Dynamic Design of a Reluctance Synchronous Machine utilising Python Scripting in Flux®.

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The Reluctance Synchronous Machine (RSM) is an AC machine with a three-phase AC stator winding. A transversally laminated 4-pole RSM is the preferred RSM rotor topology chosen in this design. The RSM has several advantages including easy control, synchronous speed, cold rotor, high speed operation and robustness. The main parameter in the control of the RSM is the current vector angle with respect to the D-axis. Maximum Torque Control (MTC) ideally requires a current vector angle of 45° but when taking into account core loss and saturation can approach higher values closer to 60°.

As the RSM rotor rotates there is an interaction between the stator slots and rotor barriers that results in torque ripple. The desirable design outcome is to have maximum mean torque and minimum torque ripple to allow minimal vibrations, acoustic noise and possible mechanical resonances. In the design, the rotor is rotated through a predefined angle with a constant current vector angle. The mean electromagnetic torque and torque ripple are then defined as:

$$T_{mean} = \sum_{a}^{n} \frac{T_{ea}}{n} \qquad (1)$$

$$T_{ripple} = \frac{(T_{max} - T_{min})}{T_{mean}} \qquad (2)$$

where

a = First element in electromagnetic torque waveform.

n = Total number of elements in electromagnetic torque waveform.

T_{ext} = Electromagnetic torque at position in the electromagnetic torque waveform.

T_{max} = Maximum electromagnetic torque.

T_{min} = Minimum electromagnetic torque.

The design presented investigates the geometric parameters effect on torque production in a linear progression. In the design one parameter is varied, the torque waveform analysed and the mean torque (eqn. 1) and torque ripple (eqn. 2) are extracted. Thereafter, the parameter value is chosen where maximum mean torque and minimum torque ripple occurs. This value is then utilised for the design procedure that follows where the process is repeated until all parameters have been varied accordingly. The order in which the design proceeds is N_{rb} and β together, W_p, a and g. Intuitively, l_{tw} and l_{rr} should be zero. However, this is contradictory to mechanical strength requirements. Thus, l_{tw} and l_{rr} are changed for purely investigative purposes in this design.

Implementation of RSM design in Flux

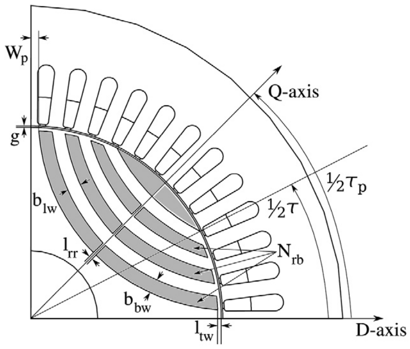
The RSM design procedure is implemented in a magnetostatic application in Flux 10.2 using Python scripts incorporating PyFlux and Python. The Flux 3-D beta solver allows all required model development, solving and post-processing to be incorporated into one environment which also allows for insight into the relevant PyFlux commands required for solving and post-processing. The geometry of the RSM is developed parametrically to allow for quick changes when required. The three stator windings have two parallel paths each assigned as stranded coil conductors with imposed currents defined by three I/O parameters sinusoidally dependant on twice the rotor angle and chosen current vector angle of 60°. Separate Flux projects are created for each parameter changed and a Python file is used to change the parameter automatically during the design. A distinct modular approach allows reuse of the Python file structure with only slight modifications required.

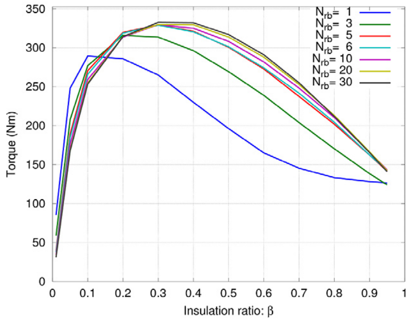
Selected design results and analysis

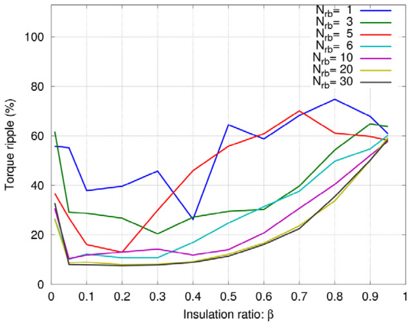
Selected design results are presented in the following where choices for geometric parameter values for the RSM rotor are made.

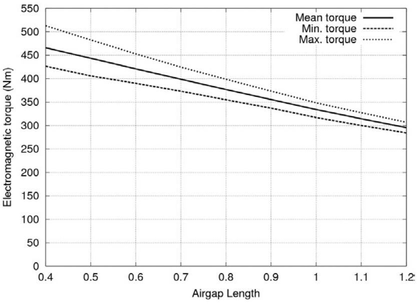
Variation of N_{rb} and β : Maximum mean torque occurs around β = 0.3 to β = 0.4 for rotor barrier numbers higher than five and minimum torque ripple occurs between β = 0.1 to β = 0.3. A value of β = 0.3 is chosen along with N_{rb} $_{= 6}$ as this allows for close to maximum torque while still maintaining mechanical strength and ease of manufacturing.

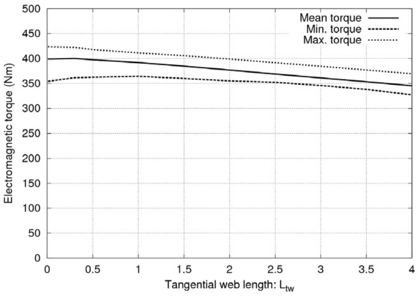
Variation of g: Mean torque increases significantly as airgap length decreases. However, torque ripple also increases as the airgap length decreases. This is expected as a result of the increased magnetic reaction between the rotor barriers and stator slots as the airgap











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Dynamic Design of a Reluctance Synchronous Machine utilising Python Scripting in Flux®. (continued)

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the length decreases. Even though increased average torque results from the decreased airgap length, consideration needs to be given to whether a smaller airgap is obtainable considering manufacturing tolerances. The airgap is left at 0.8 mm.

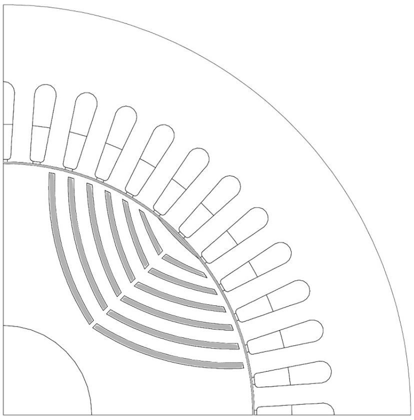
Variation of l_{tw} and l_{rr} : Both l_{tw} and l_{rr} should be zero to maximise rotor saliency however mechanical requirements impede this. The RSM rotor would disintegrate at speed if these mechanical support widths were zero. While varying the mechanical support parameters, mean torque decreases as l_{tw} and l_{rr} increase. Torque ripple increases when l_{tw} is close to zero as a result of the rotor barriers approaching the rotor surface and thus reacting more with the stator slots. Traditionally, the length of l_{tw} and l_{rr} are chosen to be a multiple of the lamination thickness. Initial design choices of $l_{tw= 2mm}$ and $l_{tw = 2mm}$ (4x lamination thickness) are chosen.

Conclusions and Future Work

Conclusions: A RSM design is dynamically developed using PyFlux and generic Python in Flux 10.2. The linear progression approach to the design is briefly described. Geometric parameter values are chosen based on where maximum mean torque and minimum torque ripple occur.

Future Work:

- Mechanical Finite Element Analysis to investigate the mechanical strength of the rotor when rotating at nominal speed (1500 rpm) and undergoing mechanical torque changes.
- Choice of the current vector angle made dynamically during the design to ensure MTC at each simulation step.
- With no induction machine rotor (no rotor bars), the thermal operating point of the RSM changes. An investigation into whether more current can be placed in the stator windings to generate more electromagnetic torque for the final mechanical process can be performed.



- A prototype of the final RSM should be built and tested in a laboratory environment for verification of performance.

Implementation of Lumped Parameter Thermal Model in Portunus®.

Dick Matheka - Cambridge University.

The lumped parameter thermal model of the nested loop rotor BDFM that has been developed for use during design, and its implementation in Portunus is presented.

The BDFM (Brushless Doubly Fed Machine) is a single frame induction machine with two stator windings, which are configured to create two different pole number fields. The pole numbers of the winding fields are selected to avoid transformer coupling and the interaction between the windings is through the rotor, which couples the fields of both windings. The popular rotor option is the nested loop rotor, which is illustrated in figure 1. The nested loops of the rotor are equivalent to the bars of a cage rotor and their number is determined by the pole numbers of the stator winding fields. This machine has potential for application as a generator in off-shore wind turbines because of the absence of brushes, which translates to reduced maintenance.

Validating the specific electric loading specified during the design of a BDFM can be complicated. This is because, the magnitudes of the stator winding currents are generally different, rotor bars have to be insulated from the laminations for performance reasons, and currents flowing in the different loops for each nested loop structure have different magnitudes. The specific electric loading is the stator current per rotor periphery and its value must be set such that the maximum operating temperatures of the machine insulation systems are not exceeded. This is difficult to do with the BDFM because the insulations for both the rotor and stator have to be taken into consideration and the rotor will likely be heated un-evenly. Therefore, knowledge of temperatures of different components of the machine is required during the design of BDFMs. This can be obtained with the use of thermal models.

Lumped parameter thermal models use a network of resistors, capacitors, current sources and voltage sources similar to an electric circuit. The nodes of the network represent the points of average temperature for regions (or components) whose temperatures are of interest. Resistors model the

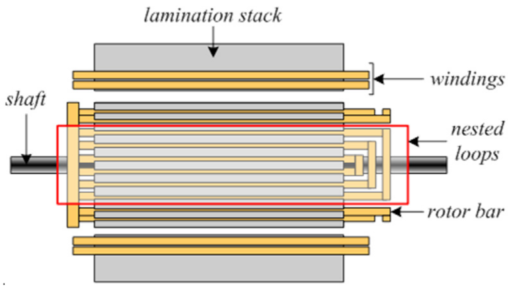


Figure 1: The structure of the nested loop rotor BDFM.

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