

Reduction of Unbalanced Magnetic Pull in Doubly-Fed Induction Machine

By

Obaid Aamir

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School of Electrical, Mechanical and Mechatronic Systems
Faculty of Engineering and Information Technology

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Certificate

I, Obaid Aamir, declare that this thesis titled, Reduction of Unbalanced Magnetic Pull in Doubly-Fed Induction Machine, and the work presented in it are my own. I confirm that:

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- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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Dedication

*To my parents,
The reason of what I become today.
Thanks for your wonderful support.*

*To my sisters,
You have been my inspiration.*

Abstract

This thesis reports on an investigation into the unbalanced magnetic pull (UMP) in a wound rotor induction machine due to static rotor eccentricity. Wound rotor induction machines are commonly used in wind turbines as doubly-fed induction generators (DFIGs). It is important to maintain them in good working order and operational. There can be substantial bearing wear in these machines due to their almost continuous operation, and it is important to maintain low bearing wear of these machines in order to maintain good operation. These machines can have high maintenance costs since they are located in remote locations and in the nacelle of the wind turbine. When the rotor becomes eccentric (non-centred) bearing wear is increased and the maintenance requirement increases. It has been illustrated that the UMP is higher per unit in a wound rotor induction machine compared to the cage induction machine equivalent.

In this study, a new measurement rig is developed in order to measure UMP. The methods for calculating UMP and splitting UMP and torque forces are addressed in this thesis. Furthermore, a new method for minimizing UMP is also introduced by using damper windings. Different tests and calculations are presented in this thesis. The understanding of the radial forces involved in producing UMP in a wound rotor induction machine is addressed. There is little literature on UMP in a wound rotor induction machine.

List of Symbols

$b(y,t)$	Radial flux density in air gap at point y and time t [T]
$b_n(y,t)$	Normal flux density in air gap at point y and time t [T]
$b_t(y,t)$	Tangential flux density in air gap at point y and time t [T]
b_r	Rotor slot opening [m]
b_s	Stator slot opening [m]
c	Number of turns in a coil
$e(y,t)$	Air gap electric field at point y and at time t [V/m]
$e_s(y,t)$	Air gap electric field due to stator current at point y and at time t [V/m]
f_e	Electrical frequency [Hz]
f_r	Rotor fundamental current frequency [Hz]
g	Mean air gap length when the rotor is concentric [m]
$g(x,y)$	Effective axial air gap length at point x,y in the air gap [m]
h	Search coil number
i_r	Rotor current [A]
$i_x(t)$	Harmonic current [A]
$j_r(y,t)$	Rotor current density at point y and at time t [A/m]
$j_s(y,t)$	Stator current density at point y and at time t [A/m]
$j_x(y,t)$	Current density at point y and at time t [A/m]
k	Inverse of average air gap radius [m]
k_r^n	Rotor slot opening factor
k_s^n	n^{th} harmonic stator slot opening factor
n	Variation in axial direction
n_s	Synchronous speed [rpm]
n_r	Mechanical speed [rpm]
p	Number of pole pairs
r	Mean air gap radius [m]
s	Motor slip [p.u.]

x	Variation in axial direction when analysing linearized machine, horizontal direction when analysing forces on axial cross section of machine, or horizontal direction of forces in UMP measuring rig [m]
y	Variation in circumferential direction when analysing linearized machine, vertical direction when analysing forces on axial cross section of machine, or axial direction of forces in UMP measuring rig [m]
x	Variation in radial direction when analysing linearized machine, or vertical direction of forces in UMP measuring rig [m]
C_w	Number of conductors in the w^{th} slot
D	Difference between centres of rotor and stator [m]
F_x	Force in x (horizontal) direction in axial cross section of machine [N]
F_y	Force in y (vertical) direction in axial cross section of machine [N]
\bar{J}_s^n	Stator current density coefficient of n^{th} current harmonic [A/m]
K_s	Slot opening factor
L	Axial length of the stator [m]
N_w	Number of slot at which winding is located
\bar{N}_s^n	n^{th} harmonic winding coefficient of stator
P	Air gap permeance [m^{-1}]
P_m	Fundamental pole pair number of machine
P_{mech}	Mechanical power [W]
R_r	Rotor resistance [Ω]
T_{mech}	Mechanical torque [Nm]
V_D	Induced Voltage [V]
∂	Degree of offset [p.u. of air gap length g]
ξ	Induced EMF [V]
μ_o	Permeability of free space
σ_n	Maxwell stress [N/m^2]
ω_m	Mechanical rotational velocity [rad/s]
Ψ_m	Air gap magnetic flux [Wb]
Ψ_r	Rotor magnetic flux [Wb]
Ψ_s	Stator magnetic flux [Wb]

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