CONTROL STRATEGY AND SIZING OF A FLYWHEEL ENERGY STORAGE PLANT FOR THE FREQUENCY CONTROL OF AN ISOLATED WIND-HYDRO POWER SYSTEM (presented in the 15th Wind Integration Workshop)

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1. INTRODUCTION

2. MODEL DESCRIPTION

3. CONTROL STRATEGIES

4. SIMULATION RESULTS

5. CONCLUSIONS

6. FUTURE WORK
OBJECTIVE:
Analyze the contribution of a flywheel energy storage system to reduce the impact of wind power variability on the frequency of an isolated wind hydropower system based on El Hierro Island (Spain)

MOTIVATION:
Penetration of Renewable Energies causing a deterioration in the system frequency (specially severe in isolated power systems)

Challenges:
- Increase the electrical energy storage
- Maintain system reliability

Flywheel Energy Storage System (FESS)
Control strategy and sizing of a flywheel energy storage plant for the frequency control of an isolated wind-hydro power system

CONTEXT:
- El Hierro Island
- 10,000 hab.
- Peak Demand 6.9 MW

11.5 MW + 11.3 MW + 12.7 MW

Pump storage hydropower plant
2. MODEL DESCRIPTION (I)

REALITY
Wind farm (5x2,3MW)
Pumped Storage Power Plant (4x2,83MW)
Diesel Power plant (12,7 MW)

MODEL
Wind  2,3 MW
Hydro  5,6 MW
FESS

Peak Demand 6,9 MW

25kW*Number of Flywheels

KEYS:
- Only inertial effects
- Pumped storage power plant only in generating mode
- Wind and FESS have frequency converters
- All loads resistive
- Wind does not contribute to frequency regulation
2. MODEL DESCRIPTION (II)

**INPUTS:**
- Load
- Wind

**OUTPUTS:**
- Frequency
- Power delivered
- State of charge (SOC)
- Nozzles position
3. Control Strategies (I)

**P_{D,fess}** UPDATE PERIOD 1 SECOND

**Droop Based Scheme**

**Non-Linear Proportional Scheme**
**DROOP BASED SCHEME:**

- Deadband
- Droop
3. CONTROL STRATEGIES (III)

NON-LINEAR PROPORTIONAL SCHEME

- Deadband
- Vertex (V)

IF $F < 50 \text{ Hz} - \text{deadband}$

IF SOC > V

$P_{d, \text{FESS}} = P_{\text{max}}$

IF SOC < V

$P_{d, \text{FESS}} = P_{\text{max}} \times (V - \text{SOC})$

IF $F > 50 \text{ Hz} + \text{deadband}$

IF SOC < 1 - V

$P_{d, \text{FESS}} = -P_{\text{max}}$

IF SOC > 1 - V

$P_{d, \text{FESS}} = -P_{\text{max}} \times (\text{SOC} - (1 - V))$
**Keys:**
- Load $5.1 \text{ MW}$ constant
- $P_{\text{hyd}} = 3.3 \text{ MW}$
- $P_{\text{wind}} = 1.8 \text{ MW}$
- $\text{SOC}_0 = 0.5$
- $3500 \text{ s}$
- Single Wind Power Scenario
- Sets of simulations:

**Strategy**

<table>
<thead>
<tr>
<th>Number of flywheels</th>
<th>Droop Based</th>
<th>Non-Linear Proportional</th>
</tr>
</thead>
<tbody>
<tr>
<td>[2, 4, 6…20]</td>
<td>[2, 4, 6…20]</td>
<td>[2, 4, 6…20]</td>
</tr>
<tr>
<td>Deadband (mHz)</td>
<td>[15, 30, 45]</td>
<td>[15, 30, 45]</td>
</tr>
<tr>
<td>Droop (%)</td>
<td>[1, 2, 3]</td>
<td>-</td>
</tr>
<tr>
<td>Vertex (p.u SOC)</td>
<td>-</td>
<td>[0.2; 0.5; 0.8]</td>
</tr>
</tbody>
</table>
500 s
6 flywheels (6x25kW)
Deadband 30 mHz
Droop 1% // Vertex 0,5 p.u SOC

4. SIMULATION RESULTS (II)
500 s
6 flywheels (6x25kW)
Deadband 30 mHz
Droop 1% // Vertex 0.5 p.u SOC
500 s
6 flywheels (6x25kW)
Deadband 30 mHz
Droop 1% // Vertex 0.5 p.u SOC
500 s
6 flywheels (6x25kW)
Deadband 30 mHz
Droop 1% // Vertex 0.5 p.u SOC
500 s
6 flywheels (6x25kW)
Deadband 30 mHz
Droop 1% // Vertex 0.5 p.u. SOC

4. SIMULATION RESULTS (VI)
### 4. Simulation Results (VII)

#### VARIABLES

<table>
<thead>
<tr>
<th>Pumped-storage power plant</th>
<th>Turbine nozzle servomotor fatigue sum(t,delta(z))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flywheel energy storage plant</td>
<td>Cycles per hour</td>
</tr>
<tr>
<td>Frequency deviation</td>
<td>Maximum frequency (max f)</td>
</tr>
<tr>
<td></td>
<td>Minimum frequency (min f)</td>
</tr>
<tr>
<td></td>
<td>Mean average frequency deviation (avdf)</td>
</tr>
</tbody>
</table>

#### Criteria to choose the optimum Controller parameters

- **Droop Based**
  - Deadband
  - Droop

- **Non-Linear Proportional**
  - Deadband
  - Vertex
4. Simulation Results (VIII)

![Graph showing simulation results for number of flywheels vs deadband and vertex.](image)

Control strategy and sizing of a flywheel energy storage plant for the frequency control of an isolated wind-hydro power system
Each number of flywheels with the optimal controller configuration
Each number of flywheels with the optimal controller configuration

![Graph 1: Servo effort vs. Number of flywheels](image1)

![Graph 2: Cycles/hour vs. Number of flywheels](image2)
5. Conclusions

- Fywheels yield better results in terms of frequency
- NLP controller action means a stronger participation than DP:
  - Average frequency v/s Fatigue
- Sizing of flywheels: More is not always better

<table>
<thead>
<tr>
<th></th>
<th>No FLYWHEELS</th>
<th>4 FLYWHEELS</th>
<th>6 FLYWHEELS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DB</td>
<td>NLP</td>
<td>DB</td>
</tr>
<tr>
<td>Min. Frequency (Hz)</td>
<td>48,80</td>
<td>49,58</td>
<td>49,51</td>
</tr>
<tr>
<td>Max. Frequency (Hz)</td>
<td>51,20</td>
<td>50,61</td>
<td>50,8443</td>
</tr>
<tr>
<td>Average frequency (Hz)</td>
<td>0,18</td>
<td>0,10 (-44%)</td>
<td>0,07 (-64%)</td>
</tr>
<tr>
<td>Turbine nozzle servomotor fatigue (p.u)</td>
<td>8,01</td>
<td>3,29 (-59%)</td>
<td>3,34 (-58%)</td>
</tr>
<tr>
<td>Cycles/hour</td>
<td>-</td>
<td>0,77</td>
<td>2,30</td>
</tr>
</tbody>
</table>
6. FUTURE WORK

- Multiple criteria analysis
- Several wind power scenarios
- More control strategies
- Review of literature and real practices
- Artificial inertial response of wind generators
- Contingency analysis

“Continuos improvement is better than delayed perfection”

Mark Twain
Control strategy and sizing of a flywheel energy storage plant for the frequency control of an isolated wind-hydro power system
7. ONGOING WORK (II)

Control strategy and sizing of a flywheel energy storage plant for the frequency control of an isolated wind-hydro power system

![Graph showing servo effort and cycles/hour versus number of flywheels]

- NLP
- NLP_Var
- DB
- No FESS
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Thank you