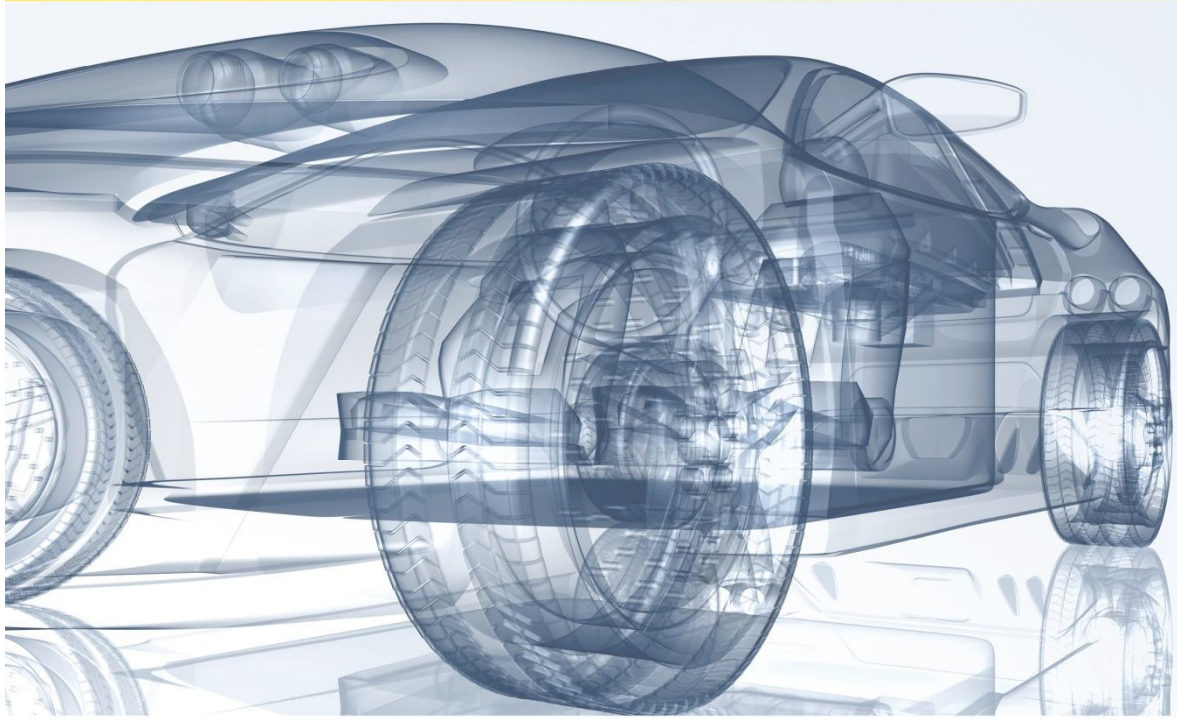
evs30



The 30th International
Electric Vehicle
Symposium & Exhibition

October 9–11, 2017

Messe Stuttgart, Germany

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Low voltage & Low cost Interior Permanent Magnet (IPM) Motor for Indian EV applications

Author: Prabhu Shanmugam, Kishor Kumar, Rajesh Gudivada

Mahindra Electric Mobility Ltd.

Agenda

- Introduction
- Motivation
- Design methodology
- Proto build
- Validation results
- Cost comparison
- Conclusion

Mahindra Electric Mobility Limited

Developing electric vehicles (EV's) since 1994

Applied/granted 50+ patents in EV technology domain

More than 5,500 EV's sold across 24 countries

More than 220 million km of customer driven data

The complete electric mobility solution provider!

We develop affordable EV's and EV ecosystem technologies

- Mahindra e2o – light & affordable highway safe electric vehicle
- Electrification of platforms from Mahindra & Mahindra for various commercial fleet applications
- Sun2Car solar and Quick2Charge fast charging station
- Telematics solution for remote diagnostics

We develop business models that maximize value for stakeholders adopting EV's in fleet applications

- Innovative business models to introduce EV's into commercial applications such as intra-city taxi, employee transport, car-sharing, intra-city goods delivery, Mass Rapid Transit feeder services, stage carriage services, etc.
- Mahindra Electric offers services across the EV business development value chain – primary & secondary research, fleet planning, operational planning, financial models, technology support, charging infrastructure planning, etc.

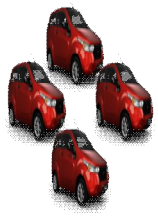
1

LIFESTYLE ELECTRIC VEHICLES & EV ECOSYSTEM TECHNOLOGIES

Safe, affordable, feature-rich intra-city EV's for all

EV-BASED MOBILITY SOLUTIONS

Affordable EV's for commercial fleet applications such as car-sharing, car-rentals, employee commuting etc.



3

IP LICENSING

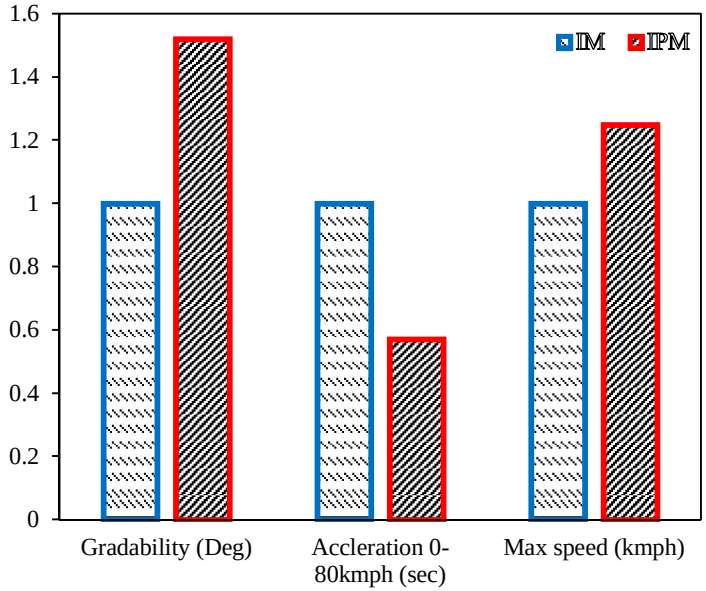
Licensing core IP and technologies related to EV's and EV ecosystem to OEMs.

Motivation

Low cost, Low Voltage drive system for Indian EV

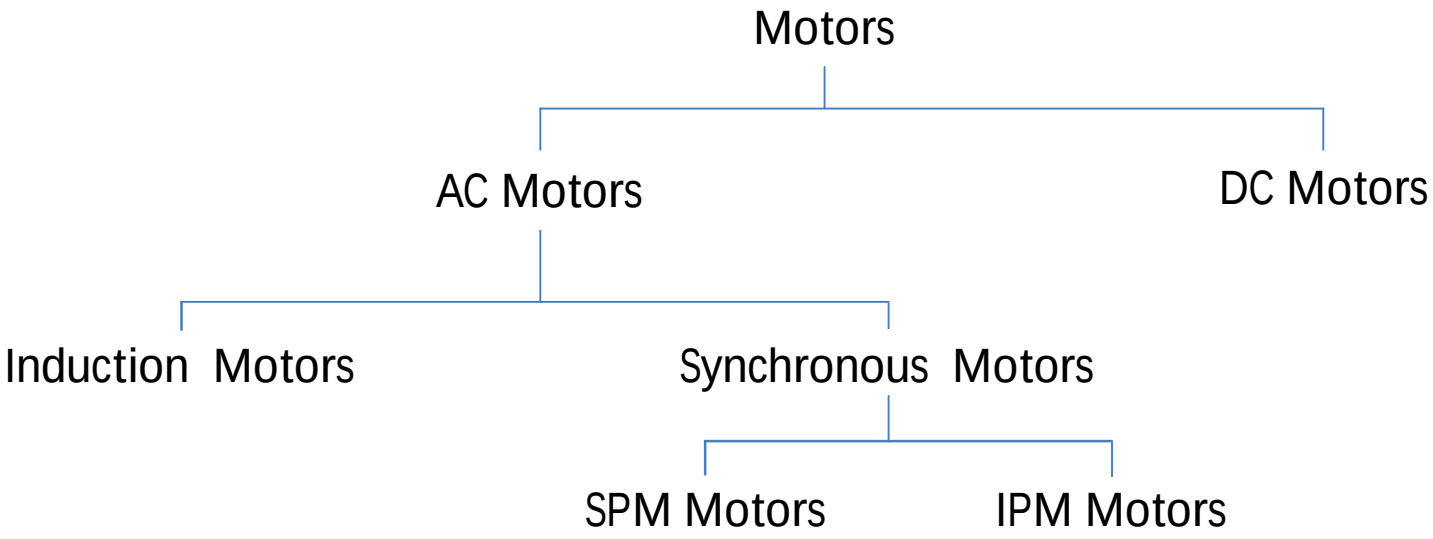
- Improve the gradability
- Acceleration time reduction
- Above 100kmph

	Model A IM (Existing)	Model B
Top Speed	89	107
Gradeability	9.1	14.5
Acc : 0-60	11.75	6.8



Different Types of motors

Comparison of different motor technology for Traction application.

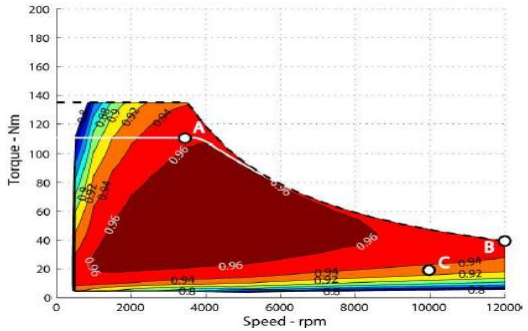


Comparsion of IM & SM machines

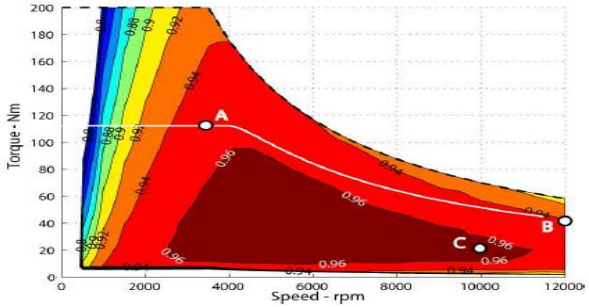
Parameters	Induction motor (IM)	Permanent Magnet Synchronous Motor (PMSM)
Power Density	-	+ +
Efficiency	+	+ +
Costs	++	+
Reliability	++	+
Technical Maturity	+	+

IPM Vs SPM

- Over load capability is higher for IPM when compared to SPM machine which provides high Gradability & acceleration
- High efficiency over the speed range, which makes IPM machine suitable for high speed vehicles

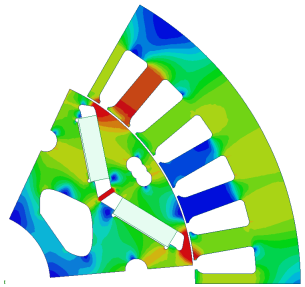


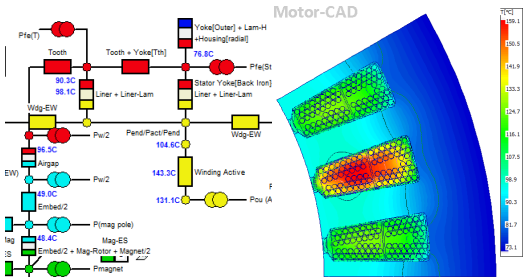
SPM - efficiency map



IPM - efficiency map

Design methodology





SOR

Stator Lamination Design
- Material Grade
- Slot/Pole combination
- OD & ID
- Tooth Width
- Slot Height

Winding Design
- Single/Double Layer
- No. of Turns
- No. of Parallel paths
- Winding Pitch
- Slot fill factor
- Insulation class

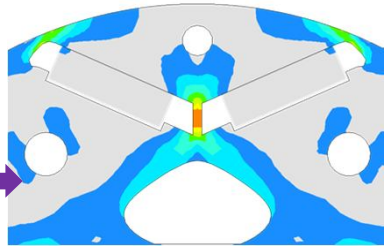
Rotor Lamination Design
- Material Grade
- No of Poles
- Pole Profile
- Pole arc angle
- Bridge & Rib Dimensions

Magnet Design
- Size
- Grade
- Segments
- Coating & Bonding

Electro Magnetic Analysis

OK → Redesign/Change Critical Parameter

Structural Analysis



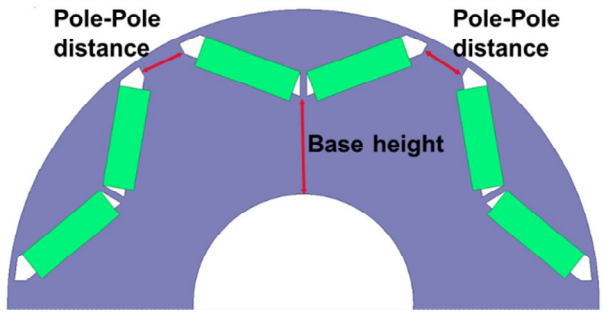
OK → Change Rib and Bridge dimensions/ Material Grade

Thermal Analysis

OK → Cooling Circuit Design

Drawing Release → Proto Build

Design methodology : Rotor DoE



Basic rotor profile of IPM motor

Baseheight (mm) \ Pole-Pole distance (mm)	4	6	8	10
18	0.050	0.051	0.051	
17	0.050	0.050	0.051	
16	0.050	0.050	0.051	0.051
15	0.049	0.050	0.050	0.051
14	0.049	0.050	0.050	0.050

PM flux linkage

Baseheight (mm) \ Pole-Pole distance (mm)	4	6	8	10
18	1.388	1.377	1.359	
17	1.395	1.383	1.365	
16	1.400	1.387	1.368	1.348
15	1.405	1.390	1.371	1.350
14	1.407	1.395	1.372	1.350

Saliency ratio

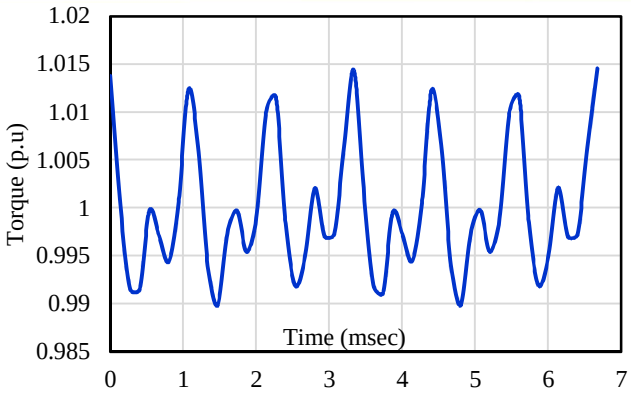
Baseheight (mm) \ Pole-Pole distance (mm)	4	6	8	10
18	0.114	0.113	0.111	
17	0.117	0.116	0.113	
16	0.119	0.117	0.114	0.111
15	0.121	0.119	0.116	0.112
14	0.122	0.121	0.116	0.112

L_q - L_d

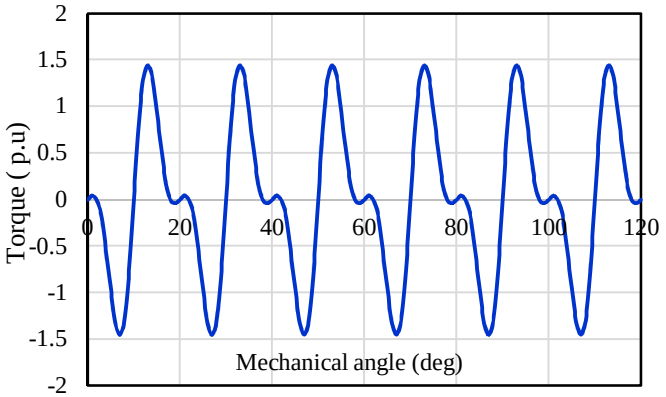
Baseheight (mm) \ Pole-Pole distance (mm)	4	6	8	10
18	168.9	168.0	165.7	
17	167.9	167.1	164.8	
16	166.6	165.7	163.6	159.0
15	165.1	164.1	161.8	158.3
14	163.2	162.6	159.9	157.0

Characteristic current

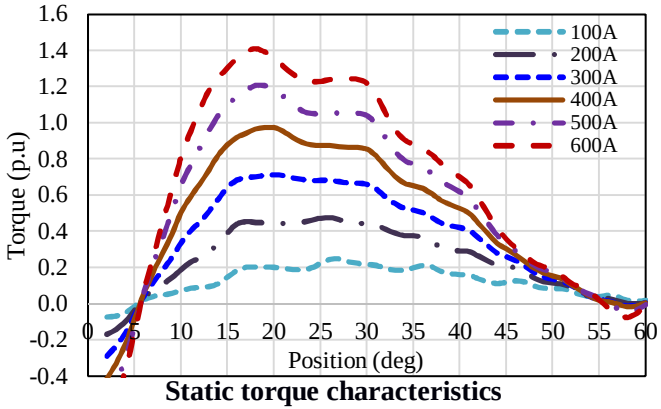
Design methodology : CAE results



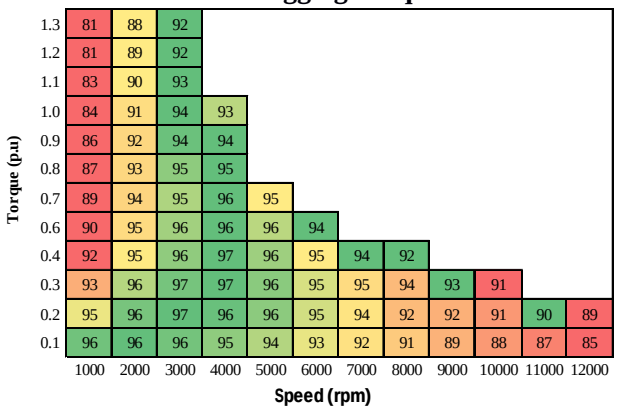
Torque ripple



Cogging Torque



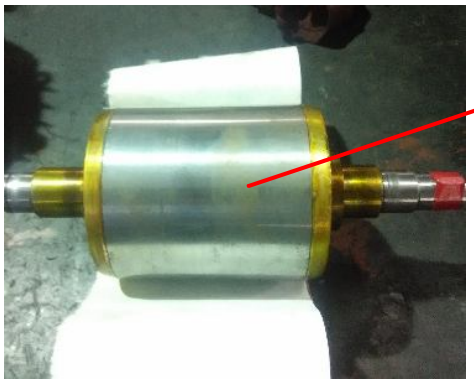
Static torque characteristics



Efficiency Map

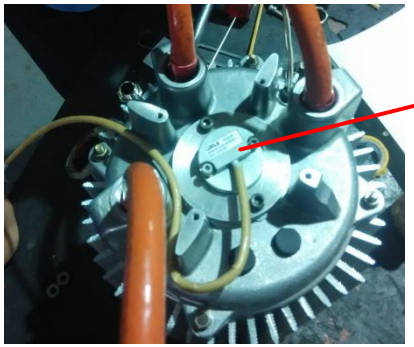
IPM - Proto

Skewed stator pack



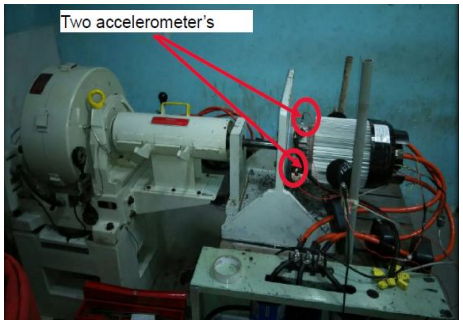
IPM rotor assembly

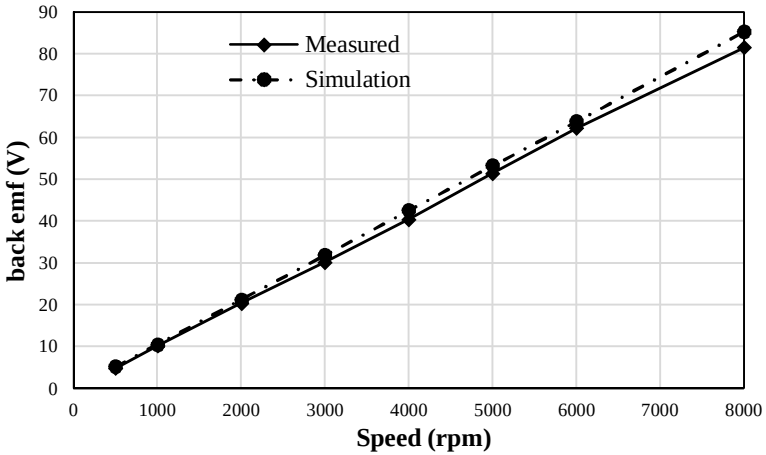
Skewed assembly with high slot fill

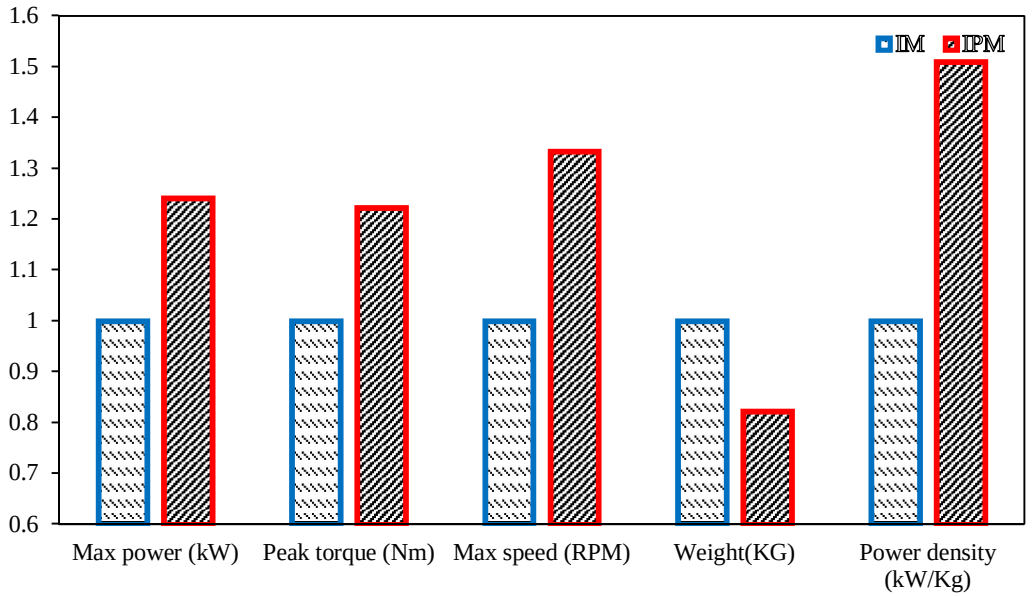


Position Sensor on NDE casing

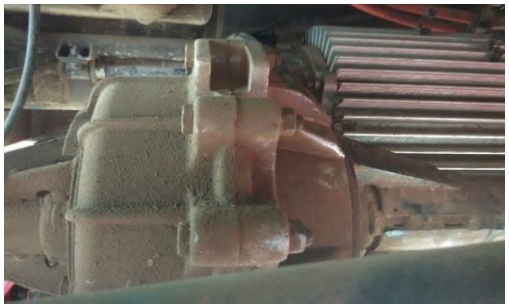
Validation results : Component level

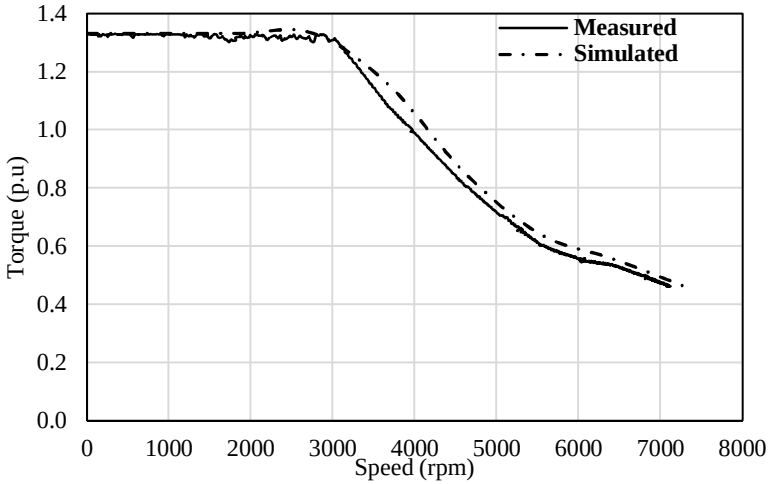


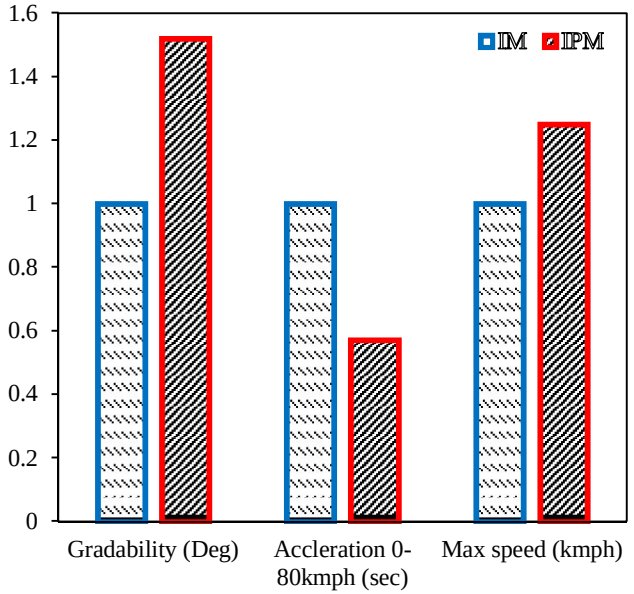




Validation results : Vehicle level

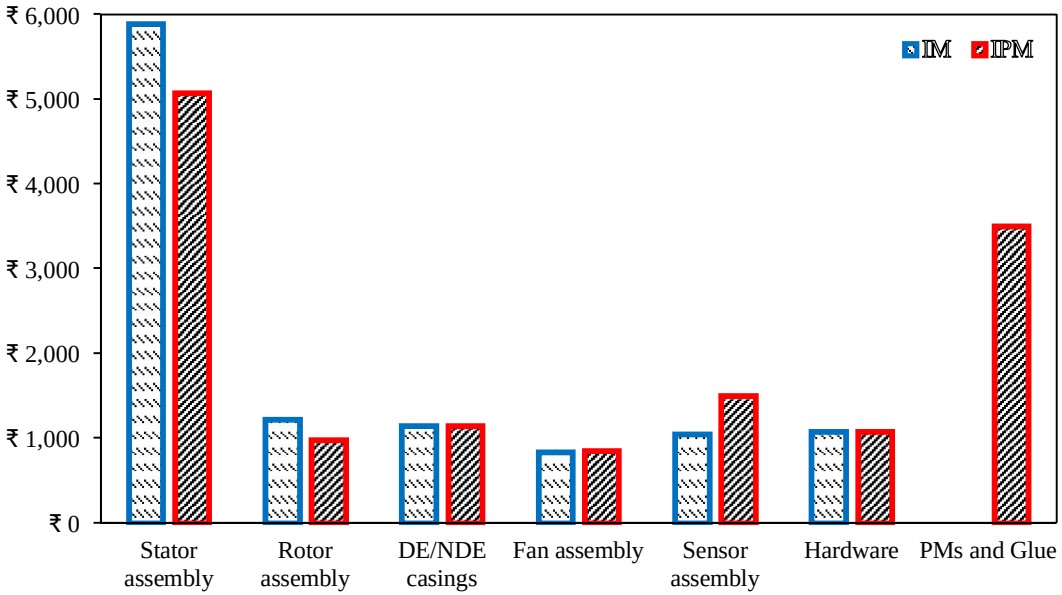






Impact of IPM motor's performance parameters on vehicle performance in comparison to Induction motor

Cost comparison



Production cost comparison of IM Vs IPM for same power rating

Conclusions

- Torque ripple and cogging torque are minimized to lower values for reducing the noise and vibration in the system level
- Power density of IPM motor increases to 1.5 times of Induction motor power density by optimizing rotor lamination to improve reluctance torque
- IPM motor is designed for higher torque, higher power and higher speed; gradability, acceleration and maximum speed of the vehicle has been improved in comparison to Induction motor powered vehicle
- Proto build price is completed and the cost is $4/kW against target price of $3.4/kW

Thank You