CFD OF AIR FLOW IN HYDRO POWER GENERATORS FOR CONVECTIVE COOLING, USING OPENFOAM

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Importance of cooling in generators

- Hydroelectric power generation stands for about half of the electricity generation in Sweden
- Modifications to the existing units would lead to significant contributions to the total energy production
- An increased power output leads to more heat that needs to be removed
- The two large sources of energy losses in the generators: thermal and ventilation losses:
  - Production of heat by the electric resistance in the generator coils (should be removed)
  - The rotor and stator are cooled by air, which causes ventilation losses
- The stators should be cooled by air flowing through the stator air channels
- Focus of the present work: Axially cooled generators
• A small generator at Uppsala University, Sweden
• 4 cooling-channel rows
• 108 cooling channel in each row
• 12 poles
• Rotational speed: 500 rpm
• The flow is driven by the rotation of the rotor, axially into the rotor and radially out through the stator
Modelling in OpenFOAM

- A periodic 1/12 sector in the tangential direction since there are exactly 9 channels per pole
- Symmetry plane in the middle of the generator (lower boundary in figure)
- No inlet and outlet boundaries, no prescribed mass flow
- Recirculating flow without inlet and outlet, thus no prescribed mass-flow
- The mass flow is given by the rotation of the rotor
Stator cooling channels

The rotor rotates clockwise. The channel numbers will be shown again in the results section
Cases

- Frozen rotor concept: MRFSimpleFOAM (MRF = Multiple Reference Frames)
- Low-Re Launder-Sharma turbulence model
- Mesh generated with blockMesh (parameterized m4 script)
- 1 base case + 3 cases with one-at-a-time geometry modifications
  - Case 1: The base case (7.2 M cells)
  - Case 2: Case 1 with modified rotor body (9.1 M cells)
  - Case 3: Case 2 with stator baffle (9.1 M cells)
  - Case 4: Case 3 with radial fan blades (9.1 M cells)
Distribution of volume flows in the channels, \((m^3/s)\)

- The stator baffle and fan blades help making the distribution of the flow more uniform.
- The volume flow decreases at the center of the pole (lower pressure).
Flow structure in the channels

- Contours of zero radial velocity separate the recirculation area from the outgoing flow
- In the cases without the fan blade, the reversed flow covers the entire downstream side of the stator windings
- The fan blades minimize the reversed flow region
Unit vectors of meridional flow

- Regions with upward velocity near the stator inner wall
- Higher pressure make-up by the stator baffle and rotor fan blades give more downward flow
- Separation just at the inlet in cases with stator baffle (less powerful separation with fan blades)
- Purely inward flow at the inlet to the stator baffle
Further parametric studies

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<thead>
<tr>
<th>Base</th>
<th>Rotor design C1</th>
<th>Rotor design C2</th>
<th>Rotor design C3</th>
<th>Rotor design C4</th>
<th>Rotor design C5</th>
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<td>Baffle</td>
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<td><img src="image3" alt="Base Design C3" /></td>
<td><img src="image4" alt="Base Design C4" /></td>
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<td><img src="image7" alt="Baffle Design C2" /></td>
<td><img src="image8" alt="Baffle Design C3" /></td>
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<td>Blade</td>
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<td><img src="image12" alt="Blade Design C2" /></td>
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<td><img src="image15" alt="Blade Design C5" /></td>
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Distribution of volume flows, $(m^3/s)$, further studies
Validation cases

- Two well-known test cases - backward facing step and Couette flow
- Comparisons with experiments and theory
- Backward Facing step: A detailed study of turbulence models in OpenFOAM, led to the selection of the Launder-Sharma turbulence model
- Laminar Couette flow, to verify the pressure and velocity distributions
Conclusions

- Modification of the height of the rotor body did not affect the results considerably
- Use of stator baffles to avoid outward flow at the inlet
- Higher and more even pressure distribution in the machine, achieved by stator baffles
- Fan blades increase the pressure inside the machine even more, leading to a higher pressure difference between the inside and outside
- Higher pressure difference between inside and outside the machine leads to a higher volume flow
- Higher pressure difference between inside and outside the machine leads to a decreased recirculation in the stator channels
Thank you!

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