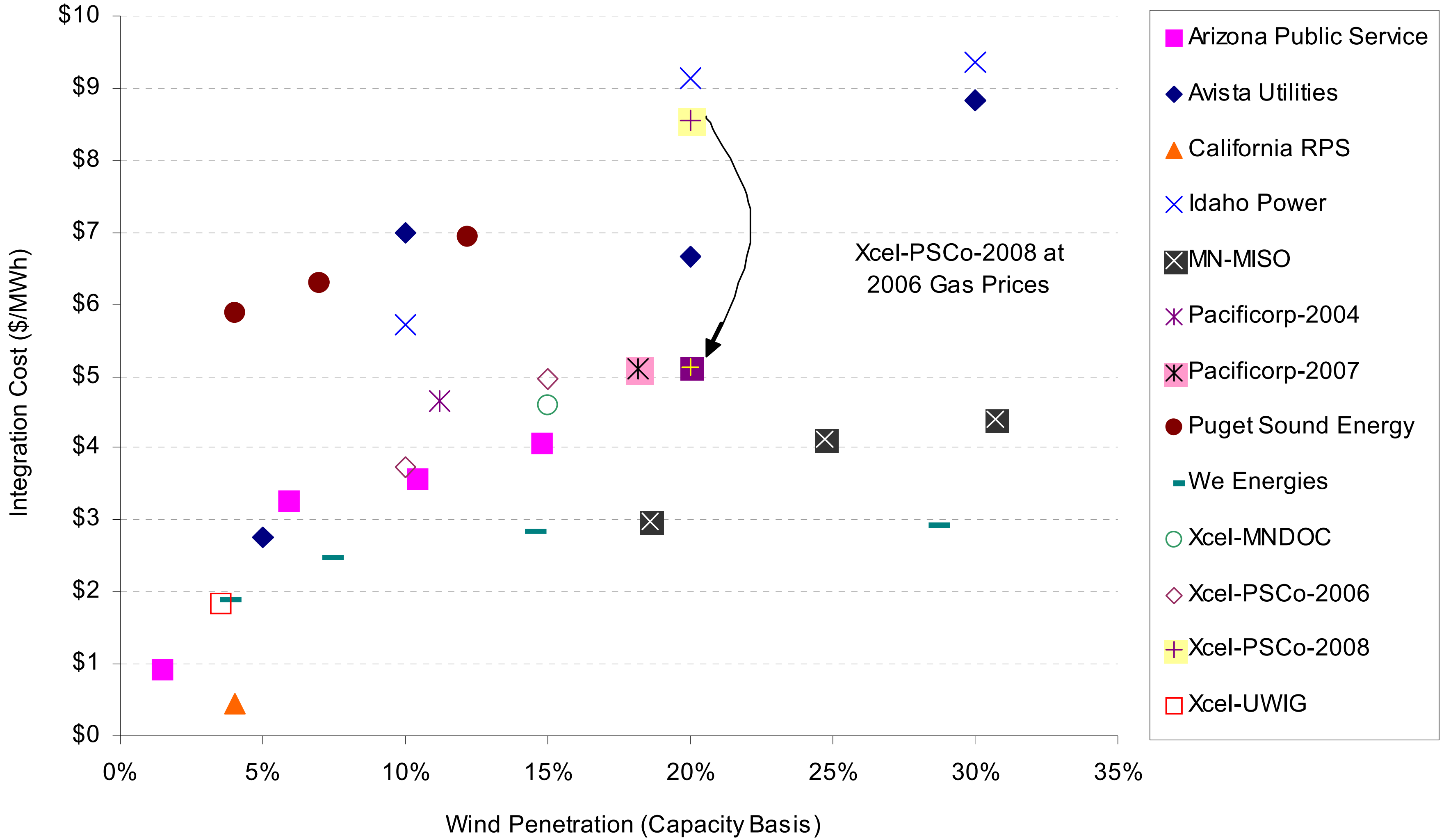
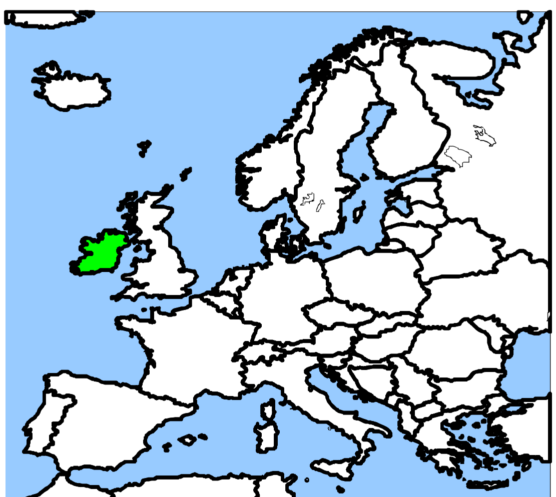
Increase in Operating Cost



Source: LBL

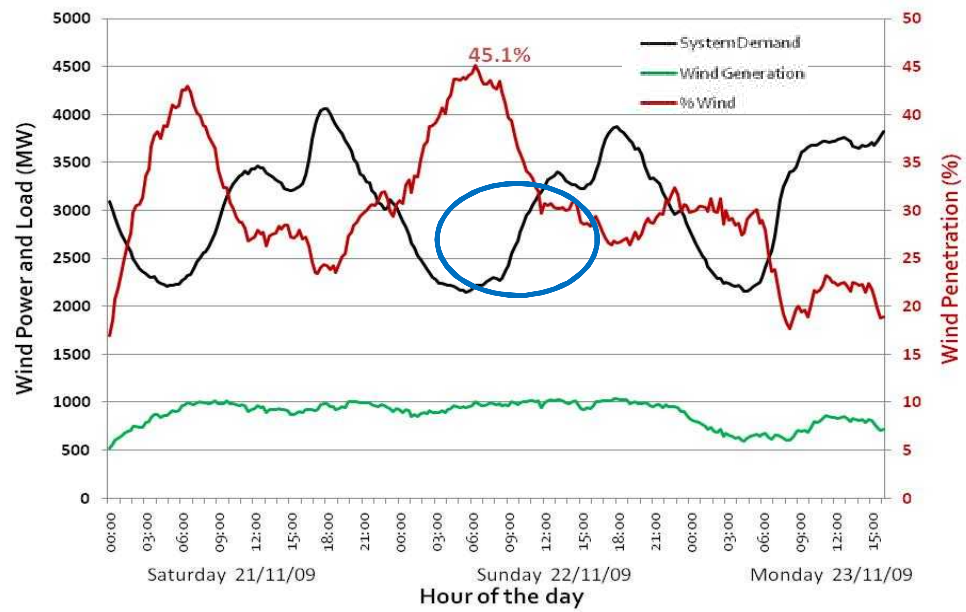
Example of High Penetration

Ireland: >1 GW wind capacity in 7 GW peak load island system



Ireland Example

- Penetration by energy approaching 15%
- Instantaneous penetration reaches 50%



Source: Mark O'Malley

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Moving the Mountain?

- **FERC policy evolution**
  - On the policy side, addressing practices that could be unduly discriminatory or lead to unjust or unreasonable cost for transmission service
  - Integration of Variable Generation NOPR (Docket RM-10-11-000)
    - Intra-hour transmission scheduling
    - Meteorological and operational data for improved forecasting
    - Generator-based regulation Service (new Service Schedule 10)
  - On the technical side
    - Order 661-A and LGIA Appendix G (specific to wind generation) addressing reactive power design criteria, voltage tolerance, SCADA integration
  - Recent inquiry into frequency impact of wind generation

Moving the Mountain?

- **NERC mandatory reliability standards**
  - Existing standards do not adequately address variable generation
    - North-America approach makes it difficult
    - Consensus-based + technology-neutral = slow to change
  - Recent Effort: Integration of Variable Generation Task Force
  - FERC's guidance to NERC: All new/revised NERC standards <u>must</u> address variable generation
    - Looking at full list of standards, including interconnection
    - NERC IVGTF issuing recommendations for changes to standards—See http://www.nerc.com/filez/ivgtf.html

Interconnection Requirements

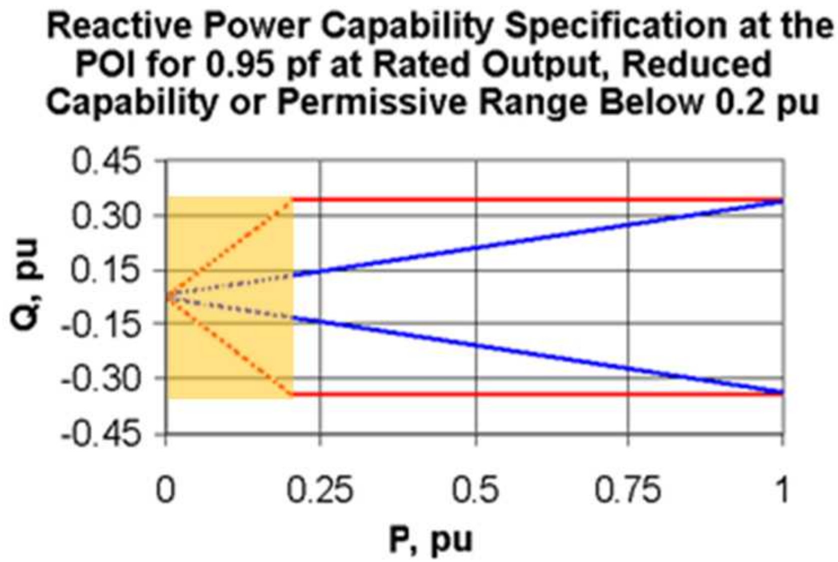
- **NERC IVGTF Task 1-3 Recommendations on Interconnection Standards and Procedures**
  - *"Interconnection procedures and standards should be reviewed to ensure that **voltage and frequency ride-through**, **reactive and real power control**, **frequency and inertial response** are applied in a consistent manner to all generation technologies."*
  - *"The NERC Planning Committee should compile all interconnection requirements that Transmission Owners have under FAC-001 and evaluate them for uniformity. If they are inadequate, action should be initiated to remedy the situation."*

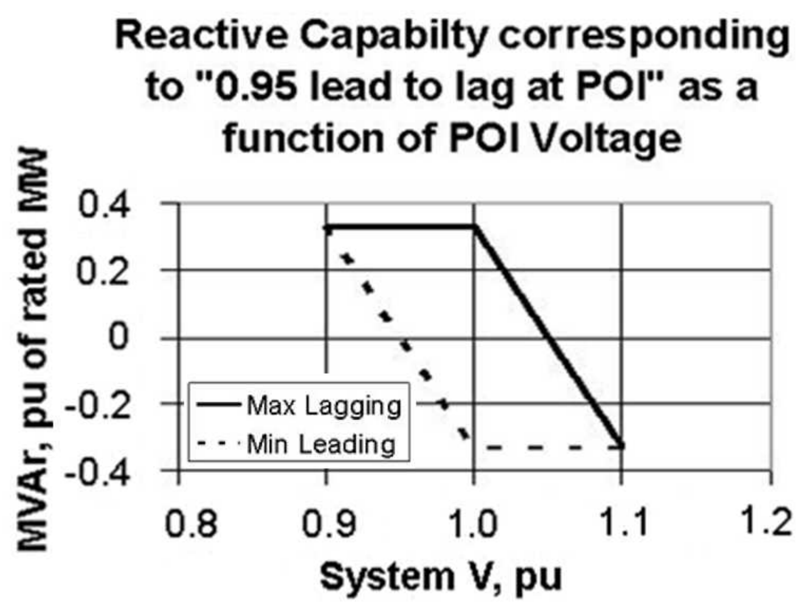
Existing Reactive Power Requirement

- **FERC Order 661A – Power Factor Design Criteria**
  - *Maintain a power PF within a range of +/- 0.95 at the POI… if the System Impact Study demonstrates that such requirement is needed for safety or reliability*
  - *Provide dynamic voltage support… if the System Impact Study demonstrates that this is required for safety or reliability*
- **Several fundamental shortcomings**
  - Process: approach to "demonstrate need" is not defined
  - Technical: Reactive range and control requirements are not defined as a function of power output or voltage level
- **Existing NERC standards don't help much**
  - NERC FAC-001 directs TOs to publish connection requirements for generators that address Reactive Power Capability and Control Requirements (R2.1.3 and R2.1.9)

General Observations by IVGTF

- **Reactive Power Capability**
  - Consider baseline requirement as opposed to “as needed” approach
  - Consider using Q vs P chart to specify reactive range
  - Consider permissive range at low output level
  - Consider using a Q vs V chart to account for the effect of terminal voltage on reactive range

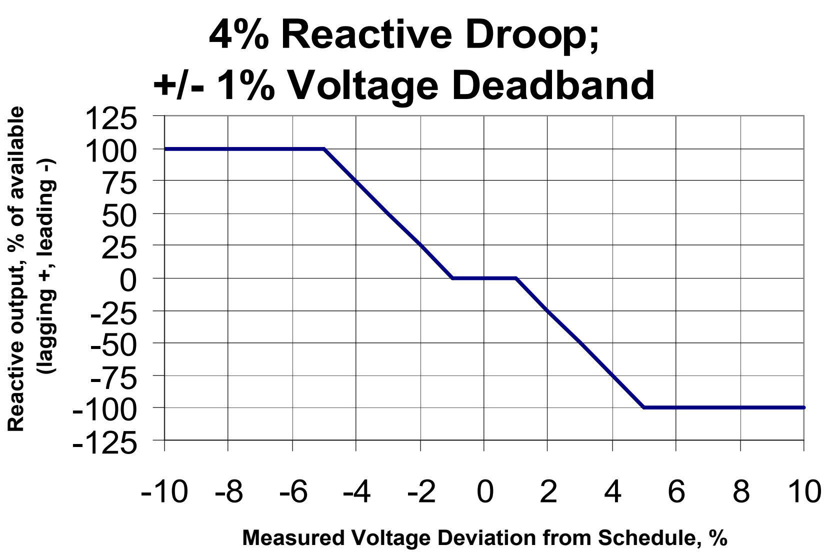


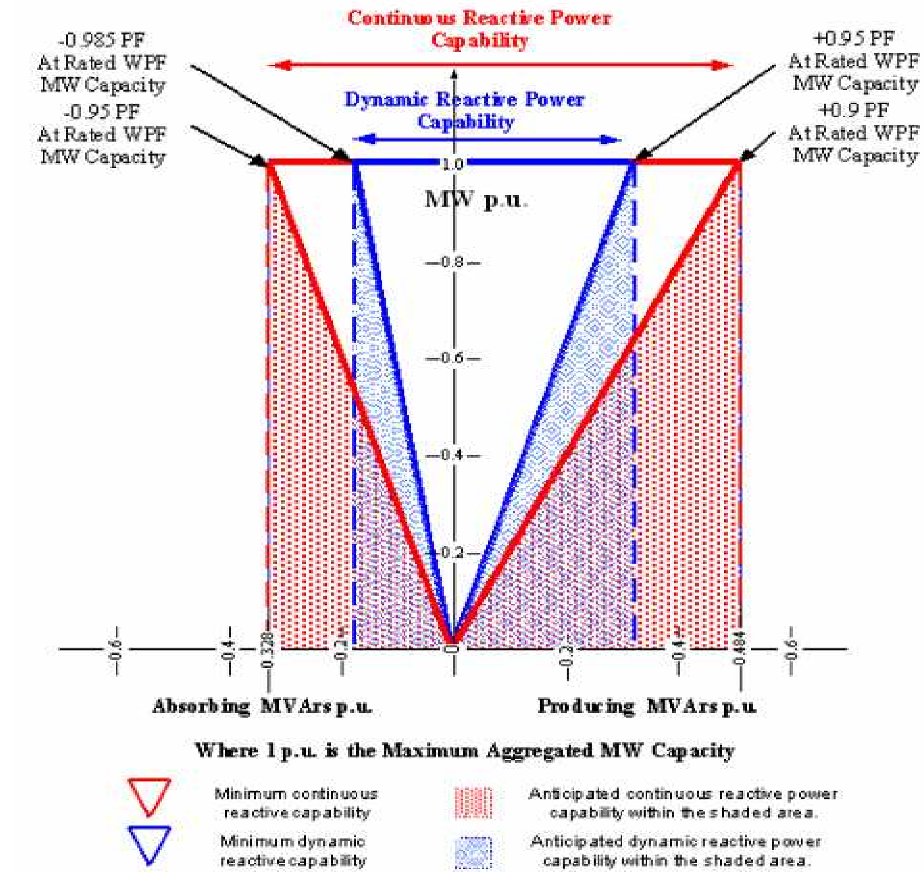


Charts are for illustration only

General Observations by IVGTF

- **Dynamic Reactive Power**
  - Consider defining the amount of dynamic vs static capability
  - Consider defining control performance
    - Closed loop voltage control
    - Volt/Var Droop





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Existing Voltage Ride-Through Requirements

- **FERC Order 661A – Low Voltage Ride-Through**
  - Remain connected after 3-ph faults cleared in *normal time (up to 9 cycles)*, and single-line-to-ground faults with *delayed clearing* time, and during voltage recovery period
    - However, the Order also states that *"The clearing time requirement for a three-phase fault will be specific to the wind generating plant substation location, as determined by and documented by the TSP."* ?
  - Voltage during fault can be 0 at the POI
- **Several shortcomings**
  - Delayed clearing time not specified for non-symmetrical faults
  - Voltage recovery characteristic not specified (e.g., no LVRT curve)
- **NERC standards don't help**
  - NERC FAC-001 directs TOs to publish connection requirements for generators that address Operational Issues, including abnormal frequency and voltage (R2.1.14)

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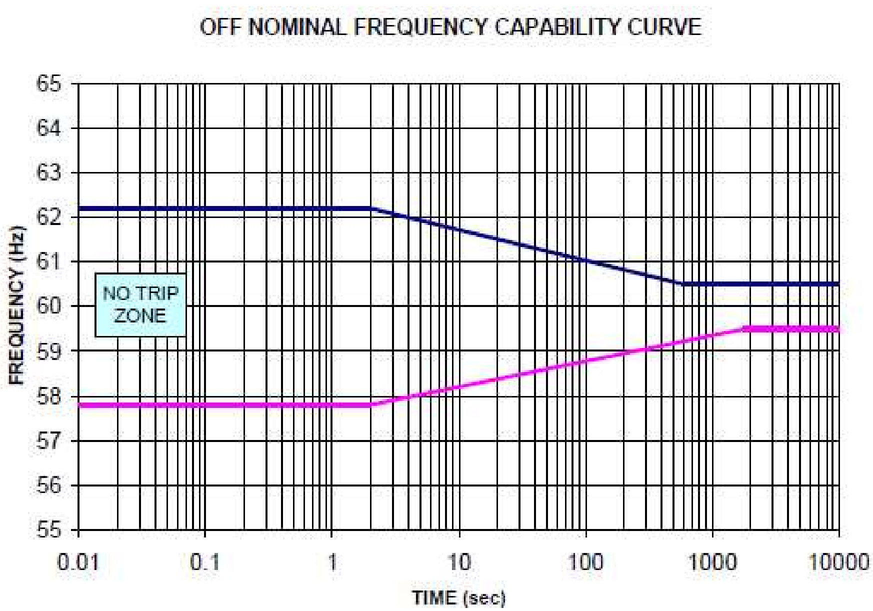
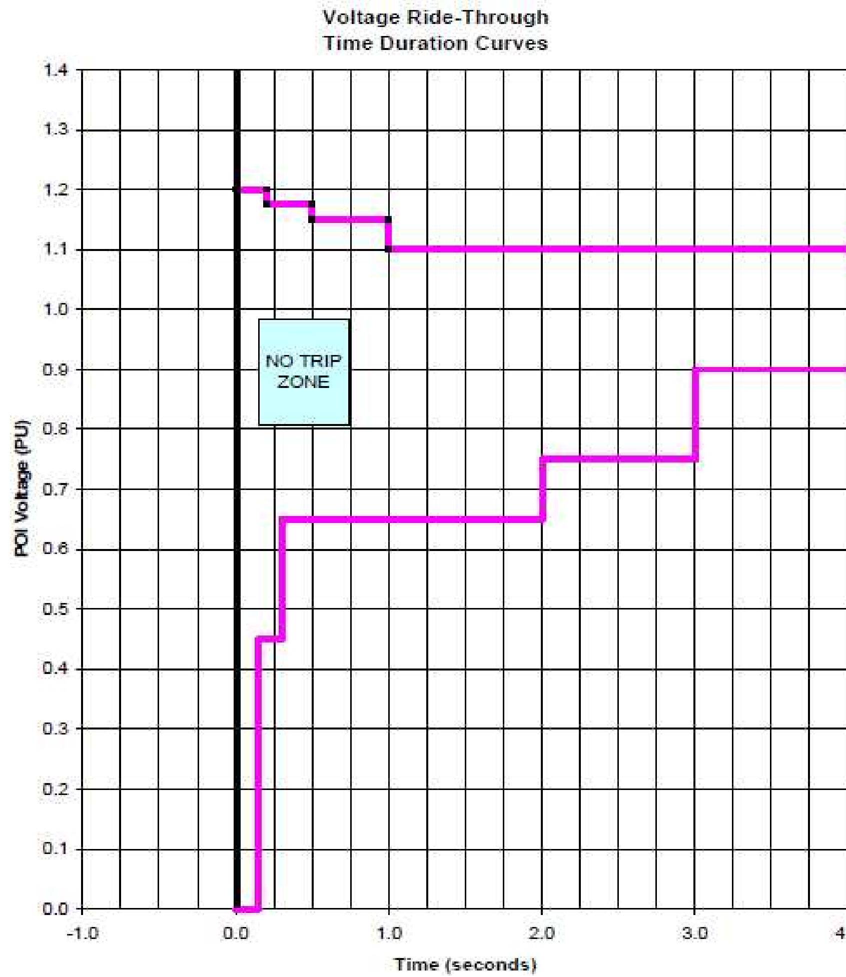
Proposed NERC PRC-024 Standard

- **Voltage & frequency tolerance**
  - Would apply to all generators > 20 MVA and multiple generator facilities >75 MVA
  - Can all generators do this?





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Summary

- **There are no <u>absolute</u> technical limits to penetration of variable generation…**
  - The issue is cost to deal with variability and uncertainty
  - Cost impacts are system specific
  - System flexibility is the key!

- **…However, transmission access is a bear!**

- **Path forward becoming more clear**
  - FERC and NERC actively revising procedures, policies and standards to address variable generation
  - Change is needed in preparation for higher penetration levels