Integrated Generator Design

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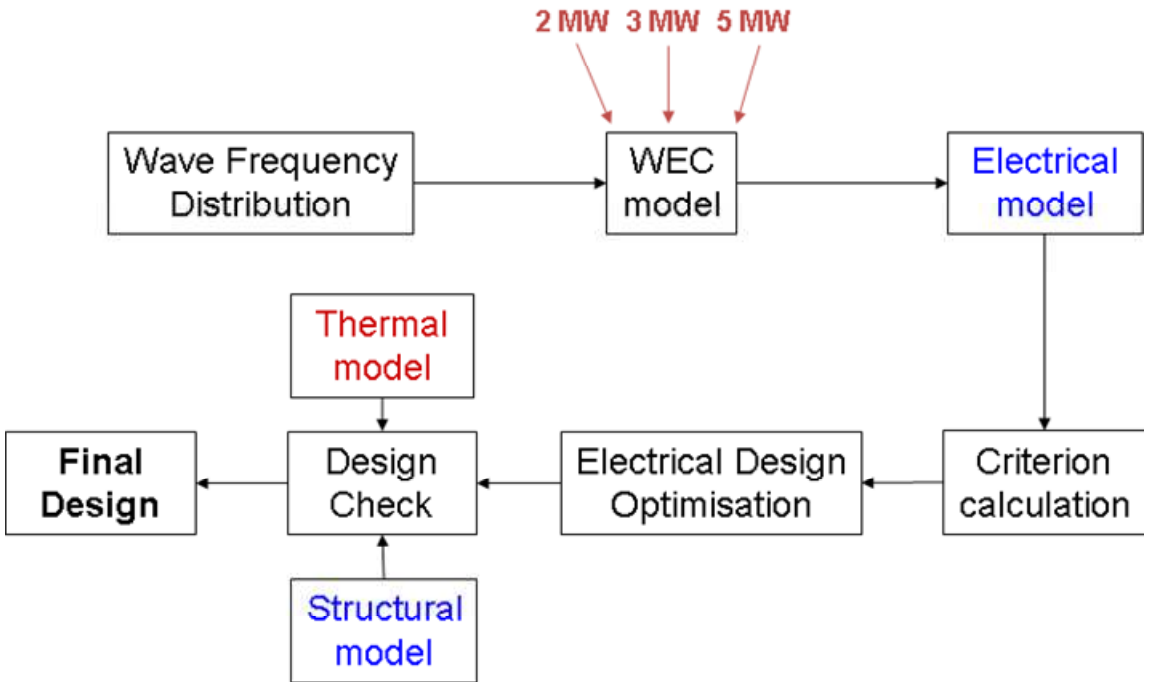
Traditional Design Procedure

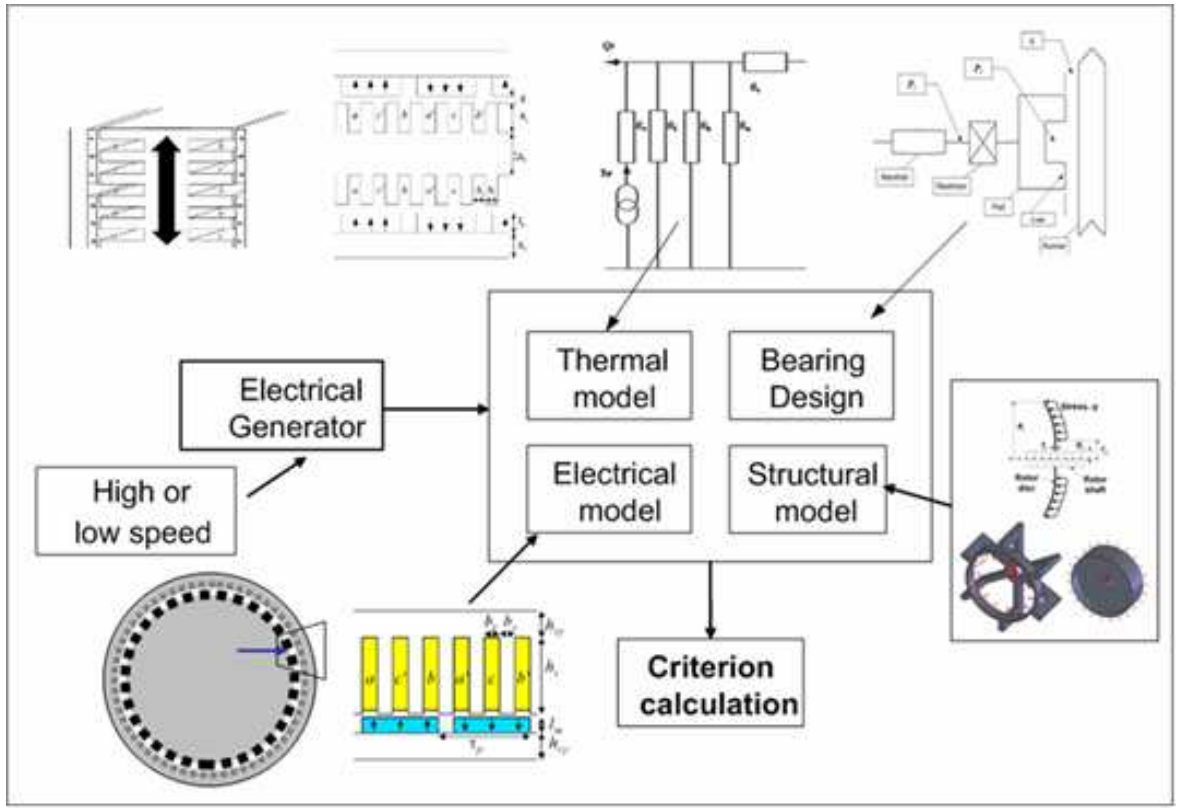


- Optimised Electromagnetic Design
- Thermal & Structural Design un-optimised
- Overall design is un-optimised in terms of cost

Integrated Design

- Optimise Electromagnetic, Structural & Thermal Aspects
- Include operational environment in thermal aspect
  - Ambient temperature likely to be lower than the 20°C standard used in machine design.
  - External fluid flow assists cooling.
- Integrated design leads to reduced material mass and reduced cost.
- Include fault tolerance within the generator design
- Integrate generator models to link the resource with the control system in wave-to-wire time domain model.

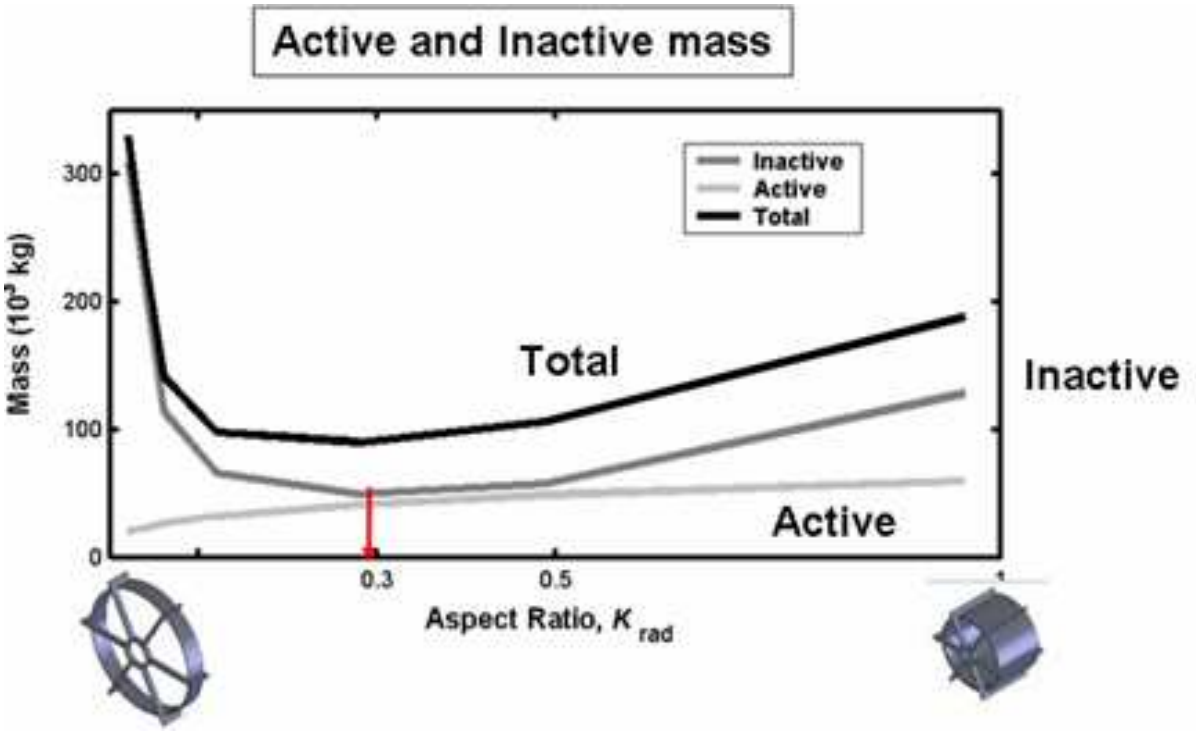
Integrated Generator Design



- Electromagnetic, structural, thermal and bearing design all integrated.
- Analytical techniques used throughout, with validation from numerical modelling.

Electrical-Structural Design

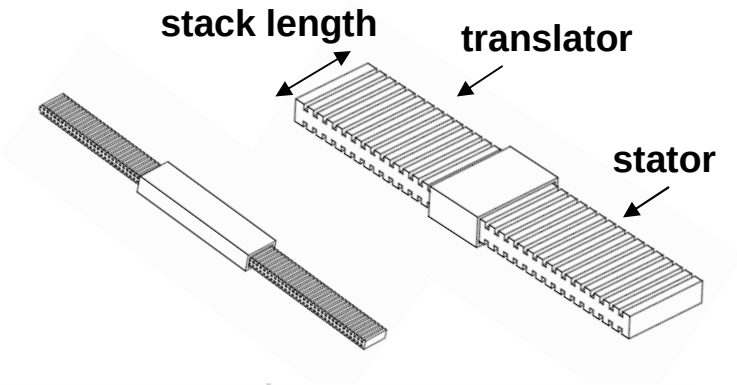
- Active
  - Copper
  - Iron
  - Magnets
- Inactive
  - Structural Steel



- Disc topology gives minimum active mass.
- Disc topology gives maximum structural mass.
- Integrate electrical & structural design to give minimum total mass.

Impact on Capital Cost

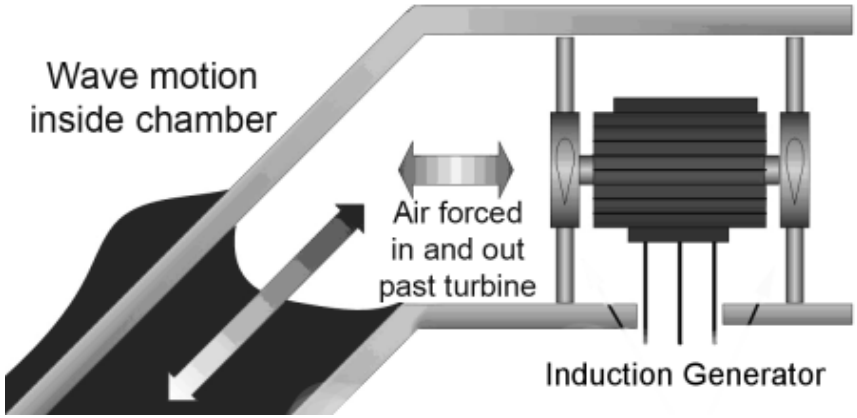
- Assumptions
  - Output constant – 0.5MW
  - Magnet volume constant
- Machine long and narrow
  - stack length = 0.5m
- Machine short and fat
  - stack length = 1.5m
- Topology affects structure and cost.
- Integrated design allows the interaction between these to be optimised to give minimum cost.

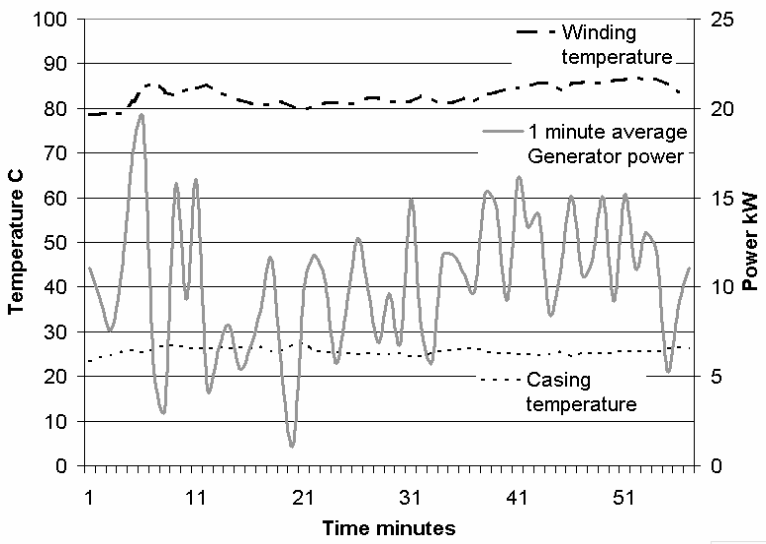


Stack Length (m)	0.5	1.5
Total Cost (kEuros)	**55.4**	**118.7**
Cost per Watt (Euro/W)	**0.107**	**0.235**
Copper Cost (kEuros)	28.8	54.8
Laminated Steel Cost (kEuros)	16.5	38.8
Structural Steel Cost (kEuros)	**2.6**	**17.9**

Operational Environment

- OWC has air-flow over generator.
- Air-flow assists cooling of generator - include in thermal model
- 16% additional power achievable without exceeding temperature limits of machine.





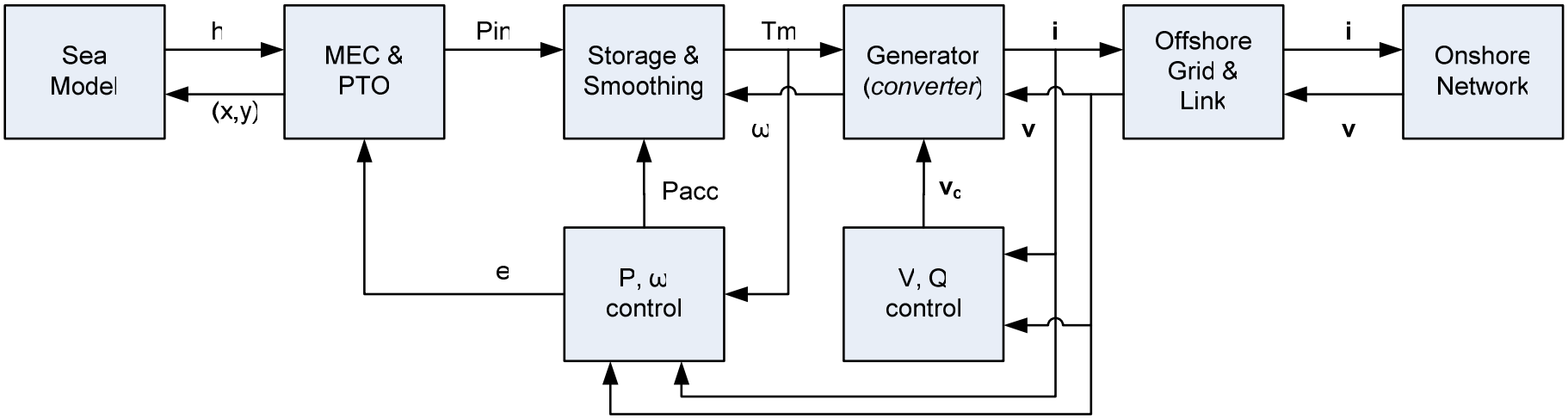
Bearings for Direct Drive Linear Generators

- Bearing design affects electromagnetic, structural and thermal design
- For fully non-contact operation:
  - Hydrostatic/ Magnetic
    - Additional control needed, fluid flow or field control
    - Nature of operation keeps running clearance hard to maintain
- Contact back-up system needed
  - Water lubricated (greaseless) polymer materials
  - Testing to verify low wear claims.

Fault Tolerant Generators

- Reliability and fault prediction.
- Main faults in generators:
  - Bearing faults due to vibration
  - Insulation breakdown due to excessive temperature rise
  - Power converter faults, the dc link capacitor is a potential weak link
- Develop electro-mechanical models to predict and monitor the development of faults.
- Investigate reduced load operation during faults.
- Condition monitoring techniques.

Wave-to-Wire Model



- Generator time domain model
  - includes full electrical-mechanical interactions
  - works simply and quickly within time-steps for control simulation
  - links resource, hydrodynamics, through PTO and generator control to grid connection.

Conclusion & Future Work

- We have developed Integrated Electromagnetic-Structural-Thermal Design Tools for Generators
- Fully optimised designs now show significant improvement in performance and reductions in cost.
- Time domain generator models can be included in a wave to wire model that integrates Lancaster control and Edinburgh hydrodynamic models.
- Further work includes
  - Expand design tools to include Design for Reliability
  - Condition monitoring techniques for fault prediction
  - Include resource and hydrodynamic models in the design procedure