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Development of Superconducting Wind Turbine Generators

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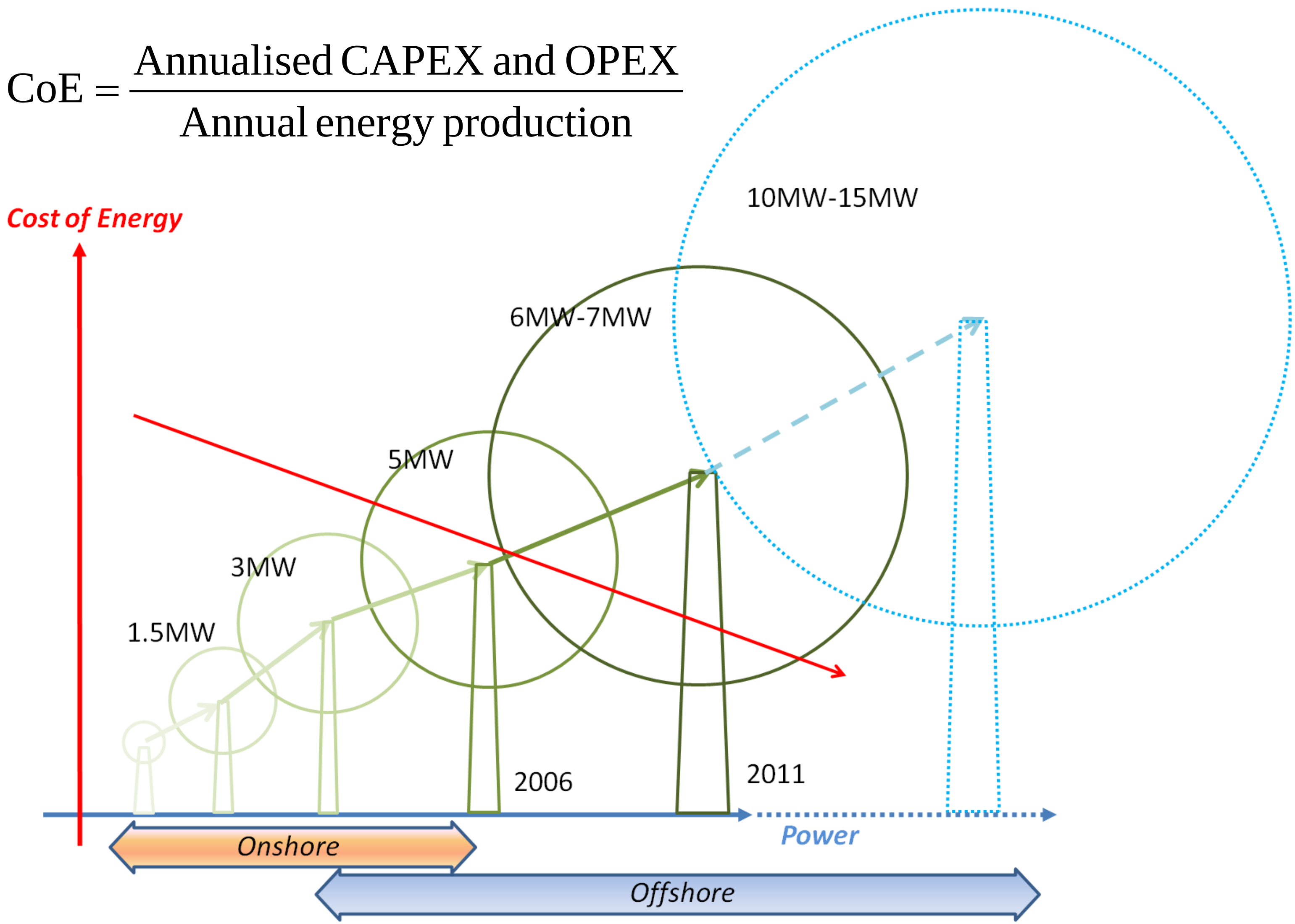
EWEA 2012 Copenhagen, Denmark

Development of wind turbines

$$\text{CoE} = \frac{\text{Annualised CAPEX and OPEX}}{\text{Annual energy production}}$$



5MW and beyond

Manufacturer	Transmission	Generator
Siemens Wind Power	Direct drive	PMSG 6.0MW
Vestas	Medium speed	PMSG 7.0MW
Enercon	Direct drive	EESG 7.5MW
Alstom	Direct drive	PMSG 6.0MW
REPower	High speed	DFIG 6.2MW
Areva	Low speed	PMSG 5.0MW

10MW and beyond – proposals/investigations

Manufacturer	Transmission	Generator
American Superconductor	Direct drive	HTS 10MW
General Electric	Direct drive	LTS 10-15MW
Advanced Magnet Lab	Direct drive	MgB_2 10MW

Schematic of a Superconducting Machine

- The superconductor must be kept at cryogenic temperatures

- The armature winding is usually proposed to be copper at ambient temperature

$$P = \omega \times T$$

$$T \propto A \times B \times V$$

P : *power*

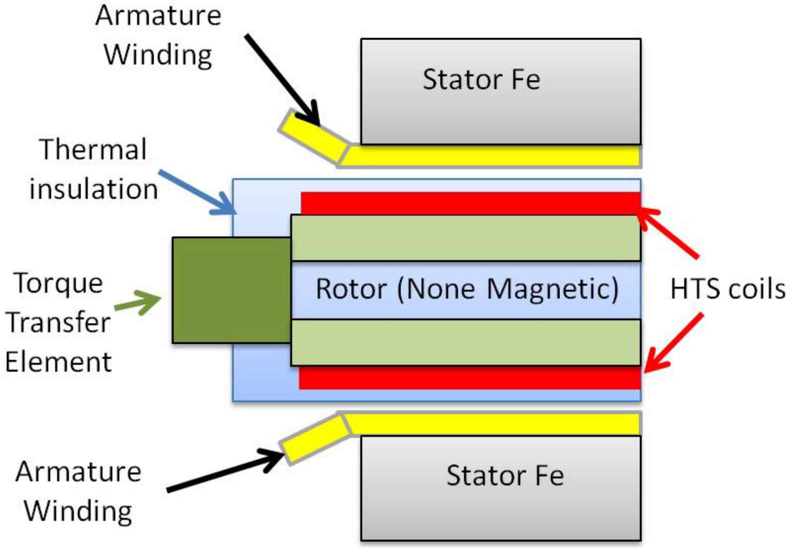
T : *torque*

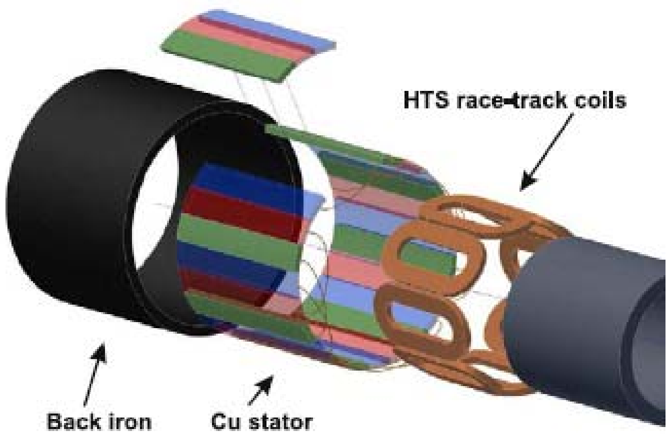
ω : *rotational speed*

A : *electric loading*

B : *magnetic loading*

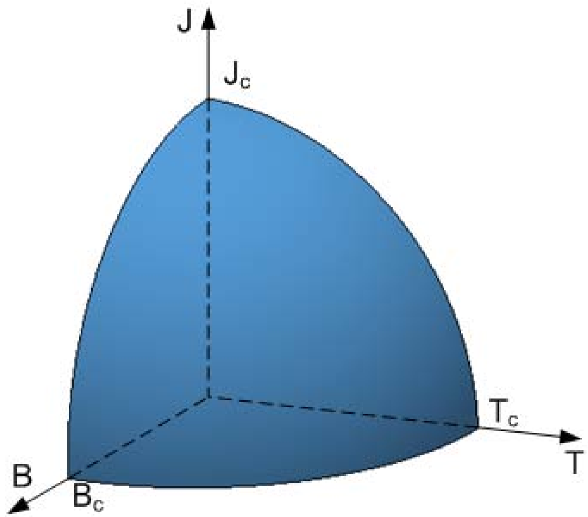
V : *volume*

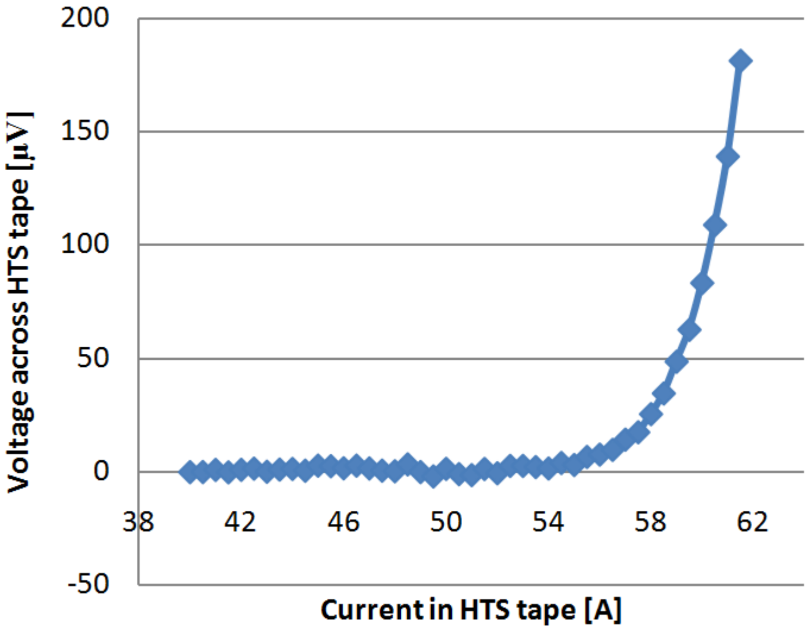




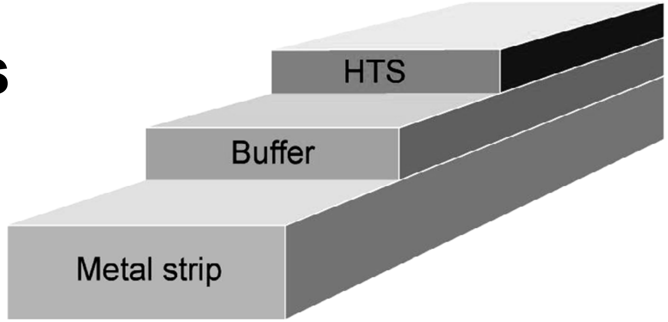
High Temperature Superconductors

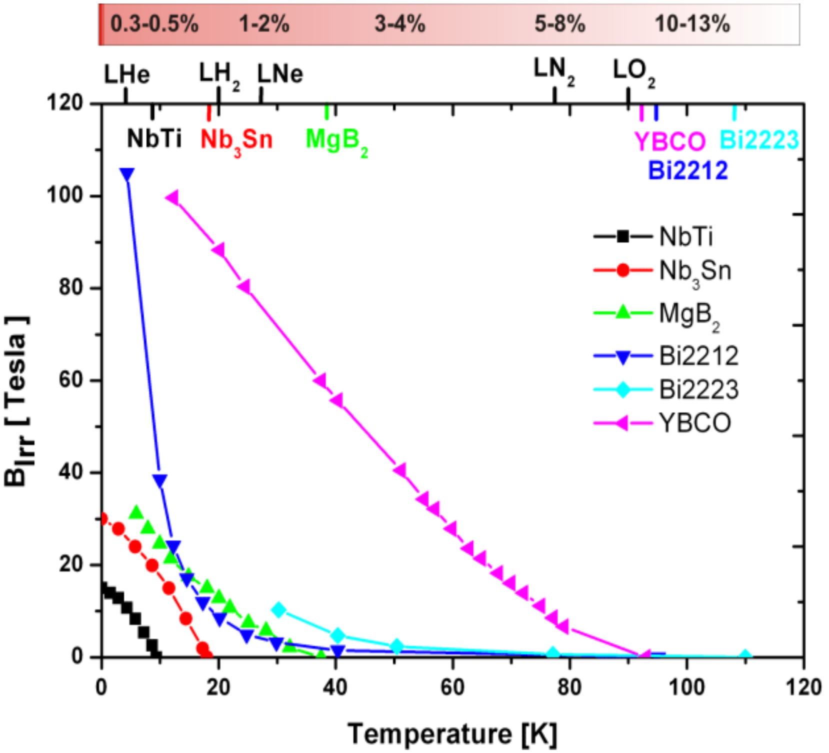
- The superconducting state is limited by
  - Critical flux density B_c
  - Critical current density J_c
  - Critical temperature T_c





Overview of superconductors

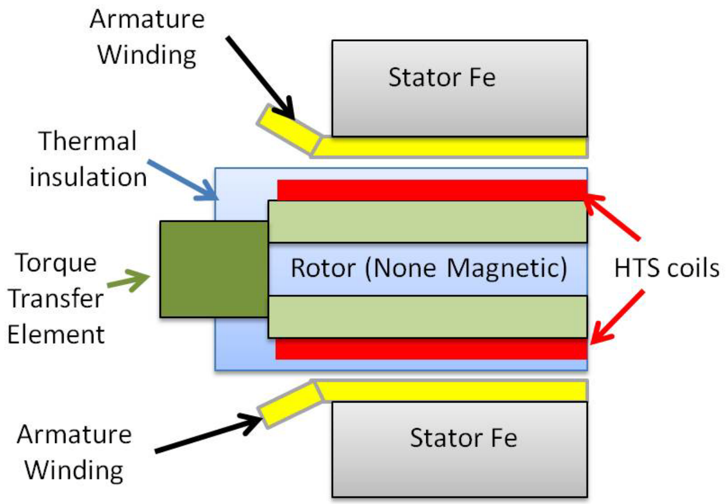




Type	Price €/m	J_e A/mm^2	Flux density [T]	Temp. [K]
NbTi	0.4	10^3	5	4.2
Nb_3Sn	3	1-4x10^3	5	4.2
MgB_2	4	10^2	3	20
Bi-2223	20	390 10	3 ⊥tape 3 ⊥tape	20 50
YBCO	30	98 (480) 49 (190)	3 ⊥tape 3 ⊥tape	20 50

Cooling system

- The superconductors need to be cold:
  - <5K for LTS
  - <20K for MgB_2
  - 30-50K for HTS



- Insulation requires large effective airgap
  - – Large fault currents and torques

- Torque transfer

- Reliability has yet to be proven and requires years of operating experience

- Production capacity of HTS and MgB_2 are currently not adequate for large-scale commercialisation – this should change if the need is present

Advantages

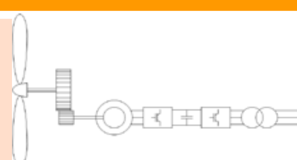
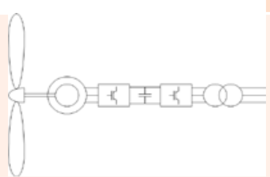
- Very high torque density

$$P = \omega \times T \qquad , \qquad T \propto A \times B \times V$$

- Higher efficiency than an equivalent direct drive PM generator

$$P_{Cu} = I_{Cu}^{2} R_{Cu} = J_{Cu}^{2} A_{Cu}^{2} \frac{l_{Cu}}{A_{Cu} \sigma_{Cu}} = \frac{J_{Cu}^{2} V_{Cu}}{\sigma_{Cu}}$$

- Very limited dependence on rare earth materials

	PM	HTS
Hybrid 	50kgR/MW	20gR/MW
Direct drive 	250kgR/MW	100gR/MW

$m_R = 0.27 m_{R\text{-}B\text{-}Fe}$

American Superconductor (AMSC) SeaTitan 10MW

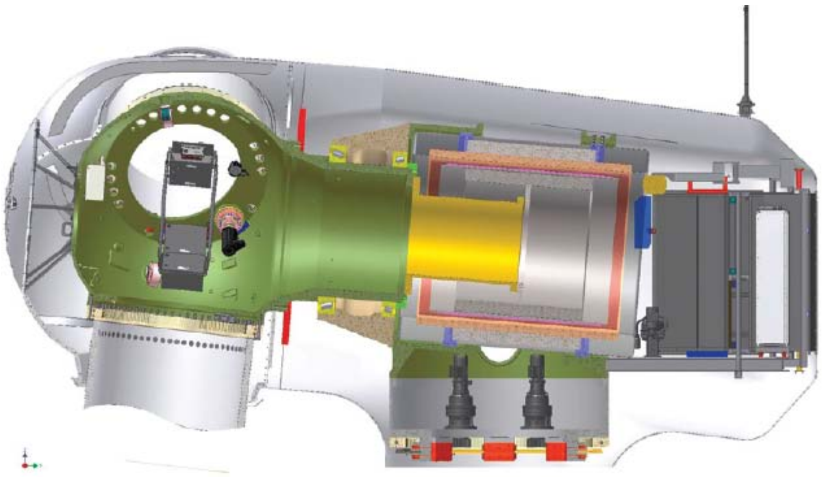
- HTS – Superconducting field winding
- Copper armature winding
- Generator diameter: 4.5–5 meters
- Weight: 150-180 tonnes (55-66Nm/kg)
- Efficiency at rated load: 96%

- Challenge
  - HTS price and availability

- Advantage
  - Relatively simple cooling system with off-the-shelf solutions
  - Cooling power

Highest torque HTS machine intended for ship propulsion:

- 36.5MW @ 120rpm
- 2.9MNm @ 75 tons
- 39Nm/kg



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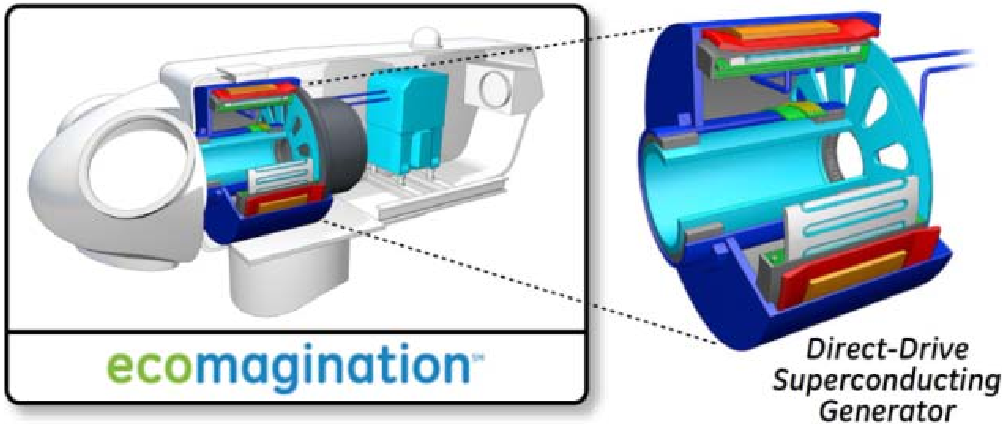
General Electric (GE) 10-15MW

- LTS – Superconducting field winding
- Extensive experience from the MRI sector
- Rotating armature

- Challenge
  – Complicated cooling system and higher cooling power

- Advantage
  – Proven technology from MRI
  – Cheaper superconductor



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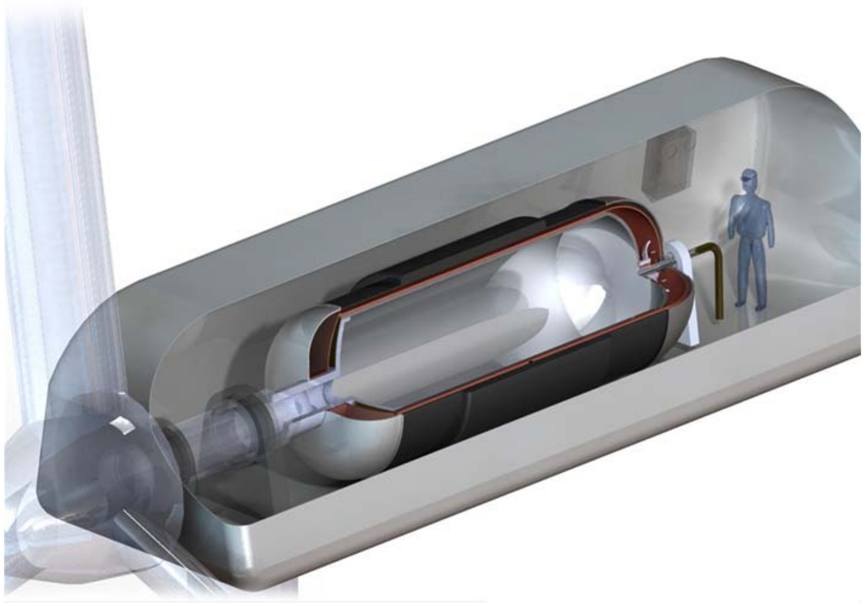
Advanced Magnet Lab (AML) 10MW fully superconducting

- MgB_2 – Fully superconducting generator
- Superconducting field winding
- Superconducting armature winding

- Challenge
  - Complicated cooling system and higher cooling power
  - Improvement in MgB_2 wire is needed

- Advantage
  - Cheap superconductor
  - Fully superconducting
  - More torque dense



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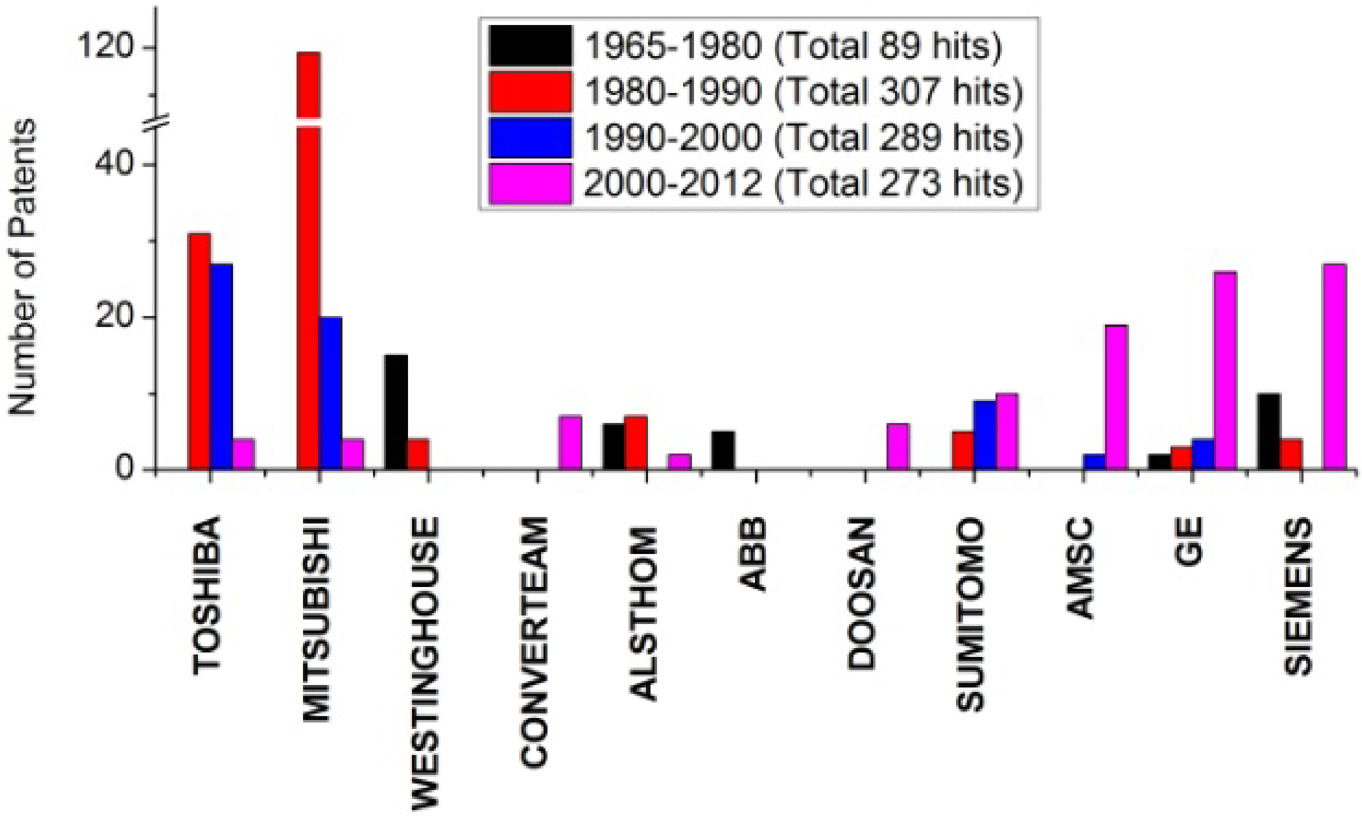
$$P = \omega \times T \qquad , \qquad T \propto A \times B \times V$$

Patent Development

- Web of Knowledge search with keywords: “Supercond*” and “machin*”



Discussion and conclusion

- Superconducting generators might be the answer to large wind turbines
  - Smaller generator
  - Less RE demand by a three orders of magnitude

- A collaborative effort is needed including:
  - Wire manufacturers
  - Wind turbine manufacturers
  - Wind turbine operators

- Large-scale demonstrators are needed
  - To test the performance in a wind turbine
  - To test the reliability

- Thank you