Optimal Design of a Rotating Transformer for a Doubly Fed Induction Generator

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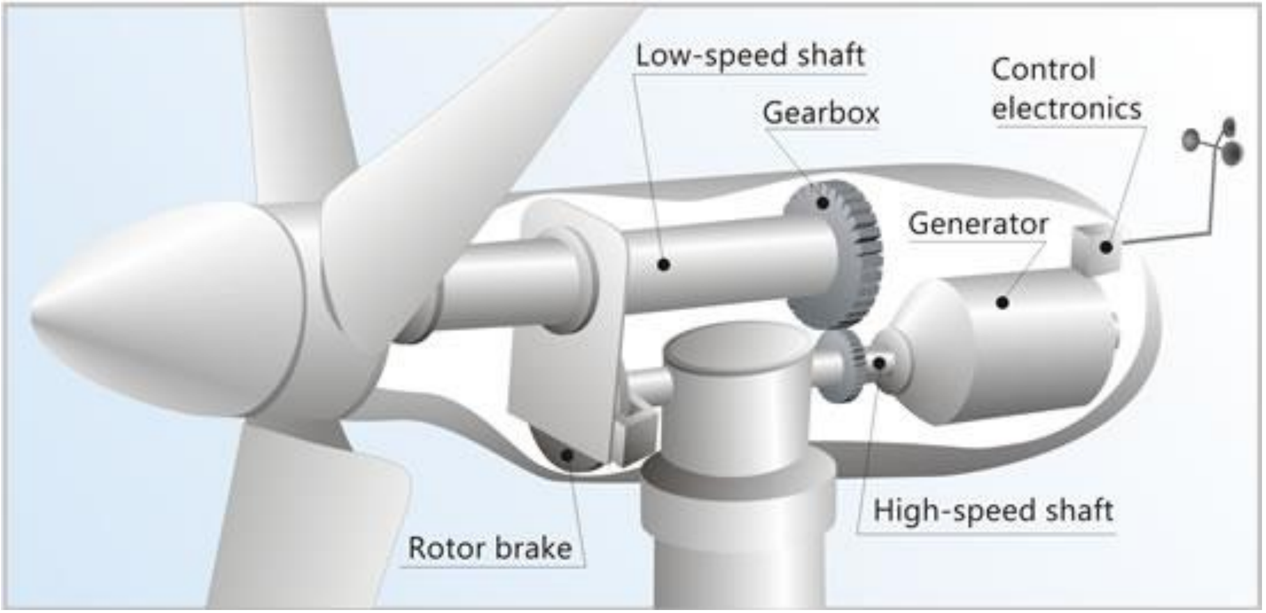
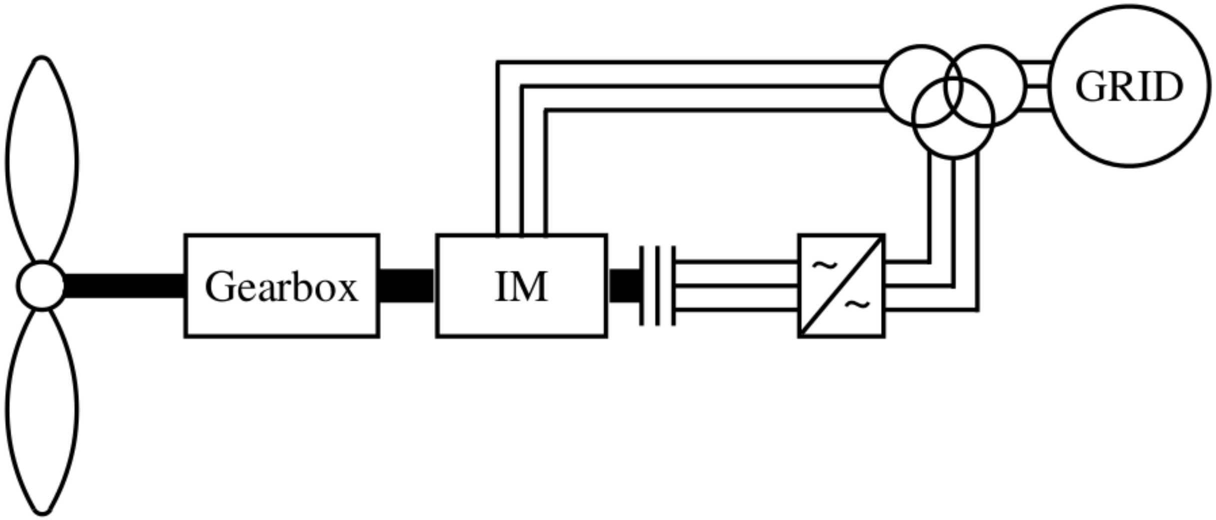
Introduction

- Global installed wind capacity of 369 GW in 2014 [1].
- Generator types: Synchronous or Asynchronous .
- Doubly Fed Induction Generator.



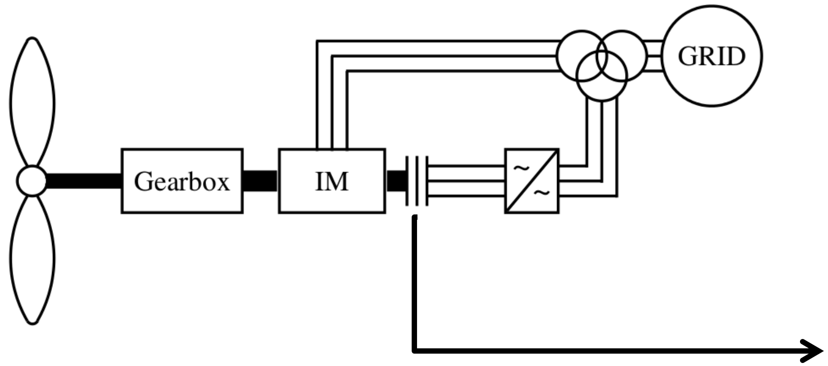
Doubly Fed Induction Generator



<u>Working principle:</u>

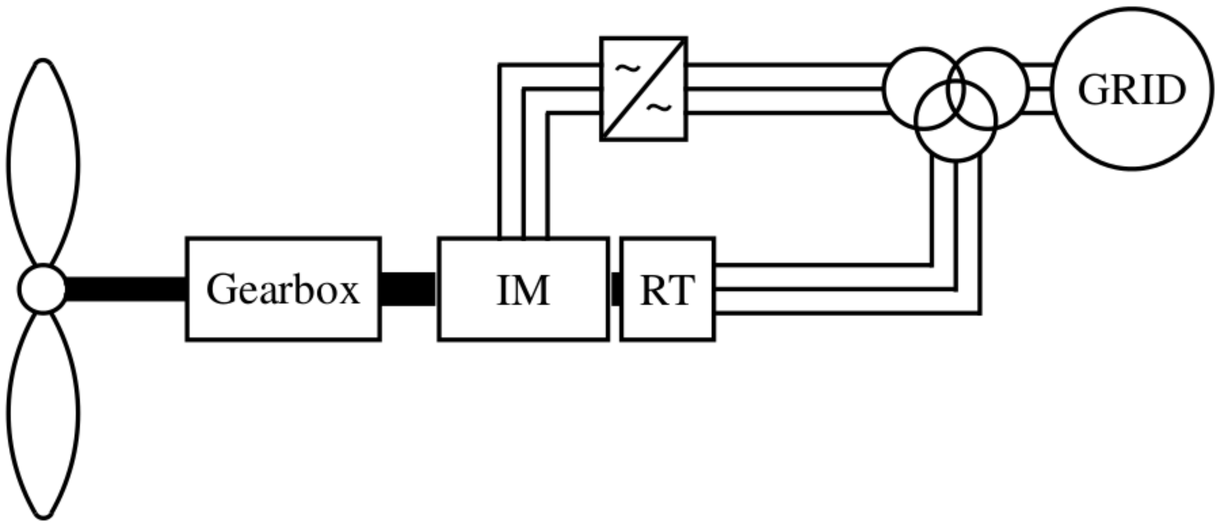
- Variable speed.
- Stator and rotor connected to sources.
- Control rotor current.

DFIG Disadvantages



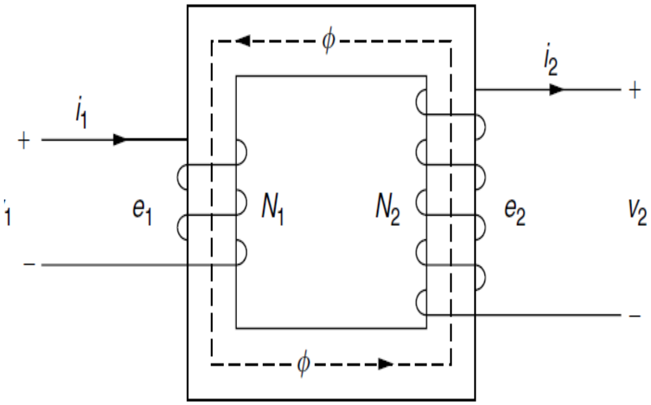
- Use of slip rings and brushes - increased maintenance
- Most common cause of downtime of the generator [2].

Rotating Transformer Concept

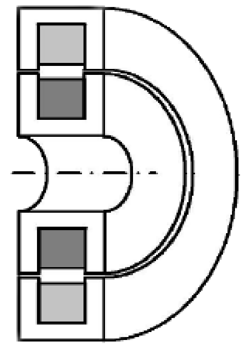


- Rotating transformer used to replace slip rings
- Provides magnetic coupling
- No mechanical contact - no wear.

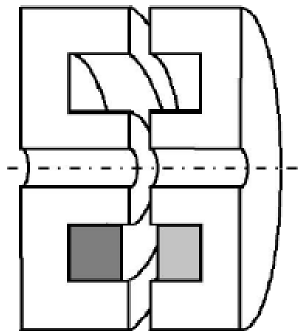
Rotating Transformer Concept



Standard



Axial



Radial

- Concept first proposed in 1971 for aerospace applications.
- Air gap between primary and secondary side to allow rotation.

Rotating Transformer Design

Limitations:

- Previously high frequency applications.
- Transformer size is inversely proportional to frequency.
- Material constraints.
- Adverse effect of air gap on transformer operation.

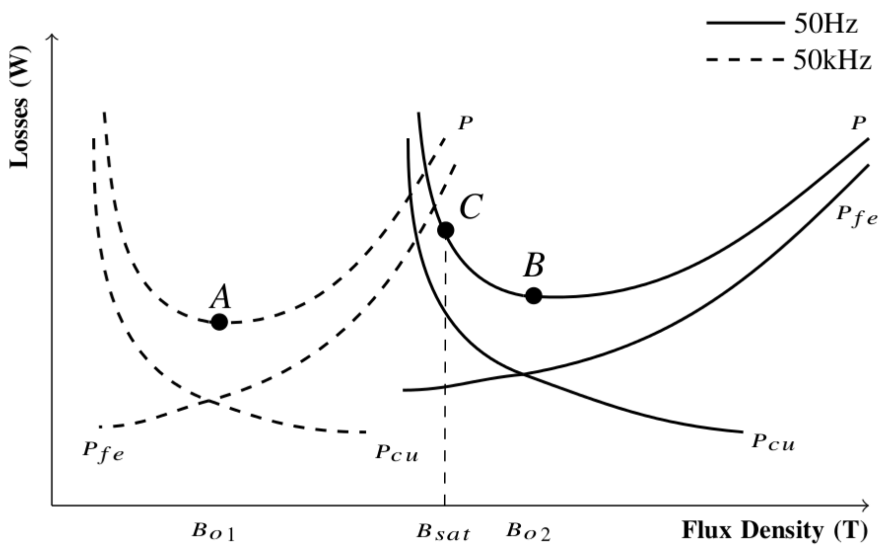
Optimal Design:

- Maximum efficiency
- Minimal size

Design Analysis

Methodology developed to find optimal design:

- Adjusted from classical optimal transformer design.
- Operating point that minimises losses and size.
- Evaluation and minimising of air gap effects.



Design Analysis

DESIGN CONSTRAINTS

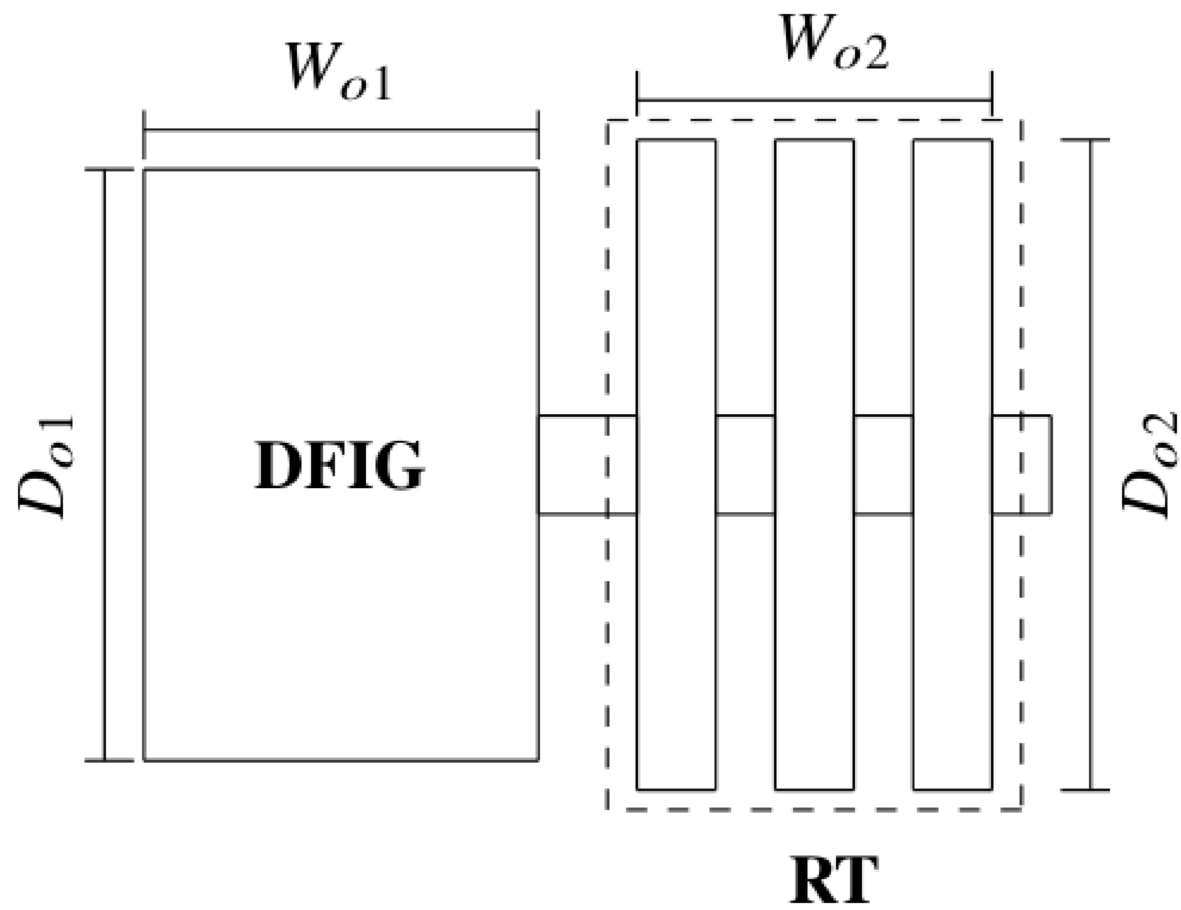
Symbol	Parameter	Value	Unit
S	rated output power	1000	VA
K_f	waveform coefficient	4.44	–
K_u	window utilization factor	0.4	–
B_{sat}	saturation flux density	1.8	T
K	emf/turn empirical constant	1.1	–
f	frequency	50	Hz
V_o	output voltage	230	V
ΔT	allowable temperature rise	40	$°C$
η_{min}	minimum efficiency	90	%

Design Analysis

DESIGN PARAMETERS OF SINGLE PHASE TRANSFORMER

Symbol	Parameter	Optimal Design	Unit
N_p	primary turns	210	–
N_s	secondary turns	210	–
B_m	maximum flux density	1.4	T
J	current density	5	A/mm^2
A_c	core area	35.39	cm^2
D_{so}	outer diameter	212.26	mm
l_1	outer width	68.89	mm
l_g	air gap length	0.35	mm

Design Analysis



Design Analysis

Rotary transformer dimensions for various power levels

	D_o	W_o	Unit
3 kVA			
DFIG	205	316	mm
Rotary transformer	212.26	206.67 (68.89 × 3)	mm
400 kVA			
DFIG	723	1317	mm
Rotary transformer	859.77	1171 (590.5 × 3)	mm
1 MVA			
DFIG	1850	3150	mm
Rotary Transformer	1292.83	1932 (644 × 3)	mm

Conclusions and future work

- Methodology developed to minimize size while maintaining low losses.
- Results in smaller core area than classic design approaches.
- Design addresses and mitigates air gap effect.

Future work:

- Prototype to be built and tested.
- Tested in conjunction with induction machine

Questions

References:

[1]. Global wind energy council, “Global wind energy statistics 2014.”

[2]. A. Stenberg and H. Holttinen, “Analysing failure statistic of wind turbines in Finland.”