Transverse Flux Permanent Magnet Machines

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Objective

Electromagnetic optimization of direct-drive generators

for large (offshore) wind turbines in UpWind project

- What is (electromagnetic) optimization of generators?
  - To make generator system with maximum energy yield and minimum cost
- What type of generator is suitable? How to achieve it?

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2. Promising direct-drive PM generators
3. Why TFPM machine?
4. What type of TFPM machine?
5. Comparative design of RF and TF PM machines
6. Conclusions and Further researches

1. Background

Increasing wind turbine power,

$$P = T \cdot \omega_m$$

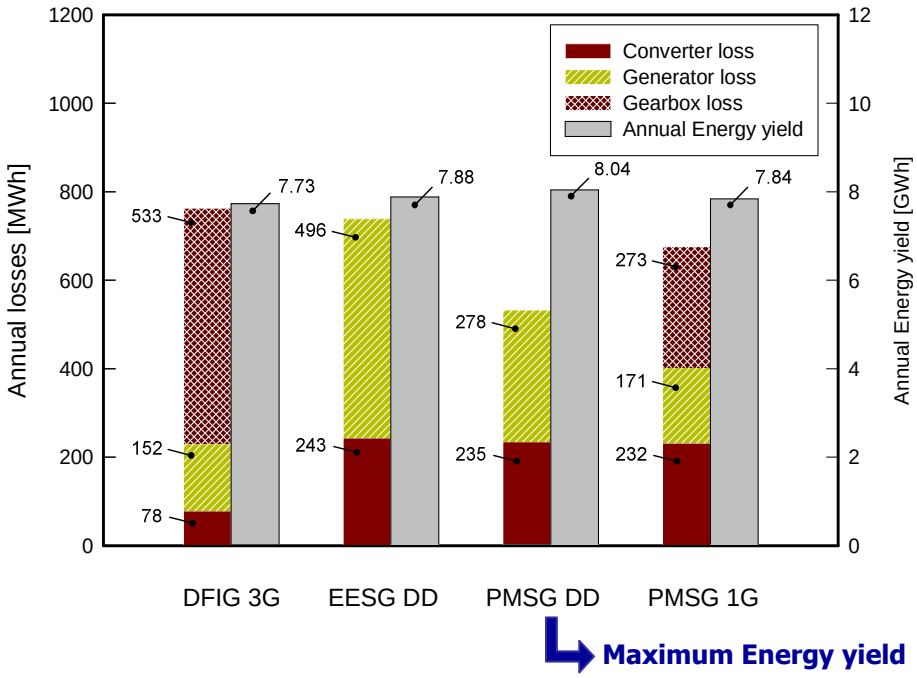
$$T = F \cdot r_g = \left(F_d \cdot 2\pi \cdot r_g \cdot l_s\right) \cdot r_g = F_d \cdot 2\pi \cdot r_g^2 \cdot l_s$$

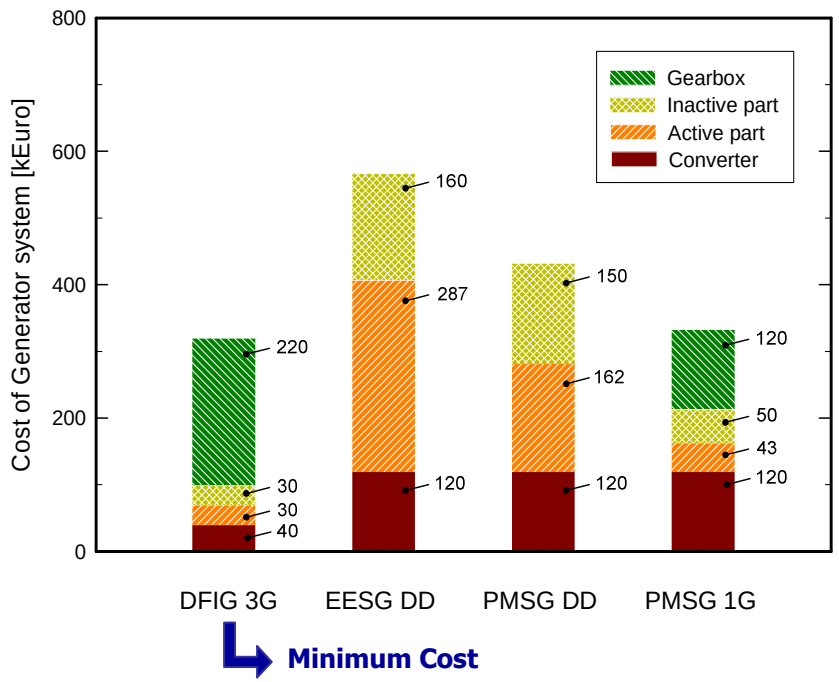
and/or

Direct-drive generator is large, heavy and expensive,

although it is superior in terms of Efficiency, Energy yield and Reliability.

• Address different generator concepts: 3 MW





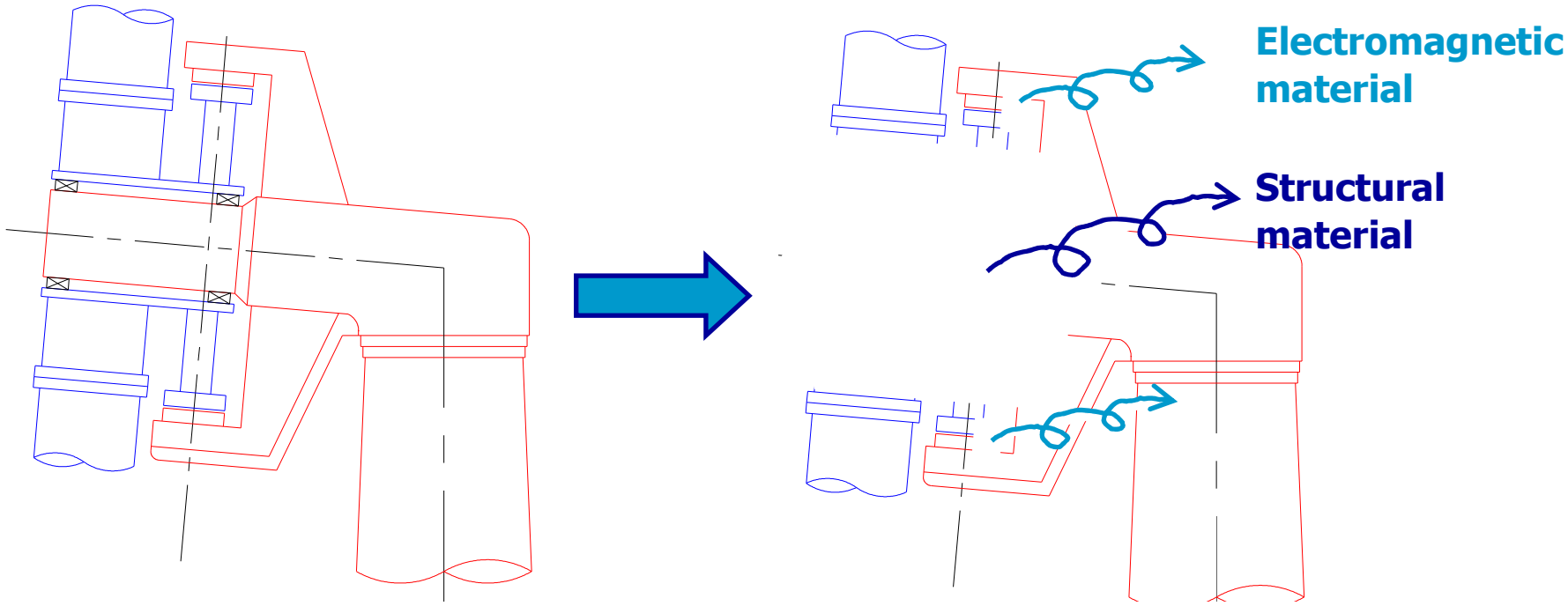
- **DFIG 3G :** *Doubly-fed induction generator system with three-stage gearbox*
- **EESG DD :** *Direct-drive electrically excited synchronous generator system*
- **PMSG DD :** *Direct-drive permanent magnet synchronous generator system*
- **PMSG 1G :** *PM synchronous generator system with single-stage gearbox*

Data source: Polinder *et al* (2006)

- **Define the most suitable generator**

  : Generator with maximum energy yield and minimum cost

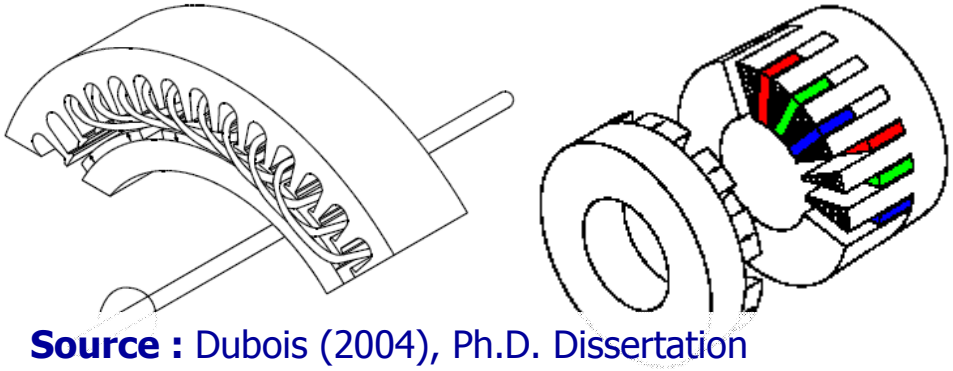
  → **a DD PM generator which is cheaper than DFIG 3G**



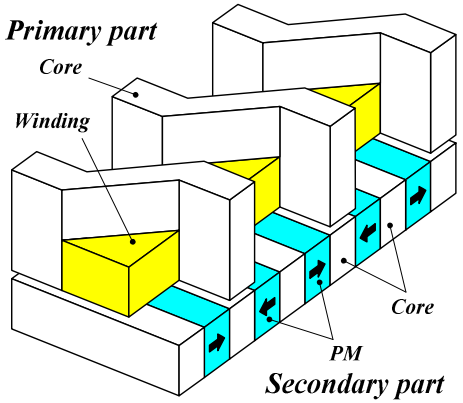
Focus : Electromagnetic structure with high force density and less material to achieve maximum energy yield and minimum cost

2. Promising direct-drive PM generators

- **RFPM / AFPM / TFPM machine**



Source : Dubois (2004), Ph.D. Dissertation



	RFPM	AFPM	TFPM
Force density	+	+	+ (in small air gap) - **(in large air gap)**
Torque/mass	+		+
Core production	+		
Winding production			+
Copper loss			+
Power factor	+	+	

2. Promising direct-drive PM generators

- **RFPM / AFPM / TFPM machine**

Large direct-drive on the market,

→ ***RF type*** **: mostly used**

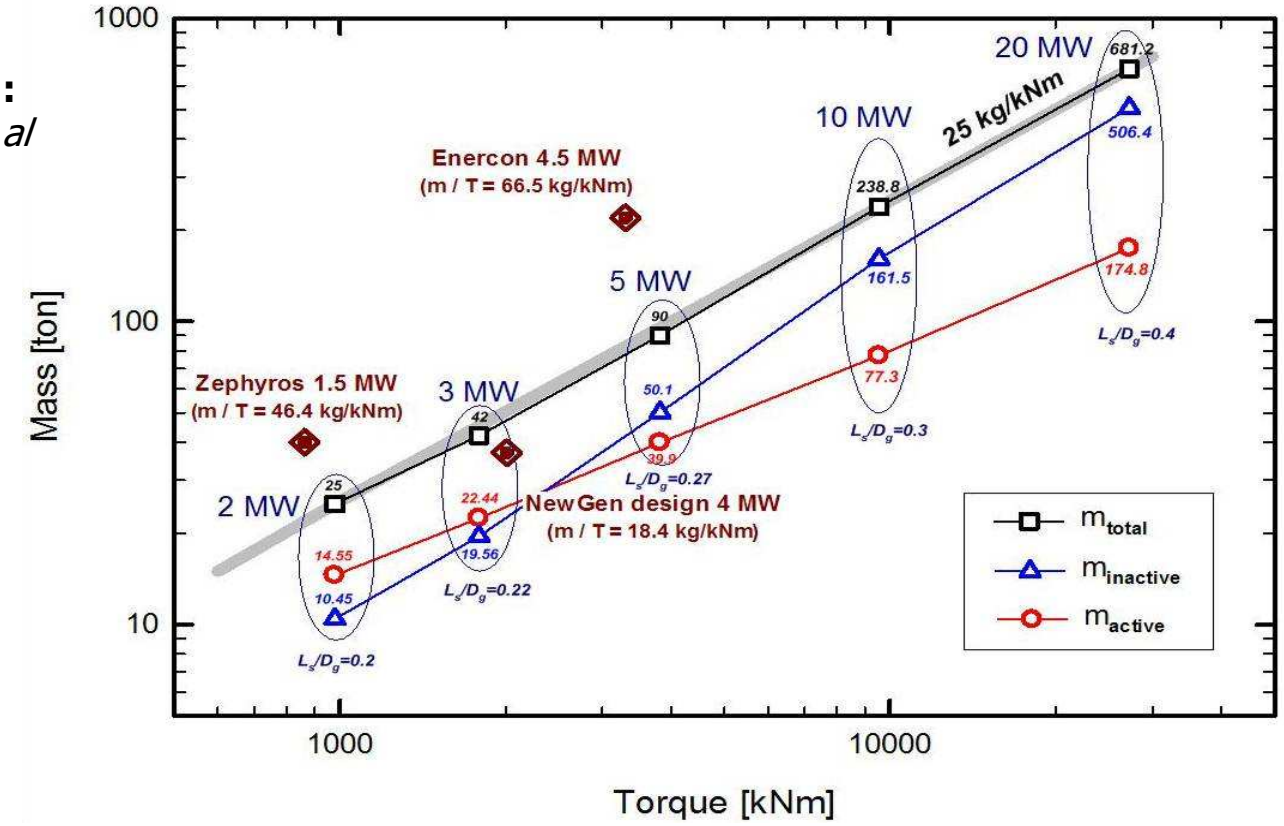
→ ***AF type*** **:** not used over 1 MW

→ ***TF type*** **:** not used

3. Why TFPM machine?

- **Large direct drive generators: RF machines**

Source of 2, 3 & 5 MW **:** McDonald *et al* (2006)

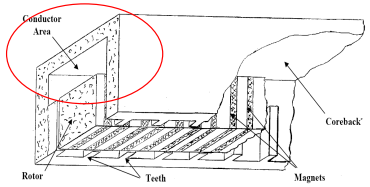


- **Questions**
  - Is the traditional RF machine technology attractive for large direct-drive?
  - How can we achieve PMSG DD cheaper than DFIG 3G?

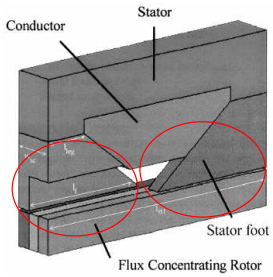
• Suitable electromagnetic structure concept

o Concept for high force density with

1) new topology

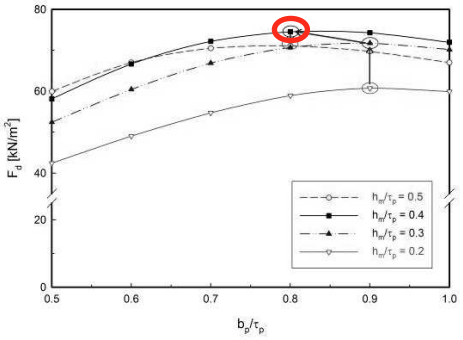


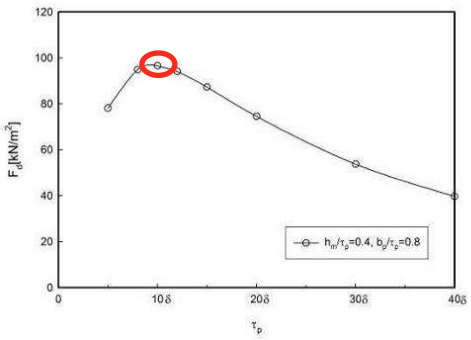
Mecrow, Weh, and Maddison *et al* .



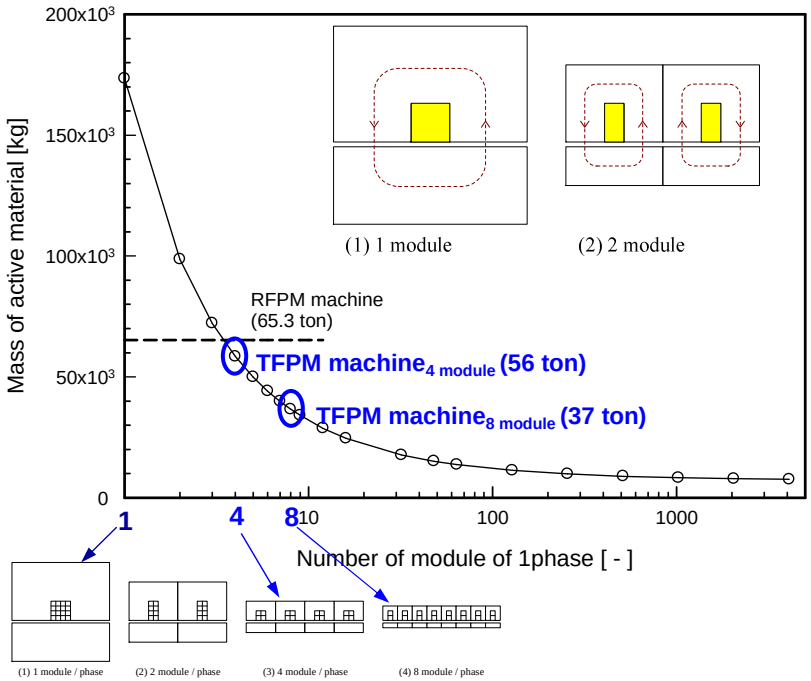
$$e_{\max} = N \cdot B_{\max.core} \cdot A_{core} \cdot 2\pi \cdot f$$

2) optimization





o Concept for material reduction with short flux path

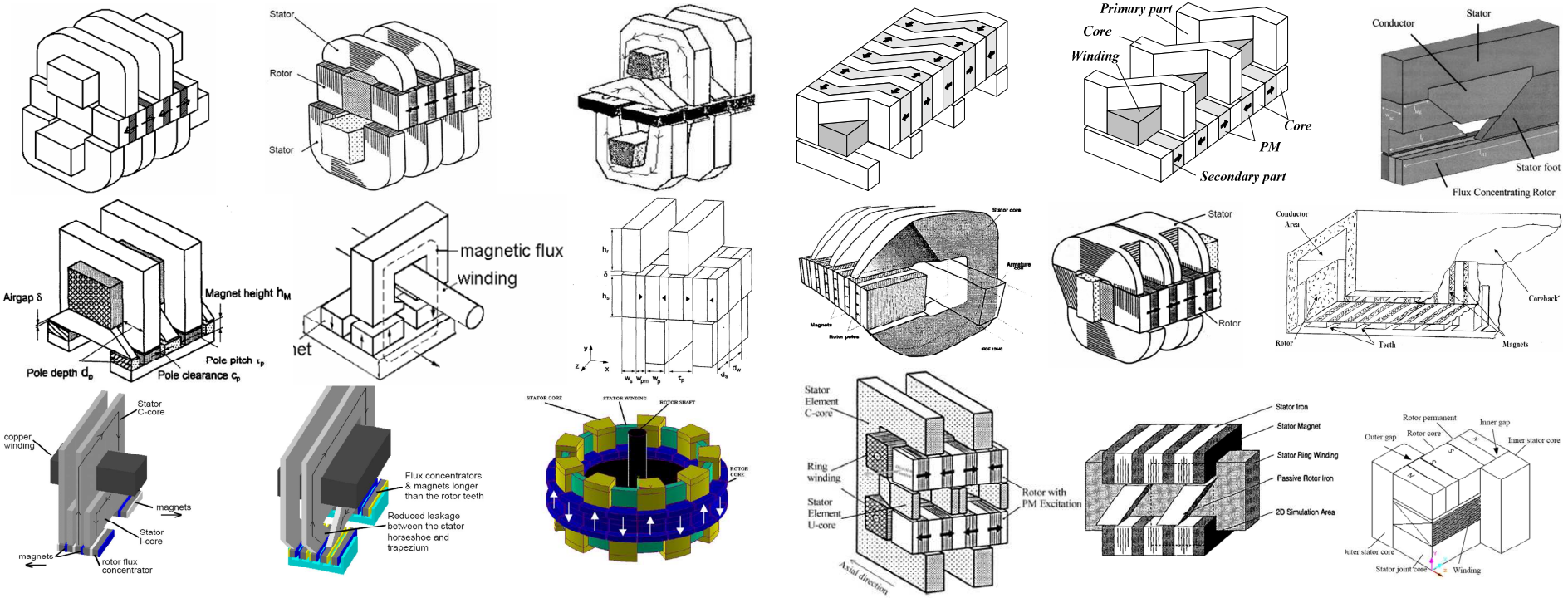


RF, AF: limited TF: ***potential***

EPP Electrical Power Processing UpWind DUWIND DELFT UNIVERSITY WIND ENERGY RESEARCH INSTITUTE

4. What type of TFPM machine?

A number of TFPM machine types have been proposed.

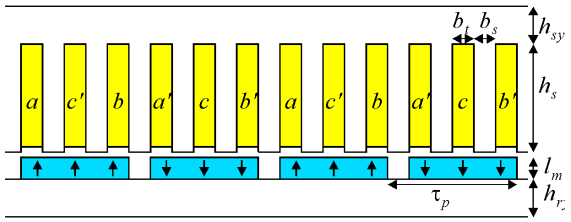


→ It is necessary to find the most suitable type. **How?**

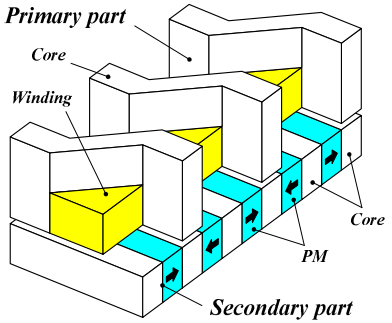
5. Comparative design of RF and TF PM machines

- **Machine type selection**

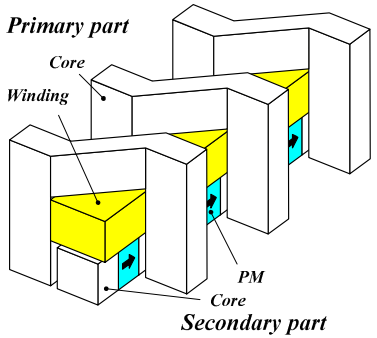
a) RFPM machine



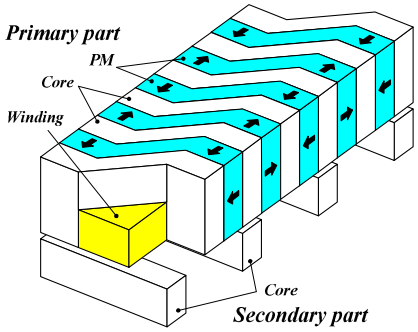
b) TFPM machine-1



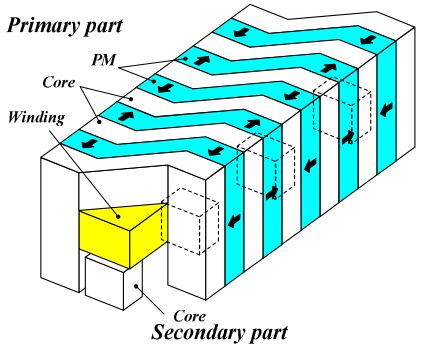
c) TFPM machine-2



d) TFPM machine-3



e) TFPM machine-4

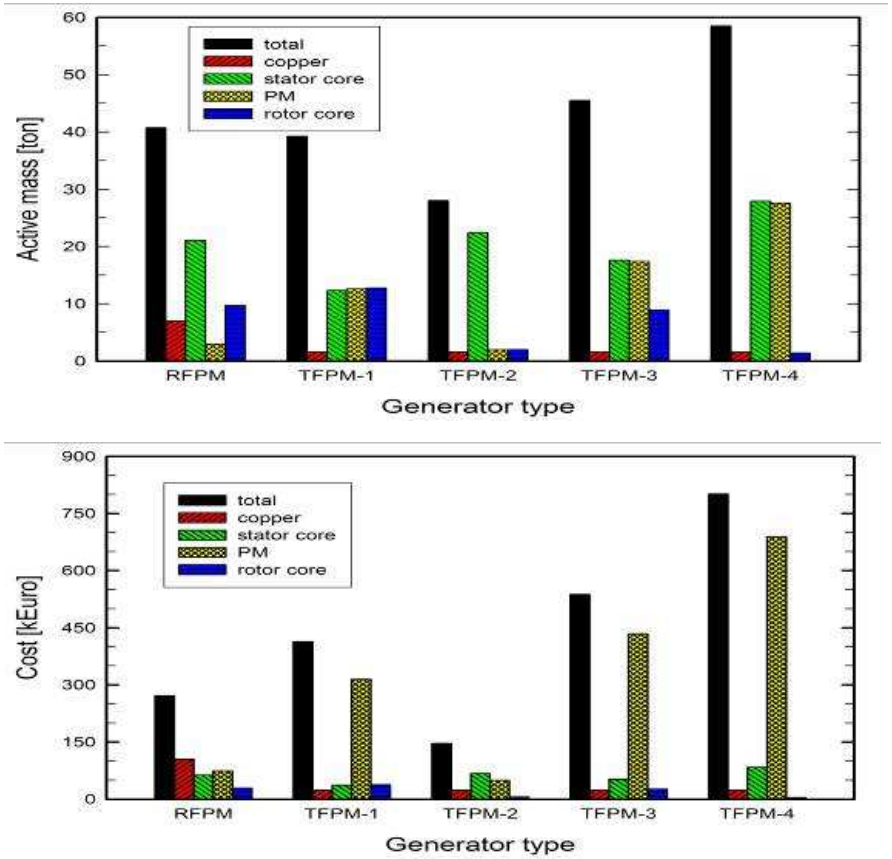


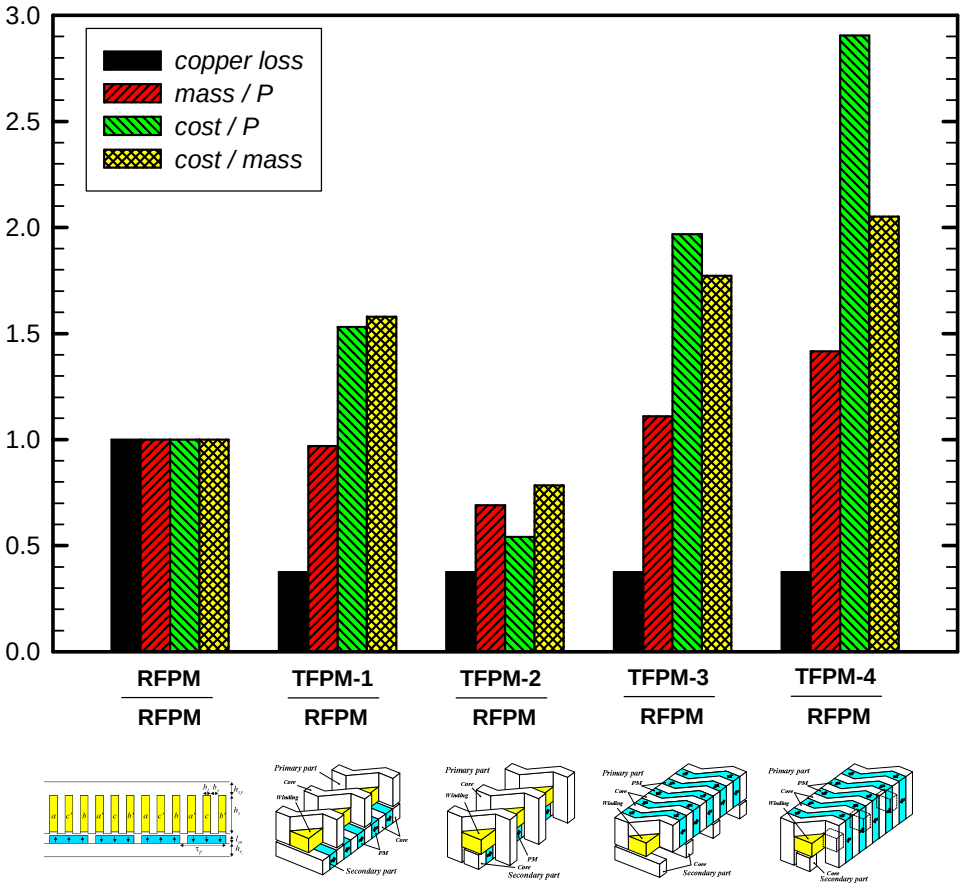
- **Design parameters**

Material parameter	
Remanent flux density of the magnets (T)	1.2
Recoil permeability of the magnets	1.06
Resistivity of copper at operating temperature (μΩm)	0.025
Cost modeling	
Laminations cost (€/kg)	3
Copper cost (€/kg)	15
Magnet cost (€/kg)	25

Generator parameter	
Generator power, P	5.56 MW
Rotational speed, rpm	12
Number of phase, m	3
Nominal current, i_s	675 A
No-load voltage, e_p	2746 V
Air gap length, l_g	6.14 mm
Air gap diameter, D_g	6.14 m

- **Design results**





6. Conclusions & Further researches

- **Conclusions**
  - Propose suitable concept for large direct-drive
  - Comparative design of a RFPM and different TFPM machines

- **Further researches**
  - Optimize TFPM machine considering *Electromagnetic construction & Module number*
  - Design new lightweight and cost-effective *Structural part (Inactive part)* with new guiding and supporting concept
  - Experimental work to verify the proposed concept

Thanks for your attention !