Direct driven generators for wave power

Challenges and possibilities

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Power Take-Off (PTO) systems and direct driven generators

- There are different types of PTO systems
  - Hydraulic or pneumatic PTO
  - Gear box with generator
  - Direct driven generator
- Direct driven generators are typically linear, but we will include rotating machines as well if a conversion system from linear to rotating motion is used without a gear
- Direct driven generators for wave power today are large and heavy – do they need to be?

The project

- We will build a linear TFM generator prototype in the lab
  - High force density (shear stress) – 100-120 kN/m^2
  - Very high efficiency – 98%
  - Near 200 kN damping force
  - Light weight – about 5-7.5 tons, 25-40 N/kg
  - 0.7 m/s – 140 kW, 17.5-28 W/kg, 3 m/s 600 kW, 75-120 W/kg
  - Maintenance free? Depend on bearings…
  - Will be built during 2017
- We will build an extra stator that will be run as a motor
- We will develop a basic power electronics system for the generator
- We will design a rotating TFM generator

The team

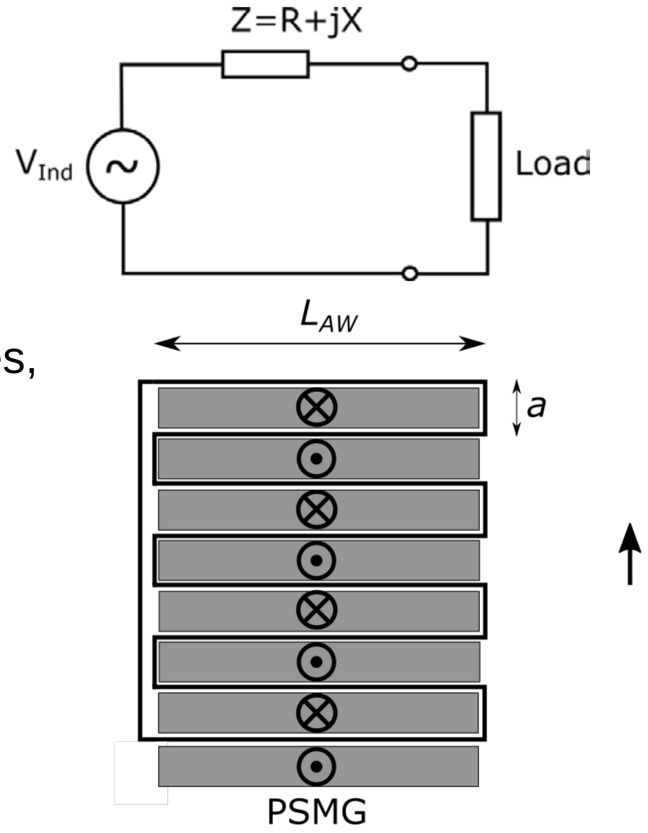
- Anders Hagnestål – project manager, researcher at KTH
- 5 master students in various subjects
- Strong support from the EPE group – electrical machines and power electronics
- Support from machine design department
- Support from the marine engineering department

The slow speed challenge

- P=v*F. Wave power is delivered with slow speeds and large forces, and located at sea
  - Large forces – PTO and structures will be large and heavy
  - Slow speed - electric energy conversion becomes difficult and inefficient
  - Located at sea – maintenance will be expensive
  - Maximum forces are huge – many times larger than average forces
  - Runs all ours of the day, all days of the year, 20 years… Very many repetitions ~80 million
- An ideal direct driven generator would have
  - High force density (shear stress) to reduce size and costs
  - Low losses
  - Maintenance free operation
- …but this is not typically what you get for any PTO system…

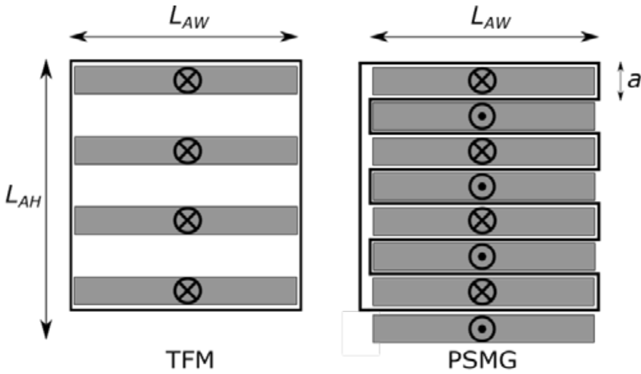
Existing technology – PMSG

- Performs well at high speed
- Can be maintenance free
- Performs less well at low speed < ~2 m/s
  - Induced voltage proportional to speed
  - Resistance independent on speed – $R = \rho l / A$
  - Low speed – low U^2/R ratio – large copper losses, low current (weak force) or both
  - The internal resistance R is rather large
    - Winding is long
    - The machine type has limited space for windings – thin winding

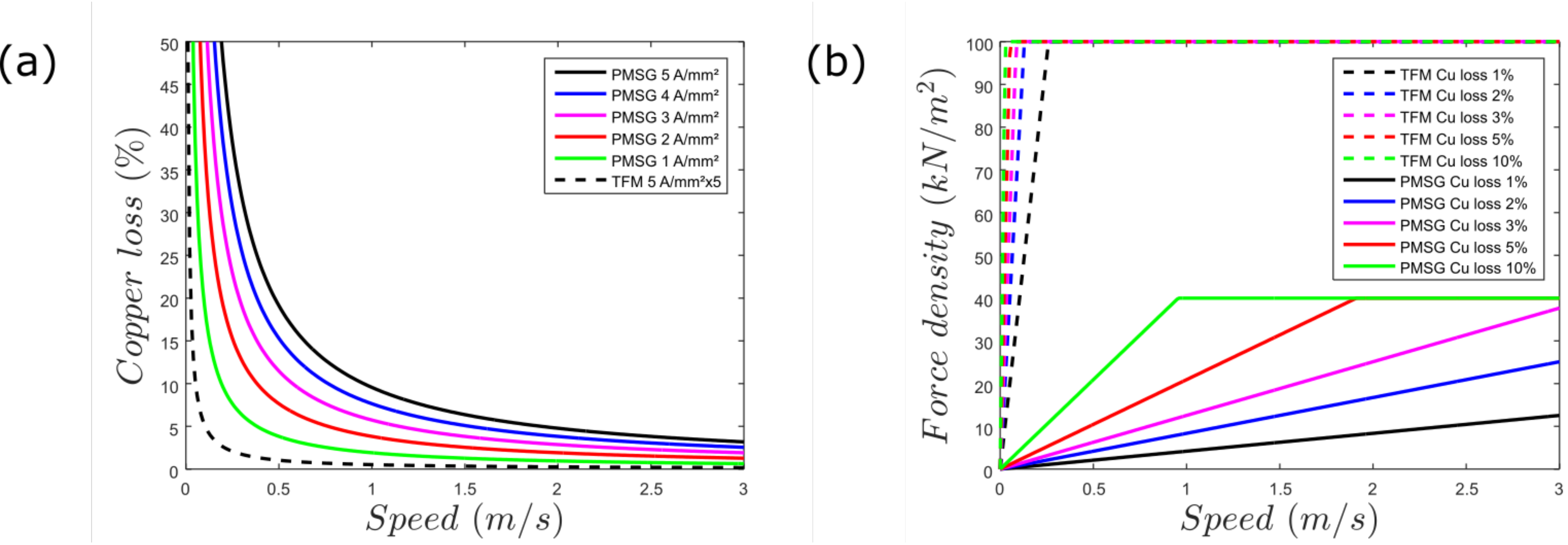


Address the problems - new TFM generator type

- Totally different geometry – optimally short winding ~ 4-8 times shorter
- Short winding and plenty of space – winding can be made thicker without adding much to cost
- $R = \frac{\rho l}{A}$:If the amount of winding is kept constant, $R \propto l^2$
- Core can be compacted – reduces conductor length further
- The copper loss ratio R/U^2 becomes up to 100 times lower
- The force density becomes higher due to geometry – up to 10 times higher
- Low speed – copper losses become very low anyway
- Uses small amount of non-oriented electrical steel per N – low iron losses



Force density and copper losses vs speed



What are the problems

- Is it complex?
- YES!!
- …the design is complex, but not the assembly so mass production will be fine
- Is the power factor low?
- Yes, but not that low, 0.5-0.7 is expected
- Can it become maintenance free?
- It depends on the bearings. Magnetic bearings may be both maintenance free and quite cheap, but requires a quite extensive and complicated design project first

What is the approximate weight and material cost for 200 kN, 7 m stroke length

- Weight, 200 kN:
  - 7 m stroke length, 7.5 tons
  - 2 m stroke length, 5 tons
- Material cost in mass production, ready to assemble, 7m stroke length
  - Total, 33 000 Euro
  - Structure material, 12 000 Euro (stainless steel, steel, glass fiber)
  - Linear bearings, 10 000 Euro
  - Active material, 11 000 Euro
    - Magnets 4 000 Euro
    - Winding 1 200 Euro
    - Electrical steel 5 800 Euro

Performance compared to a typical machine at 0.7 m/s

- 10 times as strong per unit active area – size and cost reduced grossly (typical: 10-15 kN/m^2, TFM 100-120 kN/m^2)
- Electromagnetic losses reduced by a factor of 1/10 to 1/5.
- Extremely low losses: Can even be used for reactive control which earlier has been regarded as unfeasible due to accumulation of losses, or fine tuning of another control system
- Cogging handled by current control

Thank you for listening

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