Thu-Mo-Po4.06-04 [42]

MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

Comparison of Electromagnetic Performance of 10-MW HTS Double-Stator Flux Modulation Generators With Different Topologies for Offshore Direct-Drive Wind Turbines

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Abstract

For HTS conventional synchronous generator, the SC field windings or armature windings are rotating, which could complicate their industrial feasibility for the offshore wind generation. In order to overcome this drawback, a kind of HTS double-stator flux modulation generator (HTS-DSFMG) without rotating windings is proposed. This paper compares the electromagnetic performance of 10-MW HTS double-stator flux modulation generators with two different topologies, i.e., iron-cored stators with both field and armature coils and air-cored stator with filed windings and iron-cored stator with armature windings. In addition, the system comparison of HTS-DSFMG with conventional synchronous machine is conducted. The objective is to intensive study the advantages and disadvantages of HTS-DSFMG with different topologies, and to establish some design guidelines for HTS double-stator flux modulation generator without rotating windings.

Topology introduction

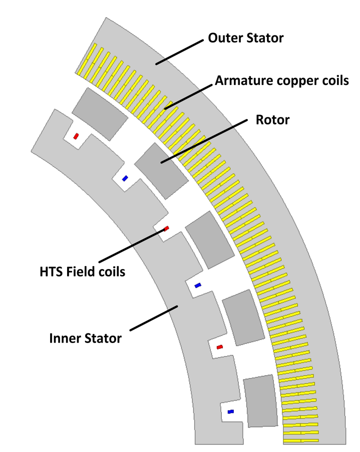

Fig. 1. 2D model of DSFMG

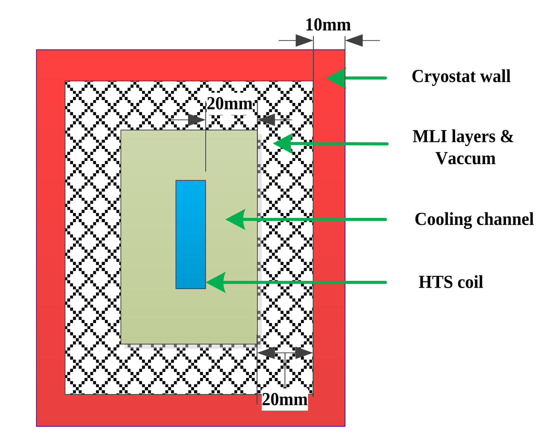

Fig. 2. The structure of cryostat

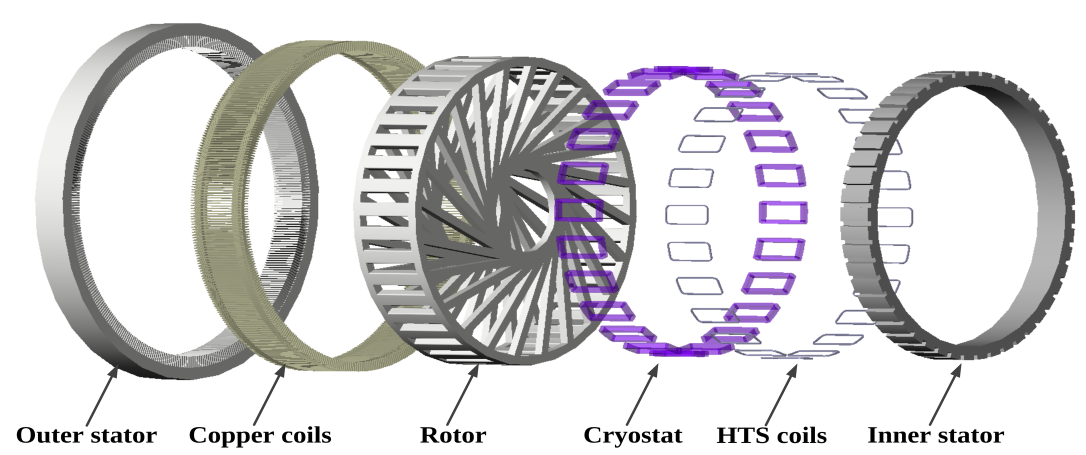

Fig. 3. 3D exploded model of DSFMG

Magnetic loading

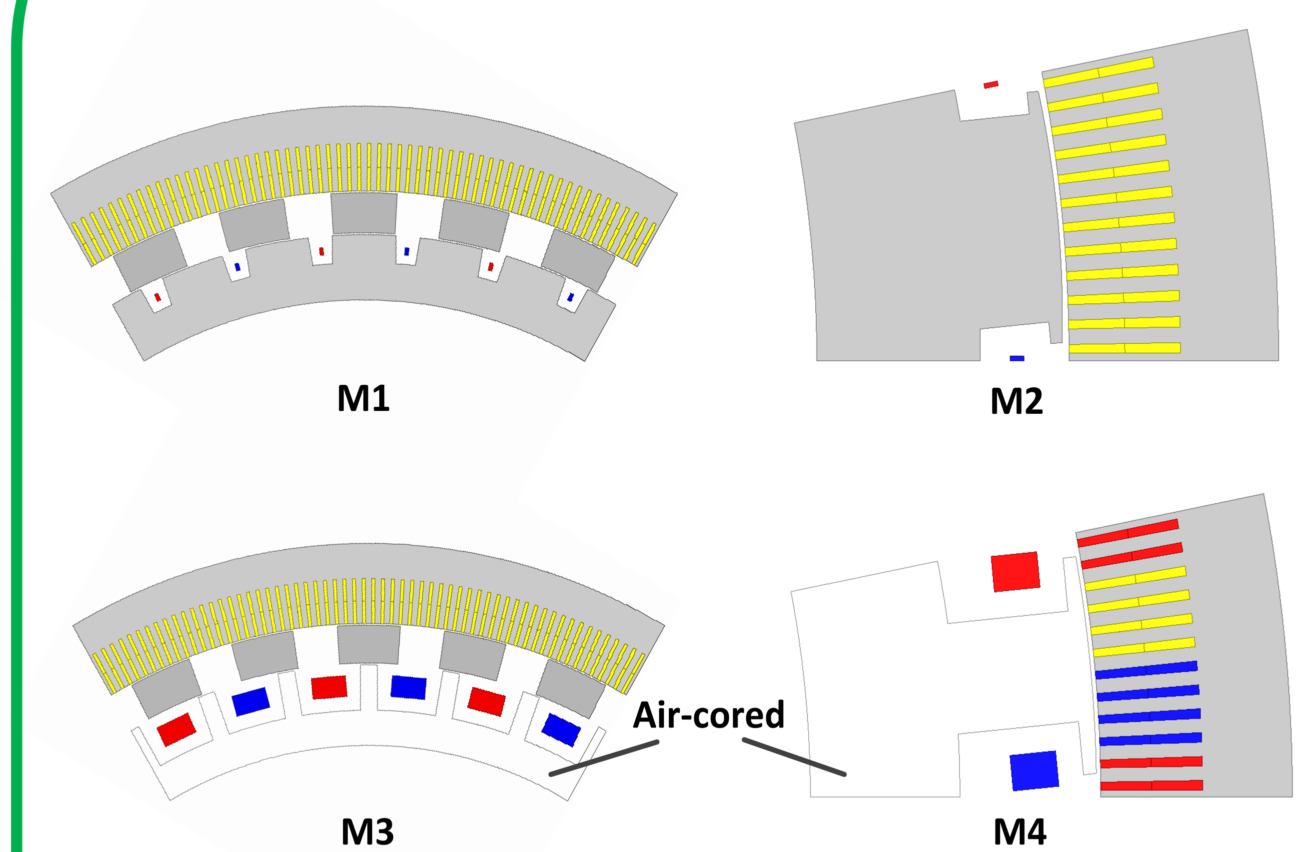

Fig. 4. Simulation model. M2 and M4 are conventional synchronous machine. The gray and white indicate the magnetic and non-magnetic material respectively.

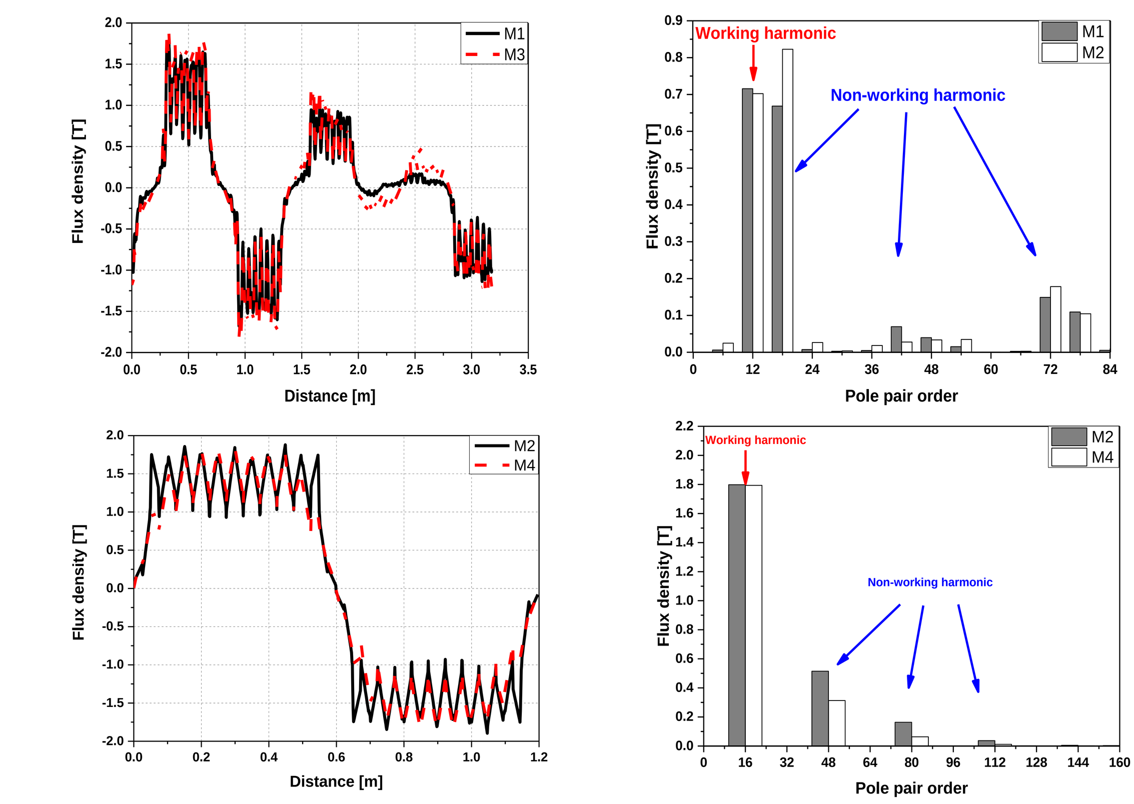

Fig. 5. No-load flux density in the air-gap (close the armature coils).

Magnetic loading = $B_{working\text{-}harmonic}$ * Pole ratio. For DSFMG, pole ratio is 2.5 while the pole ratio of synchronous machine is 1.

For M1 and M3, Magnetic loading = 0.715 * 2.5 = 1.79 T;

For M2 and M4, Magnetic loading = 1.8 * 1= 1.8 T.

Therefore, the four models almost have the same magnetic loading

Operating current of SC

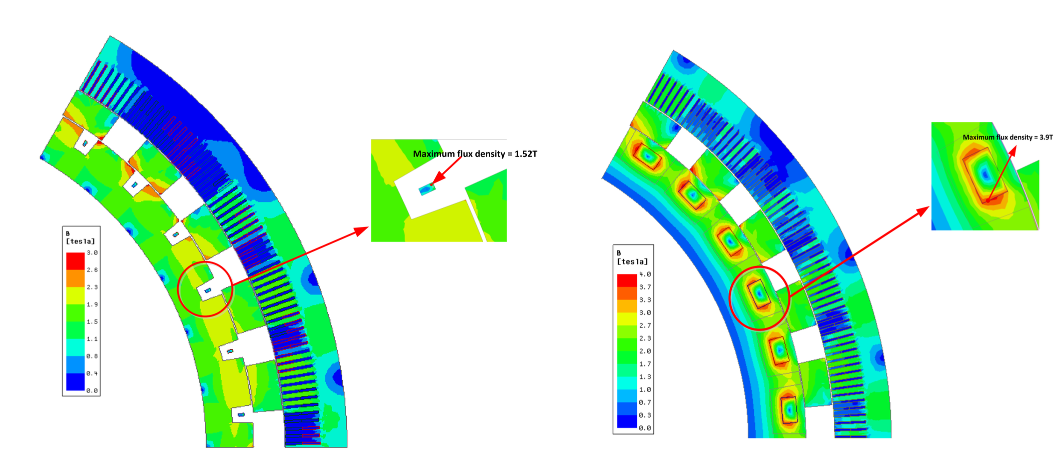
Fig. 6. Flux density distribution of M1 and M3 at the 1.8 T magnetic loading.

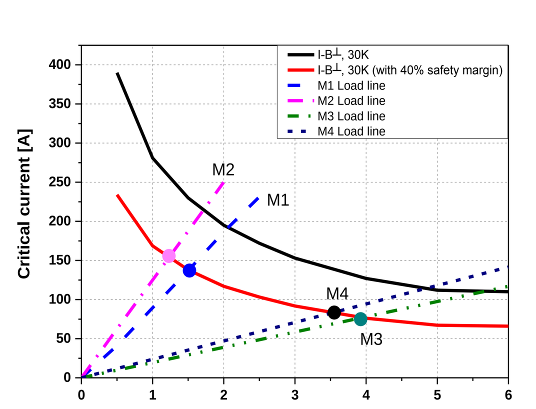

Fig. 7. Operating current of SC coils for four model

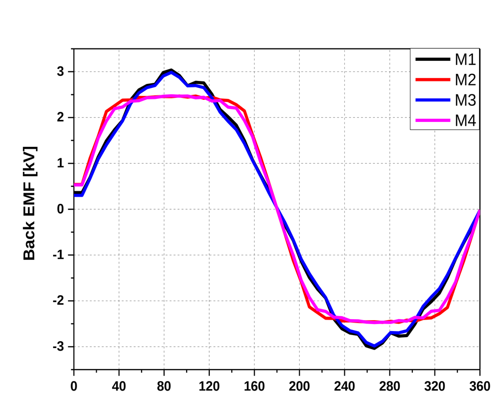

Fig. 8. No-load back EMF

Mass & Cost comparison

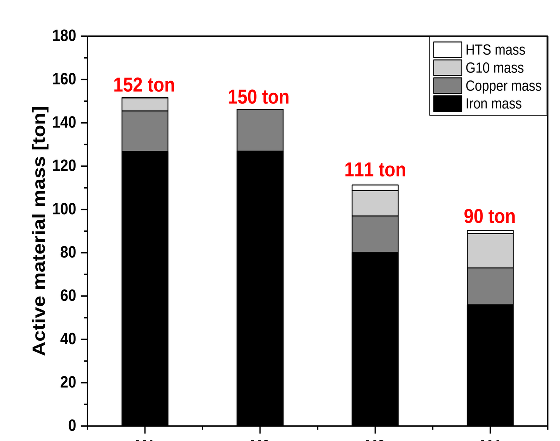

Fig. 9. Mass comparison

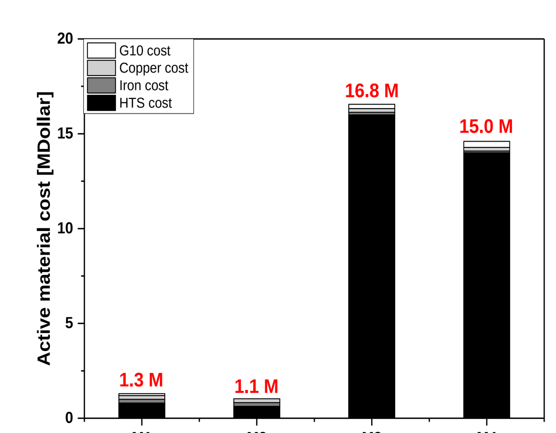

Fig. 10. Cost comparison

Parameter	M1	M2	M3	M4
Number of phase	3			
Output power [MW]	10			
Efficency	95%			
Rated revolution [rpm]	10			
Outer Stator diameter [m]	7000			
Active stack length [m]	1.20	1.15	1.05	0.92
SC operating current [A]	140	150	70	80

Short-circuit performance

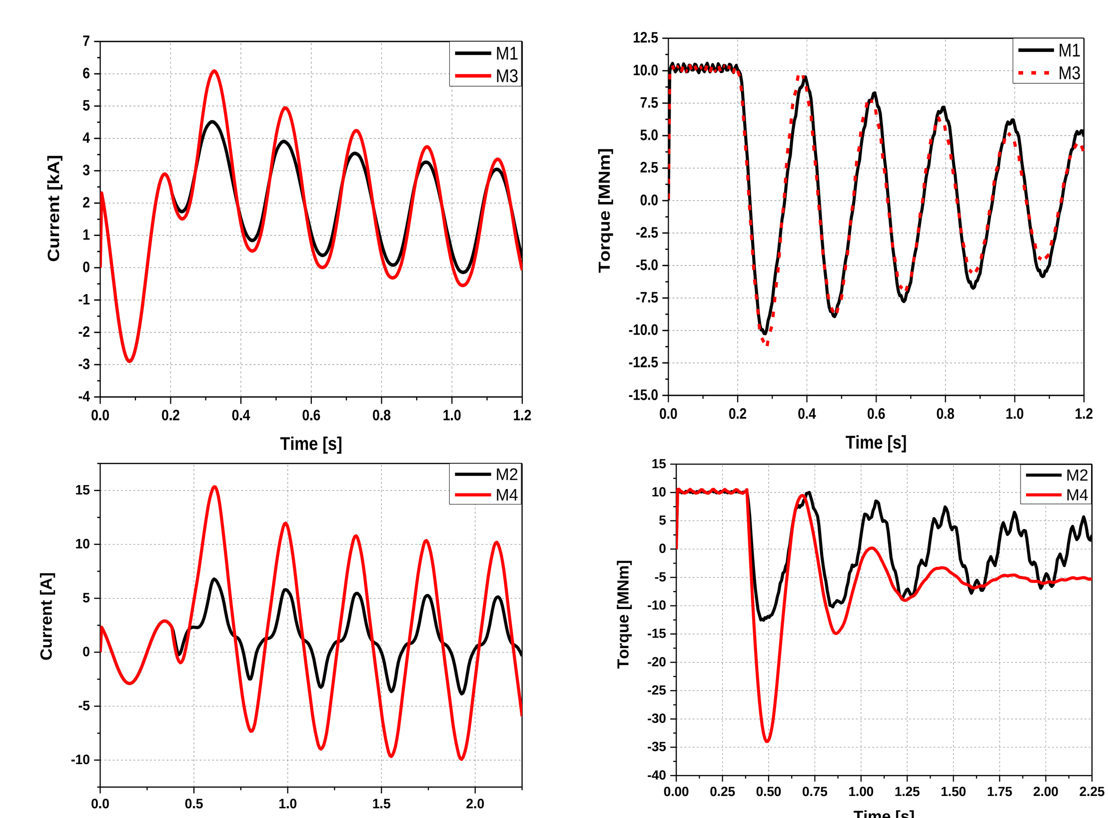

Fig. 11. Symmetrical three-phase short circuit performance comparison

The short-circuit performance of DSFMG is better than conventional synchronous machine.

Conclusion

The acitive material cost of iron-cored rotor topologies is less 2 million dollar while the cost of air-cored rotor one may exceed 15 million dollar. Due to the high cost of SC nowadays, the iron-cored stator and rotor topology is preferable to commercialize. For DSFMG, Due to the stationary armature and field windings, no brush, slip ring and rotating excitation equipment are required, which can obviously improve the reliability of the topology. Besides, the short-circuit performance of DSFMG is better than conventional synchronous machine. Therefore, the iron-cored stator and rotor HTS double-stator flux modulation generator is a potential candidate for offshore wind direct drive generator in the future.