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Wave Energy Integration in Future Power Systems

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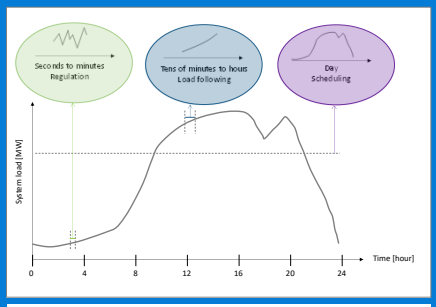
INTRODUCTION

- Wave energy converters (WECs) can be expected to provide grid support services in future power systems.
  - especially to contribute to active power balance.
- High levels of variable renewable energy (VRE), e.g., wind power, have posed many challenges in power system operation.
- The lessons learned through these challenges can anticipate future requirements for wave power integration.
  - Recent regulations have adopted more stringent requirements for VRE interconnection and developed new services for fast support.
  - In some networks, wind farms should provide grid support to ensure the security of supply, e.g., through frequency control and reactive power provision.
  - Such services were mainly provided by conventional synchronous generation in the past.

MAIN CHALLENGES WITH HIGH LEVELS OF VRE ON POWER SYSTEM OPERATION

- The electrical voltage and frequency of ac power systems must be kept within nominal values and allowed deviations.
  - Stable and reliable operation.
- Main technical challenges come from
  - the need to keep balance between generation and load demand at all timescales.



Generic daily load curve in a power system [1].

- The main challenges are associated with:

a) Reduced rotational inertia in the system.
  - Grid interconection of VRE generation is based on power electronic interfaces, which do not *naturally* add rotational inertia as synchronous generation.
  - The system is subjected to larger frequency deviations.

b) Variability and

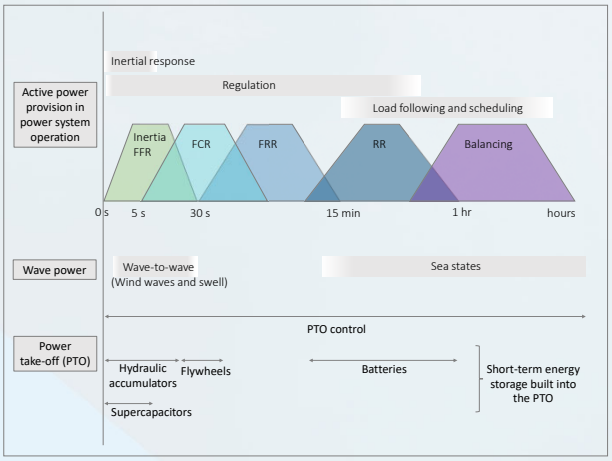
c) Uncertainty of the output power.

WAVE FARMS AND FREQUENCY SUPPORT

Service name	Acronym	Short description
Synthetic inertia	--	MW delivered within milliseconds after power imbalance events to support low inertia systems
Fast frequency reserve	FFR	MW delivered faster than FCRs to support low inertia systems
Frequency containment reserve	FCR	MW delivered through automatic control loop a few seconds after power imbalance events
Frequency restoration reserve	FRR	MW delivered through automatic control loop (or manual activation) within 30 seconds to 15 minutes after power imbalance events
Replacement reserve	RR	MW delivered through manual activation within 15 minutes up to hours after power imbalance events

Frequency support services in power systems.

- *Following the qualification process from the Irish grid operators [2], WECs have not yet demonstrated capabilities to provide frequency support to power grids.*
- *Wind power plants have proven capabilities for contributing to frequency support services on time scales from 2 s to 5 min [2].*
- *Provision of frequency support requires the availability of power reserves and a proper control system to modify the WEC operating conditions.*
- *Many WECs have short-term energy storage components in their PTOs. This can be particularly useful in providing fast frequency support.*
  - *Examples include hydraulic accumulators in oscillating bodies and flywheels in air turbines of OWCs.*
  - *In WECs with accumulators, the energy stored as pressurized air (or water) can be used for FFR provision, according to PTO capabilities.*



Timescales of active power provision services in power systems, timescales of wave power and PTO control, and discharging times of energy storage systems commonly used in PTO systems.

- *WECs can operate below the available maximum power to have a margin for ramping up and down the output power.*
- *PTO control is commonly designed for maximum power absorption, either in a wave-by-wave basis or according to sea state variations.*
- *A hierarchical control structure at a farm level should be developed to coordinate different control objectives.*
- *Resource forecasts are essential to ensure output power at the required time, especially for RR and balancing.*
- *The coordination with batteries built into the PTO can be beneficial in long timescales.*

CONCLUSIONS

- If properly controlled and power reserves are available, wave farms can contribute to frequency support in future power systems.
- WECs can operate below the maximum power point to have a margin for ramping up and down the output power, similar to wind turbines.
- WECs can rely on the short-term energy storage components built into their PTOs for providing fast and short support.
- Accurate wave power forecasting will be essential to minimize the uncertainty related to reserves.
- Provision of active power for grid support adds another layer to the PTO control, which commonly targets maximization of the power absorbed from waves.

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IMPACT

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