SAARC ENERGY CENTRE
Energy for Peace & Prosperity

Online training of SAARC Professionals on Small, Mini and Micro Hydro Power Generation (Sept 13 - 17, 2021)

Hybridization with SMMHP plants

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LECTURE CONTENT

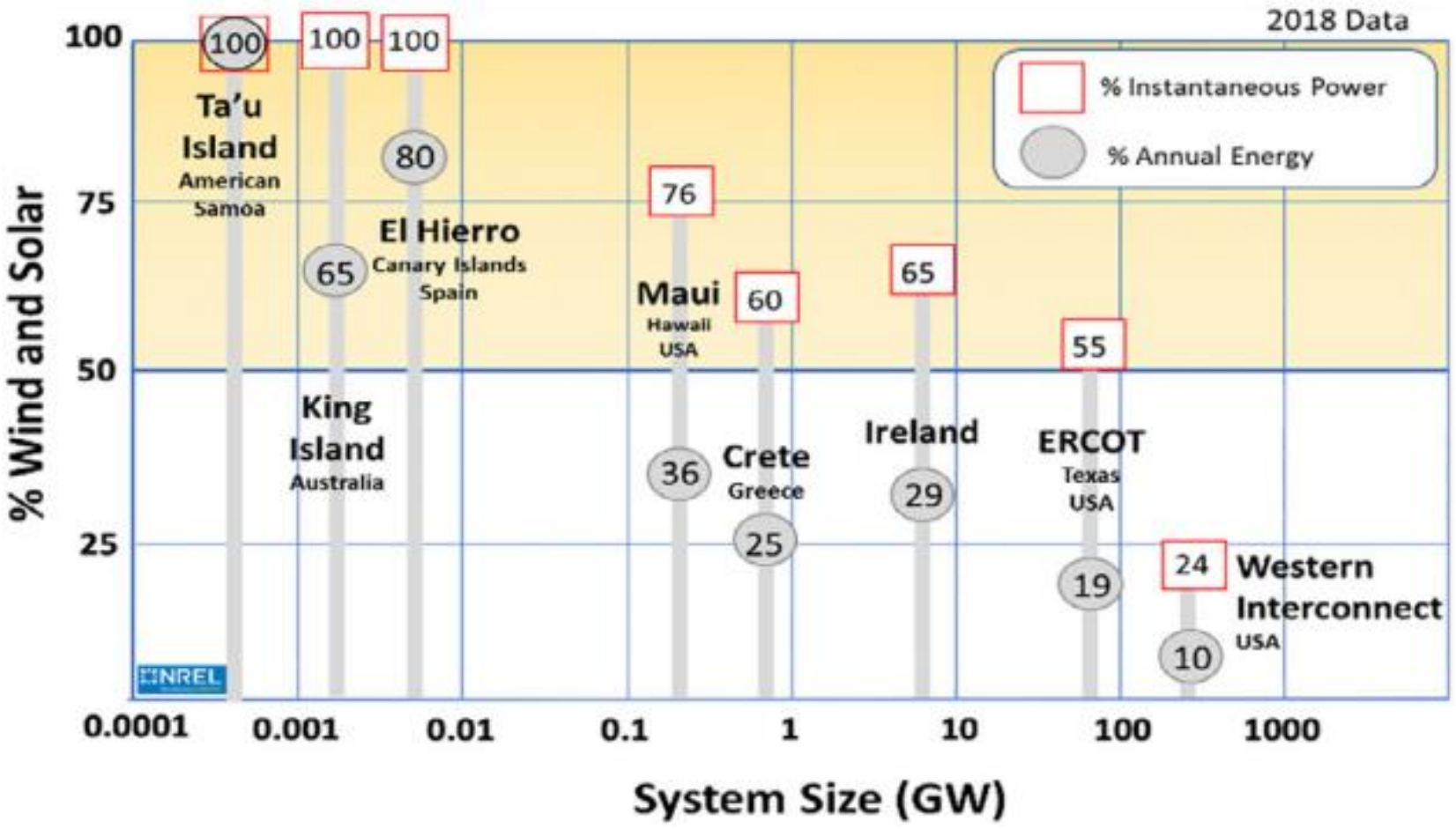
- What are Hybrid Power Plants?
- Reasons for Interest in Hybrid Power Plants
- Hybrid Power Plant Classification
- Examples of Hybrid Power Plants w/ and w/o SMMHP
- Conclusion

DEFINITION

- **Hybrid Power Plant** – When two or more generation resources are operated as a single generation asset
  - Solar PV with DC-coupled battery storage is not a hybrid resource as per this definition
  - Solar PV and Battery with own inverters but controlled as one asset is a hybrid plant
- Generation assets comprising a hybrid plant may be co-located, or remotely located creating a “virtual” hybrid plant

- For small, off-grid power systems a hybrid power plant may include all generation assets available in the system
  - A lot of research has been done on optimal operation of such off-grid hybrid energy systems
- Hybrid power plants for grid-connected systems is a new development

Reasons for Interest in Hybrid Power Plants – Increasing Variable Renewable Generation



Source: BMS Hodge, H. Jain, et al., "*Addressing technical challenges in 100% variable inverter-based renewable energy power systems*", in WIREs Energy and Environment, 2020

REASONS FOR INTEREST IN HYBRID POWER PLANTS – BETTER ECONOMICS

- Hybridization can help variable renewable power plants to:
  - extend duration of plant operation (e.g., solar PV + wind)
  - bid in capacity markets,
  - provide ancillary services, and
  - provide blackstart and restoration support

CLASSIFYING HYBRID POWER PLANTS

- By resources
  - solar PV + wind
  - solar PV + wind + storage
  - SMMHP + storage
  - SMMHP + solar + storage
  - SMMHP + biomass-based generation
- Hybrid power plants include at least one variable, renewable resource

CLASSIFYING HYBRID POWER PLANTS

- By generation technology
  - Inverter-based generators only (e.g., solar and battery)
  - Inverter-based and synchronous generators (e.g., SMMHP and storage)
  - Synchronous generators only (e.g., SMMHP and biomass-based generators)
- Control strategies differ depending on the technologies used in hybridization

RUN-OF-THE-RIVER AND STORAGE HYBRIDIZATION RESEARCH

- Research performed over the last 5 years by the National Renewable Energy Laboratory and the Idaho National Laboratory of the United States
- Motivation – Improve dispatchability of run-of-the-river hydro power plants in the US (nearly 50% of all hydro power plants in the US)
- Several aspects were considered in this project including:

- Technical and financial feasibility of hybridizing run-of-the-river plants with energy storage
- Development of a controller to coordinate operation of multiple plants and energy storage assets
- Simulation of the hybrid system in Conventional Hydropower Energy and Environmental Systems (CHEERS) model
- Simulation case studies with data from four run-of-the-river plants coupled with battery, supercapacitor, and flywheel storage
- Ongoing field test for blackstart using run-of-the-river and supercapacitors-based hybrid plant

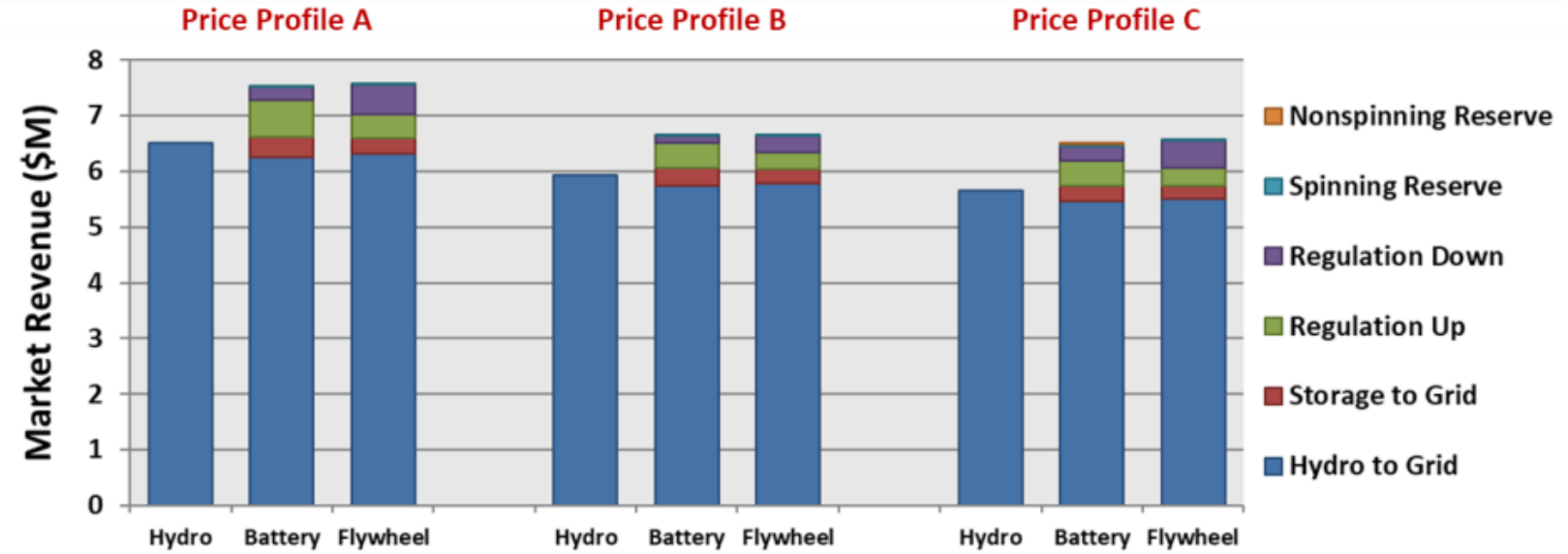
Source: US Department of Energy - https://www.energy.gov/eere/water/articles/integration-run-river-hydropower-energy-storage-creates-additional-grid-value

RUN-OF-THE-RIVER AND STORAGE HYBRIDIZATION RESEARCH

Revenue increases due to energy storage

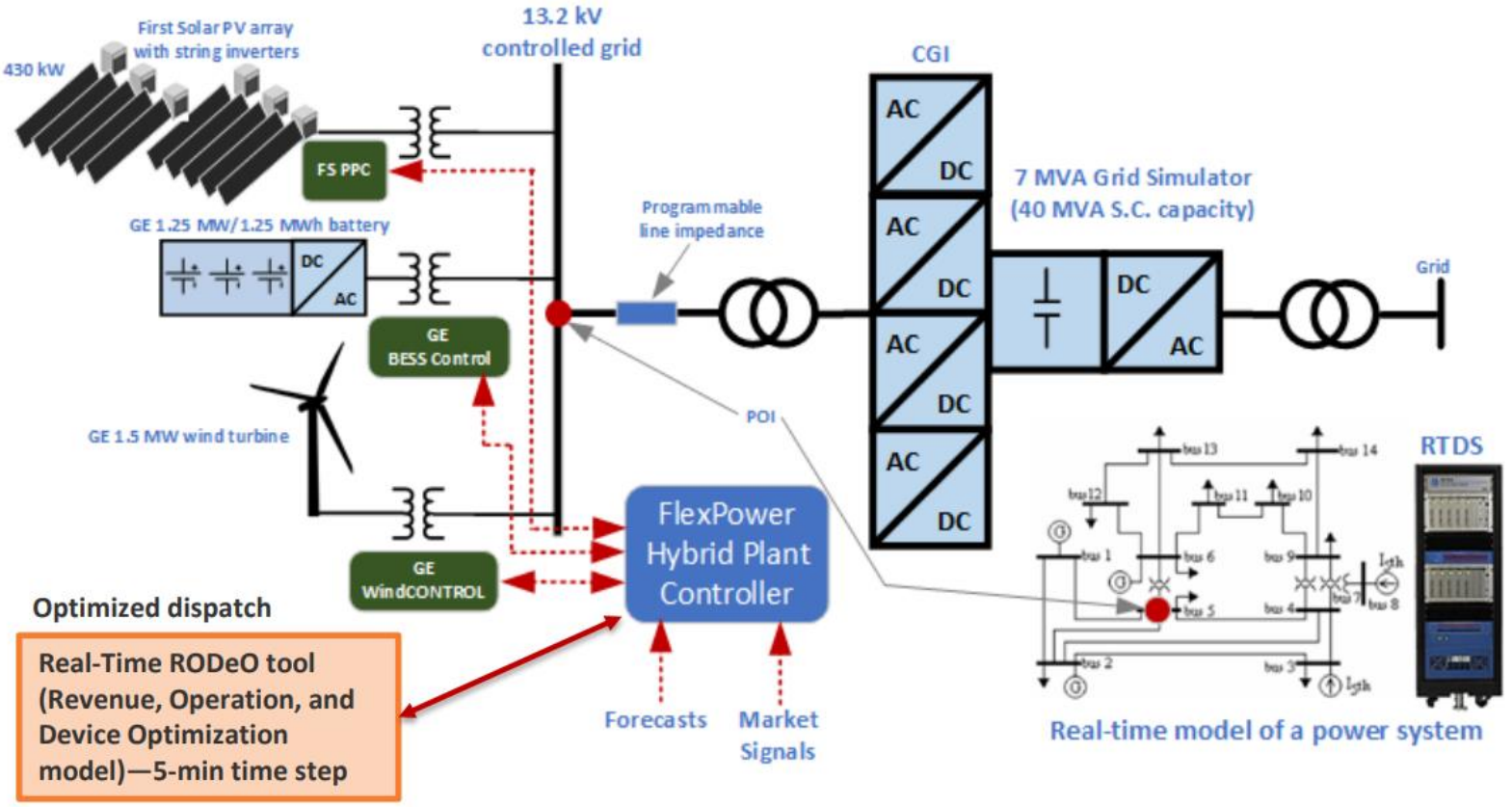
Battery storage: +12.2% to +15.8%

Flywheel: +12.0% to +16.3%



Source: US Department of Energy (https://www.energy.gov/sites/prod/files/2019/07/f64/Integrated-5June2019%20%28002%29.pdf)

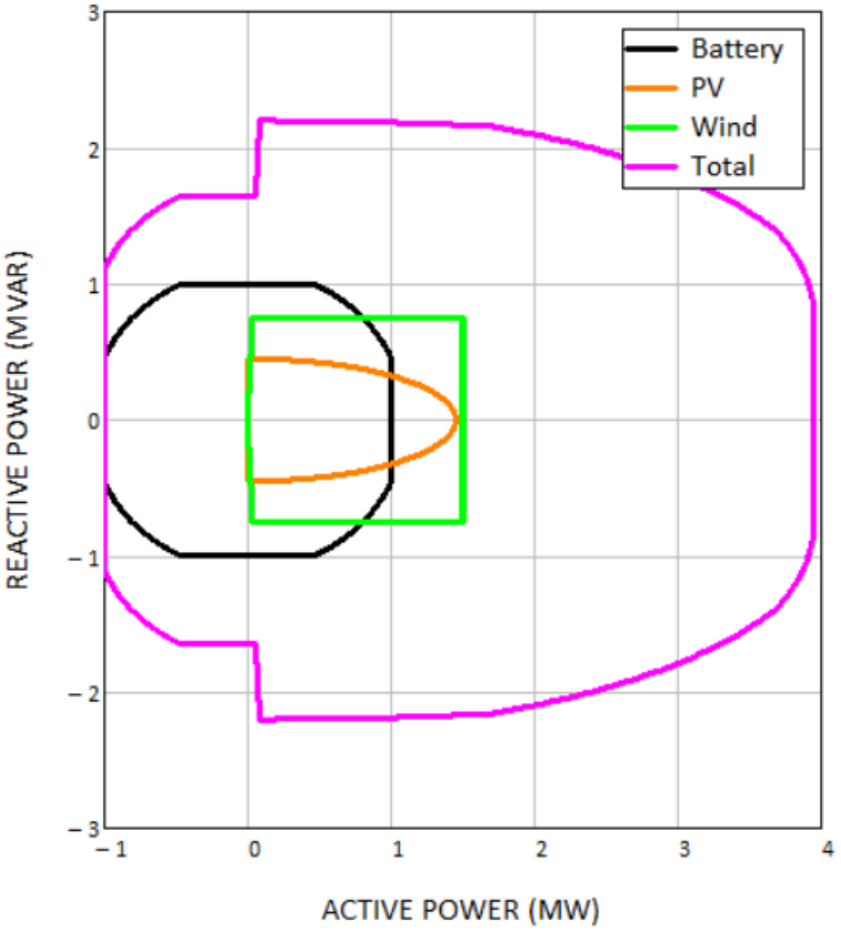
EXAMPLE OF AN ALL INVERTER-BASED HYBRID PLANT EXPERIMENTAL SETUP



Source: Gevorgian, Vahan, Rajni Burra, and Mahesh Morjaria. 2018. "Hybrid Utility-Scale PV-Wind Storage Plants for Dispatchability and Reliability Services." Golden, Colorado: National Renewable Energy Laboratory. NREL/PR-5D00-71551. https://www.nrel.gov/docs/fy18osti/71551.pdf.

BETTER P-Q CAPABILITIES W/ HYBRID POWER PLANT

1.5 MW wind, 1.5 MW solar PV and 1 MW Battery Storage Hybrid Power Plant



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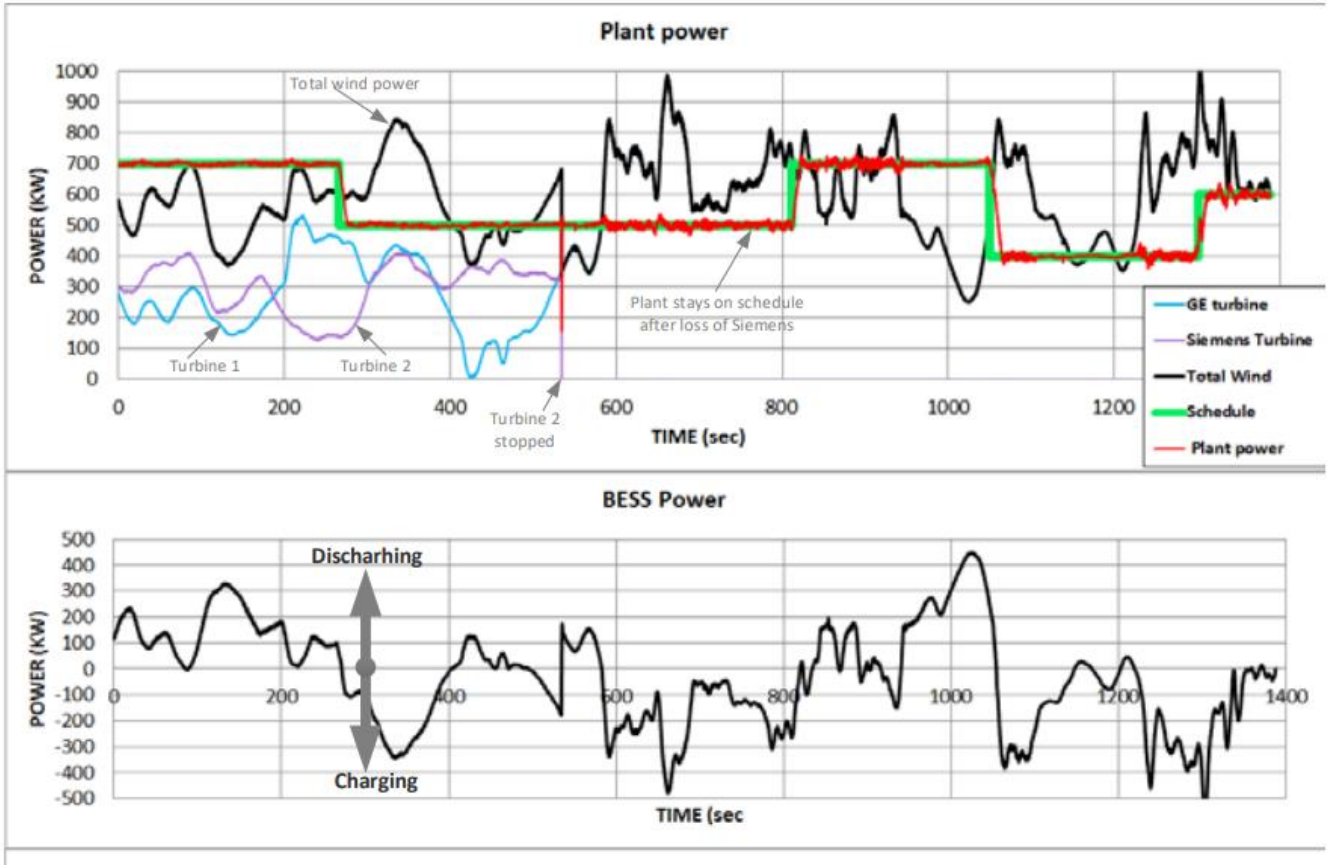
BETTER DISPATCHABILITY OF HYBRID POWER PLANT

Wind power plant becomes dispatchable with hybridization



Source: Gevorgian, Vahan, Rajni Burra, and Mahesh Morjaria. 2018. "Hybrid Utility-Scale PV-Wind Storage Plants for Dispatchability and Reliability Services." Golden, Colorado: National Renewable Energy Laboratory. NREL/PR-5D00-71551. https://www.nrel.gov/docs/fy18osti/71551.pdf.

SYNCHRONOUS VS INVERTER-BASED GENERATION

- It is important to understand how synchronous and inverter-based generation differs because that can influence our technology selection for hybrid plants
- **Synchronous Generators**
  - Operational experience of several decades
  - Natural inertia
  - High short-circuit current
- **Inverter-based Generators**
  - Relatively recent technology
  - No natural inertia
  - Low short-circuit current
  - Very fast response compared to synchronous generators

Best of both worlds if hybridized

SMMHP + solar + storage can be a promising hybridization approach

STEPS FOR DEVELOPING HYBRID POWER PLANTS

- **Selecting hybridization technologies**
  - E.g., what other technology can be combined with a SMMHP plant to achieve a certain reliability metric in an off-grid power system?
  - Selection can be done using software such as Homer and ReOpt.
- **Design and optimization of plant**
  - E.g., how should the hybrid plant design be to reduce shading on solar PV plant from wind turbines?

- **Operation and control of hybrid plants**
  - These considerations should be made at multiple timescales (e.g., inertia to minutes-level energy balancing)
- Excellent reference on hybrid plants – Katherine Dykes *et al*. 2020. "*Opportunities for Research and Development of Hybrid Power Plants*." Golden, Colorado: National Renewable Energy Laboratory. NREL/TP-5000-75026. https://www.nrel.gov/docs/fy20osti/75026.pdf

LOOKING FORWARD

- Immense interest in hybridization, particularly for solar PV and storage
- Hybridization is a promising opportunity for SMMHP plants as well
  - SMMHP plants and inverter-based generators can mutually benefit from hybridization
- Some questions that must be answered:

- Is suitable terrain available for SMMHP hybridization with say solar and storage? Should "virtual" hybrid plants be pursued?
- What is the financial viability of such projects in SAARC's context?
- Are policies and regulations in place to encourage hybridization?

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Thank you