Renewable Energy and Inter-island Power Transmission

Composite photo created by NREL

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National Renewable Energy Laboratory

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Univ. of Turabo

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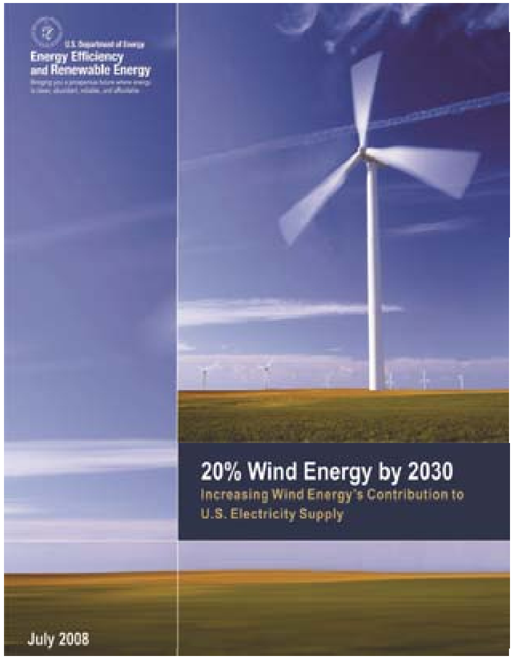
NREL's Role in Variable Renewable Energy Integration



- Integration studies and operational impacts;
- Wind/solar plant modeling and interconnection;
- Transmission planning and analysis;
- Resource assessment and forecasting.

Energy Development for Island Nations (EDIN)

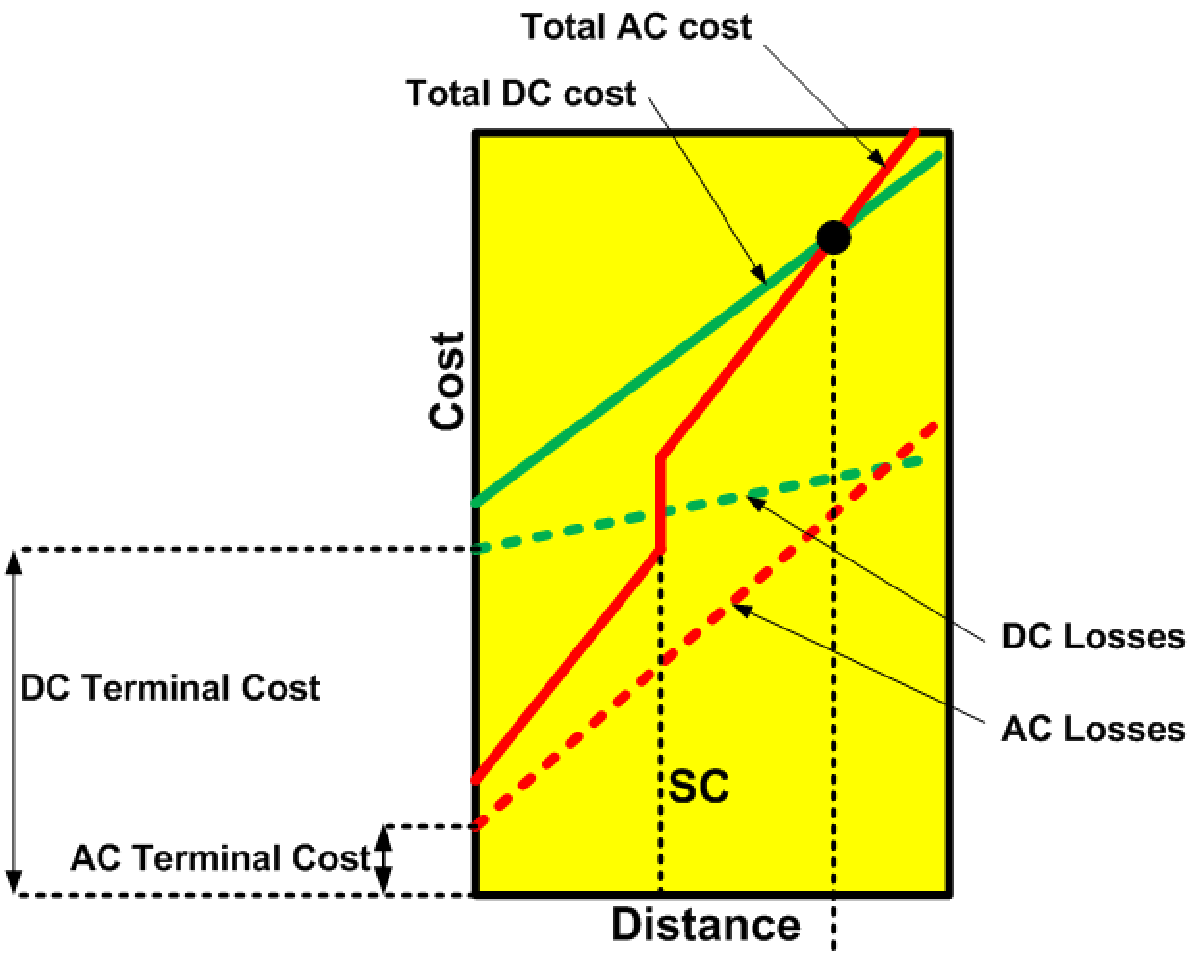
- U.S. Virgin Islands (reduce dependency on fossil fuel by 60% by 2025).
- Iceland and Dominica collaboration.
- Pacific Islands.

Wind/PV/Energy storage projects in Hawaii.

Overview

- Submarine Power Transmission Technologies.
- Hawaii Wind Integration and Transmission Study.
- Caribbean Work.

HVAC vs. HVDC



<u>Breakeven distance</u>
400-700 km overhead
50-100+km submarine

HVDC Pros and Cons

Advantages

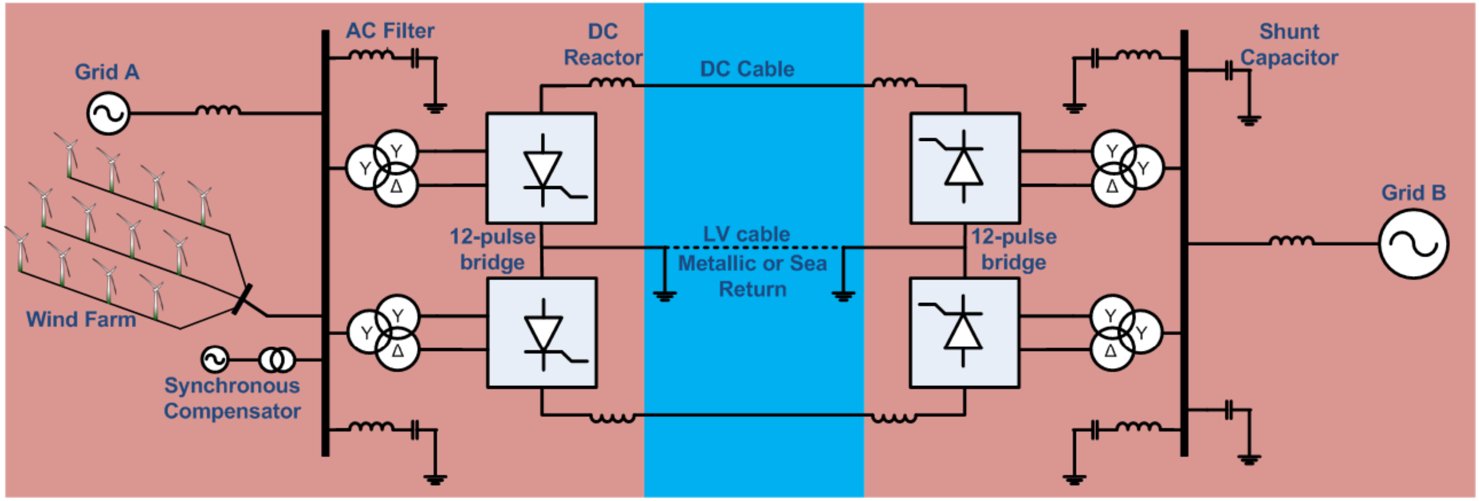
- Long distance transmission with lower costs and losses;
- No high capacitance effect on DC (no reactive losses);
- More power per conductor, no skin effect, 2 conductors only;
- Connecting unsynchronized grids, rapid power flow control;
- Buffer for some disturbances, stabilization of power flows;
- Multi-terminal operation;
- Good for weaker grids;
- Helps integrating large amount of variable generation.

Disadvantages

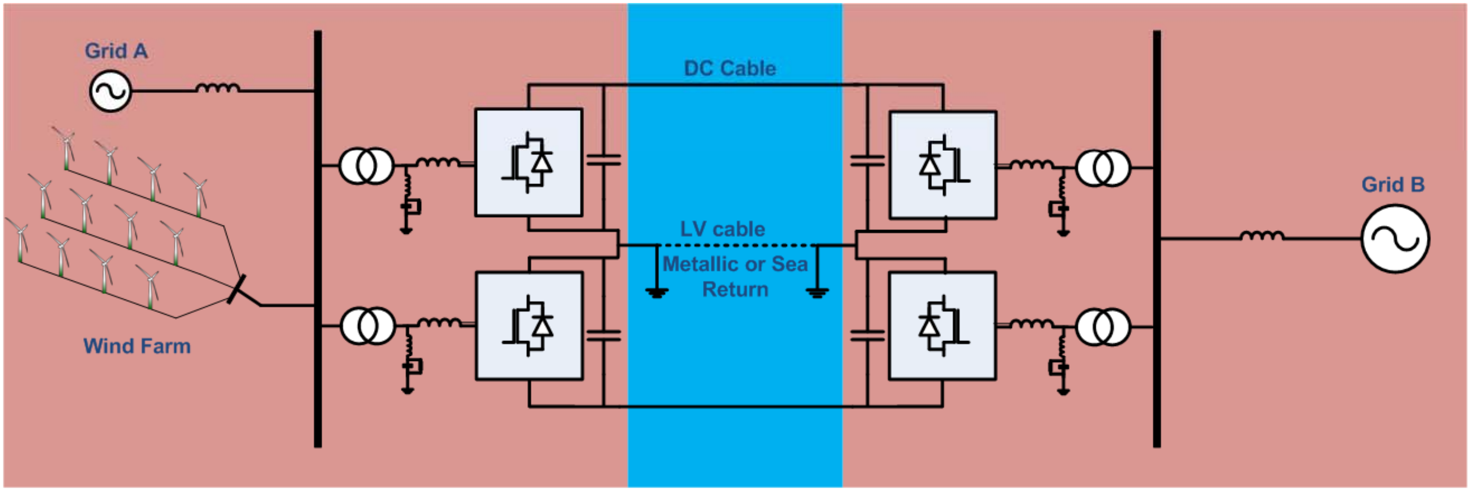
- High cost of power converters;
- Complexity of control, communications, etc.;
- Maintenance cost higher than for AC, spare parts needed;
- HVDC circuit breaker reliability issue.

HVDC Technologies

HVDC Classic – LCC Converters (bipole shown)

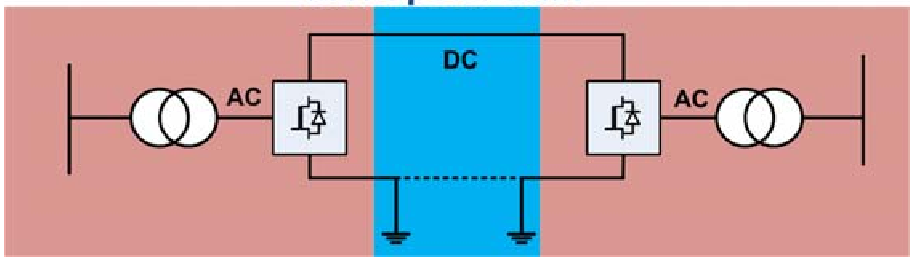


HVDC VSC Technology (bipole shown)

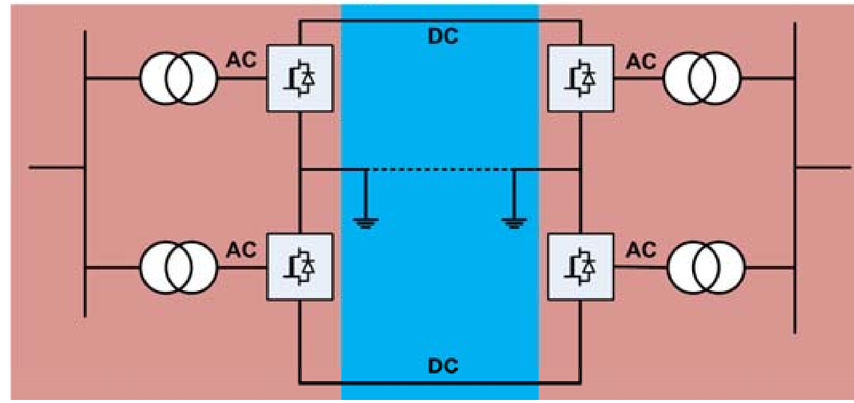


HVDC Configurations

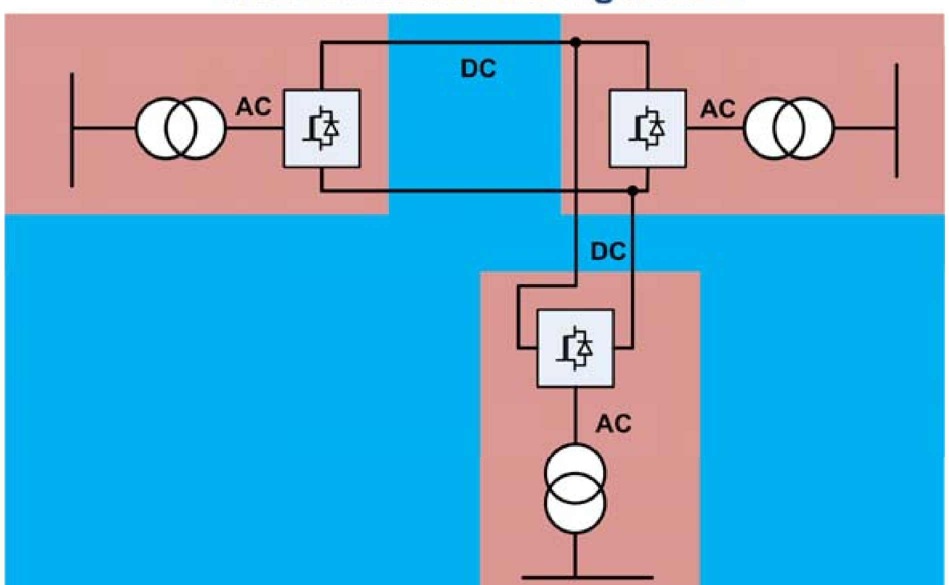
Monopolar Link



Bipolar Link



Multi-Terminal Configuration



Submarine Cables - How Deep?

- **The current experience is limited to water depths up to 1620 m;**
- **HVDC ultra-deep technology up to 2000 m possible – no experience so far;**
- **Based on published literature, 80 kVDC / 100 MW is possible even at 2200 m;**
- **Additional development and testing including full-scale sea trial is needed for higher depths.**

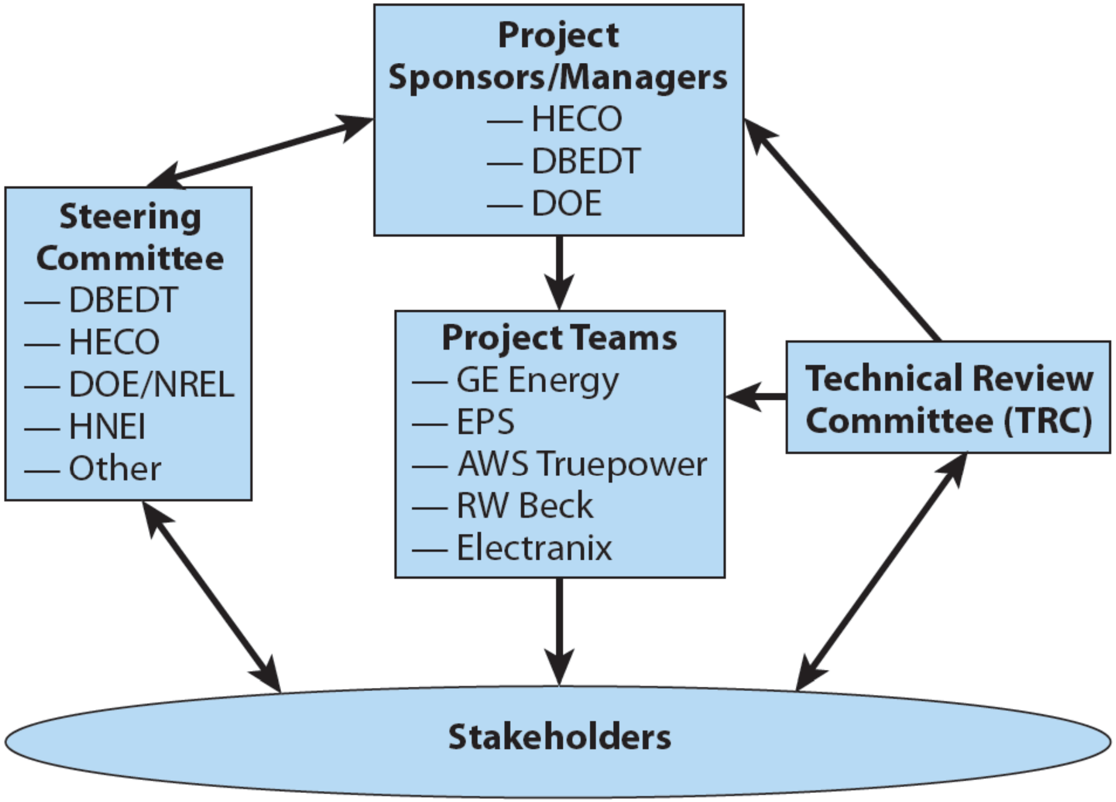
Oahu Wind Integration and Transmission Study (OWITS)

Hawaii Clean Energy Initiative (HCEI) – October 2008

- Multi-year initiative;
- 70% clean energy by 2030 (40% by renewables);
- Agreement between state of Hawaii and HECO:
  - 400 MW of wind from Lanai and/or Molokai to Oahu (Stage 1);
  - 200 MW of wind from Maui to Oahu (Stage 2).

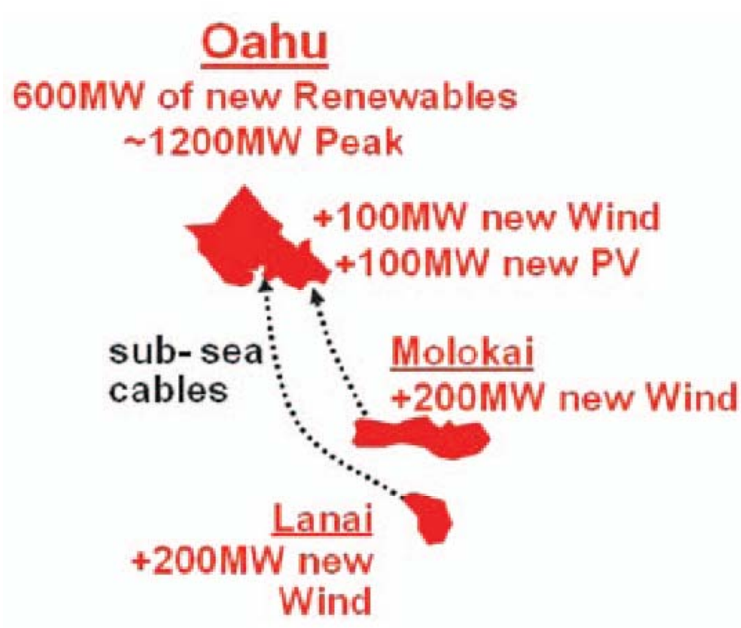
OWITS Study

- Support to HCEI and HECO;
- FY 09/10;
- TRC consists of regional, national, and international experts;
- TRC held 5 in-person meetings;
- Reviewed and provided feedback on study methods, data needs, and results.



Big Wind Scenarios for HCEI (Stage 1)

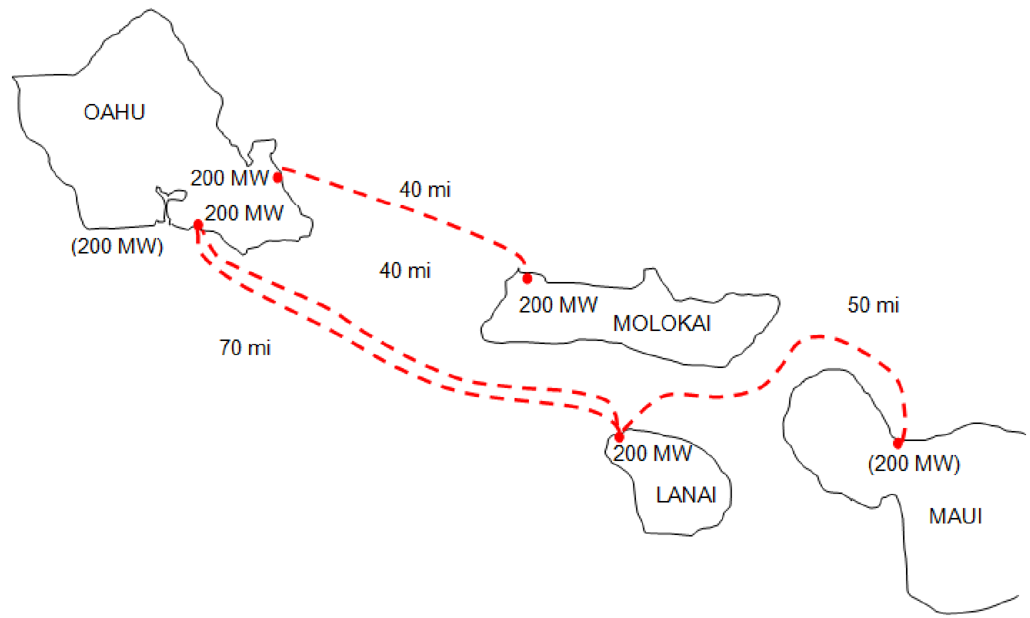
Scenario	Wind (MW)			Solar (MW)
	Oahu	Lanai	Molokai	Oahu
1. Oahu Wind	100			100
2. Off-island Wind	100		200	
3. Concentrated Wind	100	400		100
4. Oahu Solar				100
5. High Renewables	100	200	200	100

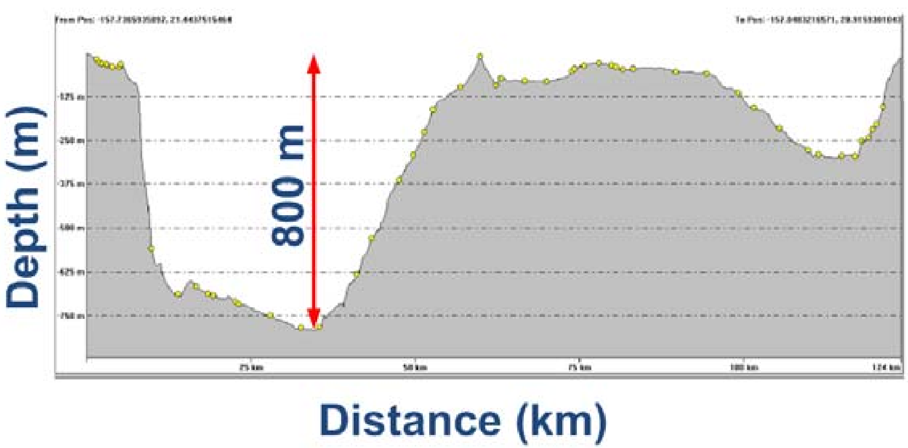


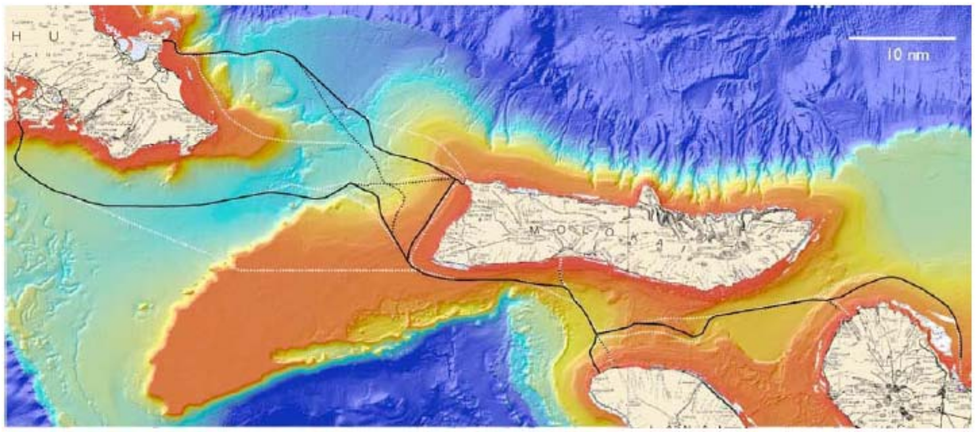
Stage 2 includes interconnection to Maui.

OWITS Cable Study Inputs

- **Potential cable landing points and inter-island routes have been identified in Ocean Floor Survey Report (DBEDT);**
- **Maximum water depth – around 800 m;**
- **Sending and receiving end voltages – 138 kV;**
- **PSSE load flow data from HECO;**
- **Contract between NREL and Electranix for transmission modeling.**







OWITS Option Screening Methodology

18 options analyzed (AC, DC, or combination of both).

Stage 1

Costs (HVAC)	Costs (HVDC)
AC Cables	DC Cables
AC substations	DC converter stations
Sea/land cable transition	Sea/land cable transition
Fixed compensation reactors	-
Other components	Other components
AC losses (20 years)	DC losses (20 years)
Total HVAC cost	*Total HVDC cost*

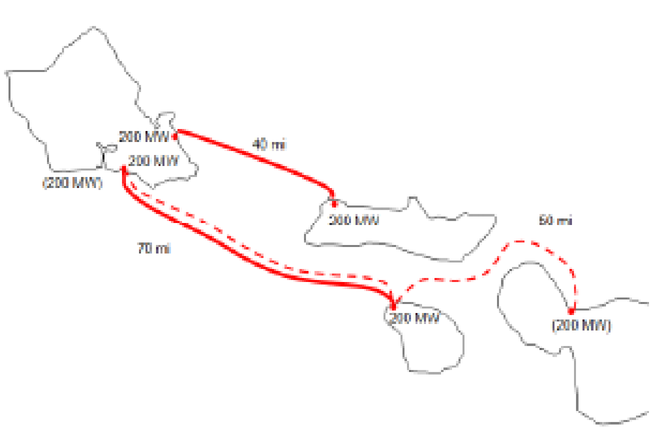
Only 6 selected for detailed simulation (AC and DC).

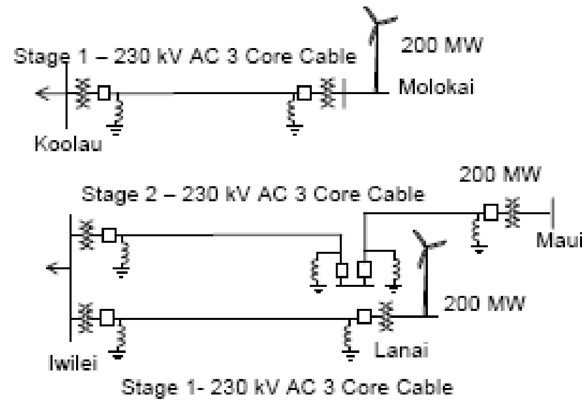
Stage 2

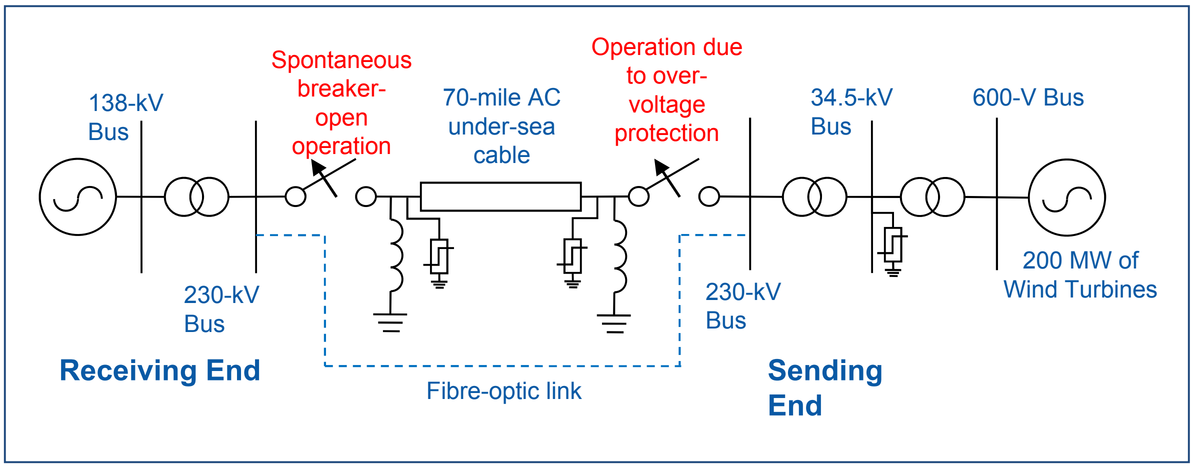
Only 3 final scenarios (including interconnections to Maui) selected for further detailed dynamic simulation.

→ RFQ

All AC Option



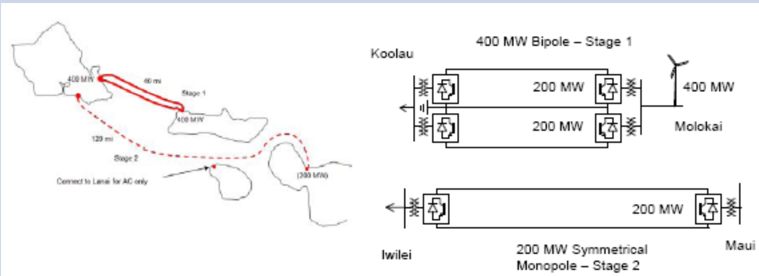




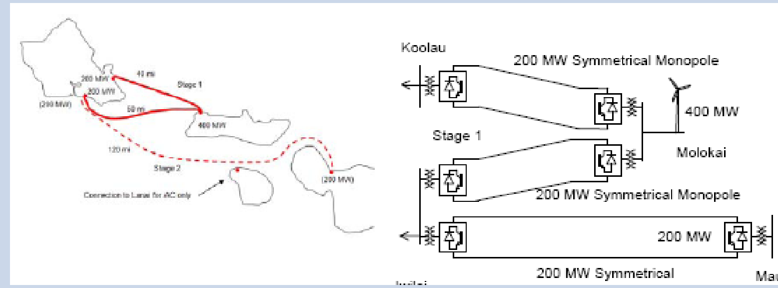
- Simulations were conducted for worst case contingencies.
- 230 kV / 3-core cable.
- AC solution will work without SVC or STATCOM enhancements (100% shunt compensation is required).
- Depths may represent challenges for 3-core AC cables.

HVDC Option

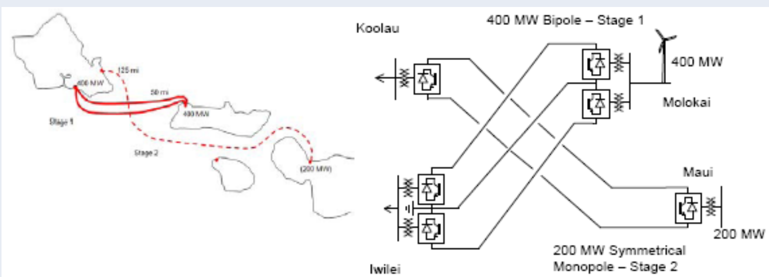
HVDC Option C3-2



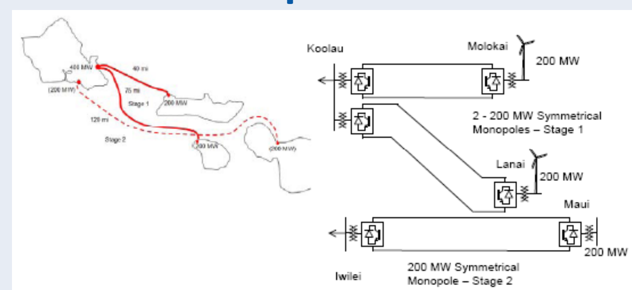
HVDC Option A3-2



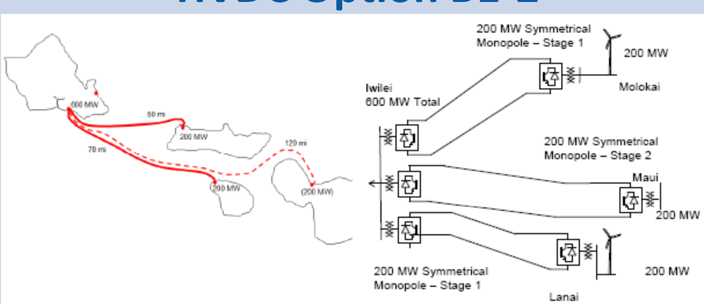
HVDC Option B3-2



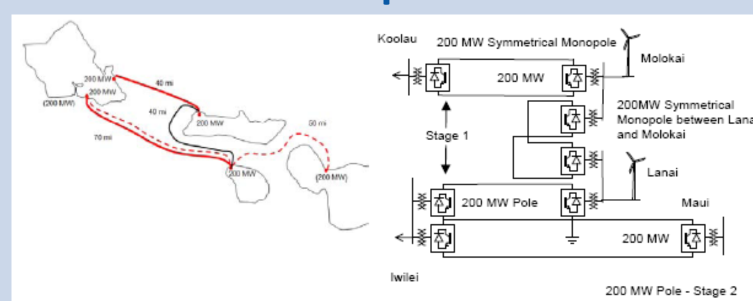
HVDC Option C1-2



HVDC Option B1-2



HVDC Option A1-2



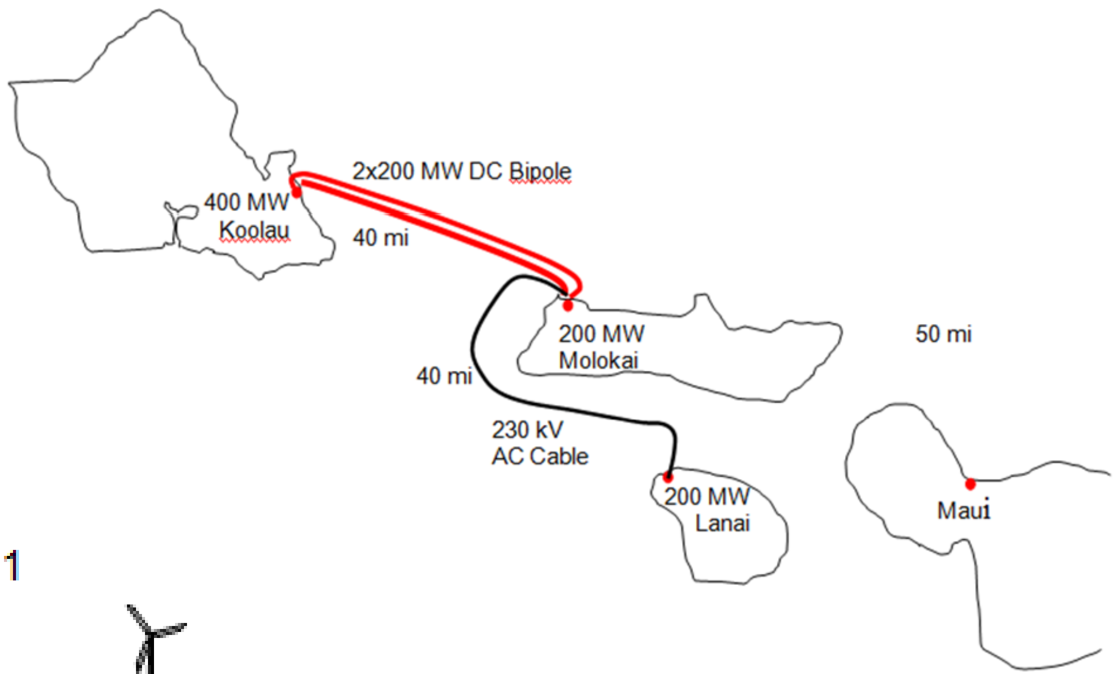
Range for Budgetary Capital costs for HVDC options (including burial and termination)

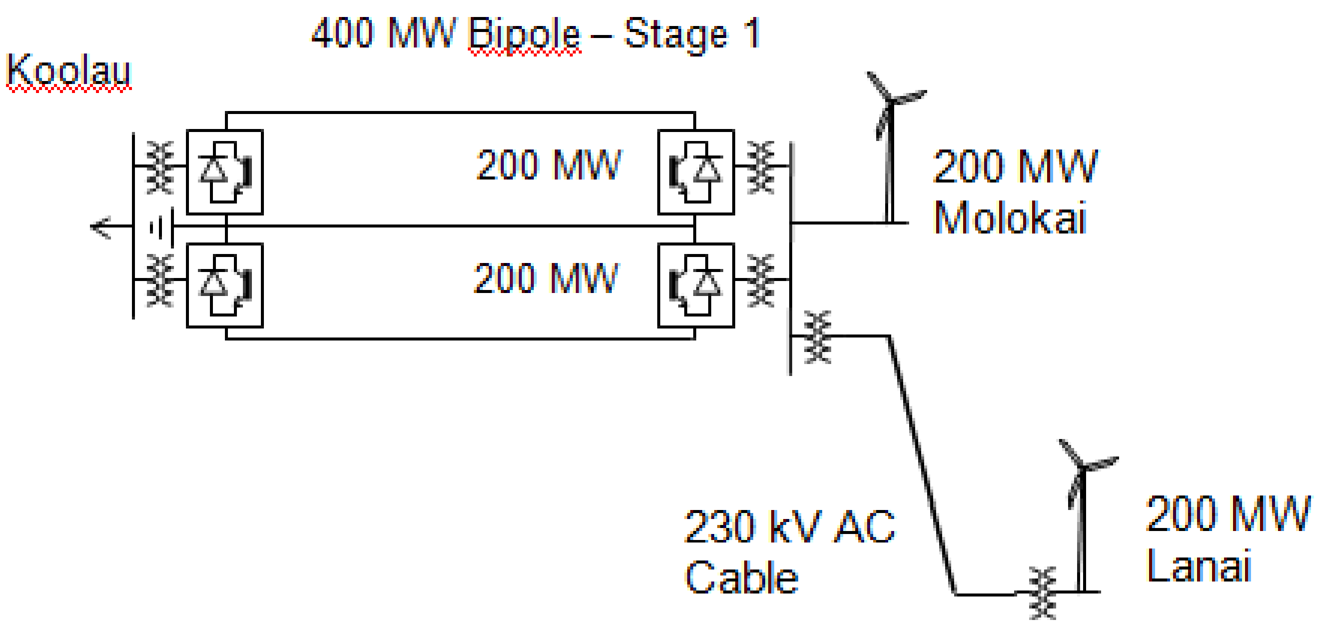
Option	C3-2	A3-2	A1-2	B3-2	C1-2	B1-2
Description	400MW Koolau to Molokai	200MW Molokai to Koolau, 200MW Molokai to Iwilei	200MW Molokai to Koolau, 200MW Lanai to Iwilei, 200MW Lanai to Molokai	400MW Molokai to Iwilei	200MW Molokai to Koolau, 200 MW Lanai to Koolau	200MW Molokai to Iwilei, 200 MW Lanai to Iwilei
Converter Stations $M	234	288	414	234	288	288
DC Cables $M	154	180	367	221	216	245
Total Stage 1 Price $M	388	468	781	455	504	533
Stage 2 Maui to Oahu (Approx)						
Converter Stations $M	144	144	117	144	144	144
DC Cables $M	420	420	192	283	272	272
Total Stage 2 Price $M	564	564	309	427	416	416
Total Stages 1 & 2 $M	951	1,032	1,090	882	920	949

Source: OWITS summary report, NREL, Nov 2010 (available at: www.nrel.gov/wind/systemsintegration/pdfs/2010/owits_summary_report.pdf)

OWITS Final Scenario 1

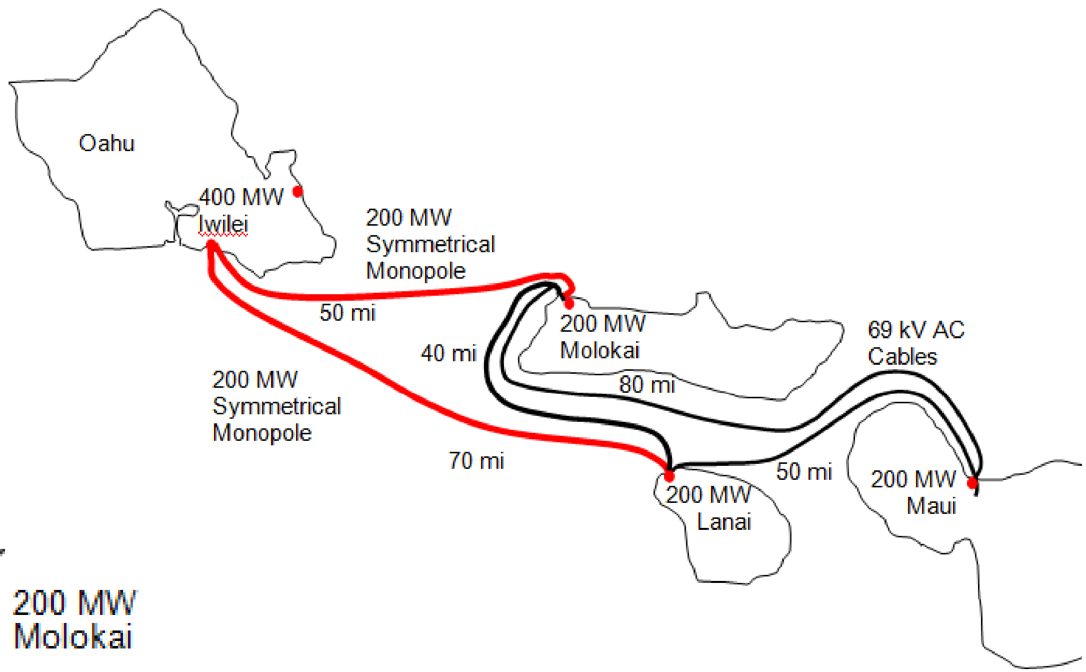
- 400-MW bipole VCS link between Molokai and Oahu.
- AC cable between Molokai and Lanai.

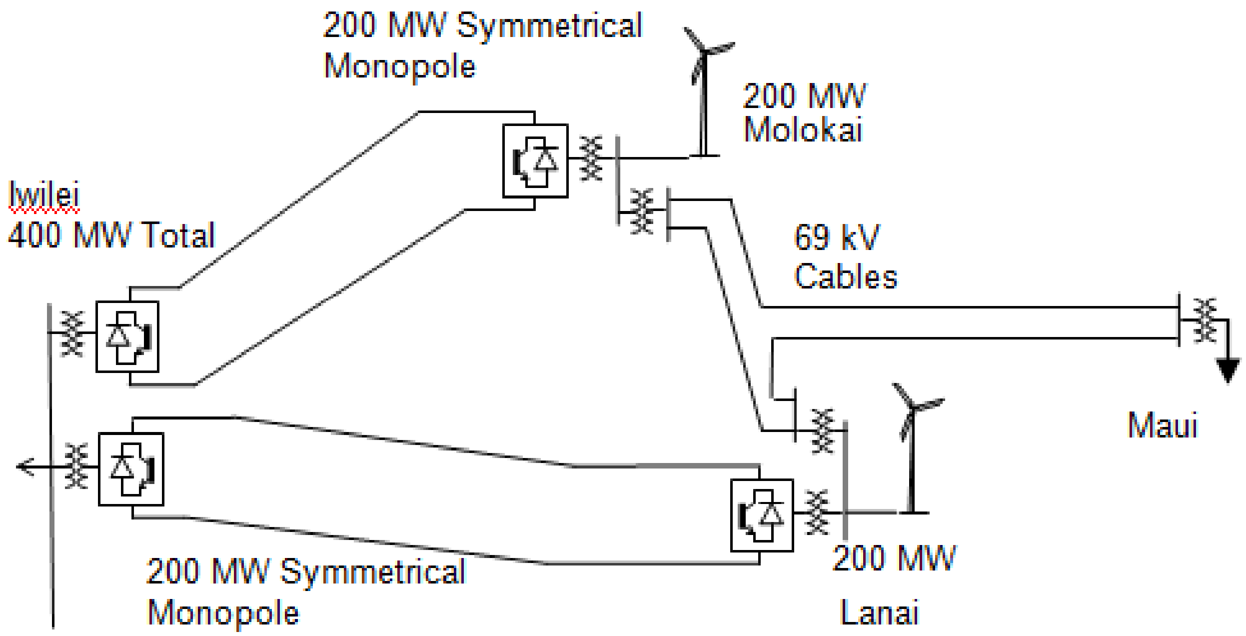




OWITS Final Scenario 2

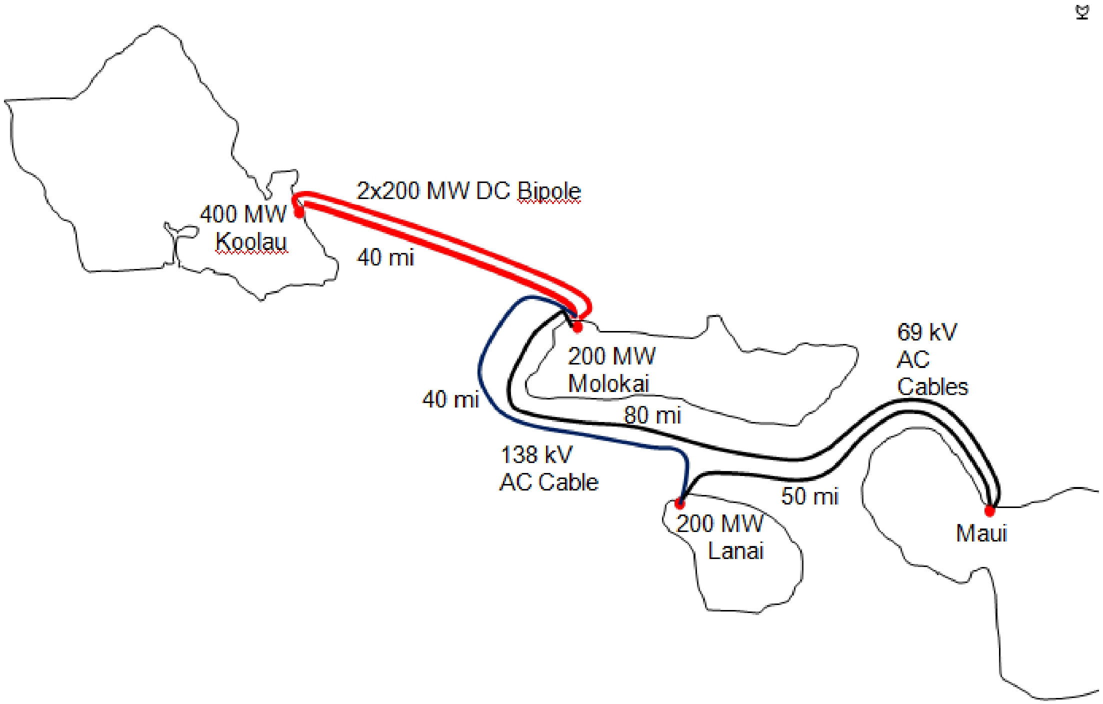
- 200-MW monopole VCS link between Molokai and Oahu.
- 200-MW monopole VCS link between Molokai and Lanai.
- AC cable between Molokai, Lanai, and Maui.

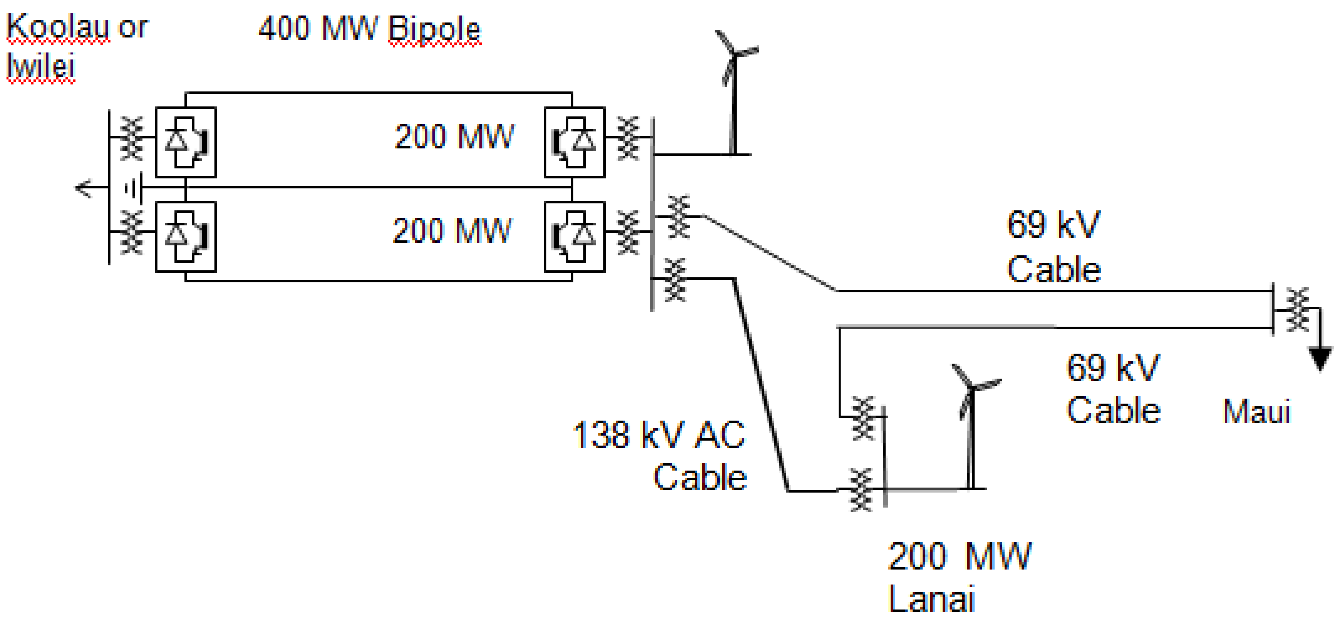




OWITS Final Scenario 3

- **400-MW bipole VCS link between Molokai and Oahu.**
- **AC cable between Molokai, Lanai, and Maui.**

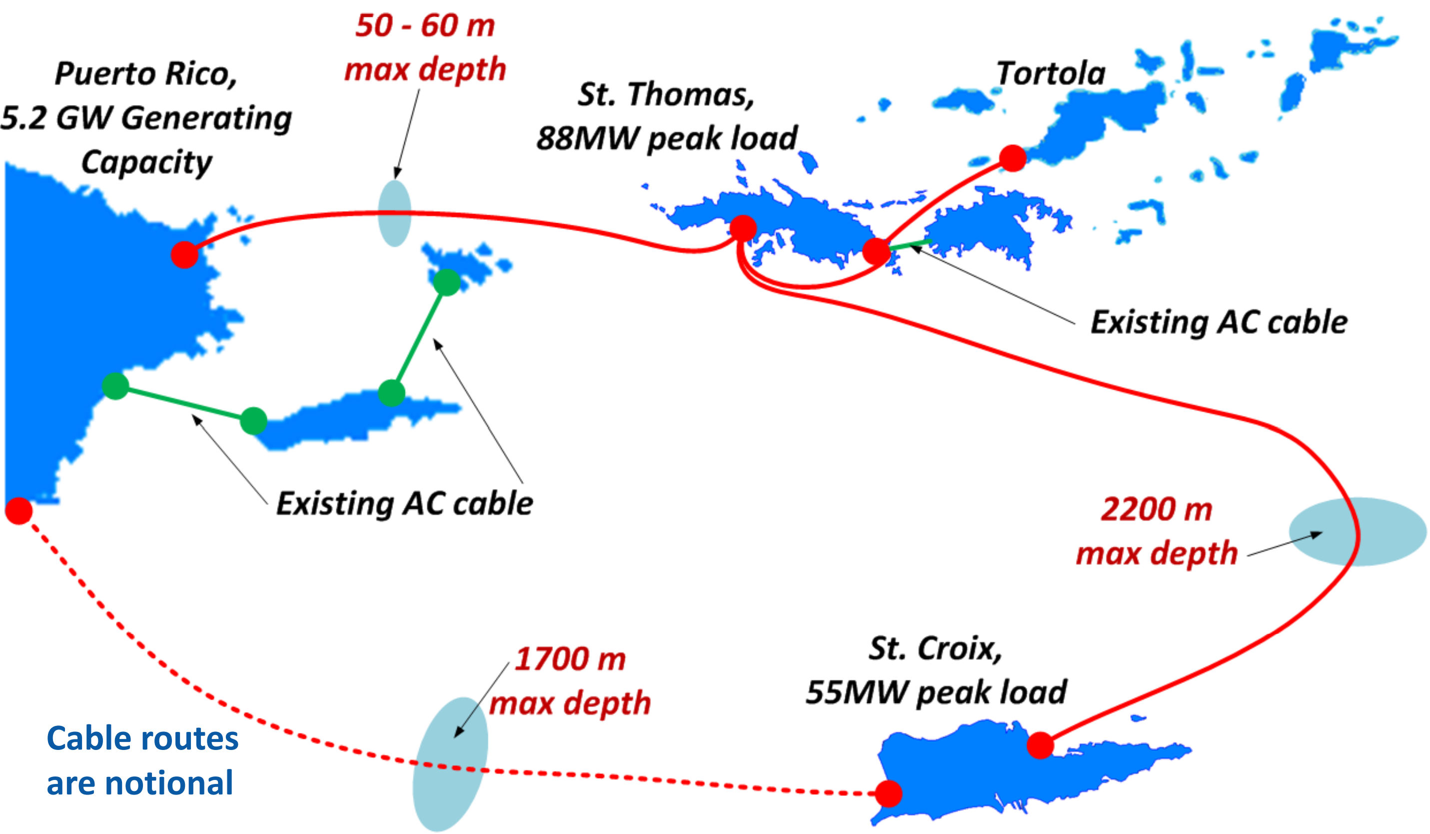




OWITS Cable Study Summary

- **Strategies were developed to enhance integration of renewables for each scenario:**
  - **Wind power forecasting to improve commitment;**
  - **Refining the up-reserve requirements by using fast start units and load control;**
  - **Reducing minimum power of the baseload units;**
  - **Seasonally cycling off some selected baseload units\Increasing the thermal unit ramp-rate capability and enhancing the droop;**
  - **Considering advanced wind turbine technologies (inertia and frequency control);**
  - **Some aspects of short term storage were examined for implementing ramp rate limits of wind plants.**
- **Adequate reserve requirements for sustained drops in wind over an hour;**
- **The largest drop in wind and solar power over 10-min. periods can be handled with future improved AGC ramp rates;**
- **Quick variations in wind and solar (1 to 5 min. time frame) might require short-term storage for up/down ramp rate limiting;**
- **Detailed transient modeling to evaluate the system's response to worst case contingences (voltage faults at different locations) was conducted;**
- **PPAs were signed between HECO and Castle & Cook ($0.11 to 0.13/kWh plus transmission costs).**

On-going Puerto Rico – USVI: BVI Interconnection Study

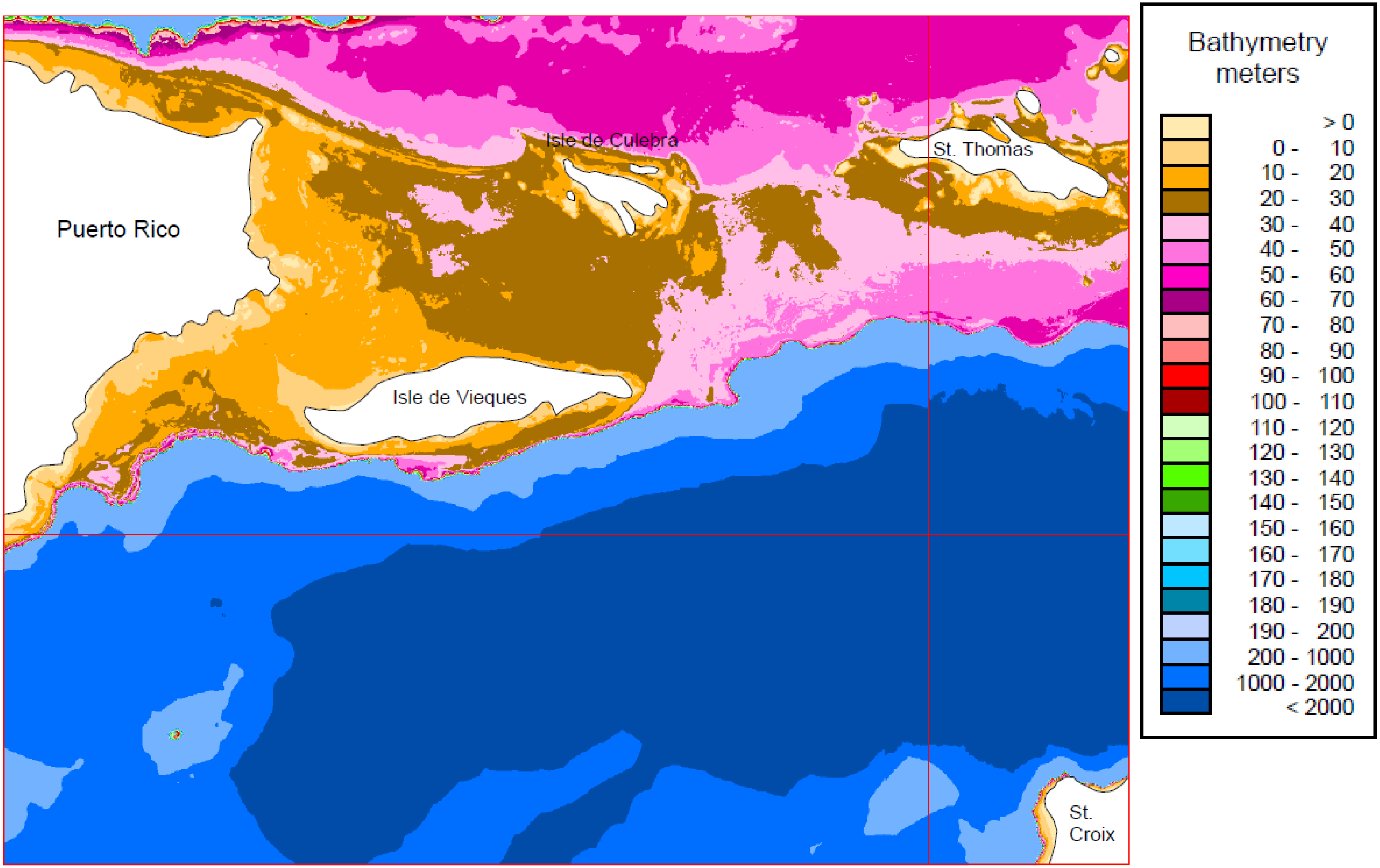


- DOE funded project
- Participants
  - NREL
  - VI WAPA
  - PREPA / IAES
  - Siemens

The study is focused on options for:

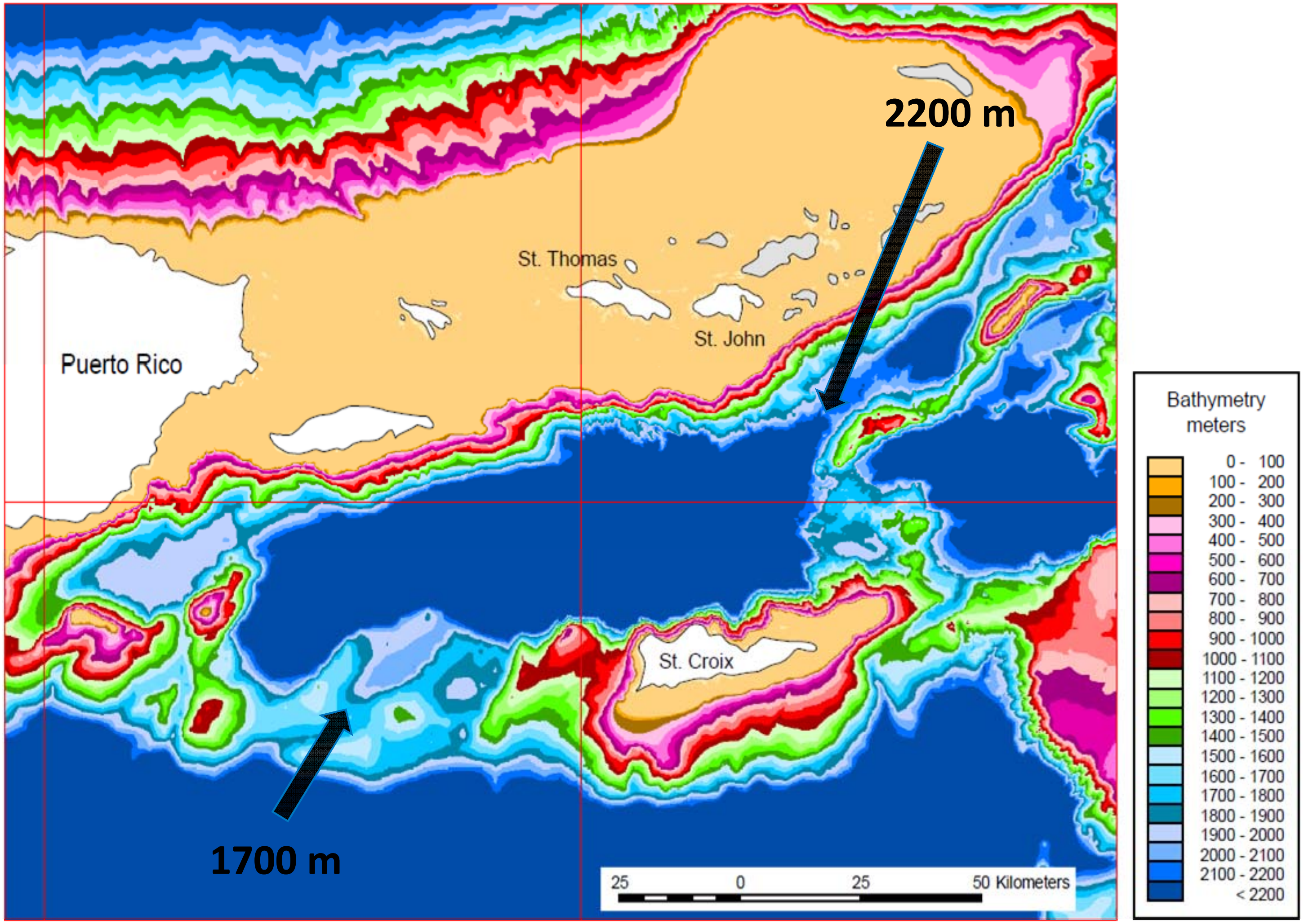
- 50-mile interconnection between PR and STT;
- 10-mile interconnection between STT and BVI;
- 80+ mile interconnection between STT and STX; or
- Direct interconnection between PR and STX as an alternative.

PR-USVI Bathymetry



NREL-developed map. Combination of 10, 30, and 100-m horizontal resolution, and based on NOAA data.

Puerto Rico – USVI Bathymetry



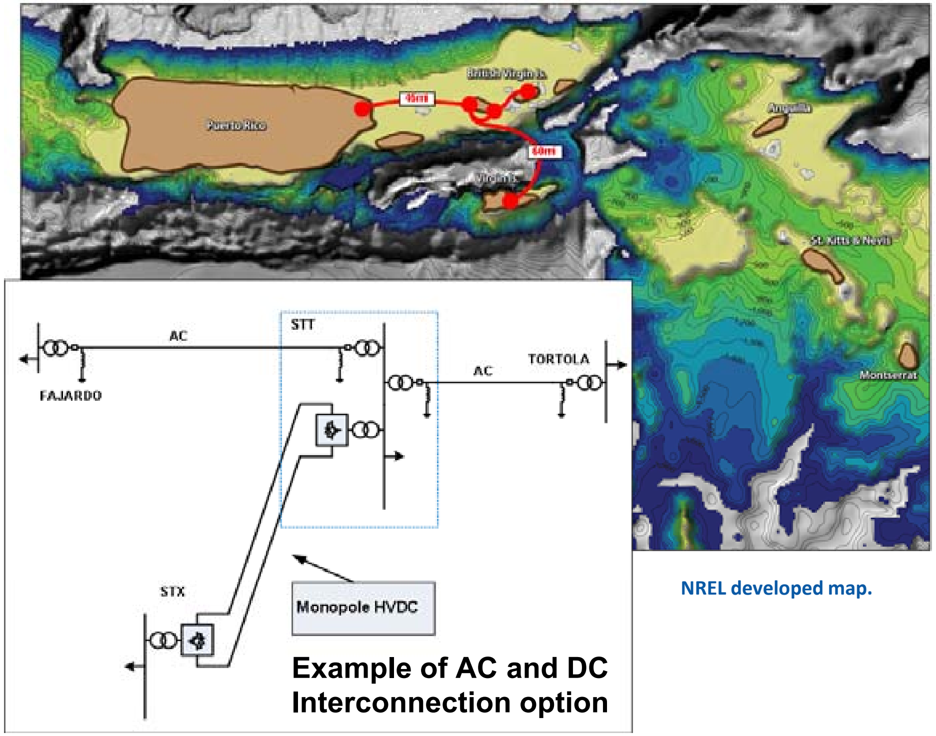
NREL-developed map. Combination of 10, 30, and 100-m horizontal resolution, and based on NOAA data.

Puerto Rico – USVI: BVI Interconnection Study Objectives

- **Determine power capacities, types, and requirements of the three interconnections;**
- **Perform power system study and identify necessary infrastructure reinforcements;**
- **Demonstrate potential benefits (generation costs, reliability, etc.);**
- **Estimate project costs.**

Project Timeline

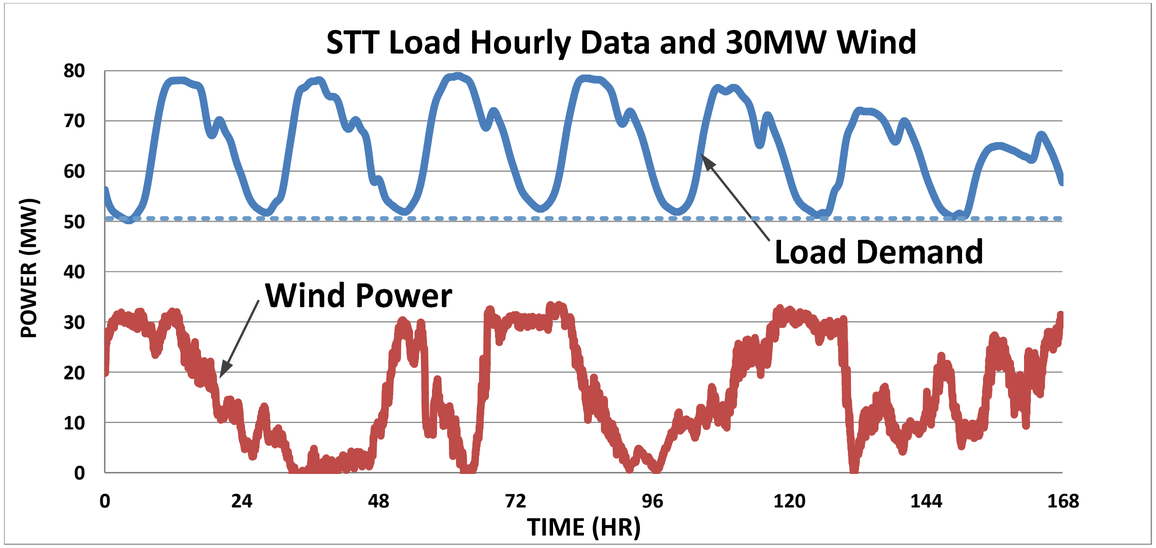
- **October 2010 – Project kickoff**
- **January 2010 – Interim report #1**
  - **HVAC/HVDC requirement**
  - **Submarine cable study**
- **April 2011 – Interim report #2**
  - **Power system study**
- **July 2011 – Final report.**

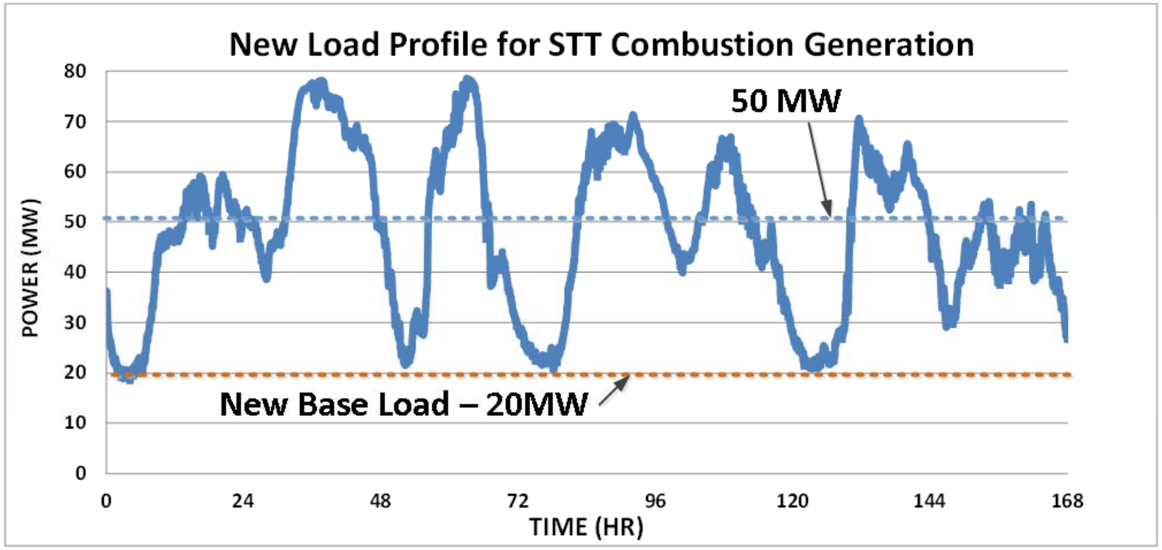


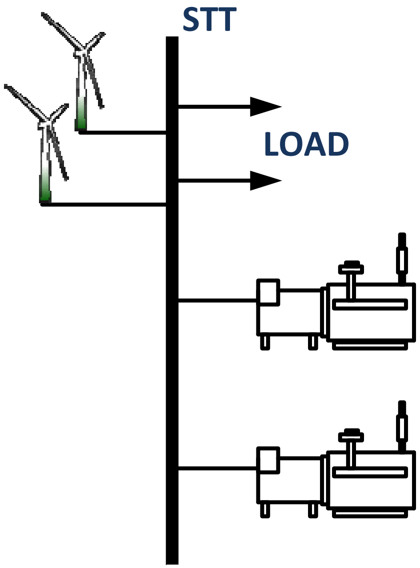
Example of AC and DC Interconnection option

NREL developed map.

Adding 30 MW of Wind (Extreme Scenario)

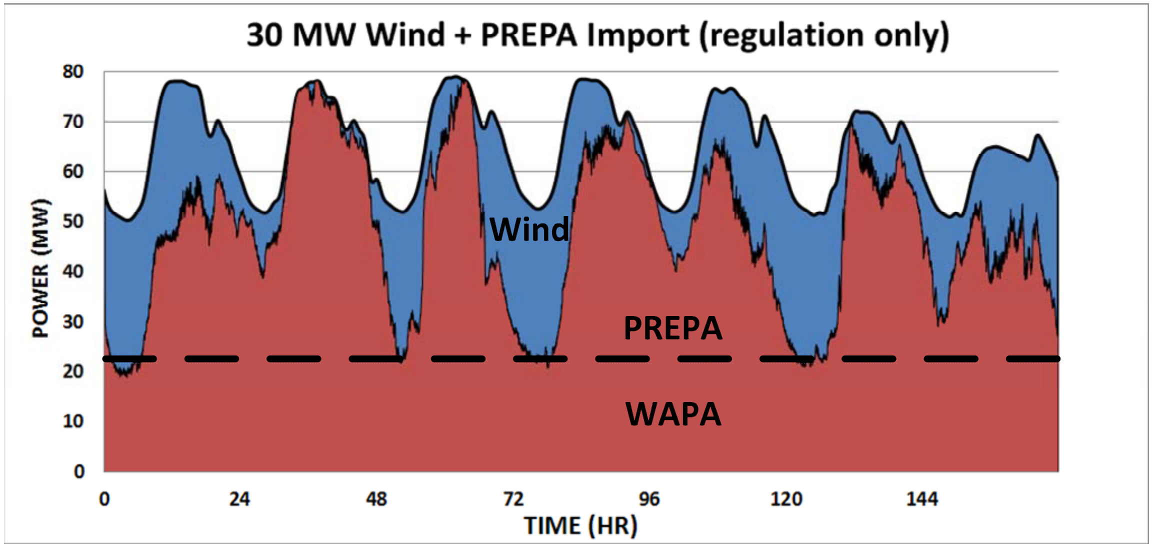


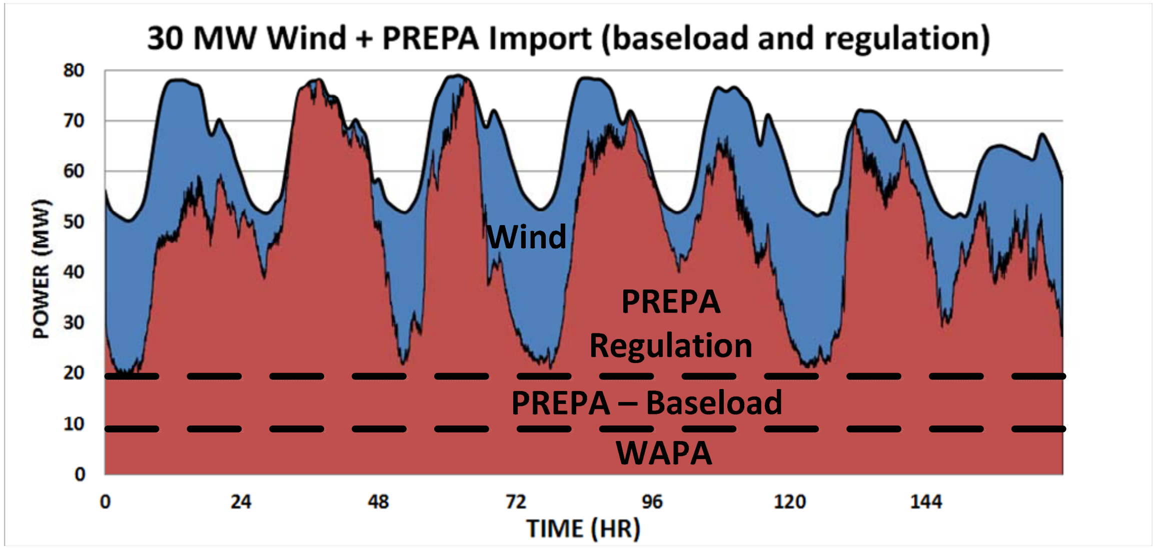


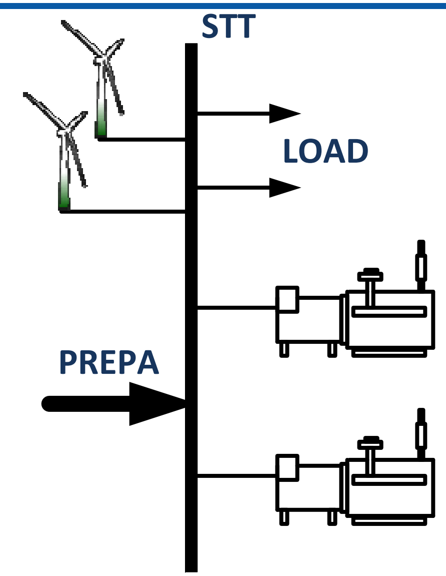


- Baseload for combustion generation reduced to 20 MW;
- 60 MW of variable load;
- No day /night peaks;
- Big change in power system operation.

How PREPA Interconnection Can Help?

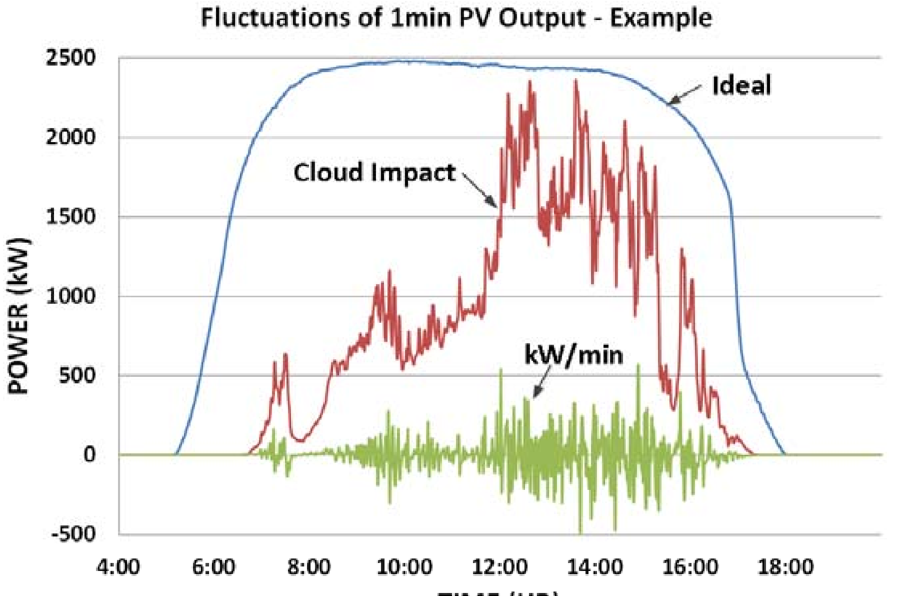






- PREPA can provide both base load and/or regulation power to WAPA.
- Different energy cost structure may be associated with each service.

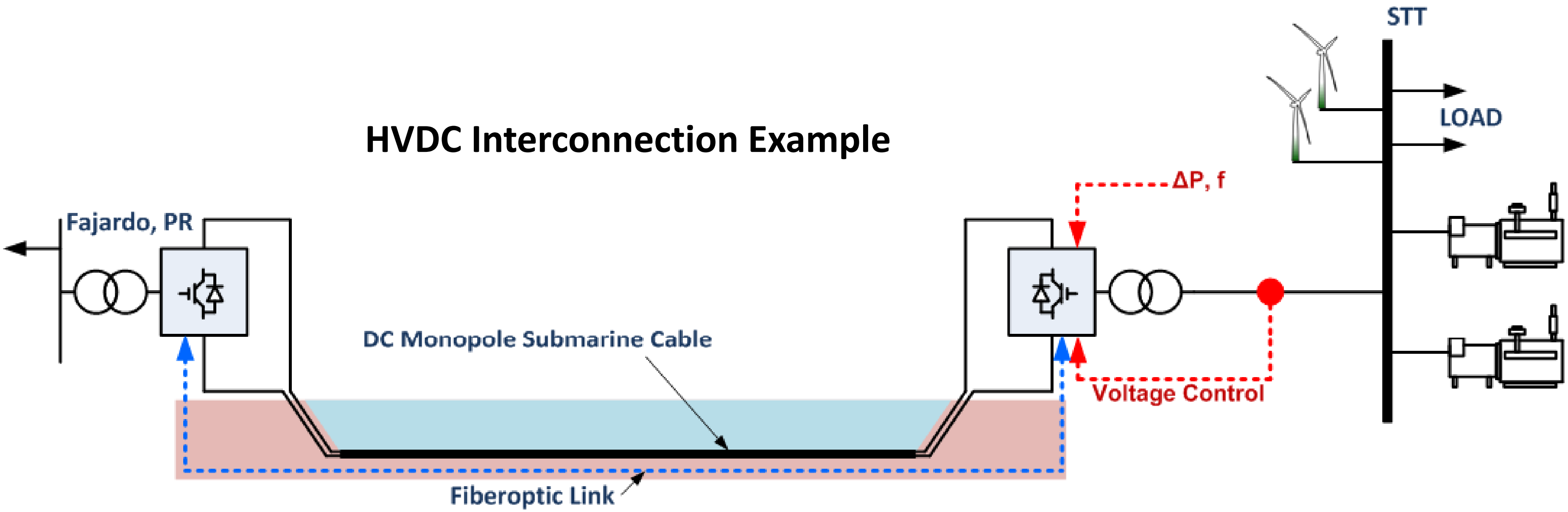
PV Variability Will Contribute to Regulation Requirements



2.5-MW PV, measured in Las Vegas, NV area *Single-axis tracking*

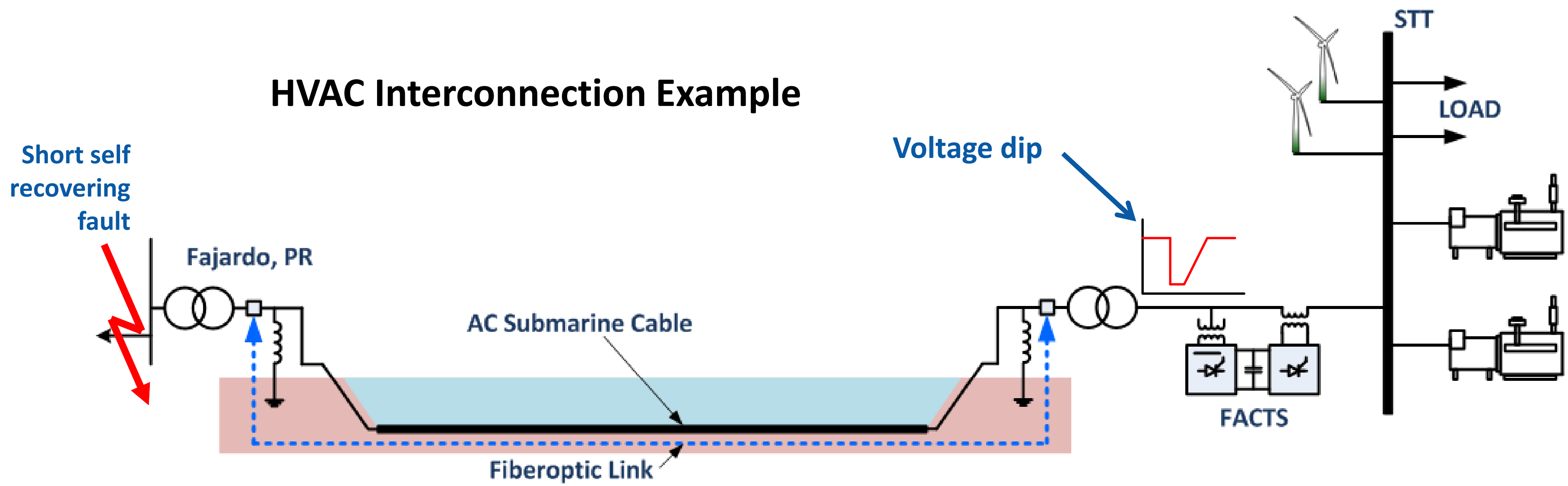
23.3MW PV in Trujillo, Extremadura, Spain (source: Suntech)

Submarine Interconnection Can Help with Fast Regulation



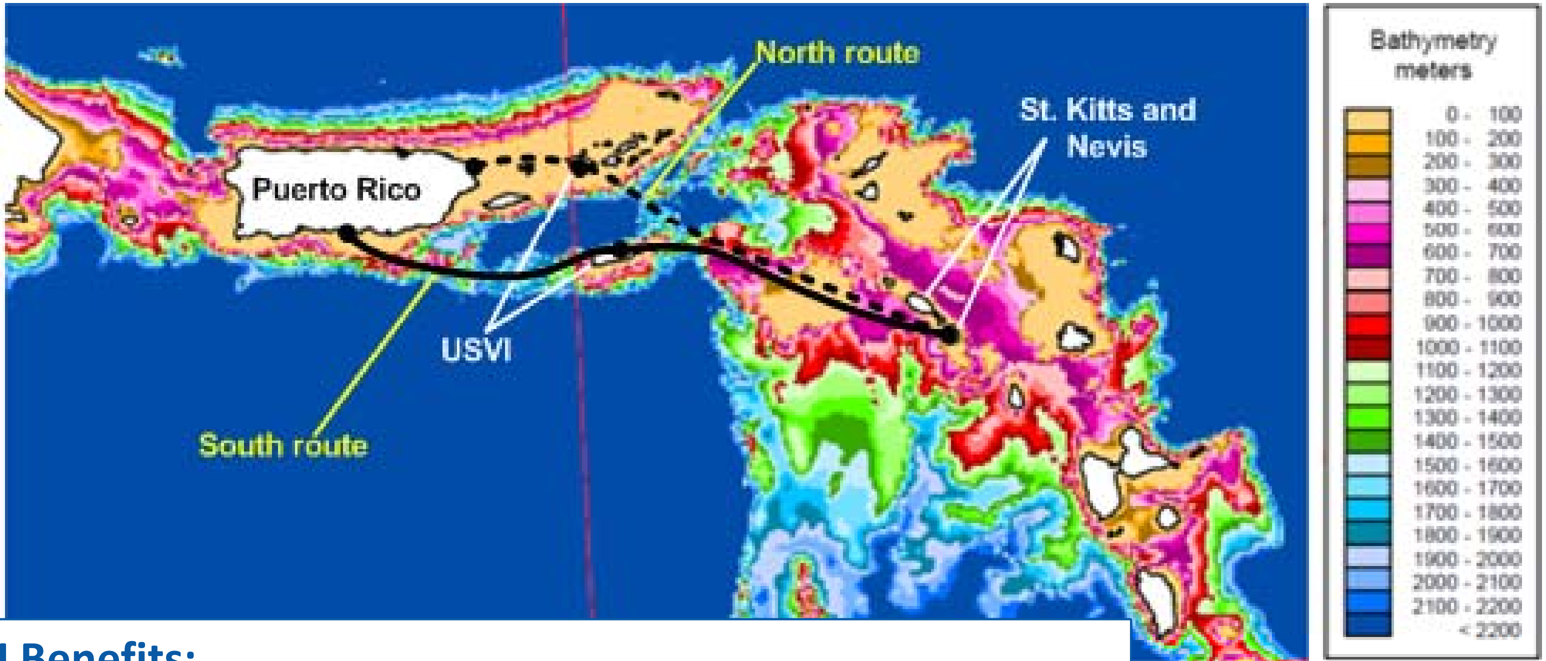
- **PREPA maintains large reserve capacity for Automatic Generation Control (AGC).**
- **Faster (sub-second) power control is possible with HVDC option (built-in feature).**
- **Voltage control simultaneous with power control.**

Interconnection & Variable Generation – Possible Contingencies



- Short self-recovering faults will create voltage dips in WAPA system (AC link);
- May be a serious reliability issue during times of large power imports;
- Wind power low voltage ride-through (LVRT) capability is essential for reliable operation;
- Overall LVRT capability of WAPA system can be improved by FACTS in case of HVAC interconnection;
- Modeling is necessary for various contingency scenarios, target penetration levels and wind turbine topologies, etc.

Larger Regional Interconnection



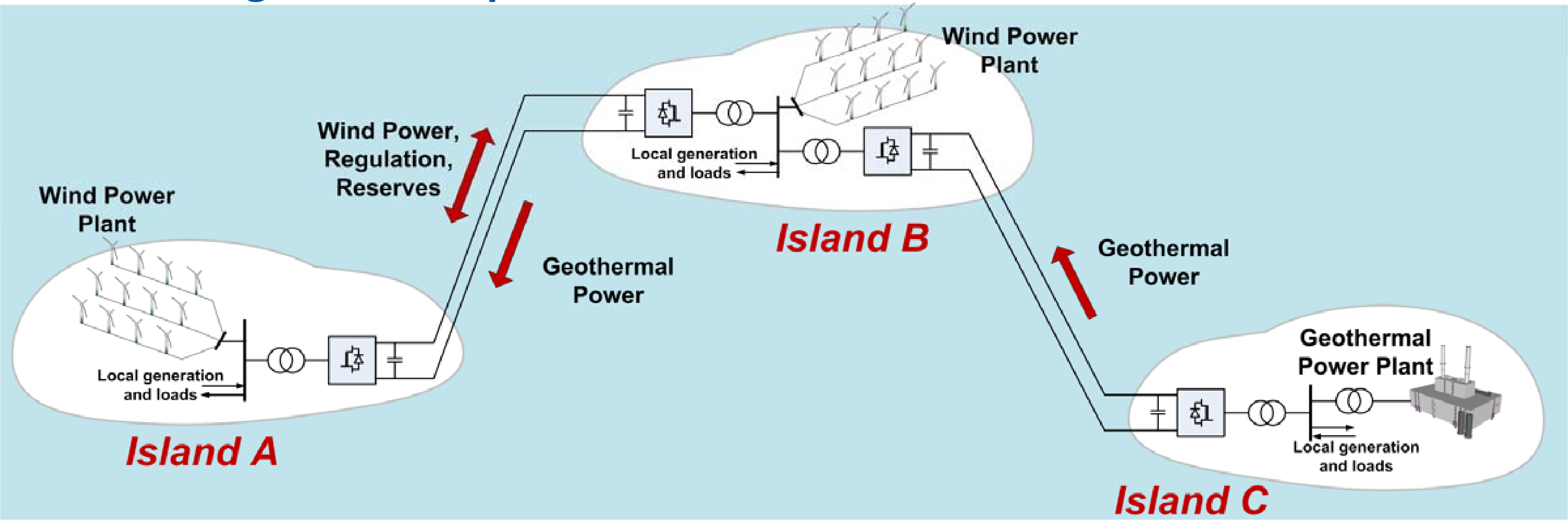
USVI Benefits:

- **Diversified supply of energy;**
- **Clean baseload geothermal power from St. Kitts/Nevis;**
- **LNG-generated power from PR;**
- **Higher reliability;**
- **Lower energy costs.**

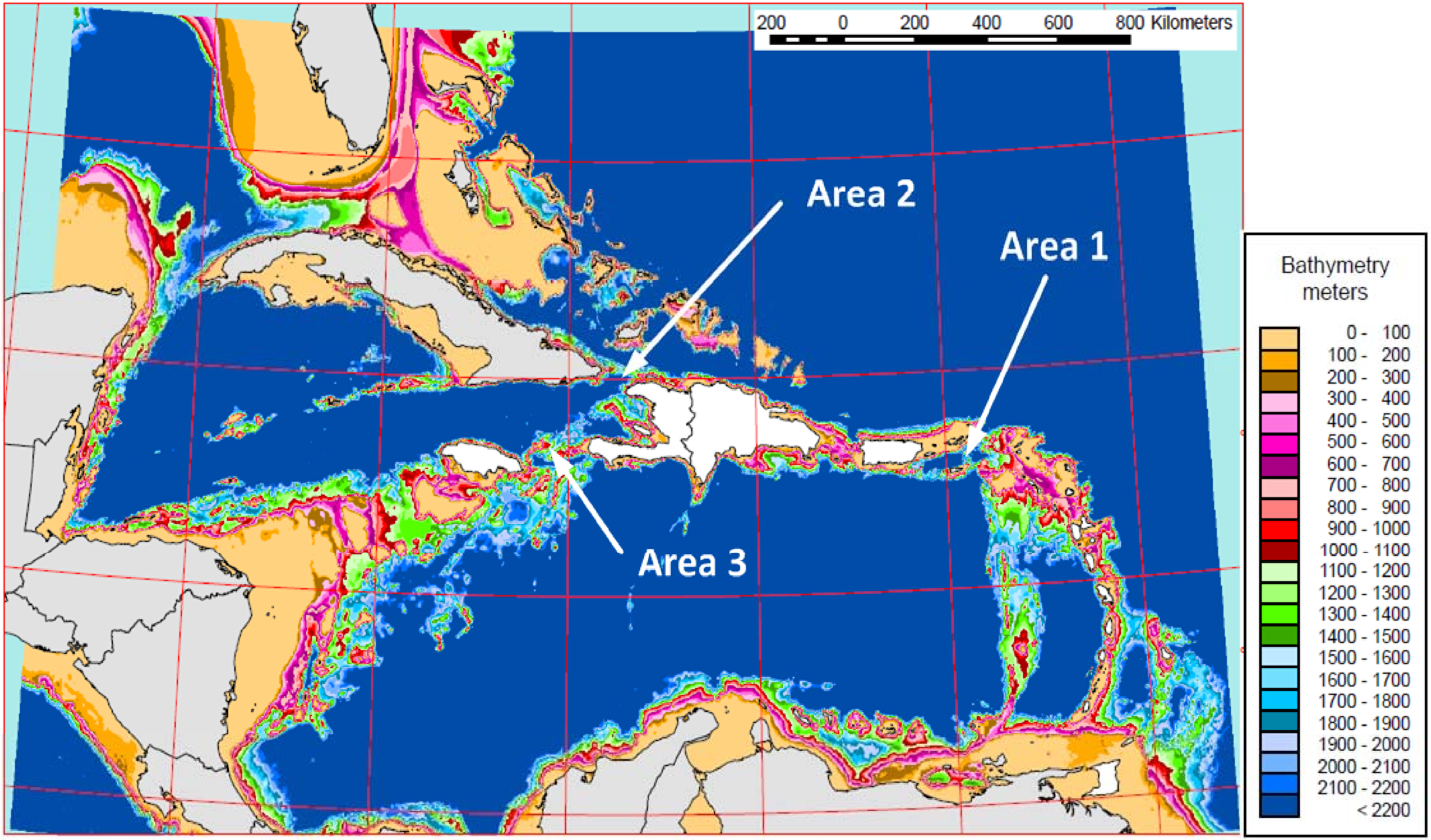
NREL developed map.
Cable routes are notional.

Caribbean Power Interconnection and Renewable Energy

- The energy solutions for the Caribbean region include new fuels (e.g., LNG), new energy resources, and electrical interconnections between islands;
- Geothermal power is considered as a main driver for the interconnection;
- Caribbean wind energy (estimated at 3.7 GW) as a driver for interconnection?
- Variability of wind power represents significant challenges compared to baseload geothermal power.



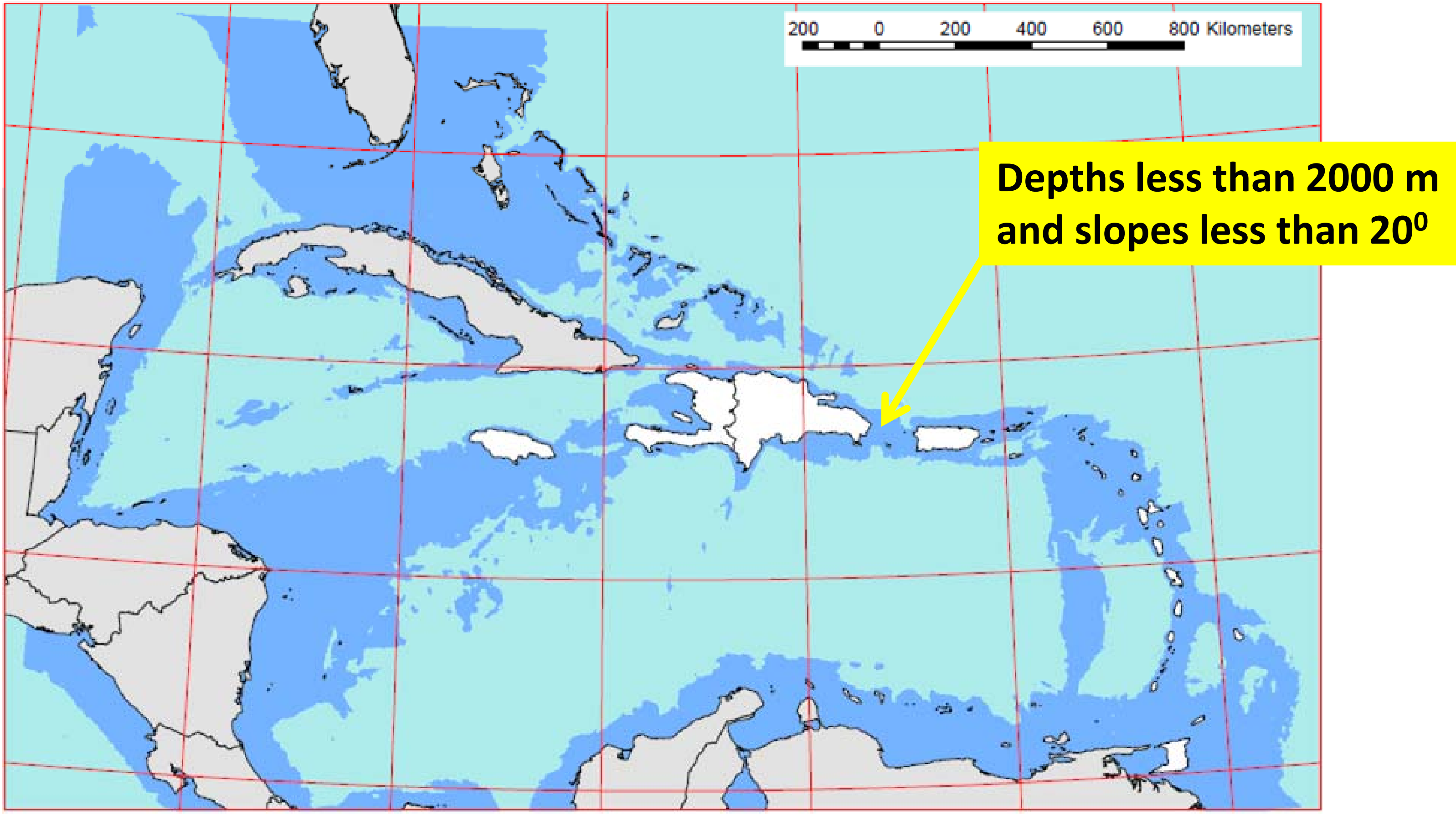
Caribbean Bathymetry



NREL-developed map , 1-km horizontal resolution, based on GEBCO data.

Areas 1, 2, and 3 – may have gaps deeper than 1650 m.

Caribbean Bathymetry and Slopes



NREL-developed map , 1-km horizontal resolution, based on GEBCO data.

Potential Benefits of Regional Interconnections in Caribbean

- Deliver lower cost electrical power from the island (or country) that has such power to an island (or country) that does not;
- Possibility of transmitting large amounts of electrical energy generated by renewable sources;
- Increased reliability, reduced spinning reserve requirements, and shared frequency regulation without adding new generation;
- Increase the potential for high-penetration variable renewable generation;
- Reduce dependence on high price imported oil and increase high level utilization of renewable energy sources on the regional level;
- Integrating fiber-optic communication cables.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Thank you !