Comparison between TFPM generator with toothed rotor and Conventional PM Synchronous generator for direct-drive wind turbines

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Wind turbines have slow rotating mechanical shafts, with high torque. Since the generator costs is related to its torque value, the use of direct-drive generators is in many cases more costly than the conventional combination of gearbox and high speed generator. Earlier research has identified transverse-flux PM (TFPM) machines as an interesting possibility for reducing the costs of direct-drive generators in wind turbine applications. Especially, the TFPM machine with toothed rotor was identified in [1] as a candidate of a flux-concentrating TFPM machine leading to easier manufacturing.

The paper investigates the comparison between the TFPM machine with toothed rotor and the conventional PM synchronous machine. For both machine topologies, the machine designs are optimized for various diameters and rotational speeds and the designs with the best cost/torque or torque/mass are retained. Our aim is to evaluate how the best designs of TFPM machine with toothed rotor compare with the best designs of conventional PM synchronous machine.

Two optimization runs are performed. The first run finds the maximum of the torque/mass function. The second one finds the minimum of the cost/torque function.

The following parameters are set constant during the optimization process:
- outside diameter d_{out};
- rotational speed n;
- magnet remanent flux density B_r= 1.1 T;
- PM relative recoil permeability μ_{rec}= 1.09;
- rotor tooth clearance h_{ru}= 3 mm;
- relative permeability of stator laminations μ_{rFe} = 1000;
- stator winding filling factor = 0.6 ;
- air gap thickness g= d_{out} /1000.

Design optimization is done for outside diameters of d_{out} = 0.5 m, 1.0 m, 2.0 m and 3.0 m. For each value of d_{out}, a corresponding rotational speed n is assigned as follows: 130 rpm, 75 rpm, 46 rpm and 34 rpm.

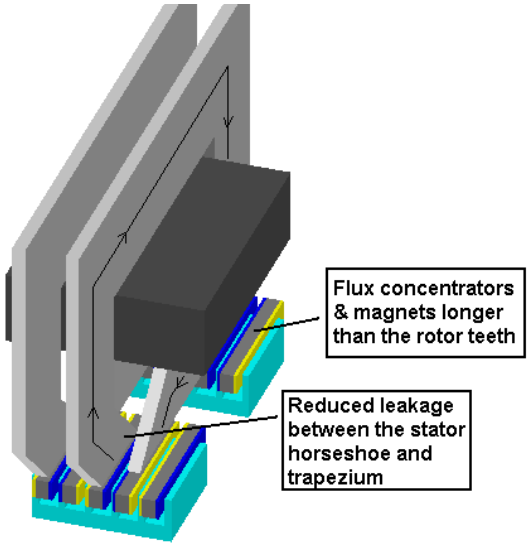

Fig.1. TFPM machine with toothed rotor.

The following parameters are allowed to vary:
- magnet thickness h_m;
- stator core width w_{sc};
- flux concentrator width w_{rc2};
- rotor tooth width w_{rc1};
- flux concentrator length l_{rt1};
- ratio of stator foot length over flux concentrator length l_f /l_{rt1};
- magnet radial dimension w_m;
- conductor current density J;
- phase angle ψ.

The following constraints are used:
- efficiency η = 90% and η = 95%;
- rotor tooth width $w_{rc1} \geq$ 2 mm;
- flux concentrator length $l_{rt1} \geq$ 30 mm;

The nine variables listed above are varied between a lower value and an upper value, using ten intermediate values for each variable. In total, 10^9 machine designs are calculated with a computer program which uses the linear model described in [2]. The torque calculated with the linear model was checked with FEA calculations and the analytical model yields about 30 to 40% higher torque than with finite element analysis. The efficiency target was first set to either 90% and 95%, but needed to be corrected to a lower value for all machine designs as a result of lower machine torque obtained with FEA.

The performances of the TFPM with toothed rotor are compared to those of optimized conventional PM synchronous machines. To ensure a valuable comparison, the same torque, efficiency, outside diameter, rotational speed, air gap, steel and magnet characteristics are used in both topologies. The results are presented in fig. 3 and fig. 4.

Conclusion

According to the optimization results depicted in fig. 3 and fig. 4, the TFPM machine with toothed rotor obtains favorable performance for diameters of 1 m and above. Above 1 meter, the conventional PM synchronous machine obtains better performance and the advantage increases as the diameter increases.

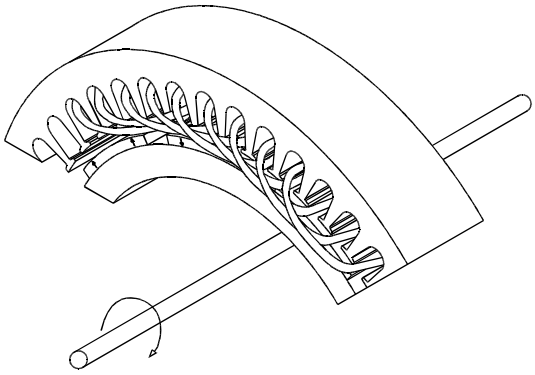

Fig.2. Conventional PM Synchronous machine.

References

[1] M.R. Dubois, H. Polinder and J.A. Ferreira, "Transverse-Flux Permanent Magnet (TFPM) Machine with Toothed Rotor", in Proc. IEE Conf. Pow. Electr. Mach.&Drives 2002, pp. 309-314.

[2] M.R. Dubois, H. Polinder and J.A. Ferreira, "Prototype of a new Transverse-Flux Permanent in

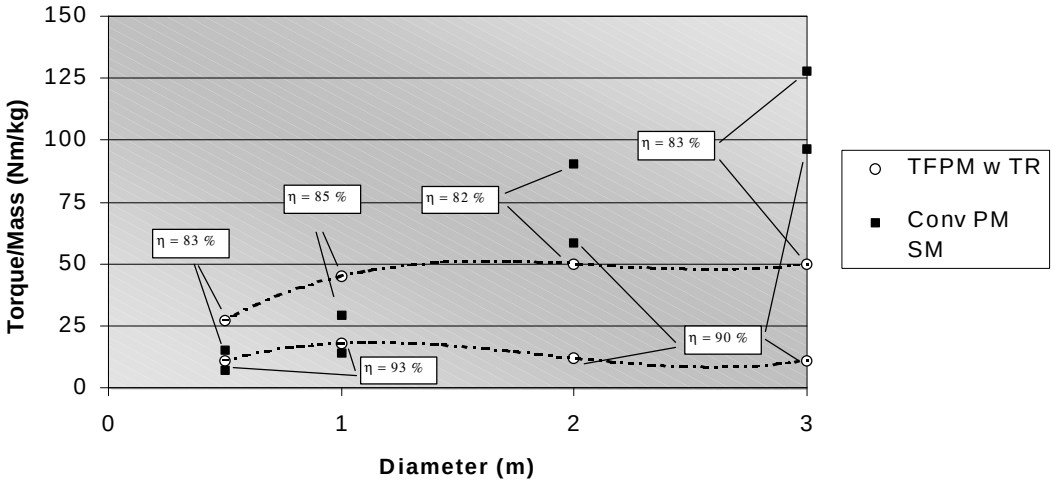

Fig.3. Torque/mass for both machine topologies.

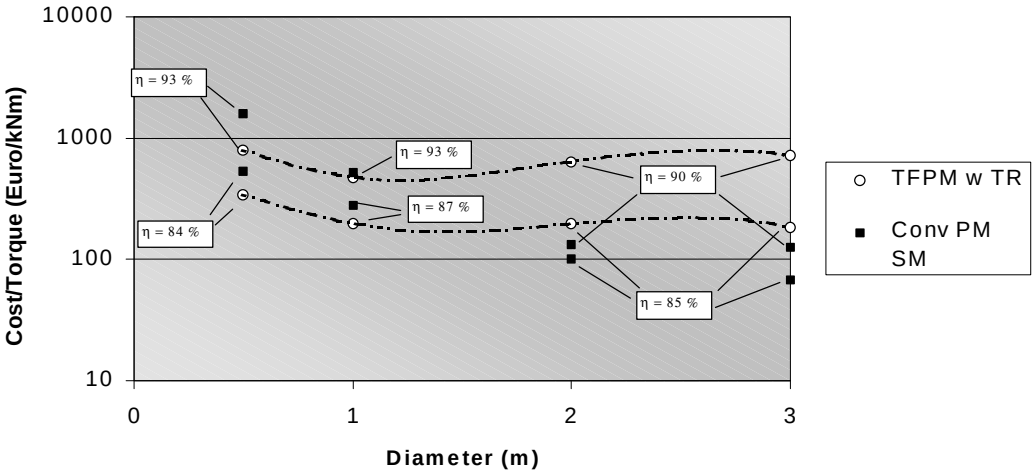

Fig.4. Cost/torque for both machine topologies.