Power Electronics and Motor Drive Technologies for Automobile Electrification

https://www.nissan-global.com/JP/TECHNOLOGY/OVERVIEW/e_powertrain.html

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Power Electronics(PE) and Motor Drive(MD) Technologies for Automobile Electrification

1. Introduction
2. Expectation to SiC-MOSFET.
3. Technologies for high power motor drive system
4. Conclusions

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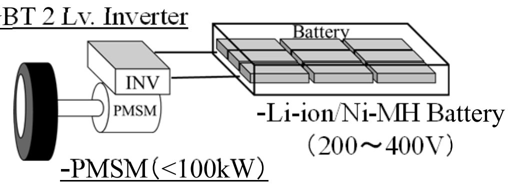
Once typical design of electric traction system

B segment

https://www3.nissan.co.jp/vehicles/new/leaf.html



Recent requirement for EV

Market	B segment, C segment･･･Commercial Vehicle
Motor power	Expand to more than 100kW
Battery voltage	Expand to 800V

More recent design for traction system

Motor : PMSM, IM, WFSM…
Inverter : 2Lv, 3Lv…IGBT, SiC-MOSFET, GaN-MOSFET…

What is better design?

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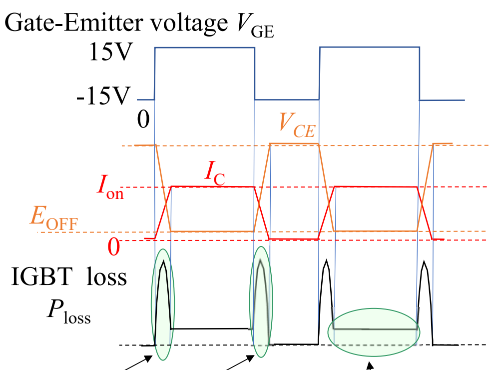
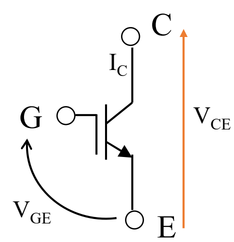
Loss of power semiconductor devices



switching loss
loss with transient current and voltage

conduction loss
loss with steady current and forward voltage

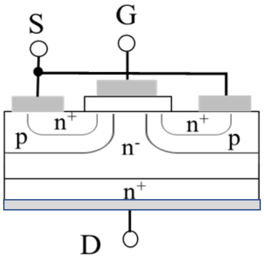
Example : IGBT



cooling fin for power devices

https://www.spp.co.jp/netsu/products/pdc/

SiC-MOSFET power semiconductor devices



<u>Benefit of Power MOS-FET</u>

・High speed switching
(No tale current)

<u>Draw back due to Unipolar device</u>

High conduction resistance
→Lower voltage application (Less than 800V by **<u>Si</u>** device))

<u>Wide Band Gap semiconductor (SiC)</u>

Down sized DC/DC converter and traction inverter
with SiC-MOSFET

Property of SiC-MOSFET power semiconductor devices

600V Si IGBT vs. 600V MOSFET

	Si-MOSFET	Si-IGBT	SiC-MOSFET
on loss	1	0.1	0.01
switching loss	1	10	1
switching duration	1	5 - 10	1
switching frequency	1	0.05 – 0.1	1
operating temp.	1	1	1.5 – 2.0

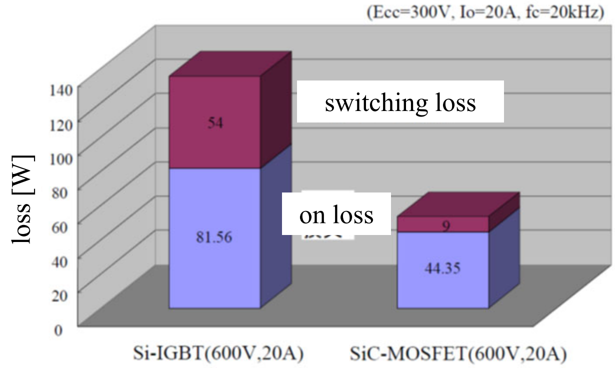
http://www.iae.or.jp/PROJECT/nws/pdf/d2/s6.pdf

Wide band gap

Less loss and higher connection surface temperature

Property of inverter loss

loss comparison in 2 kW class inverter



http://www.iae.or.jp/PROJECT/nws/pdf/d2/s6.pdf

Loss of SiC MOSFET 2 kW inverter

50% less loss than IGBT inverter

Conduction loss of 3.3 kV SiC-MOSFET vs 3.3 kV Si-IGBT

SiC-MOSFET →1/3 conduction loss @800A of Si IGBT

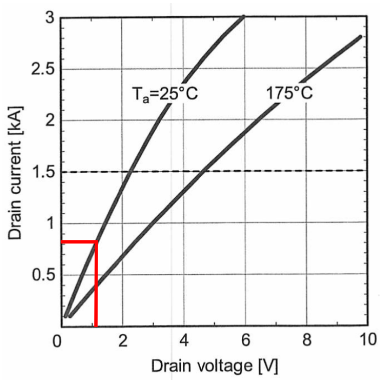
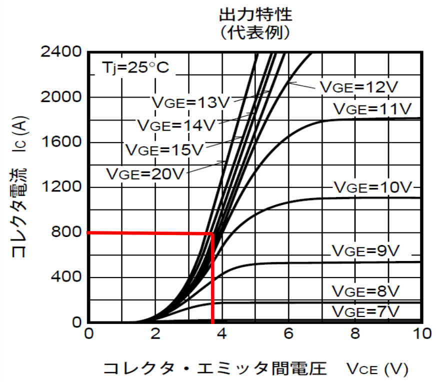


Figure 2. I_{DS}-V_{DS} characteristics of a 3.3 kV all-SiC traction inverter module.

3.3kV SiC-MOSFET



3.3kV Si-IGBT

IGBT:MELCO IGBT module CM1200HA-66H date sheet

MOSFET: M.Furuhashi et el "Practical Application of SiC-MOSFETs and futher development" Semiconductor Science and Technology 31 (2016) 034003, 9P

Switching loss of 3.3 kV SiC-MOSFET vs 3.3 kV Si-IGBT

SiC-MOSFET →Less than 1/3 witching loss of Si IGBT

3.3kV Si-IGBT

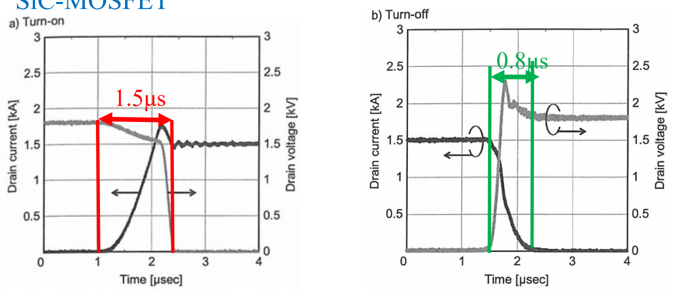
		Conditions	Value	Unit
td (on)	turn on delay time	VCC = 1650V, IC = 1200A	1.60	µs
tr	turn on rise time	VGE1 = VGE2 = 15V	2.00	µs
td (off)	turn off delay time	RG = 2.5Ω	2.50	µs
tf	turn off fall time	rheostatic load	1.00	µs

3.6µs

3.5µs

IGBT:MELCO IGBT module CM1200HA-66H date sheet

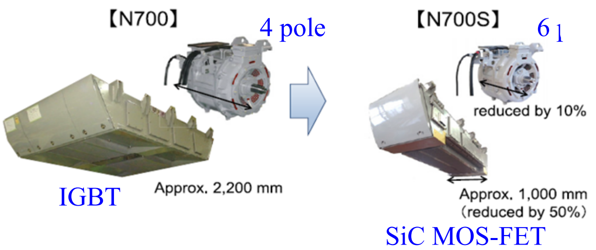
3.3kV SiC-MOSFET



M.Furuhashi et el "Practical Application of SiC-MOSFETs and futher development" Semiconductor Science and Technology 31 (2016) 034003, 9P

Example of down sized power converter for Shinkansen vehicle by 3.3kV SiC MOS-FET

Cited to Nippon-syaryo web-site

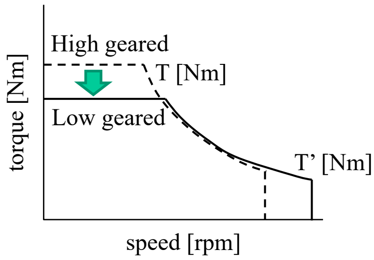


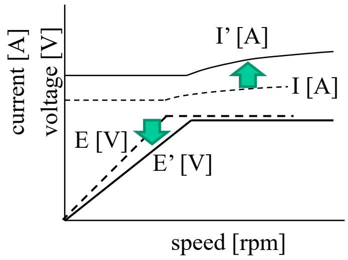
Kenji Sato, Hirokazu Kato, Takafumi Fukushima,"Outstanding Technical Features of Traction System in N700S Shinkansen New Generation Standardized High Speed Train", Journal of Industrial Application of IEEJ, Vol.10 No.4 pp.402-410,2021.3

Comparison mass of the traction systems

	Number per train	N700	N700S
Transformer	4	3600kg	3500kg
Power converter	14	1500kg(IGBT)	1000kg(SiC MOS-FET)
Traction motor (305kW)	56	approx. 400kg	approx.350kg
All over Traction system		58t (100%)	47t (81%)

Expectation to SiC MOS-FET -Expanding the current region -





Changing N-T characteristics

Mechanical traction system	⇨	Changing Gear ratio
Electricals traction system	⇨	Changing current-voltage characteristics

SiC MOSFET

Easy to increase current : More freedom of N-T characteristics

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Enhancing the DC input voltage1.

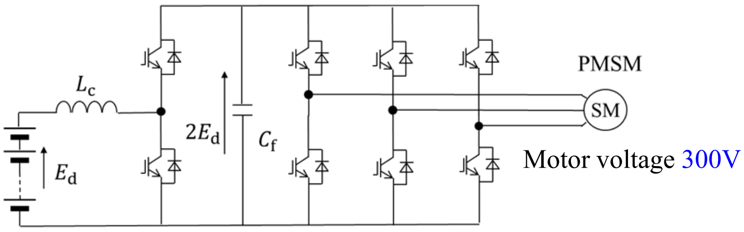
EV for C segment vehicle

Motor voltage 150V → 300V

https://www.subaru.jp/solterra/solterra/grade/index?=view_menu

Conventional circuit configuration

DC/DC convert + IGBT 2 Level inverter



Battery voltage
E_d =400V

Inverter input DC voltage
$2E_d$ =800V

Enhancing the DC input voltage2.

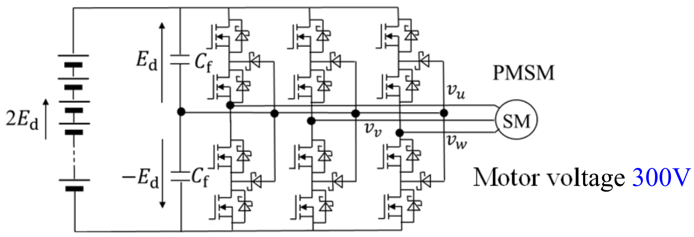
EV for C segment vehicle

Motor voltage 150V → 300V

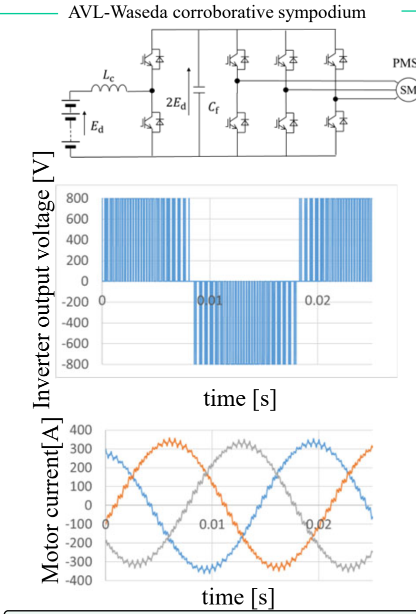
https://www.subaru.jp/solterra/solterra/grade/index?=view_menu

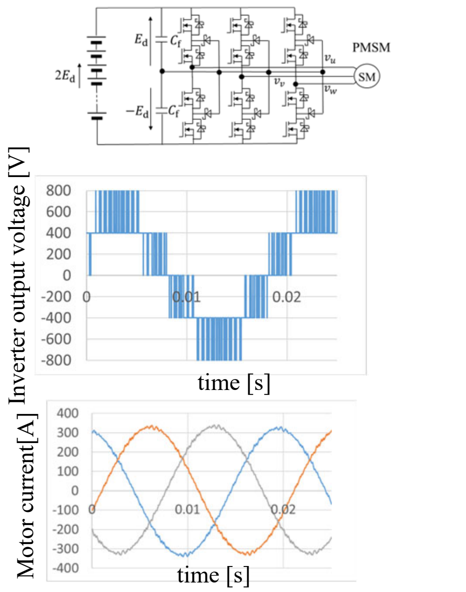
Higher battery voltage
+ SiC MOSFET Level inverter

Less size and lower switching loss even more semiconductor devices



Battery voltage
$2E_d$ =800V





Less Harmonics current in 3 Lv. Inverter → Less loss in motor 17 17

Design of traction motor

https://ansys.oatnd.com/ntc-article-2-2

Permanent magnet synchronous motor (PMSM)

- -Highest efficiency
- -Expensive permanent magnet
- →Most applied traction motor type

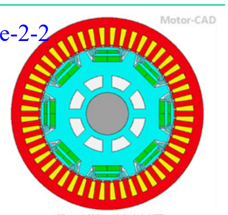


図1.IPM設計の半径方向断面

Winding field synchronous motor(WFSM)

- -wide speed operation range
- -lotter lower efficiency than PMSM
- →appropriate for part time operation

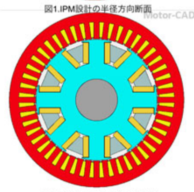


図16.WFSM設計の半径方向断面

Induction motor (IM)

- -lowest cost
- -lower efficiency than PMSM
- →appropriate for part time operation

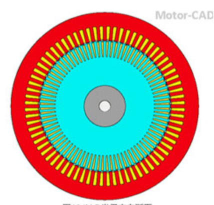


図10.IMの半径方向断面

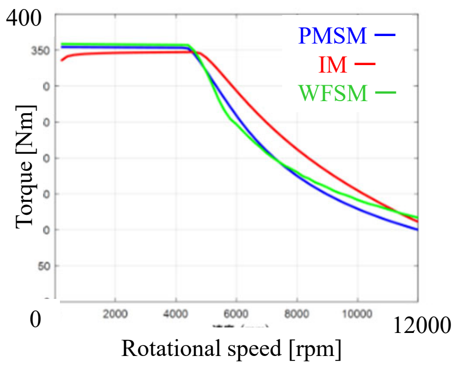
Which is appropriate type of motor ?

AVL-Waseda corroborative sympodium

Design comparison of type of traction motor

Max Torque :350Nm
Max rotational speed :12000rpm
DC link volt. 400V
Max. current 500A(rms)
Outer size of stator: 250mm

https://www.nissan-global.com
/JP/TECHNOLOGY/OVERVIEW/e_powertrain.html



N-T curve at max.torque performance

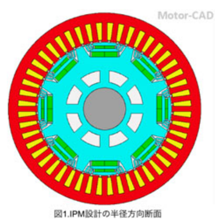
https://ansys.oatnd.com/ntc-article-2-2

160kW@max. class traction motor assumed

AVL-Waseda corroborative sympodium

Design results 1 -PMSM-

Permanent magnet synchronous motor (PMSM)



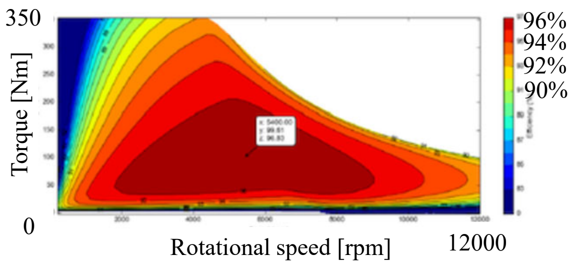
Design results

length of core[mm]:PMSM 100, IM 120, WFSM 120
over all length[mm]: PMSM 160, IM 200, WFSM 180
mass[kg]:PMSM 33.2, IM 47, WFSM 36.7

-Most down sized motor design

-High efficiency in the middle speed and partial load range.

-Appropriate for the town ride purpose.



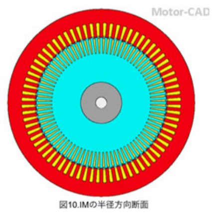
efficiency map

https://ansys.oatnd.com/ntc-article-2-2

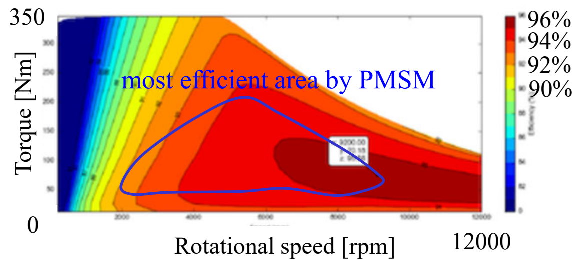
Design results 2 -IM-

Induction motor (IM)

length of core[mm]:PMSM 100, IM 120, WFSM 120
over all length[mm]: PMSM 160, IM 200, WFSM 180
mass[kg]:PMSM 33.2, IM 47, WFSM 36.7



- -Most bulky motor design.
- -High efficiency in the high speed and right load range.
- -Appropriate for the higher speed cursing.



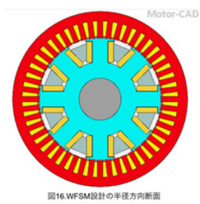
efficiency map

https://ansys.oatnd.com/ntc-article-2-2

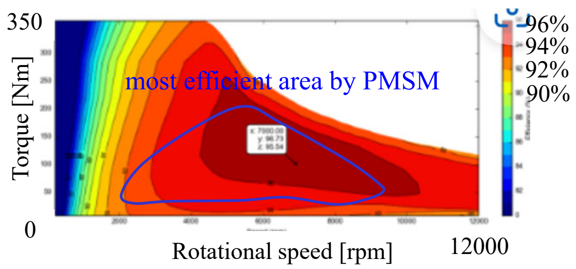
Design results 3 -WFSM-

Winding field type synchronous motor (WFSM)

length of core[mm]:PMSM 100, IM 120, WFSM 120
over all length[mm]: PMSM 160, IM 200, WFSM 180
mass[kg]:PMSM 33.2, IM 47, WFSM 36.7



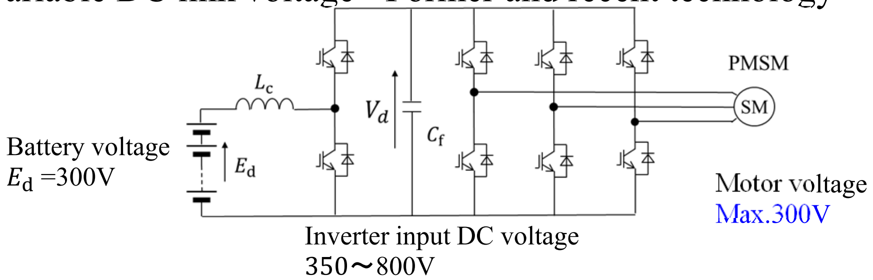
- -Bulky motor design.
- -High efficiency in the middle speed and middle load range.
- -Appropriate for the suburban running.

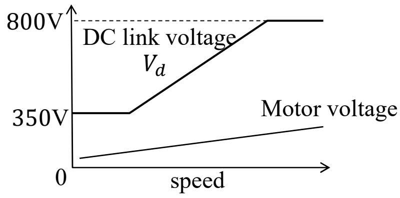


efficiency map

httpsansys.oatnd.comntc-article-2-2

Variable DC link voltage -Former and recent technology-





Former power devices

IGBT tale current loss reduced by variable DC link voltage.

Recent power devices

-Less switching loss (ie: SiC-MOSFET)
-Saving harmonics loss of motor

➡ Constant DC link voltage and higher switching

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Summarizing today talk.

-Wide band gap device: Drastic less loss in power converter

-Type of traction motor : PMSM is not only choice!

-Inverter configuration : More choice along with the voltage and power

Appropriate Design is diversified along with the Market

https://www3.nissan.co.jp/vehicles/new/leaf.html

https://www.tesla.com/ja_jp

https://press.siemens.com/global/en/feature/ehighway-solutions-electrified-road-freight-transpor

Thank you for kind attention