Novel Self-Excited Brushless Topology for Wound Field Vernier Machine

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This paper proposes a novel self-excited topology for the brushless operation of wound field vernier machines (WFVMs). The proposed topology involves a new armature winding configuration that develops fundamental and sub-harmonic magnetomotive force (MMF) components in air gap once the armature winding of the machine is supplied current from the inverter. The rotor of the machine is equipped with a harmonic winding which is used to induce current from the sub-harmonic MMF component of the air gap flux. The induced power is rectified to energize the main rotor field winding to the main rotor field. The electromagnetic interaction of stator and rotor fields along with the existence of the gearing effect develop torque. 2-D finite element analysis (FEA) was carried out to validate the theory for an outer rotor wound field vernier machine model.

***Index Terms*— Brushless, vernier machines, wound field machines, sub-harmonic field excitation.**

I. Introduction

WOUND FIELD vernier machine (WFVM) is an emerging candidate to replace permanent magnet vernier machines (PMVMs) and reluctance-type vernier machines (RVMs). This is due to the increasing cost of rare-earth metals (REMs) used for the development of permanent magnets (PMs), which makes PMVMs expensive, and the low power density concerns associated with RVMs [1]. On the other hand, WFVMs offer flexible field current control, making them indispensable for certain applications such as large power-generating units and sensitive load-connected systems [2]. The major drawback associated with these machines is the requirement of either brushes and slip rings or exciters and pilot-exciters for their rotor field excitation, which increases the cost and size of the machine systems [3].

In this paper, a new armature winding configuration that involves a combination of single and double-layer winding patterns for the stator slots is proposed. This new armature winding arrangement for a 4-pole, 24-slot (4p24s) machine model is presented in Fig. 1. The proposed winding configuration develops a magnetomotive force (MMF) in the air gap of the machine (shown in Fig. 2) that contains 4-pole fundamental and 2-pole sub-harmonic MMF components (presented in the FFT plot of Fig. 3) in the air gap of the machine once it is supplied current from the inverter. The rotor of the machine is equipped with a 2-pole harmonic winding and a 44-pole main rotor field winding, as shown in Fig. 4. The developed sub-harmonic MMF is used to induce a harmonic current in the harmonic winding of the rotor. This current is rectified to excite the main rotor field winding which is connected with the harmonic winding through a diode rectifier to develop torque and achieve brushless operation for WFVM.

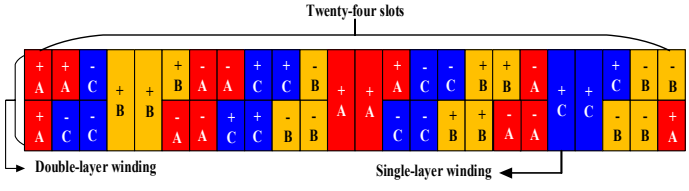


Fig. 1. Proposed armature winding configuration for a 4p24s machine model.

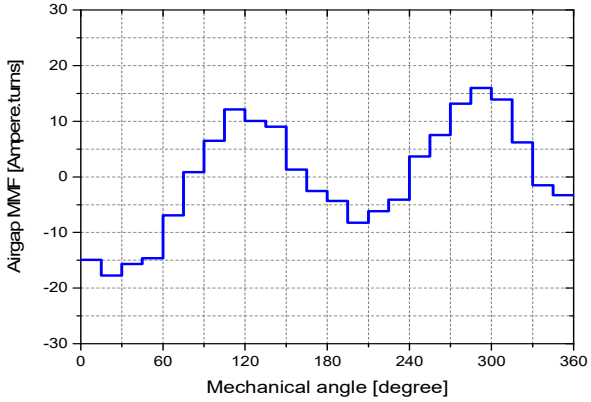


Fig. 2. Air gap MMF developed through the proposed winding configuration.

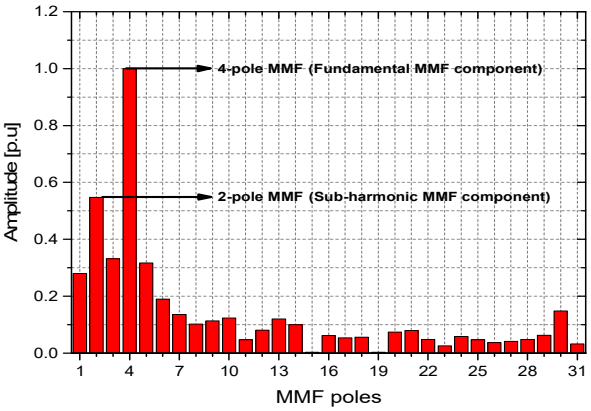


Fig. 3. FFT plot of the air gap MMF.

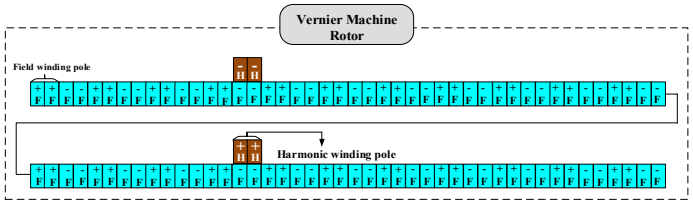


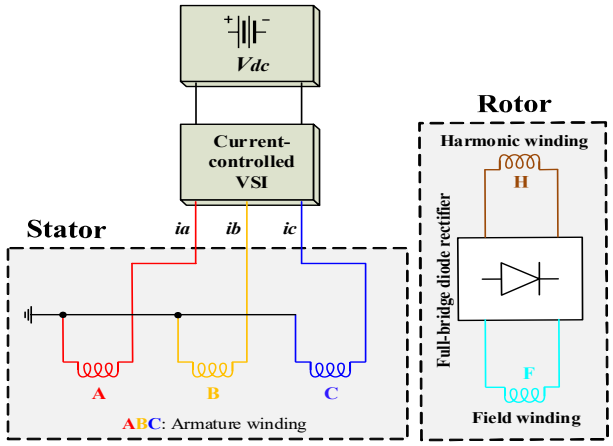
Fig. 4. Rotor winding configuration.

II. Electromagnetic Analysis

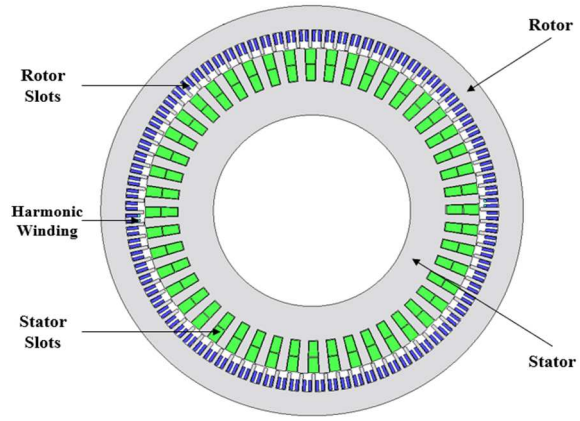
To achieve the electromagnetic performance for the proposed self-excited brushless topology for WFVM, finite element

analysis (FEA) is carried out for a 4p24s outer rotor vernier machine model in JMAG-Designer. The proposed topology and the employed machine model are shown in Fig. 5(a), and (b), respectively, and the machine parameters are presented in Table. 1.

For the electromagnetic analysis, the employed machine model is supplied with a current of 3 A (peak) having a frequency of 110 Hz from a current-controlled voltage source inverter. The rotor speed of the machine is 330 rpm, and the simulations are carried out for 0.8 s.



(a)



(b)

Fig. 5. Rotor winding configuration.

TABLE. I
MACHINE PARAMETERS

Attribute	VALUE
Rated power (in kW)	1.5
Stator outer diameter (in mm)	238
Air gap (in mm)	0.5
Rotor outer/inner diameter (in mm)	300/239
Stator slots-to-pole ratio	24/4 (6)
Rotor poles	44
ABC-winding turns per phase	270
Harmonic winding turns	8
Field winding turns	36
Stack length (in mm)	30

The induced harmonic and rectified field winding currents are presented in Fig. 6 whereas the developed torque of the machine is shown in Fig. 7. The obtained results show that an average torque of 36.27 Nm is developed for the employed machine model, however, its ripple is around 21.22%. These results are presented in Table. 2.

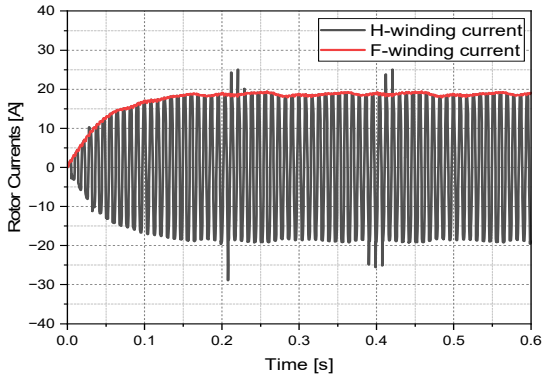


Fig. 6. Rotor winding currents.

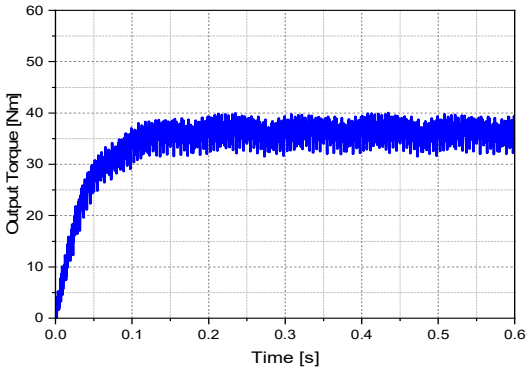


Fig. 7. Output torque.

TABLE. 2
FEA RESULTS

Attribute	PROPOSED WFVM
Minimum Torque (Nm)	31.5
Average Torque (Nm)	36.27
Maximum Torque (Nm)	40
Torque Ripple (%)	21.22

III. CONCLUSION

A novel self-excited brushless topology for the WFVM was proposed in this paper. The proposed topology involves a new armature winding configuration that contains single and double-layer winding arrangements for the stator slots. This results in fundamental and sub-harmonic MMF components in the air gap once the armature winding is supplied current from the inverter. The sub-harmonic component induces the harmonic current in the harmonic winding of the rotor which is rectified to excite the field winding and achieve brushless operation for WFVM as validated by FEA.

REFERENCES

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