

# Prototype development of a multi-phase PMSM e-motor and experimental validation

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EECOMOBILITY (ORF) &  
HEVPD&D CREATE

## Project Description

- This is collaborative work and most of the actions have been completed by Himavarsha Dhulipati.
- Design a permanent magnet synchronous machine (PMSM) for direct drive electrical vehicle (EV) application and prototype development.
- Design challenges to meet:
  - a. Higher torque at a low operating speed
  - b. Lower torque ripples
  - c. Higher torque per permanent magnet volume

## Objectives

- Analytical modeling of torque and torque ripple for FSCW PMSM incorporating space harmonics.
- Using the developed analytical model, a novel fractional slot concentrated winding (CW) PMSM has been designed for direct drive EV application with;
  - a. Low torque ripple,
  - b. High torque density,
  - c. High torque per PM volume.
- Scaled-down 6 Kw (peak) prototype development and experimental validation of performances using no-load and load tests.

## Tasks/Plan and deliverables

- A novel extended dq-frame-based accurate torque and torque ripple model for n-phase CW PMSM incorporates higher-order space harmonics in the PM flux linkage and machine inductances.
- A novel rotor topology utilizing fewer rare earth magnets is developed and a magnetic equivalent circuit-based magnet for reduction of torque ripple.
- Prototype development of the proposed machine and experimental validation of research objectives.



Fig. 1. Prototyped scaled-down proposed PMSM.

- Developed the scaled-down FSCW PMSM for direct-drive EV application with;

**Torque ripple < 5%**

**Torque density > 7.5 Nm/kg**

**PM volume per unit torque > 1.496  $\mu\text{m}^3/\text{Nm}$**

## Progress Report

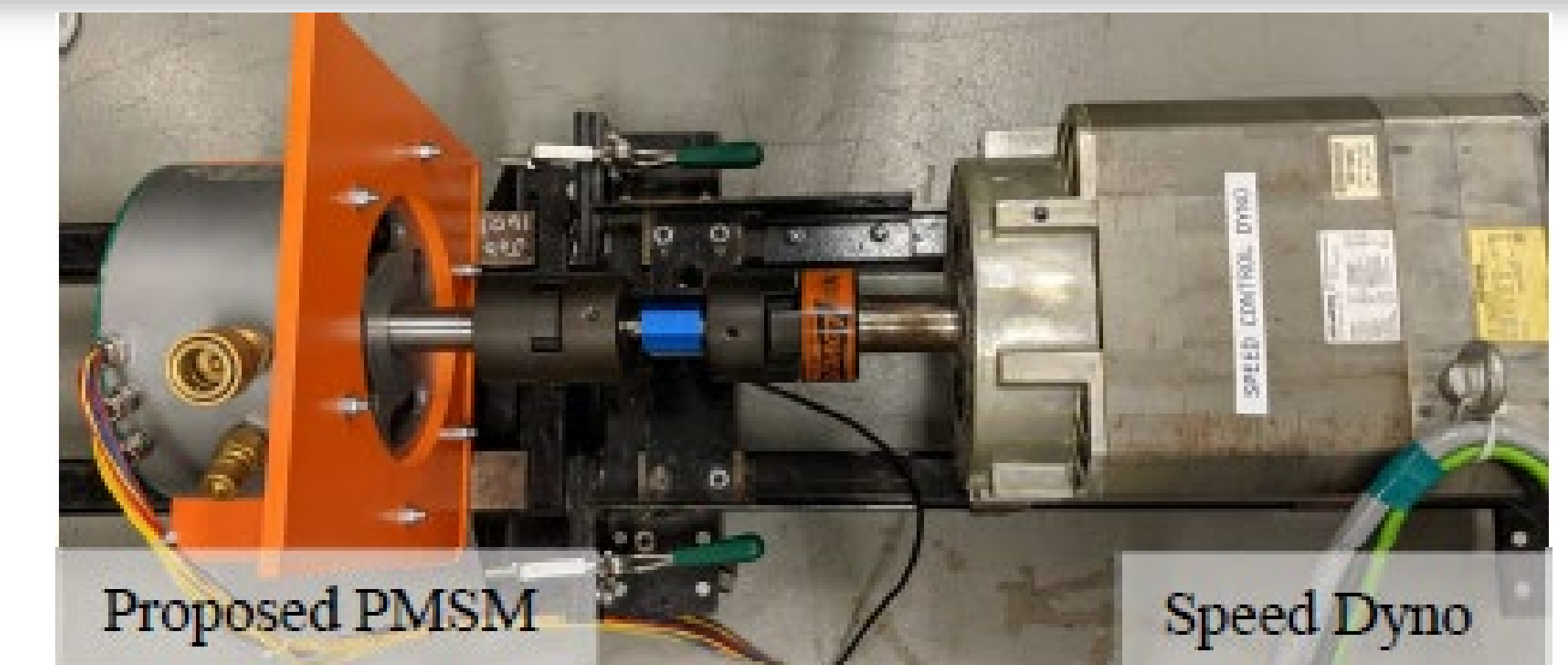


Fig. 2. Experimental setup of prototyped PMSM

- 0.2% difference in analytical and experimental flux linkage was observed.
- Torque density of 13.2 Nm/kg (without housing).
- Average torque of 70 Nm torque at the rated speed of 405 rpm and 2.6% of torque ripple.
- 37% improvement in torque per PM volume compared to the baseline PMSM.
- Maximum efficiency of 93.3% at under constant torque region.

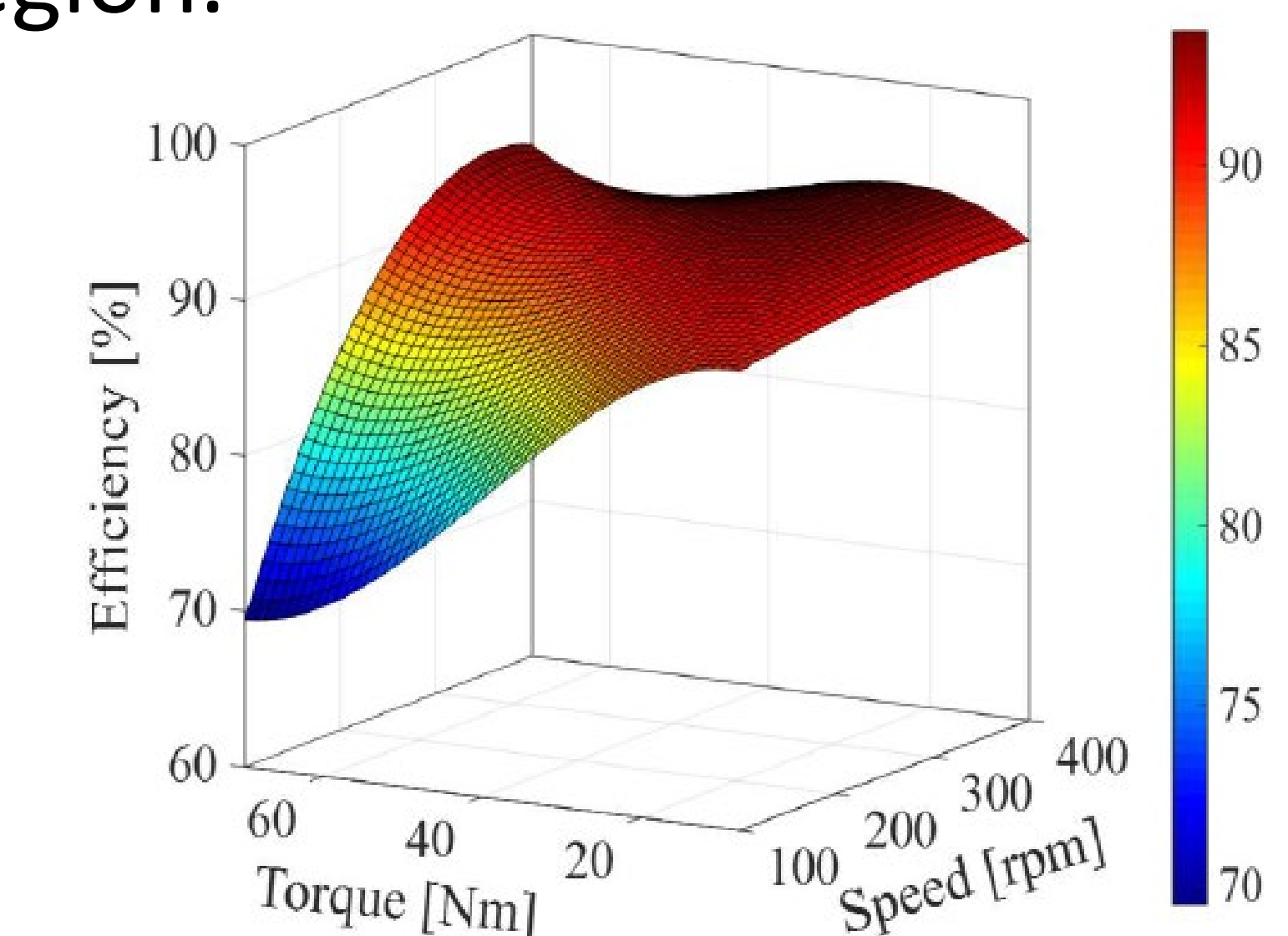


Fig. 3. Efficiency map under constant torque region from experiment

H. Dhulipati, S. Mukundan; E. Ghosh; Z. Li; B. Vidalanage, J. Tjong; N. C. Kar., "Slot-pole Selection for Concentrated Wound Consequent Pole PMSM with Reduced EMF and Inductance Harmonics," in *proc. IEEE Conference on Electrical Machines and Systems (ICEMS)*, 2019, pp. 1-6.

Himavarsha Dhulipati, "Modeling and Analysis of Multi-phase PMSM: Direct-Drive Electric Vehicle Application", 2019.