Doubly Excited Brushless Reluctance Machine for Advanced Wind Power Generation

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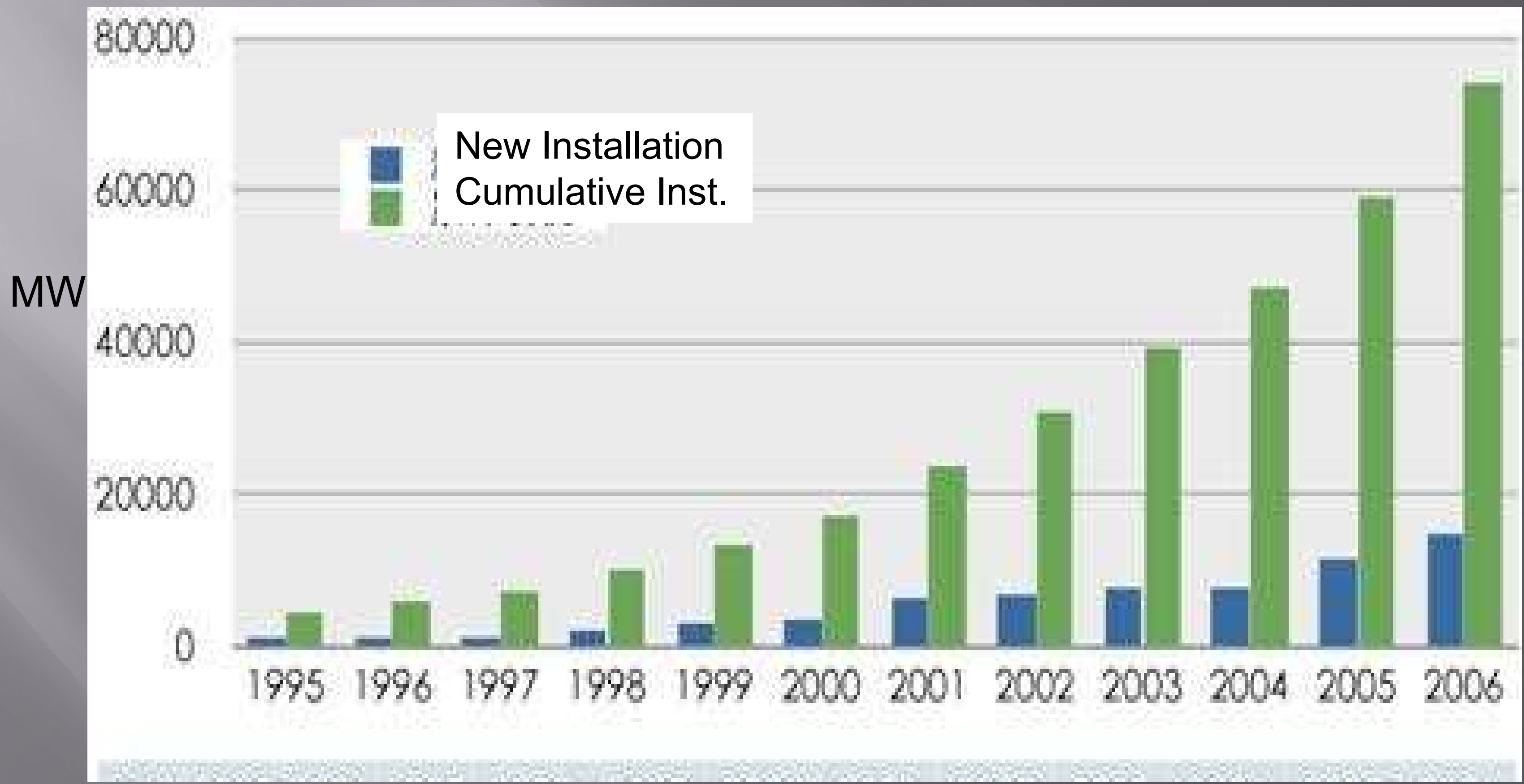
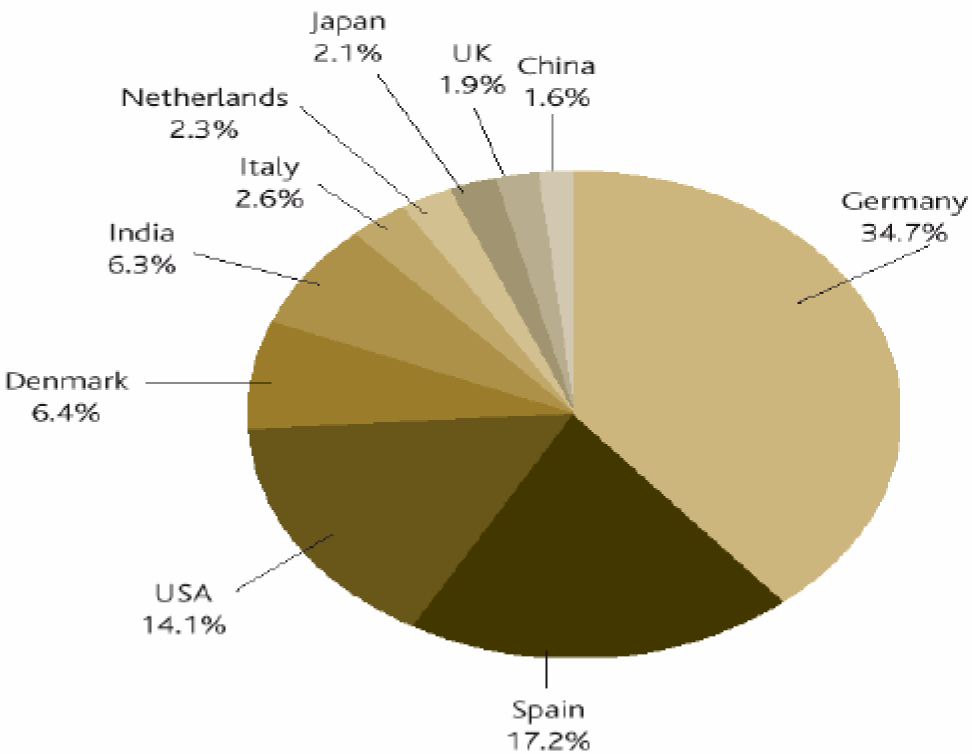
1. Introduction

1.1 Wind Power Generation – Rapid Growing Energy Technology – **Renewable, Sustainable, Non-Polluting**



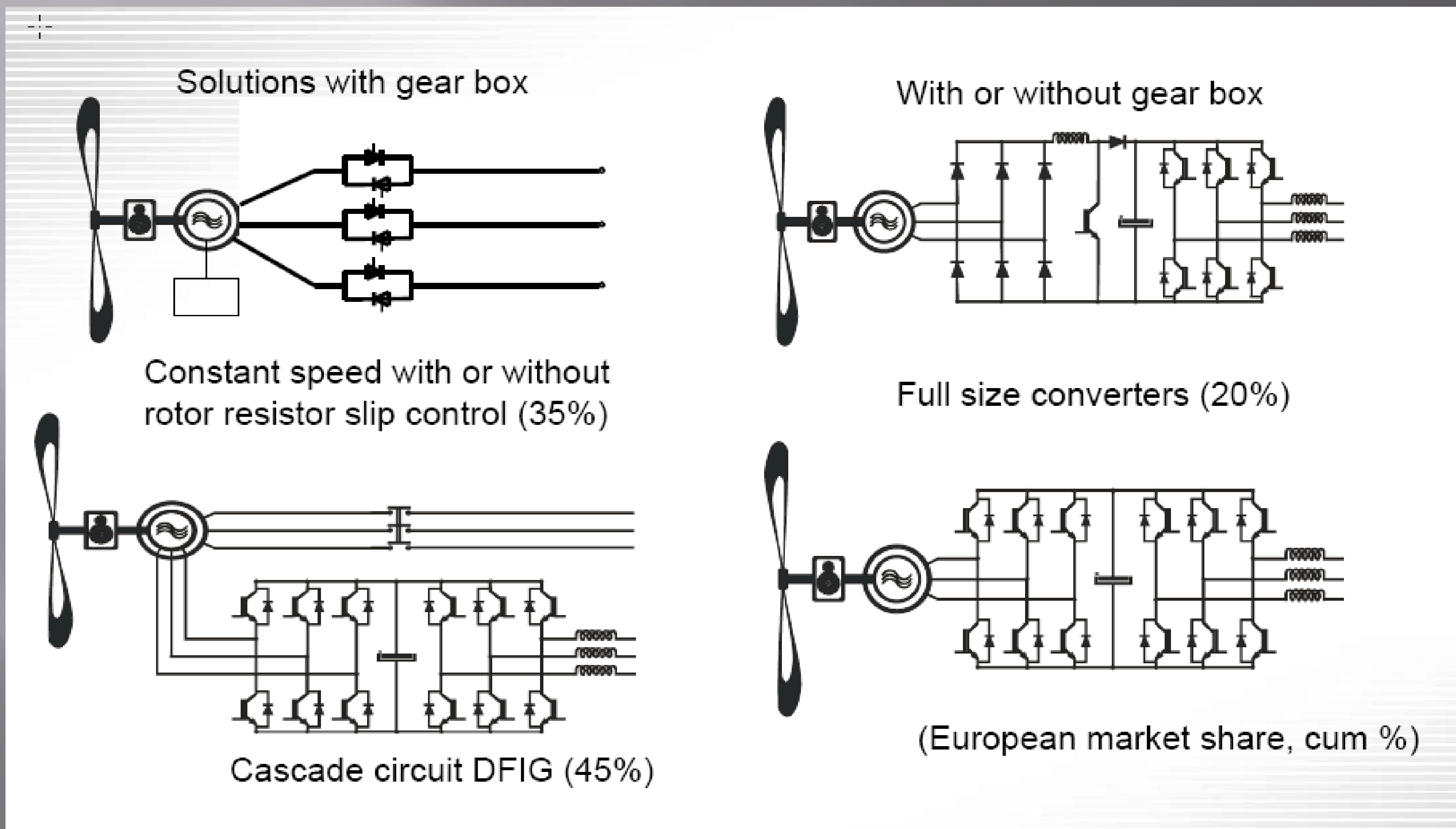
2004: 10 Largest Market in World

TOP TEN WIND POWER MARKETS 2004: CUMULATIVE MW INSTALLED

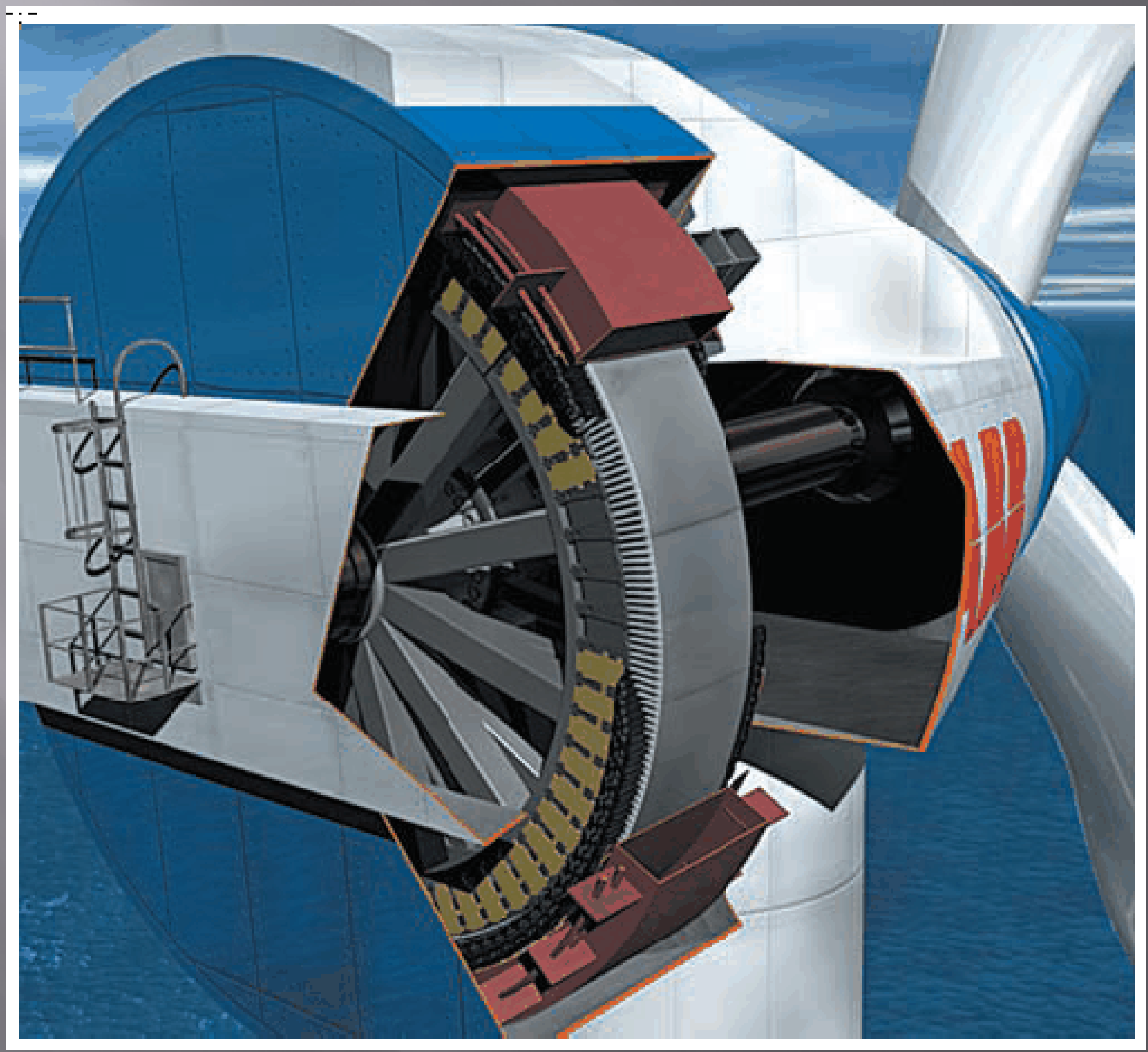


Country	Total capacity End 2004 (MW)
Germany	16,649
Spain	8,263
USA	6,750
Denmark	3,083
India	3,000
Italy	1,261
Netherlands	1,081
Japan	991
UK	889
China	769
Total	**42,735**

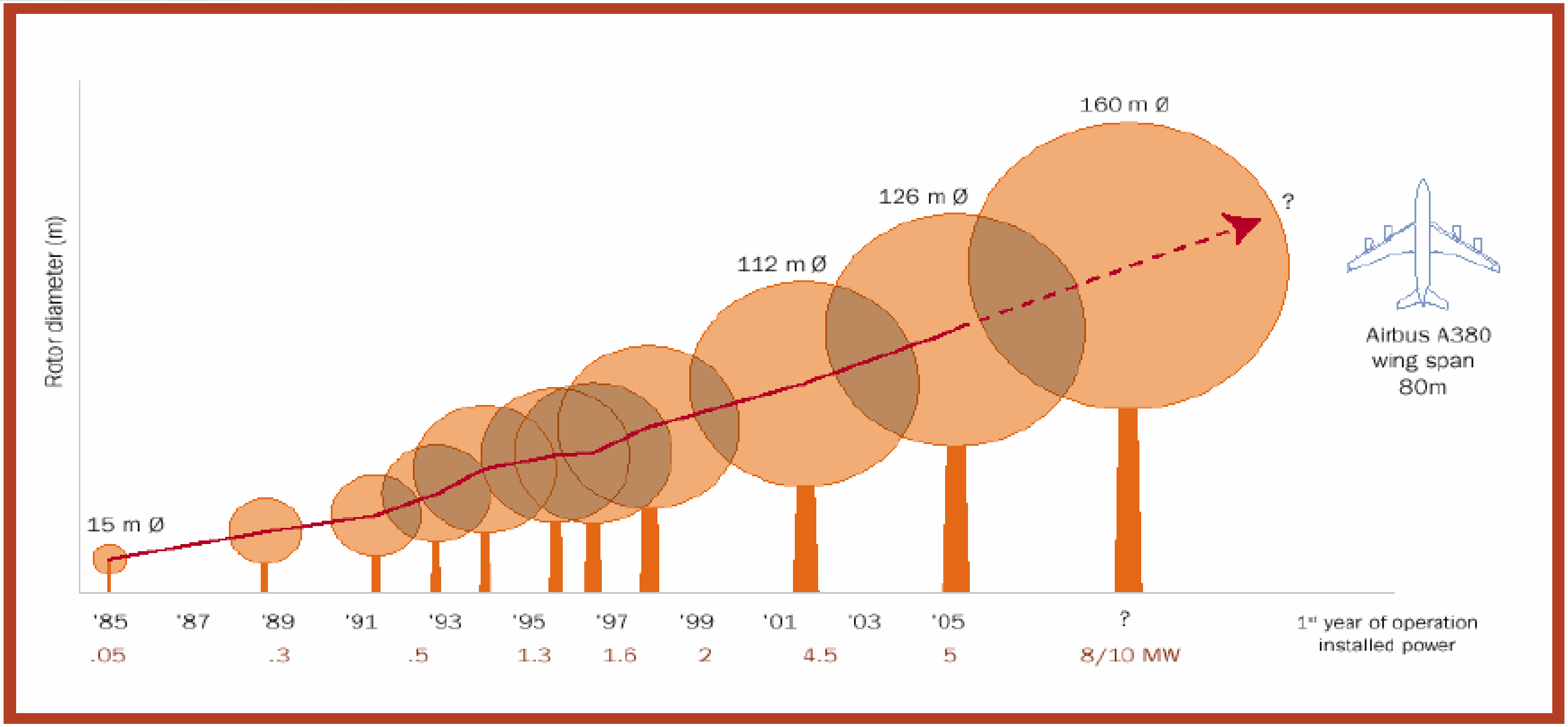
1.2 Major Wind Power Generation System Configurations



Example: Windformer (ABB)



Capacity Trajectory of Single Unit



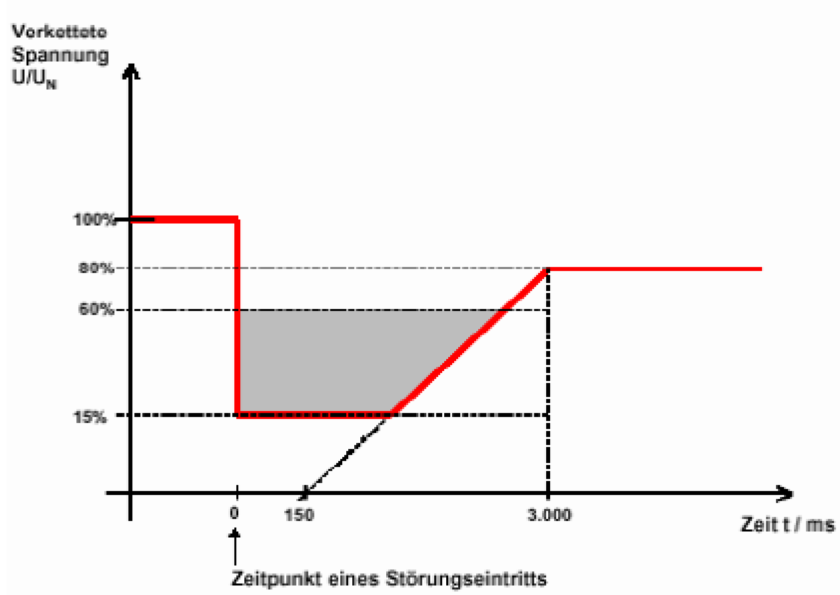
Source: Jos Beurskens, ECN

Mid 2005 the largest wind turbine had a diameter of 126 meters and an installed power of 5 MW.

1.3 Challenges to Remain in Power Grid

Voltage drop at three-phase short-circuit conditions

E-on was the first power supply company which, four years ago, issued instructions for connecting wind energy turbines to the high voltage grid.
Amongst other things, one requirement was that wind turbines should remain in the grid in the case of a short circuit



For network voltage values beyond the red line the automated disconnection from the network is not allowed

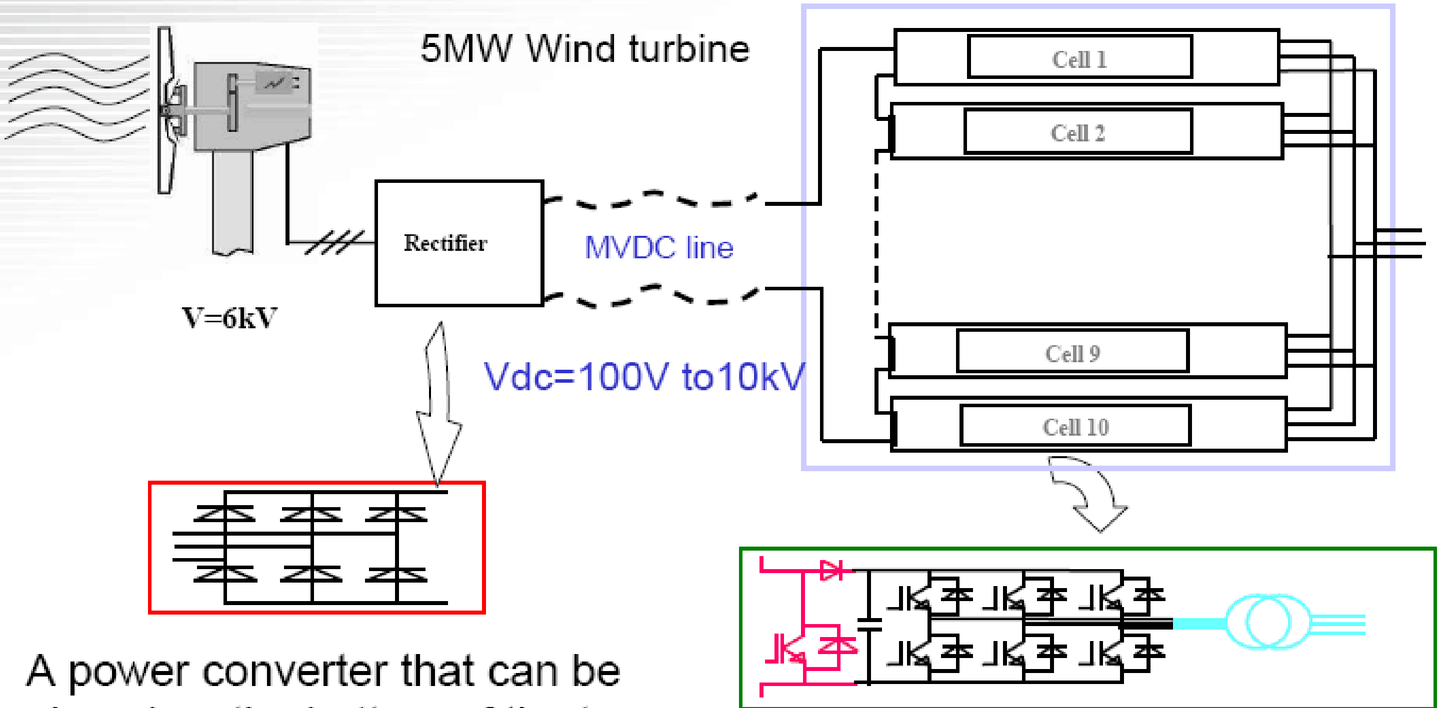
1.4 HVDC - Promising in Wind Power

HVDC Transmission new power electronics challenge

Recent advances in HVDC technology using IGBT based converters seem to offer a solution and facilitate cost effective construction of multi-terminal HVDC networks. These modern HVDC- IGBT systems offer clear technological advantages, especially in the area of controllability and efficiency, though their present transmission capacity is still too small to connect large amounts of offshore wind power capacity to the grid. A specific advantage of HVDC systems is reactive power control capability, favoring grid integration and system stability. The technical and economical aspects of offshore transmission systems are being actively investigated by the supply industry and by electric power companies in order to be ready with the most cost-effective solutions, when large scale offshore wind power takes off .

Off-Shore Wind Farm Based on HVDC

Medium voltage windmill on cell principle



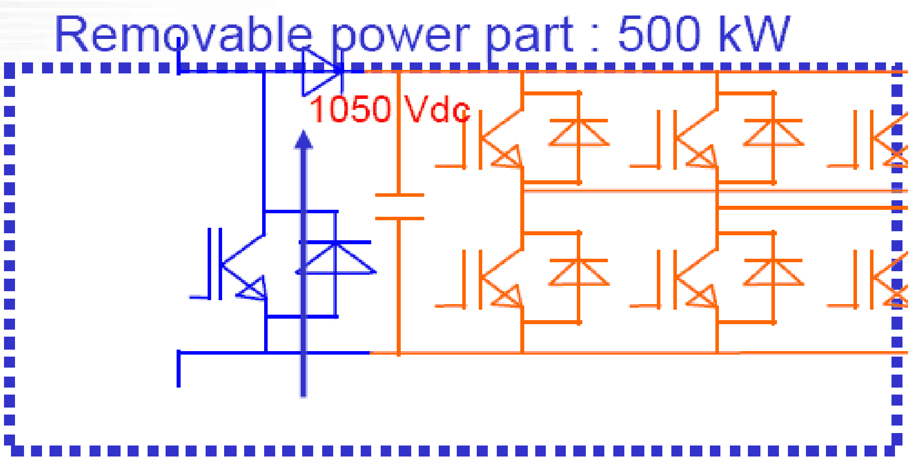
A power converter that can be placed on the bottom of the tower (less weight in the nacelle),

MV Cell

500KW VSI Module
- based on low power rating devices

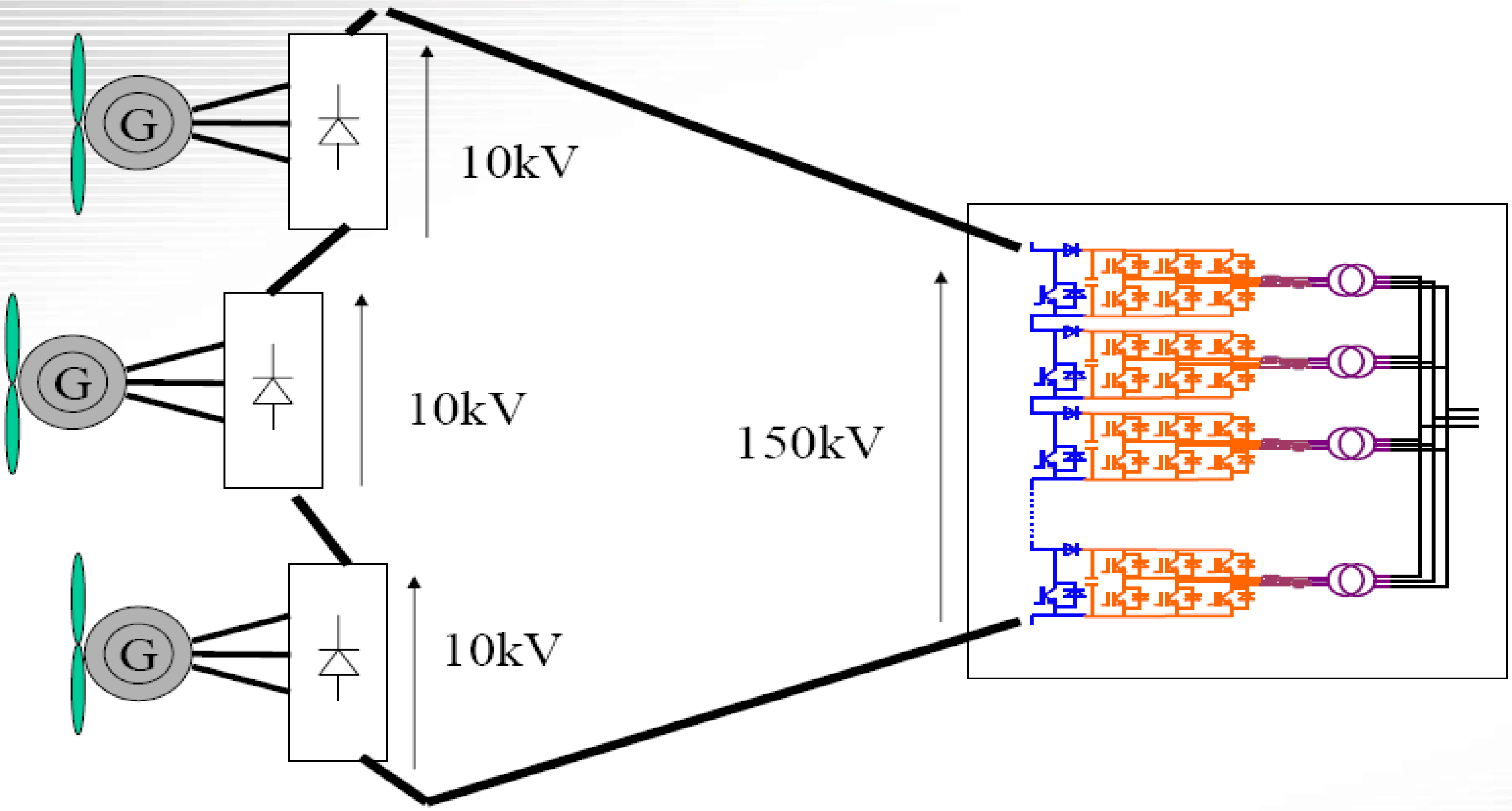
Basic 500kW cell example

Only low voltage semiconductors



Multi Units connected in series and power transmitted through HVDC

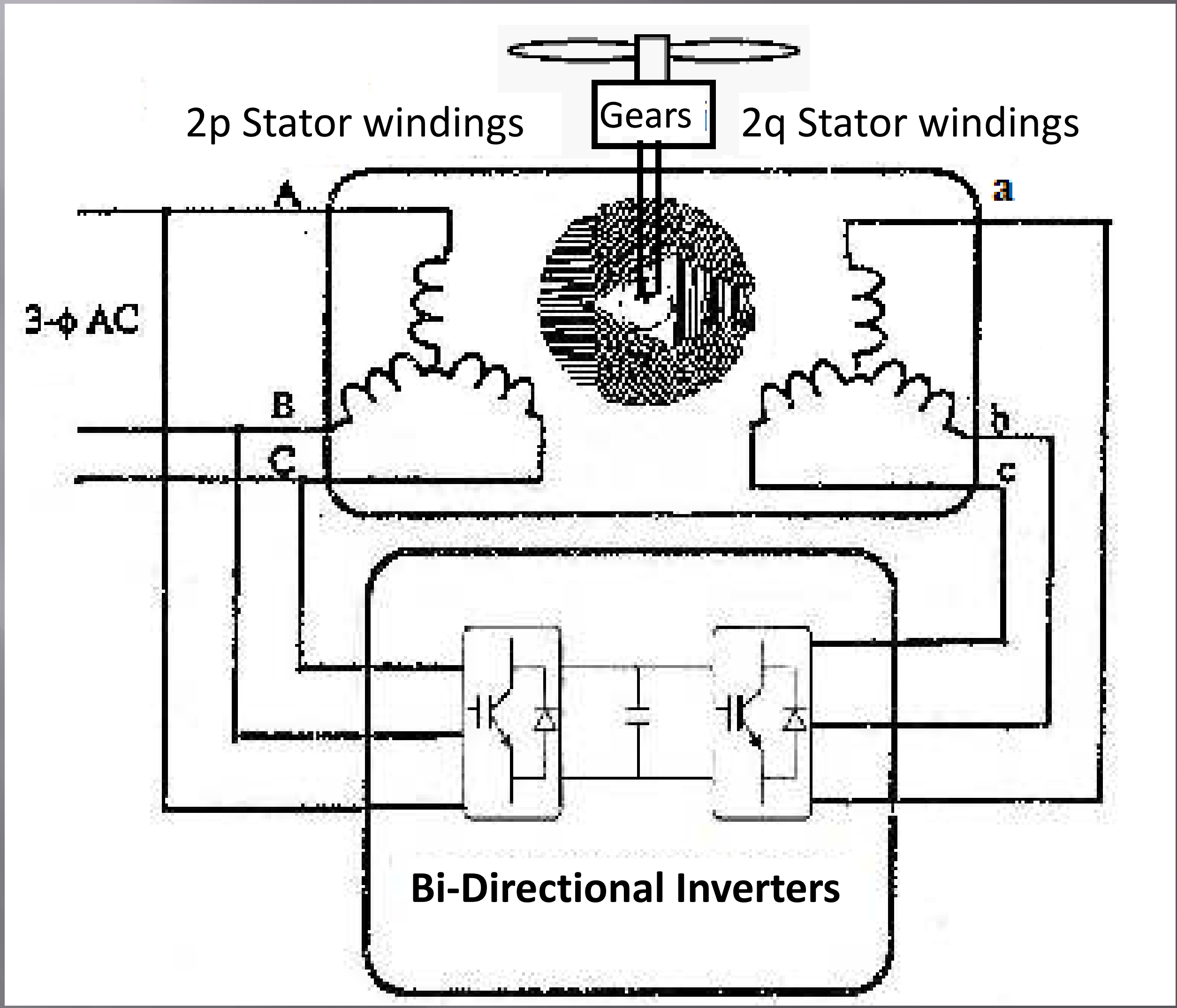
Series connection of several windmills



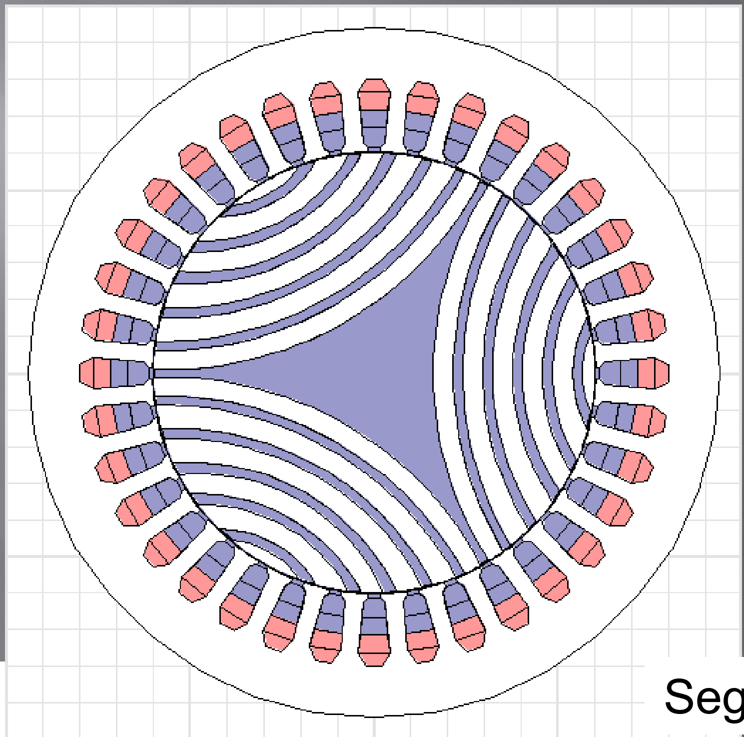
Connecting several windmills in series for DC voltages of 100kV or more; the power converter is on the shore, and the windmills are connected with a single cable

2. What and Why DEBRM ?

2.1 System Configuration



2.2 Magnetic Features



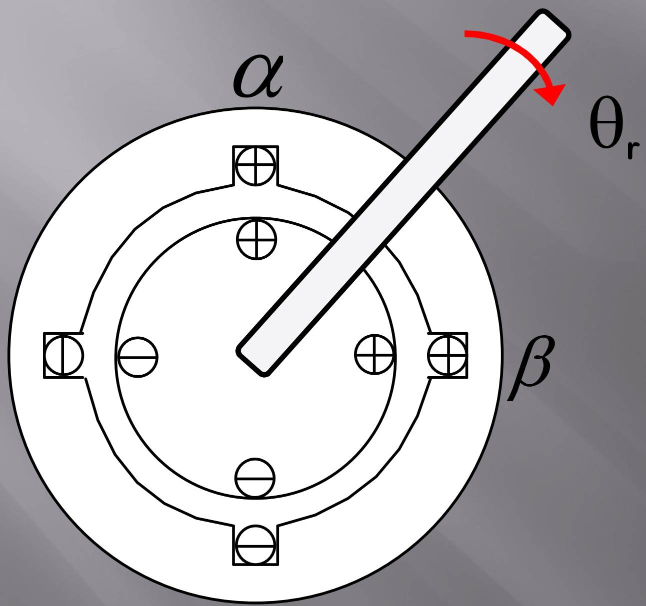
Dual Stator Windings

Segmental Reluctance Rotor

No windings, No Slip Rings and Brushes, No Magnets on Rotor!!

Review of E-M Energy Conversion 101

Sample 2-Phase
AC Machine



$$[V]=[i]r+\frac{d}{dt}\{[L][i]\}$$
$$=[i]r+\left(\frac{d}{dt}[L]\right)[i]+[L]\frac{d}{dt}[i]$$
$$=[i]r+\omega_r\left(\frac{d}{d\theta_r}[L]\right)[i]+[L]\frac{d}{dt}[i]$$

$$\frac{\partial[L]}{\partial\theta_r}=\begin{bmatrix} 0 & 0 & \vdots & -K_{sr}\sin\theta_r & -K_{sr}\cos\theta_r \\ 0 & 0 & \vdots & K_{sr}\cos\theta_r & -K_{sr}\sin\theta_r \\ \cdots & \cdots & + & \cdots & \cdots \\ -K_{sr}\sin\theta_r & K_{sr}\cos\theta_r & \vdots & 0 & 0 \\ -K_{sr}\cos\theta_r & -K_{sr}\sin\theta_r & \vdots & 0 & 0 \end{bmatrix}$$

Observations:

- All windings - magnetically coupled
- L_{mutual} - rotor position dependent
- Speed (motion induced) voltage exists

$$V_{speed} = \omega_r \left(\frac{d}{d\theta_r} [L] \right) [i]$$

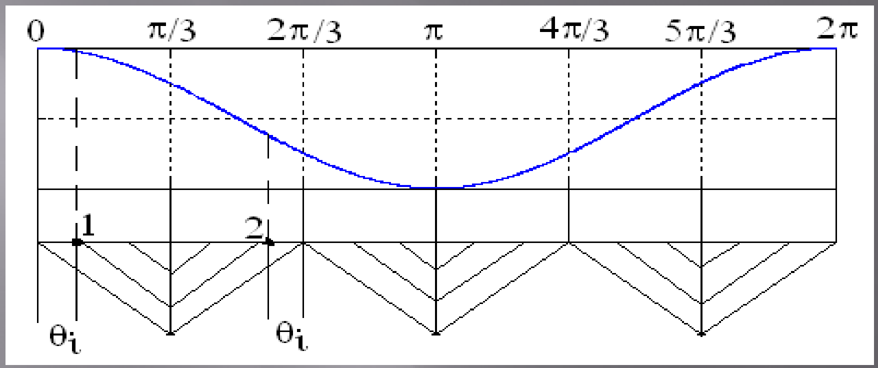
- Electromagnetic torque

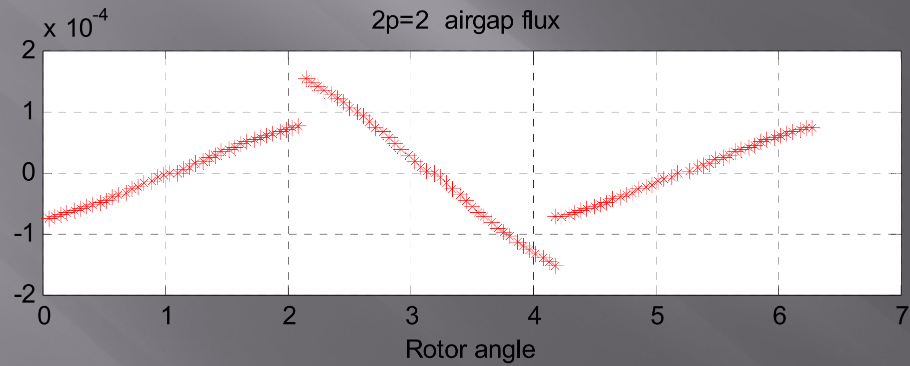
$$T_e = \frac{\partial W_{c0}}{\partial \theta_r} = \frac{1}{2} [i]^T \frac{\partial [L]}{\partial \theta_r} [i]$$

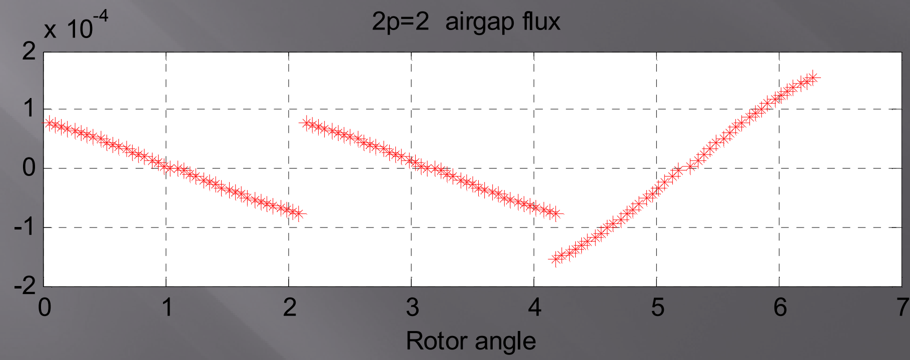
Electromechanical power

$$P_{EM} = \omega_m T_e$$

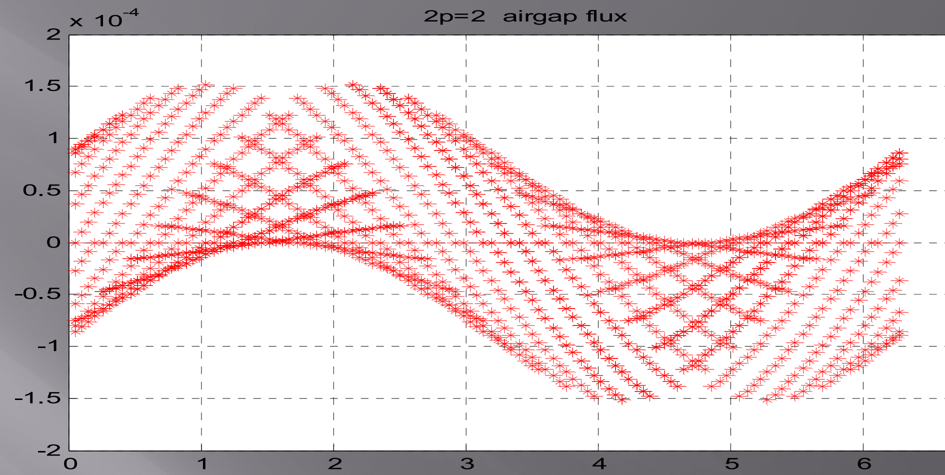
Inside Story of DEBRM



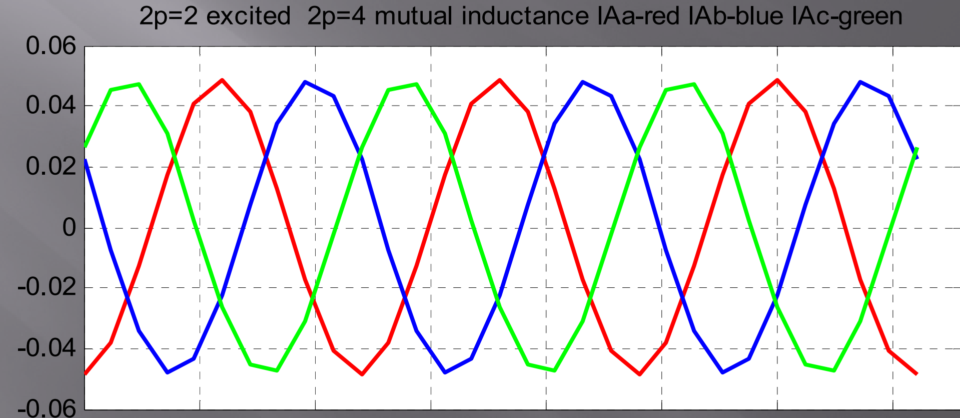




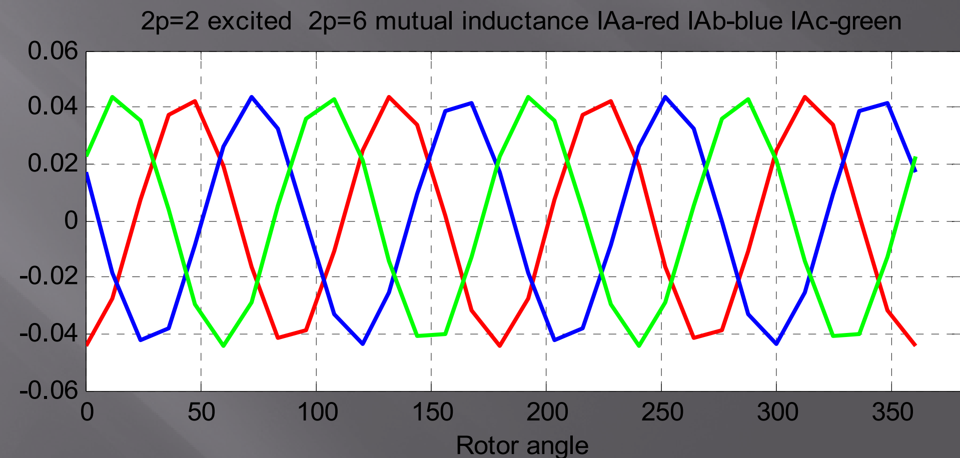
Air gap Flux Variation With Rotor Rotating



Mutual Inductance (Flux Linkage) Variation



Mutual Inductance (Flux Linkage) Variation



Pole #, Speed and Frequency Relation

$$p + q = p_r$$

With the above equation , the rotor speed *n_r* of the machine will be determined by

$$n_r = \frac{60\,(f_p \pm f_q)}{p+q}$$

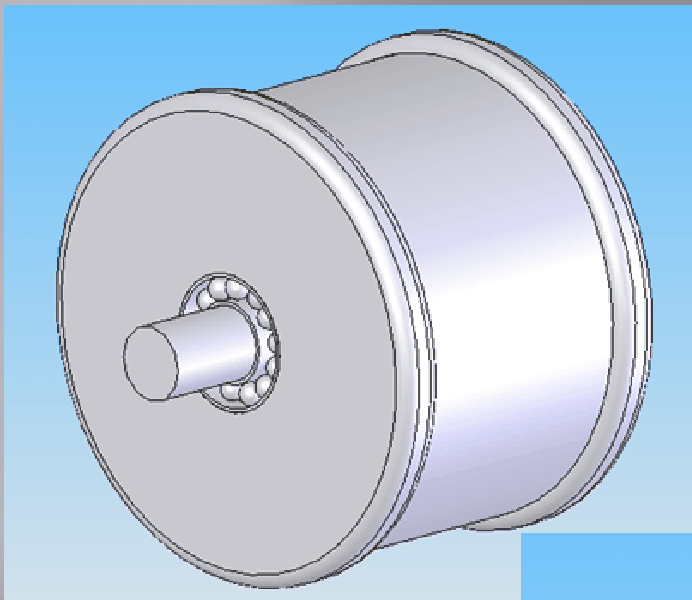
Can Be Made Very Low Speed without Severe Size Penalty!!

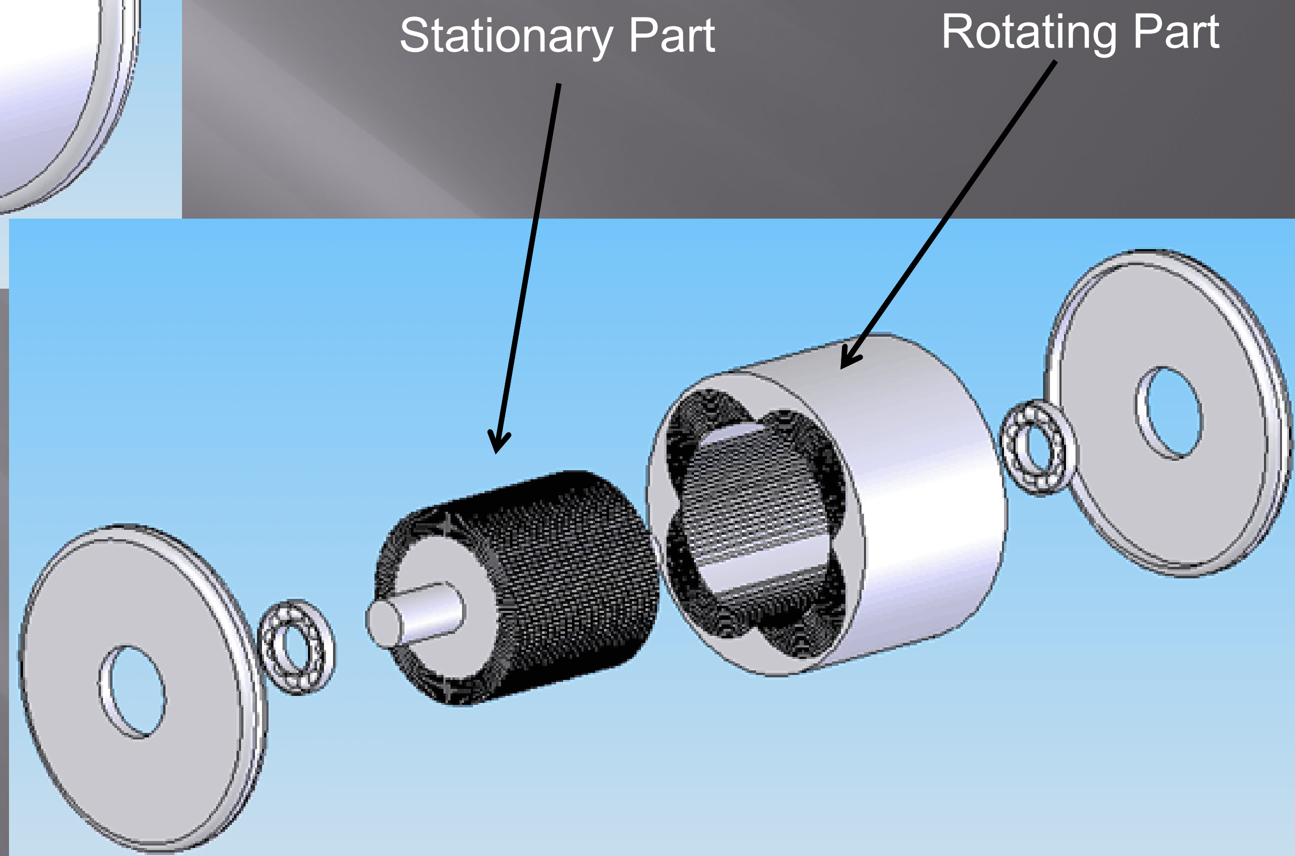
2.3 DEBRM Design in Wind Power Generation

Design Requirements:

Direct-Driven:	**No gear box**
Power Rating:	**2,000,000w**
Speed Range:	**10-30rpm**
Max. Torque:	**750,000 Nm**
Voltage:	**690 volts**
Current:	**1,700 amps**

Structure Illustration of Outer Rotor DEBRM





Result Highlights:

Rotor Pole Number： $2p_r=240$

Dual Stator Pole Numbers： $2p=60$ $2q=180$

Stator OD： 3698.4mm Stator ID： 3200mm

Rotor OD： 3850mm Rotor ID： 3700mm

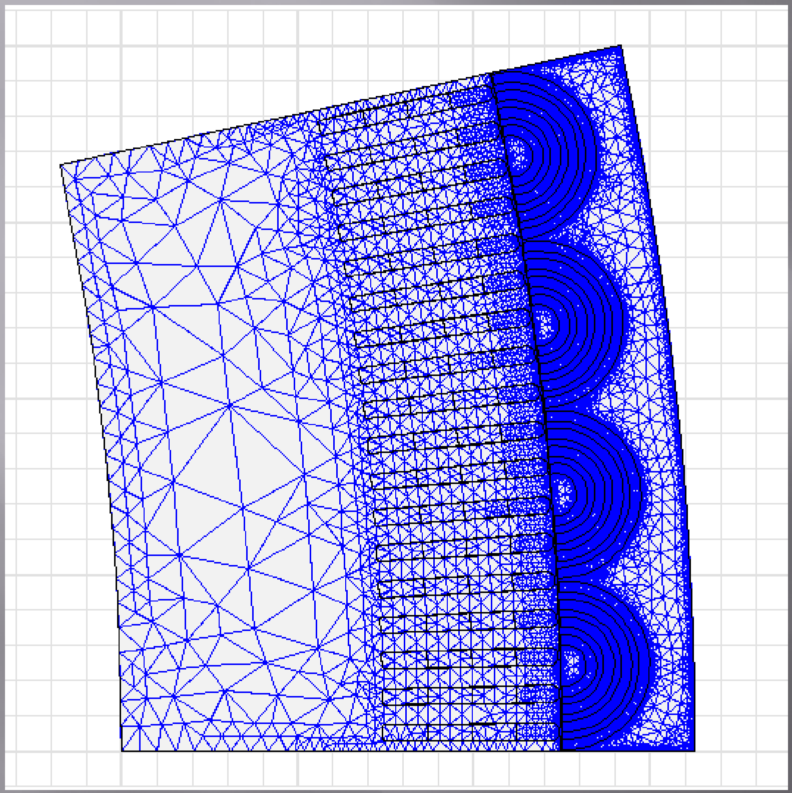
Effective L： 1300mm

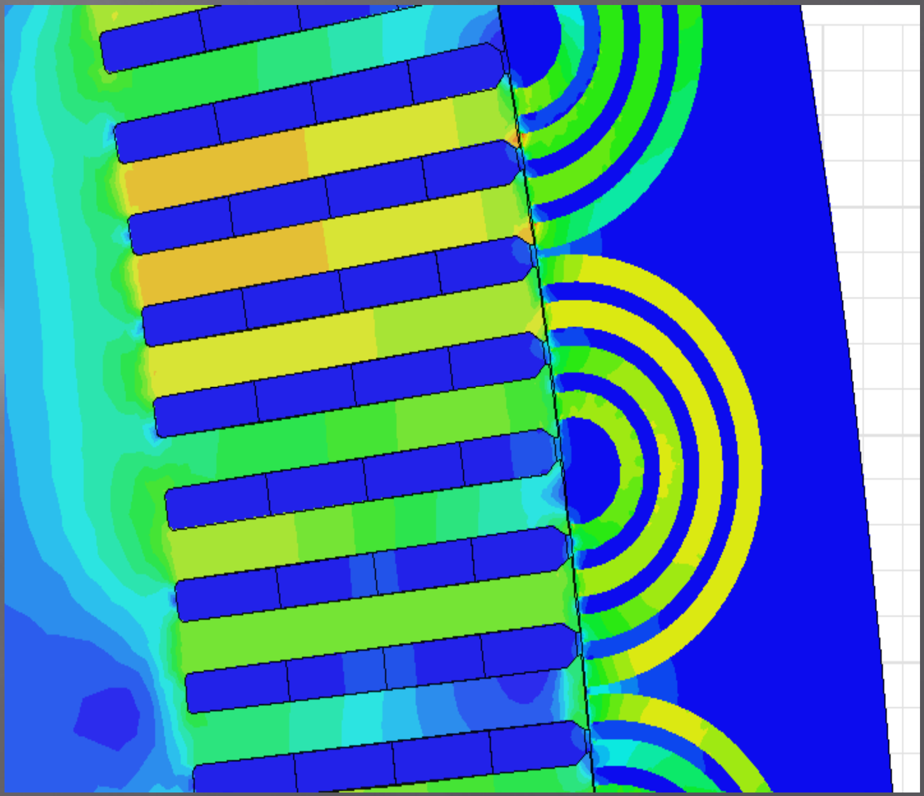
Estimated Weight of Copper： 7.3T

Estimated Weight of iron ： 25T

Estimated Weight of Total ： 35T

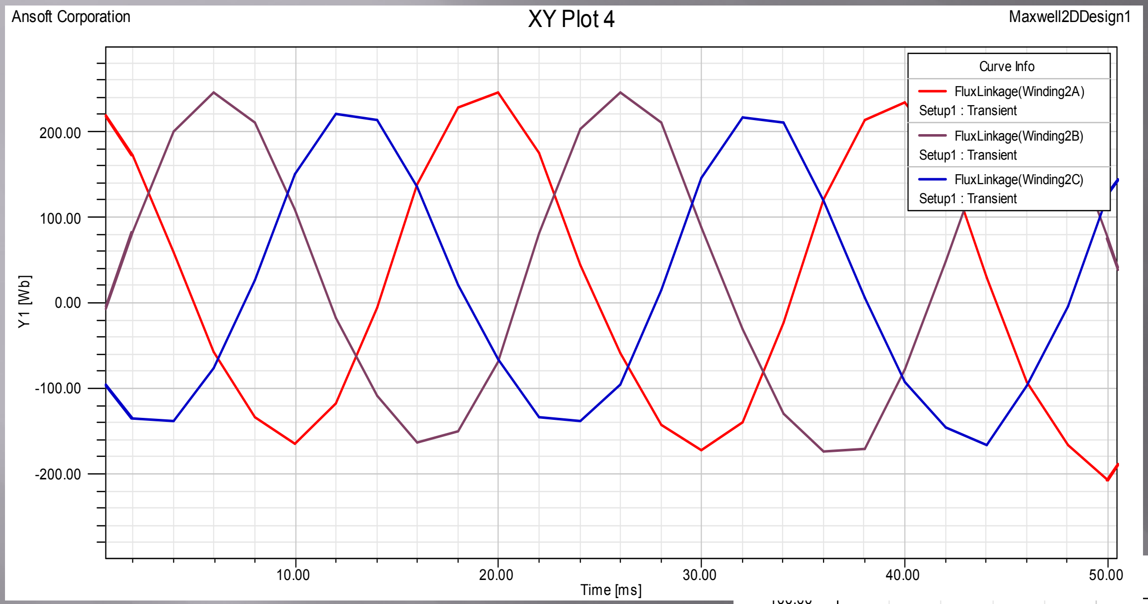
Stator-Rotor Geometry & FEM Evaluation

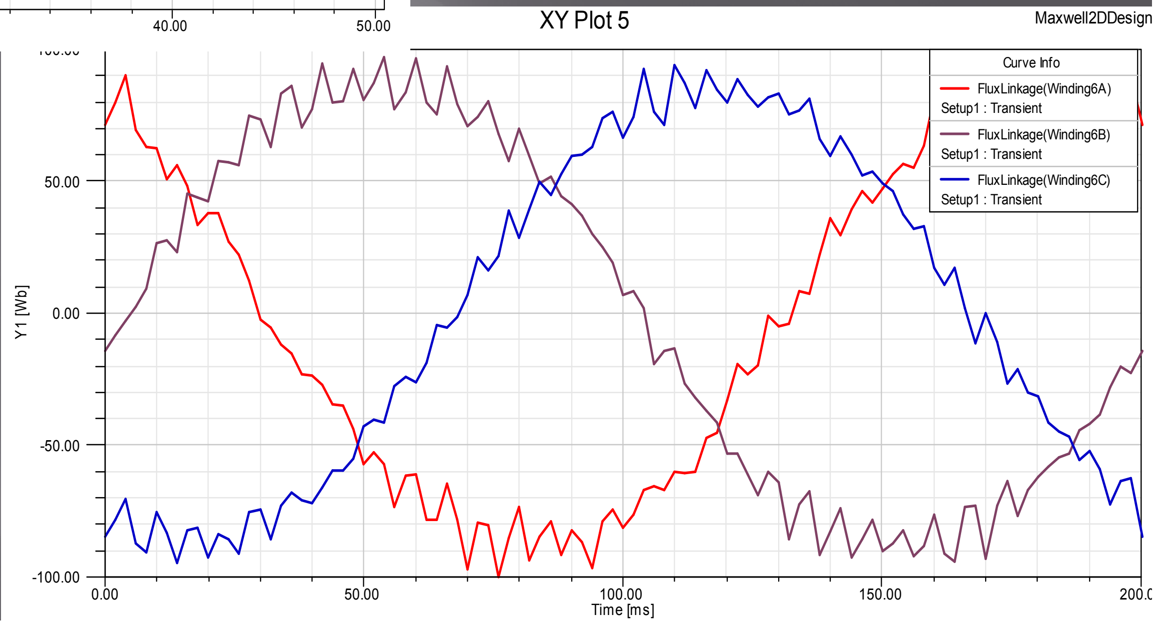




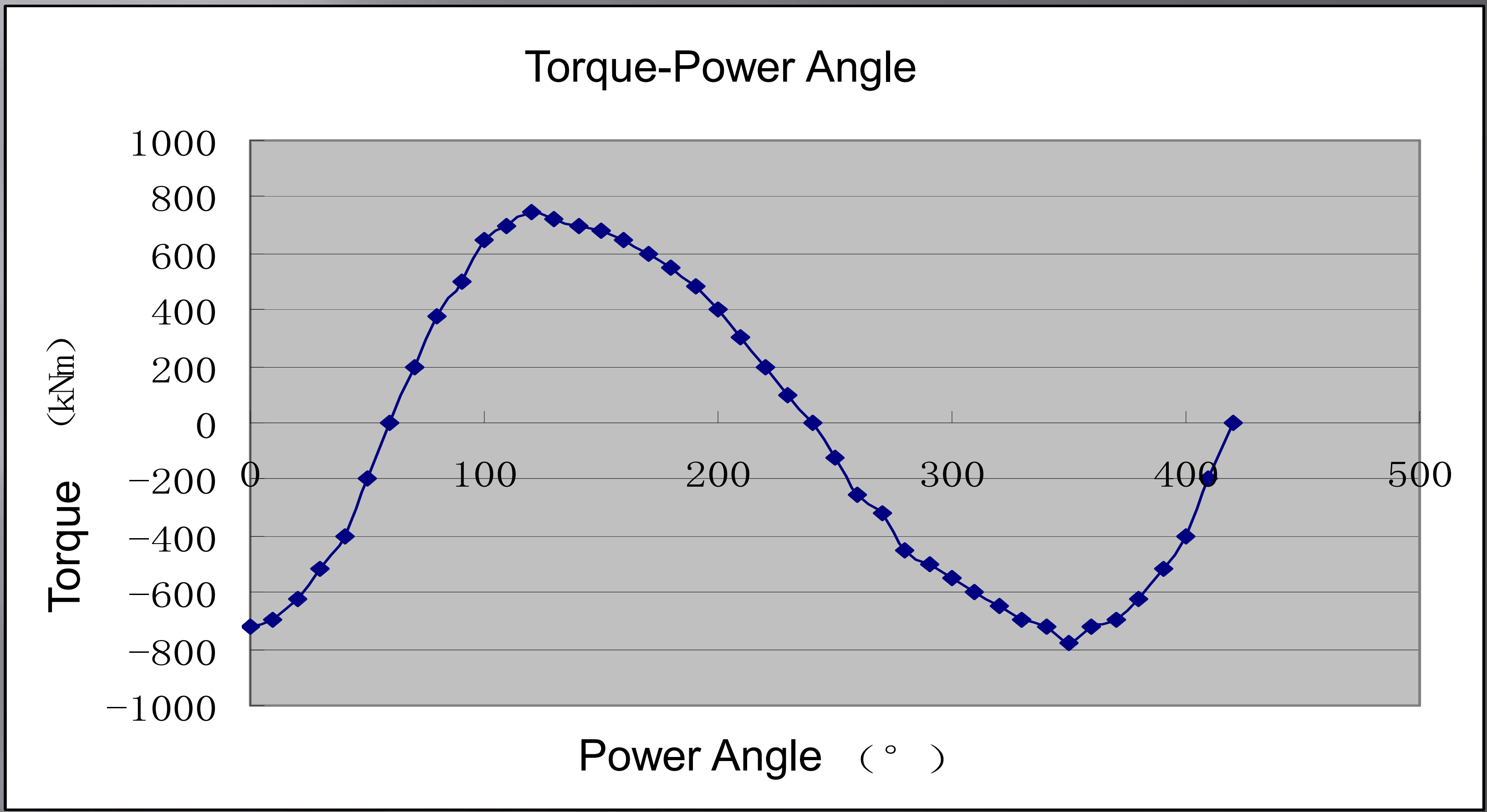
Modular Design – 1/30 of Total Geometry

Winding Mutual Flux Linkages as Function of Rotor Positions





Torque Capability



Comparison to Existing Technologies

Machine / Performance	Doubly Fed IMG	Direct-Driven PMG	DEBRM Generator
Gear Box	Required	No	No/Flexible
Size and Weight	Small	Very Big	Big/Small
Inverter Capacity	30%	100%	100-30%
Brushes -Slip Rings	Required	No	No
Permanent Magnets	No	Required	No
Control Complexity	Complex	Less Complex	Complex
Manufacturing	Conventional	Conventional	Rotor-New
HVDC Compatibility	No	Yes	Yes
Costs	Less	Heavy	Less

3. Conclusions

- Wind power technologies are growing in fast-pace. Advanced wind power generation system demands new technologies to enhance system reliability and reduce costs;
- DEBRM has no windings, no brushes and slip rings on the rotor，with a rugged structure、and easy maintenance, showing high potentials;
- It is possible to build doubly excited, directly driven wind power generating system using DEBRM. Compared to PM direct-driven systems, DEBRM direct-driven system needs no permanent magnets and has a controllable field;
- Operated in the doubly excited mode, the capacity of the inverter in DEBRM wind system is only a fraction of the total system capacity;
- DEBRM based wind power generation system is suitable for HVDC power transmission for off-shore wind farm.

Q & A

Thanks!