UNIVERSITEIT·STELLENBOSCH·UNIVERSITY

Simplified Analysis Technique for Double Layer Non-overlap Multiphase Slip Permanent Magnet Couplings in Wind Energy Applications

Petrus JJ van Wyk - Prof. Maarten J. Kamper

Renewable Energy Postgraduate Symposium

ELECTRICAL MACHINES LAB

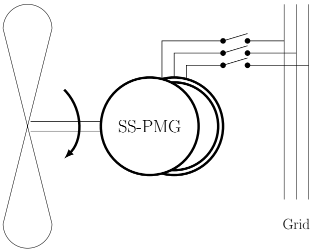
July 13, 2015

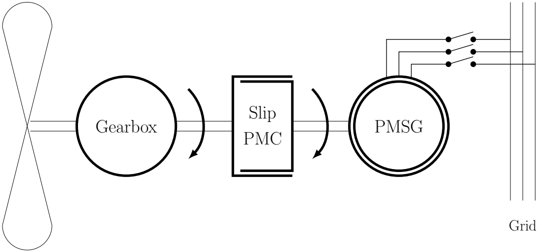
- Electromagnetic couplings are well known in industry
  - Permanent magnet couplings
  - Eddy current couplings
- Recently a new concept wind generator was introduced [1]
  - Slip PM coupling
  - Sharing common PM rotor with a Synchronous Generator
  - Called Slip Synchronous PMG
  - Slip-PMC filters transient torque
- Double layer, non-overlap winding slip-PMC introduced in Potgieter (2014)[2]
- Calculations made for these machines - accurate, but not necessarily applicable to all machines

[1] J.H.J. Potgieter and M.J. Kamper (2012), Design of New Concept Direct Grid-Connected Slip-Synchronous Permanent-Magnet Wind Generator, *IEEE Transactions on Industry Applications* 48(3), 913 – 922.

[2] J.H.J. Potgieter and M.J. Kamper (2014), Optimum Design and Comparison of Slip Permanent-Magnet Couplings With Wind Energy as Case Study Application, *IEEE Transactions on Industry Applications* 50(5), 3223 – 3234.

Introduction

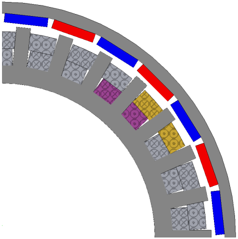


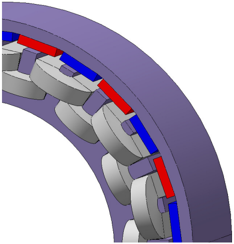


The machine analysed in this paper is a

- Double layer,
- Short Circuited,
- Non-overlap winding,
- Permanent magnet motor
- Operating under slip conditions as a coupling.

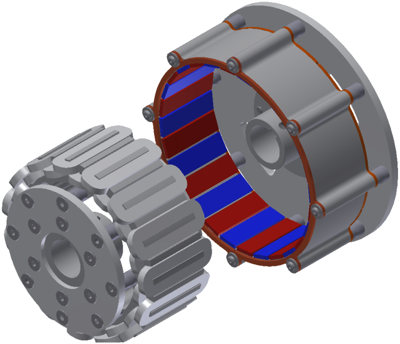
This machine is thus referred to as a slip coupler.





Slip coupler specifications:

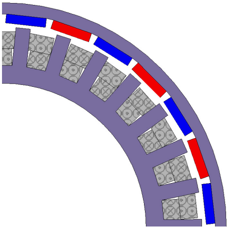
- 28 poles
- 30 slots
- Solid aluminium windings
- Output speed of 600 r/min
- Rated slip of 3%
- Torque at rated slip - 35 Nm

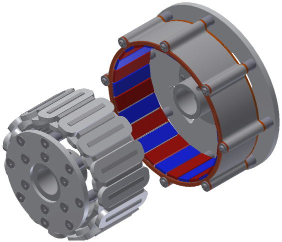


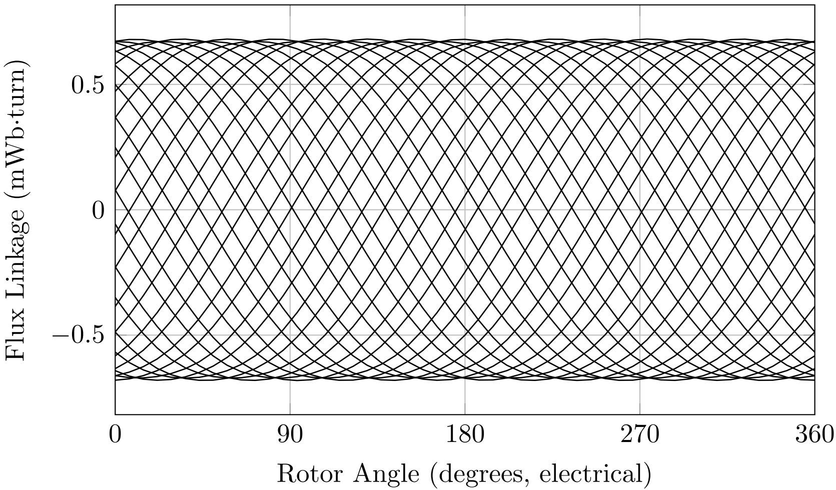
The slip coupler concept presents several unique analysis problems:

- It is a 30 phase machine
- Different cross sectional areas between upper and lower layer coils
  - Different resistance values
  - Thus different current values
- Cannot be analysed using standard three-phase analysis methods

How can such a machine be analysed?

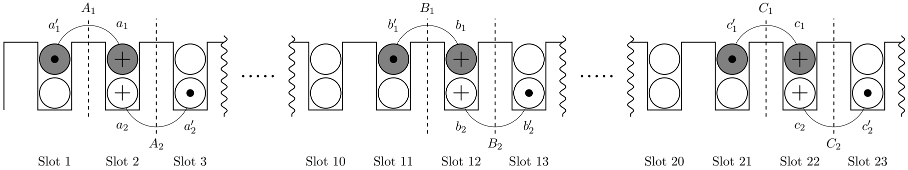


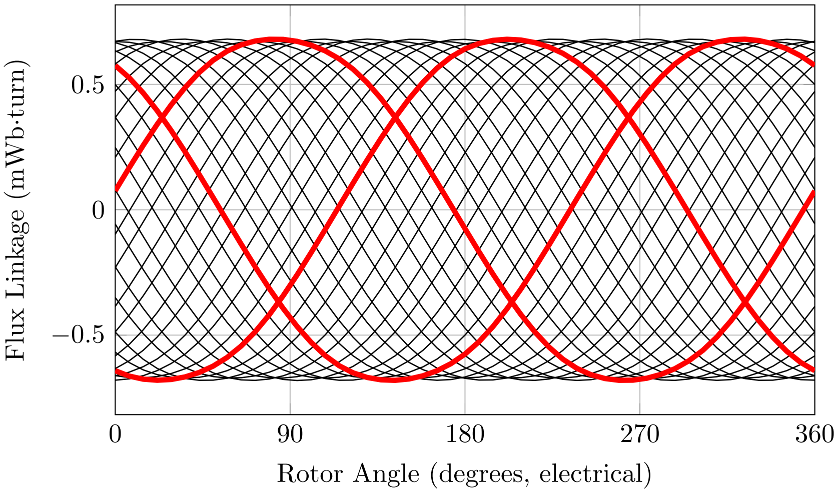


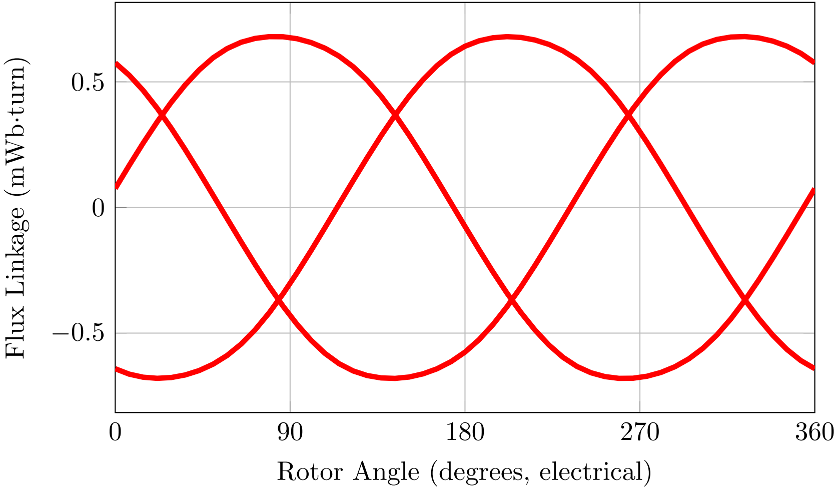

Flux Linkage (mWb·turn)
0.5
0
−0.5
0
90
180
270
360
Rotor Angle (degrees, electrical)

Phases are divided into sets of three:

- Each phase is chosen 120 electrical degrees apart
- 28 pole machine, also 120 mechanical degrees apart
- 30 phase machine means 10 sets
- Phases in set must be from same winding layer

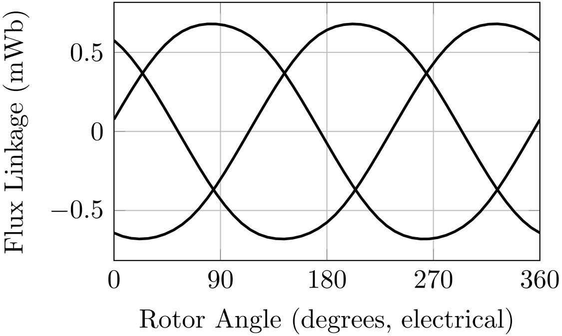


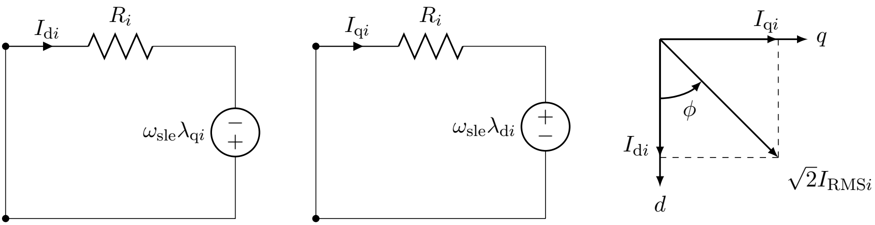

0.5
0
−0.5
Flux Linkage (mWb·turn)
0
90
180
270
360
Rotor Angle (degrees, electrical)


Flux Linkage (mWb·turn)
0.5
0
−0.5
0
90
180
270
360
Rotor Angle (degrees, electrical)

Each set contains balanced three-phase quantities

- Sets can be analysed separately ("10 separate machines")
- Calculated torques are added to get total torque
- Allows use of all existing three-phase theory





dq Voltage equations are written as:

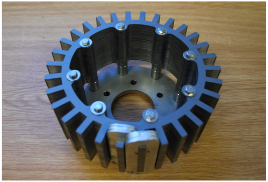
$$0 = R_i I_{\mathrm{d}i} - \omega_{\mathrm{sle}}\lambda_{\mathrm{q}i} \tag{1}$$

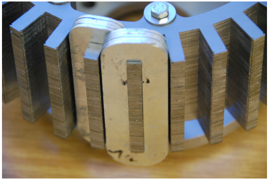
$$0 = R_i I_{\mathrm{q}i} + \omega_{\mathrm{sle}}\lambda_{\mathrm{d}i} \tag{2}$$

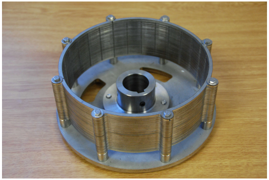
with i as the set number.

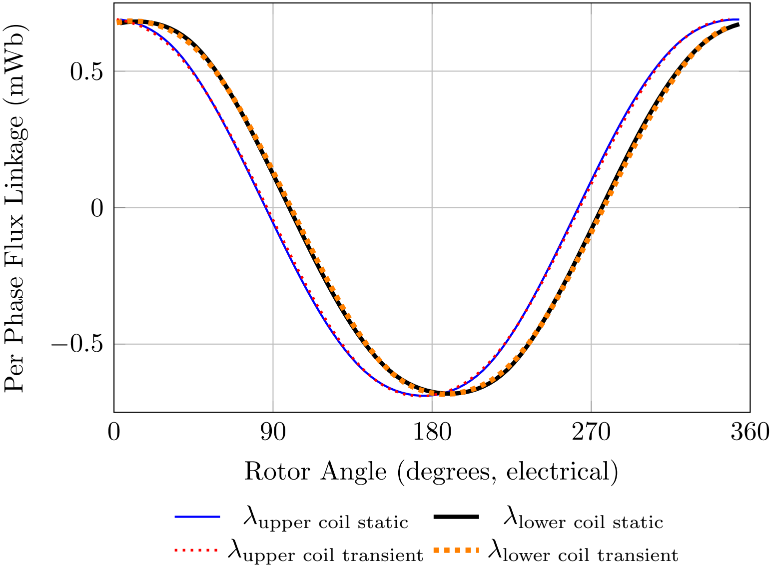
After machine optimisation is done, method is assessed:

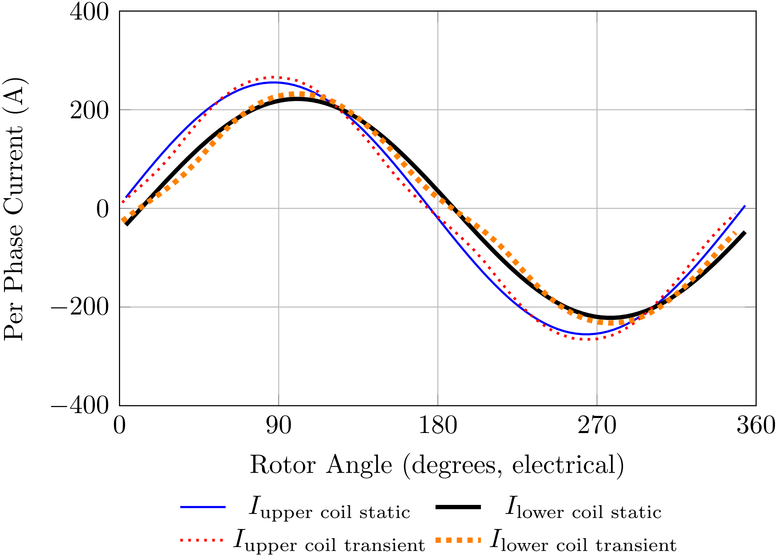
- Method uses four time-stepped static FE solutions
- Machine is also simulated using a transient FE solution
- Transient is considered as most accurate method available
- Results between static and transient are compared
- Unfortunately, prototype still under construction, thus no experimental results

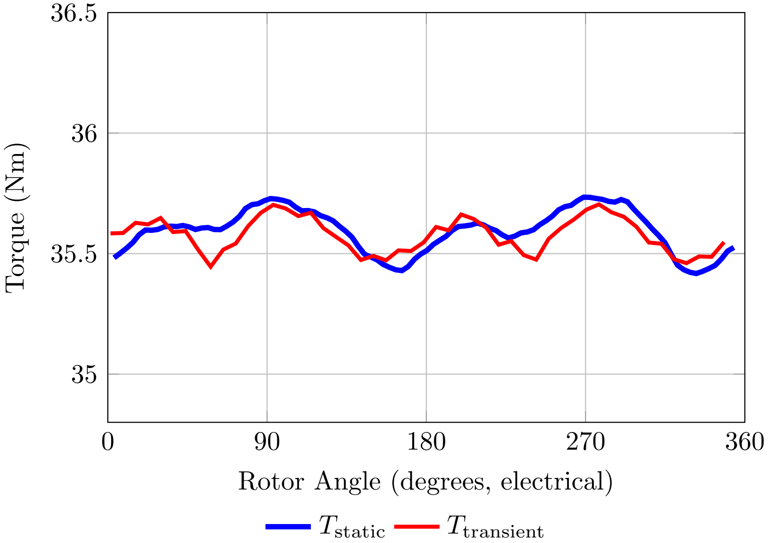




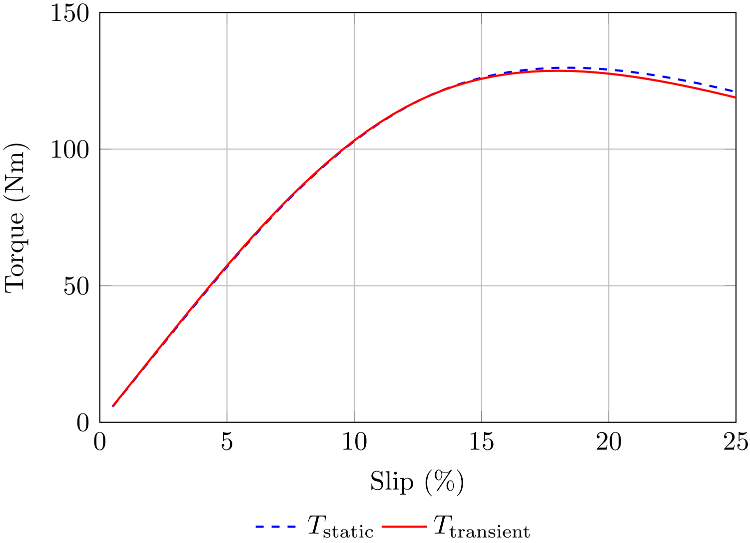



Per Phase Flux Linkage (mWb)
0.5
0
−0.5
0
90
180
270
360
Rotor Angle (degrees, electrical)
$\lambda_{\text{upper coil static}}$
$\lambda_{\text{lower coil static}}$
$\lambda_{\text{upper coil transient}}$
$\lambda_{\text{lower coil transient}}$


400
200
0
−200
−400
0
90
180
270
360
Per Phase Current (A)
Rotor Angle (degrees, electrical)
$I_{\text{upper coil static}}$
$I_{\text{lower coil static}}$
$I_{\text{upper coil transient}}$
$I_{\text{lower coil transient}}$



36.5
36
35.5
35
Torque (Nm)
0
90
180
270
360
Rotor Angle (degrees, electrical)
T_{static}
$T_{\text{transient}}$

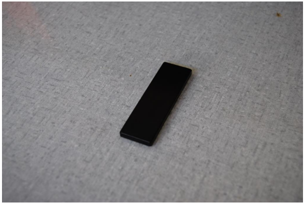
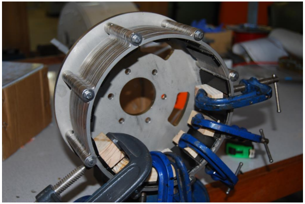
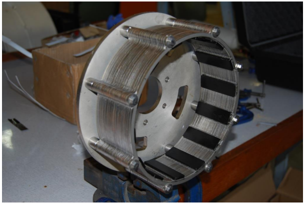
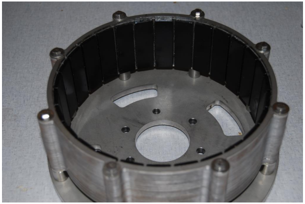

150
100
50
0
Torque (Nm)
0
5
10
15
20
25
Slip (%)
T_{static}
$T_{\text{transient}}$

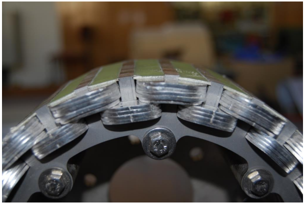
It is concluded that

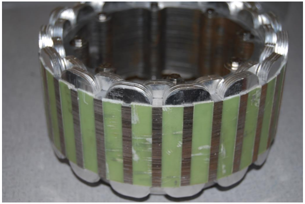
- Static and transient
  - Currents and flux linkages-
  - Torque, over a large slip range-

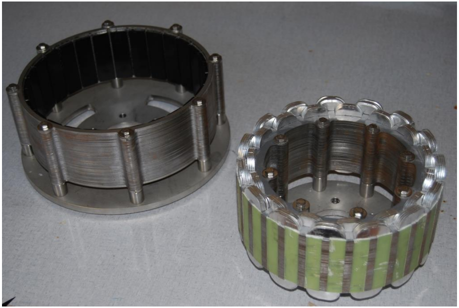
  are in excellent agreement
- Proposed method of grouping phases into sets gives accurate results
- Fast results - only four static FE simulations
- Can be used for optimisation of similiar machines
- Much faster than transient solutions
- Method can be used on any double layer, non-overlap, multiphase PM machine









Thank You