Energy storage system – design and modeling considerations

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Content

• Purpose and role in the whole project

• Hydraulic energy storage – design and optimization
  ➢ System topology
  ➢ Verification
  ➢ Case study - WaveStar
  ➢ Optimization
Purpose and role in the whole project
Advantages offered by an energy storage system

It behaves like a filter (buffer) – smoothing the energy generated by irregular energy sources (e.g. waves).

• The output power to the grid is more stable, predictable, and controllable.

• Secure the energy supply.

• Extra economic benefits like moving off-peak power to on-peak periods with higher electricity prices. (smart grid)
In this project, we need to

- Understand the performances of energy storage systems
- Understand their interactions with the rest of the Wave Energy Converter (WEC). – require a proper model that can be inserted in the complete WEC mode.
Hydraulic energy storage – design and optimization
Basic configuration

- hydraulic accumulator
- hydraulic pump/motor
- Reservoir
- connecting lines
- controller

Diagram:

- System topology
- Mechanical input/output
- Hydraulic input/output
- Controller
- Pump/Motor
- Reservoir
- Accumulator
- Gas
- Oil
- Shaft
- Connecting lines
- Control signal

Hydraulic energy storage system
Mathematical model is established in Simulink

- A regeneration system is used for verification

[A. Pourmovahed, etc. all, 1992], Ref [1]
Mathematical model is established in Simulink

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Model of hydraulic accumulator

Continuity Equation

Gas Energy Equation

Absolute Gas Temperature

Pressure Equation
Verification

Simulation and reference results comparison

- Flywheel Speed (r/min) vs. Time (s) for P/M Angle = 20 Deg, Cold Oil
- Gas Pressure (MPa) vs. Time (s) for P/M Angle = 20 Deg, Cold Oil
- Round-trip Efficiency, % vs. Cycle Number, i for P/M Angle = 20 Deg, Cold Oil

[A. Pourmovahed, etc. all, 1992], Ref [2] 02-06-2014
System topology

- The excessive wave energy enters the energy overflow system, where energy storage system is installed.
- Hydraulic pump/motor works at motor mode only.
- Output power to generator is controlled by adjusting the swivel angle.

[Ref [3]]
Work procedure

1. Too much input, relief valve open to limit the system pressure to max; swivel angle (capacity) is limited in order to limit the shaft power output;
2. No input, system pressure drops as stored energy is used; no pump capacity limitation;
Key parameters regarding system efficiency optimization

• System maximum allowable pressure – $p_m$
  – How much energy can be stored in accumulator
  – How fast hydraulic motor can convert energy
• Accumulator size – $V_{acc}$
  – How much energy can be stored
• Hydraulic motor displacement (power) – $D_{hyd}$
  – How fast it can convert energy – from hydraulic to mechanical
System maximum allowable pressure

At sea state 3:

\( V_{\text{acc}} \uparrow \rightarrow \eta_{\text{sys}} \uparrow \)
\( D_{\text{hyd}} \uparrow \rightarrow \eta_{\text{sys}} \uparrow \)
\( p_{\text{m}} \uparrow \rightarrow V_{\text{acc}} \downarrow \)

At sea state 2:

\( V_{\text{acc}} \uparrow \rightarrow p \downarrow \)
\( \rightarrow \eta_{\text{hyd}} \downarrow \)
\( \rightarrow \eta_{\text{sys}} \downarrow \)

\( D_{\text{hyd}} \uparrow \rightarrow p \downarrow \)
\( \rightarrow \eta_{\text{hyd}} \downarrow \)
\( \rightarrow \eta_{\text{sys}} \downarrow \)
Generator rated power

At sea state 3:

- $V_{\text{acc}} \uparrow \rightarrow \eta_{\text{sys}} \uparrow$
- $D_{\text{hyd}} \uparrow \rightarrow \eta_{\text{sys}} \uparrow$
- $P_{G} \uparrow \rightarrow \eta_{\text{sys}} \uparrow$

At sea state 2:

- 30kW is big enough
- At very small $V_{\text{acc}}, \eta_{\text{sys}}$ drops due to waste of energy
Discussions

- Balance sea state 1, 2 and 3 to obtain the highest possible average system efficiency
  - Relative low hydraulic motor capacity and high system pressure is preferred
  - It can ensure that the hydraulic motor works with a relative high average efficiency and give much smooth output torque

- Balance the system max. allowable pressure and size to obtain optimal cost
  - High $p_m$ requires high quality component, thus high cost
  - High $p_m$ can reduce the requirement of accumulator size and hydraulic motor displacement, which may reduce cost
  - High $p_m$ can give high system efficiency, which save money
Summary

• The model can be used to analyse the performance of hydraulic energy storage system, and give reasonable accuracy

• Key parameters regarding system efficiency optimization are found and discussed

• A system efficiency around 85 percent seems to be an attainable theoretical value. In a real system, system efficiency of 80 percent may be practically expected.
Reference


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SDWED

STRUCTURAL DESIGN OF WAVE ENERGY DEVICES

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Aalborg University
Department of Civil Engineering

Technical University of Denmark

Ramboll

Fraunhofer

WaveEnergy Centre
Centro de Energia das Ondas

Universidade Federal do Rio de Janeiro

Alma Mater Studiorum
Università di Bologna

DNV