

Tecnologie elettriche innovative per i treni merci del futuro

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*I treni merci lungo i corridoi europei:
prospettive 2030*



FAULT-TOLERANT SYNCHRONOUS MOTORS

OUTLINE OF THE PRESENTATION

- 1 Synchronous PM Motors
- 2 Design to limit the impact of fault
- 3 Dual Three-Phase Motors
- 4 Five-Phase Motors
- 5 Power electronic solutions
- 6 Conclusions

Synchronous PM motors

Design to limit the impact of fault

Dual Three-Phase Machine

Five-Phase Motors

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Synchronous PM motors

Synchronous PM motors

Design to limit the impact of fault

Dual Three-Phase Machine

Five-Phase Motors

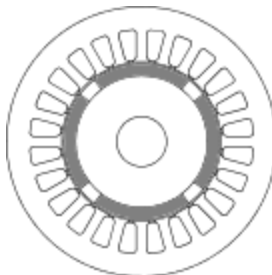
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The PM motors are distinguished in two classes

Surface-mounted PM (SPM) motor, whose PMs are mounted on the surface of the rotor.



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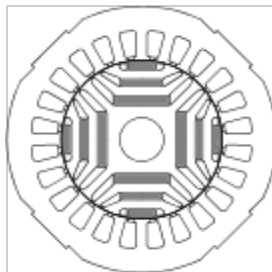
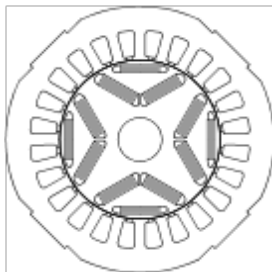
Conclusions

The PM motors are distinguished in two classes

Interior PM (IPM) motor, whose PMs are buried in the rotor, in proper holes.

Flux barriers canalize the magnetidflux.

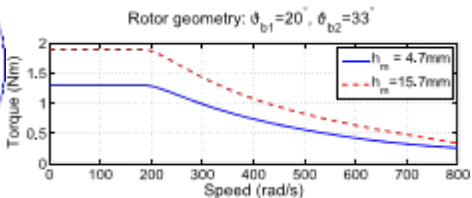
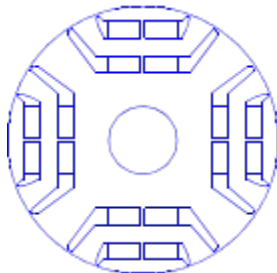
Two torque components: PM torque and reluctance torque.





IPM Rotor configurations are suitable to achieve

- Constant torque and
- Constant power versus speed regions



Synchronous PM motors

Design to limit the impact of fault

Dual Three-Phase Machine

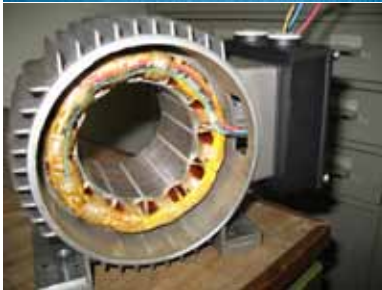
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Fractional slot windings exhibit very short end-windings



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Synchronous PM motors

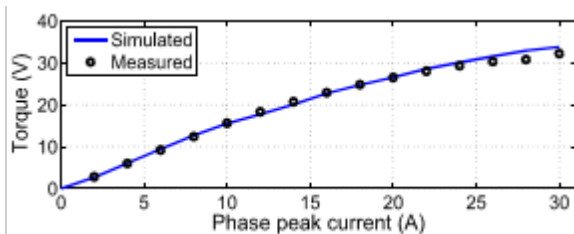
Design to limit the impact of fault

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Synchronous PM motors

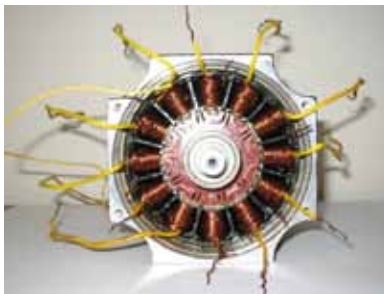
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Design to limit the impact of fault

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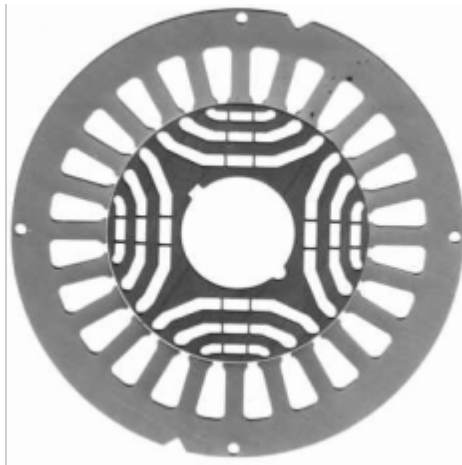
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Interior PM motor lamination, designed for a steer-by-wire mechanism



Synchronous
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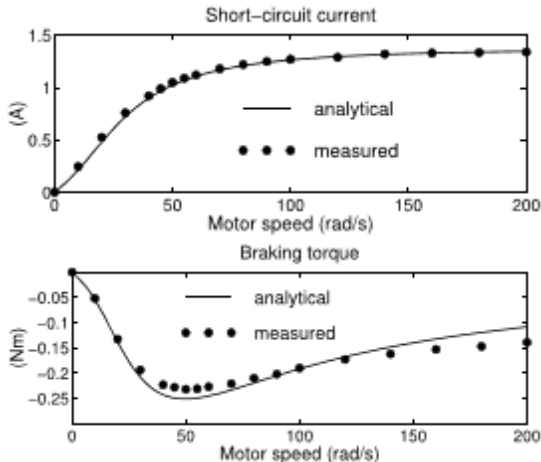
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Short-circuit current and braking torque as a function of the motor speed.



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Dual Three-Phase Machine

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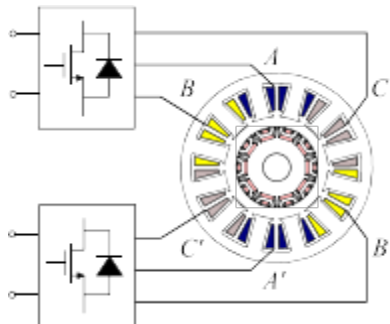
Dual Three-Phase Machine

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Scheme of the dual three-phase machine drive.



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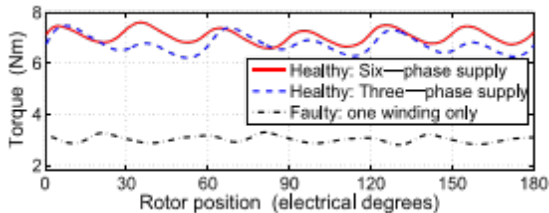
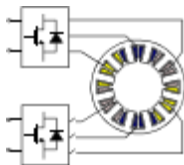
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In the event of a fault:

one of the two three-phase systems is disconnected
the machine is operated by healthy three-phase system.



Measured torque behaviors under healthy
and open circuit faulty conditions.



Synchronous PM motors

Design to limit the impact of fault

Dual Three-Phase Machine

Five-Phase Motors

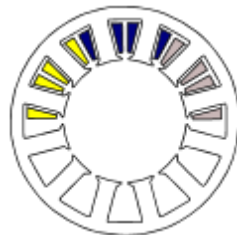
Power electronic solutions

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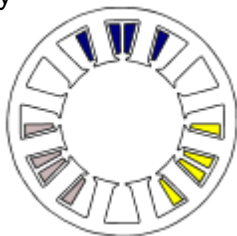
DL-healthy



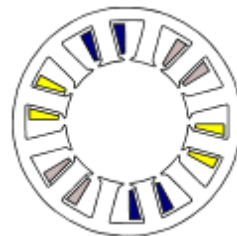
DL-1



DL-2

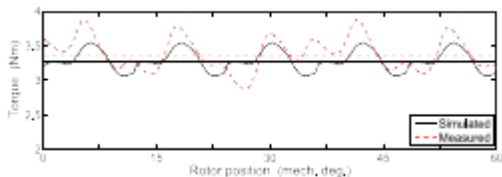


DL-3

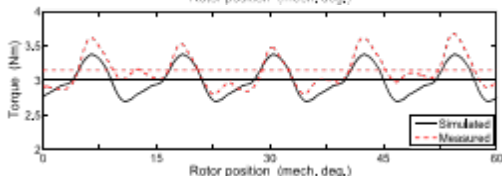




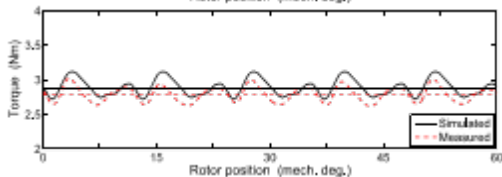
IPM machine: simulated and measured torque versus rotor position with various double-layer winding arrangements.



DL-1



DL-2



DL-3

Synchronous PM motors

Design to limit the impact of fault

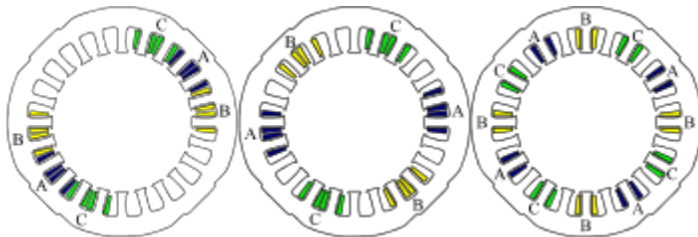
Dual Three-Phase Machine

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Symmetric 24-slot 20-pole configurations.



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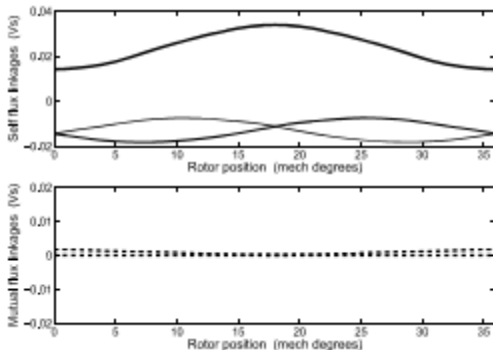
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Flux linkages versus rotor position with DL-1 double-layer winding arrangement



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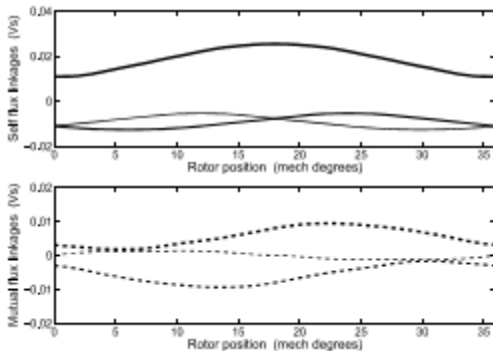
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Flux linkages versus rotor position with DL-3 double-layer winding arrangement.



Synchronous PM motors

Design to limit the impact of fault

Dual Three-Phase Machine

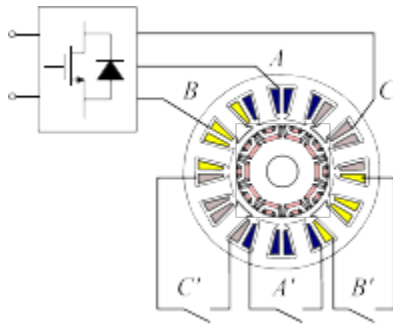
Five-Phase Motors

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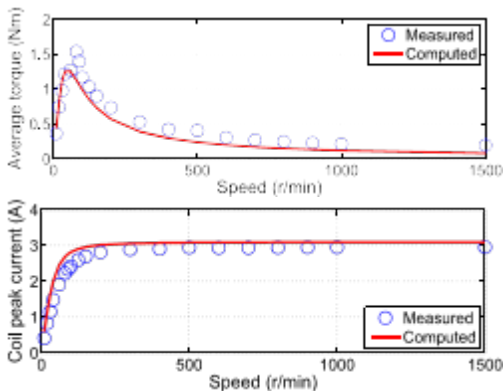
Test layout for testing the machine capability with a single phase or a complete three-phase winding short-circuited.



- Synchronous PM motors
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(a) Measured braking torque and
versus speed with dragged rotor and all coils



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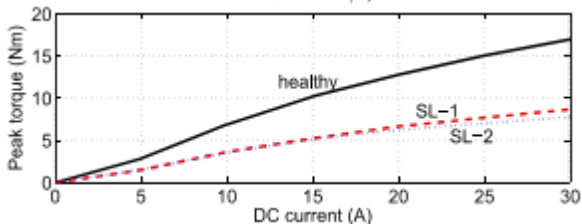
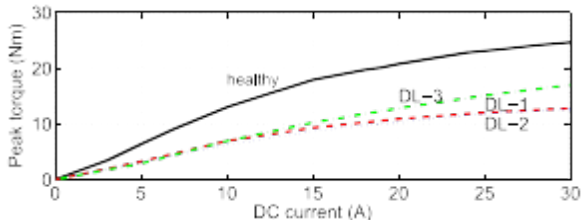
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Measured torque versus current with
 (a) single-layer winding configurations and
 (b) single-layer winding configurations
 — DC current supply and dragged rotor —



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Five-Phase Motors

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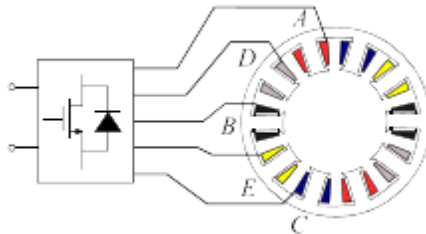
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**Five-Phase
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Scheme of the five –phase motor drive.



Synchronous
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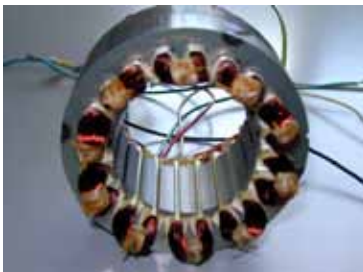
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Five-phase PM prototype: photo of the (a) stator and (b)



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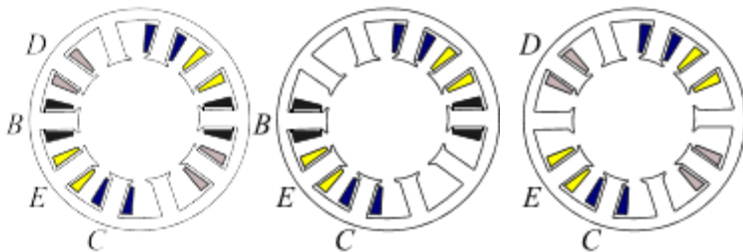
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Five-phase PM motor: examples of the loss of one or two

(b): two adjacent phases open circuit;
 (c): two non adjacent phases open circuit.



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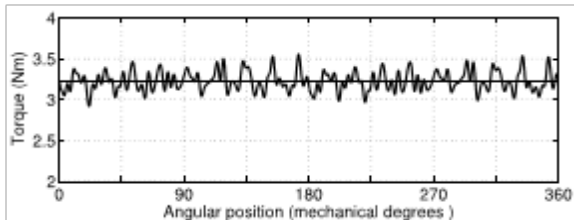
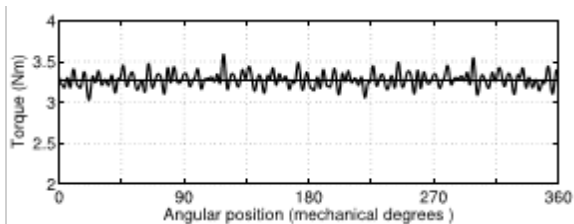
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Measured torque behaviours in a five –phase PM motor with open circuit of **two non-adjacent** phases.
 (a) half–bridge converter; (b) full–bridge converter.



Synchronous PM motors

Design to limit the impact of fault

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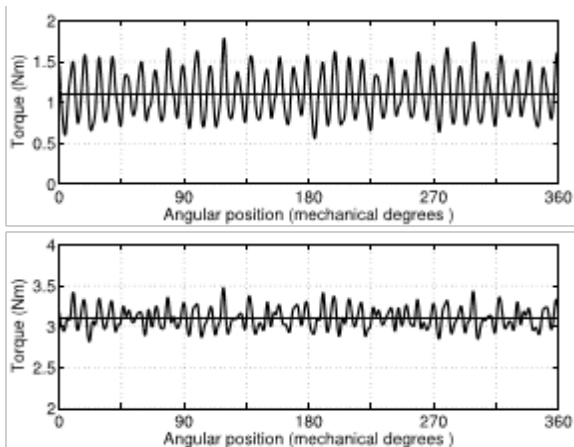
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Measured torque behaviours in a five –phase PM motor with open circuit of **two adjacent** phases.
(a) half–bridge converter; (b) full–bridge converter.



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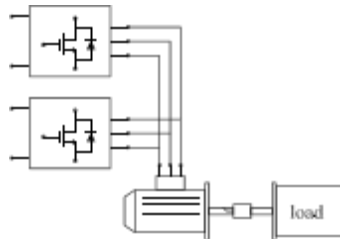
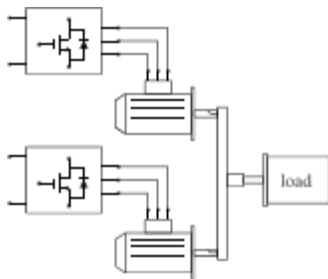
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Complete and partial redundancy:

- 1 all components of the electrical motor drive are
- 2 inverter is doubled, while only one PM motor is



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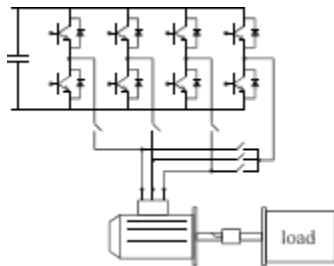
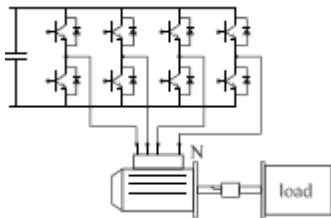
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Conclusions



To reduce costs, only a part of the inverter is redundant:

- 1 with neutral point connection
- 2 with redundant leg



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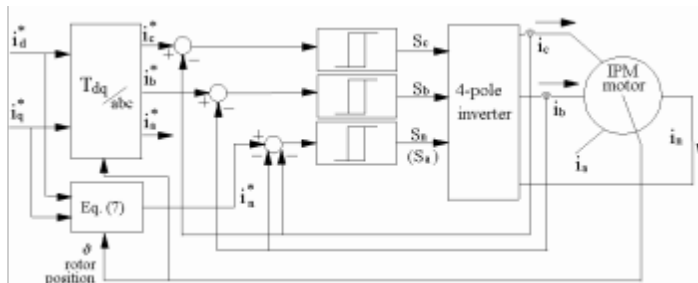
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Inverter with neutral point connection



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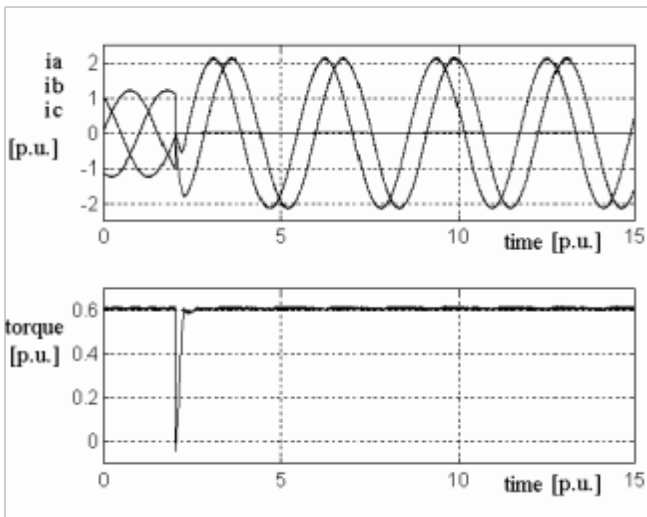
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Inverter with neutral point connection



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Electric motor configurations exist suitable to:

- to limit the fault rise up,
- to limit the impact of a fault,
- to resist a fault event,
- to operate in coexistence with a fault,

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Thank you for the attention.

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