Open-winding multiphase machines with two different storage sources

Prof. Eric SEMAIL, Dr. Ngac Ky NGUYEN
L2EP, Arts et Métiers ParisTech
Eric.SEMAIL@ensam.eu
NgacKy.NGUYEN@ensam.eu
Open-winding multiphase machines with two different storage sources

- Outline -

1. EMR for open-winding multiphase machines
2. Inversion-based control of the open-winding machine
3. Strategies of control for open-winding machine structure
« EMR for open-winding multiphase machines »
Open-winding multiphase machines with two different storage sources

- EMR for open-winding multiphase machines -

More flexible:
- Different dynamic energy storage sources
- Increasing the battery life
- Increasing the degrees of freedom for control
- Increasing the fault tolerance capacities
- Higher machine voltage

One VSI

Two VSIs
Open-winding multiphase machines with two different storage sources

- EMR for open-winding multiphase machines -

EMR'13, Lille, Sept. 2013
Open-winding multiphase machines with two different storage sources

- EMR for open-winding multiphase machines -

EMR’13, Lille, Sept. 2013

Sources → LPF → Inverters → AC Motor → Transmission-Wheels → Chassis

$u_{bat}$ $i_{bat}$ $v_{motor}$ $i_{motor}$ $T_{em}$ $F_{tran}$ $v_{ev}$ $F_{res}$

$u_{sup}$ $i_{sup}$ $u_{C}$ $i_{C}$ $v_{INV1}$ $i_{INV1}$ $v_{INV1}$ $v_{motor}$ $i_{motor}$ $T_{em}$ $F_{tran}$ $v_{ev}$ $F_{res}$

BAT

SUP
« Inversion-based control of the open-winding machine »
Open-winding multiphase machines with two different storage sources

- Inversion-based control of the open-winding machine -

Sources — LPF — Inverters — AC Motor — Trans.-Wheels — Chassis — Environment

Control objective: $v_{ev} \rightarrow \vec{v}_{motor}$ (dimension 3)

Tuning variables: $S_{INV1}$ and $S_{INV2}$ (dimension 6)

Constraint (6-3=3)

Strategies of control
Open-winding multiphase machines with two different storage sources

- Inversion-based control of the open-winding machine -
« Strategies of control for open-winding machine structure »
Open-winding multiphase machines with two different storage sources

- Strategies of control for open-winding machine structure -

Voltage

\[ \vec{v}_{dq-motor} = \vec{v}_{dq1} - \vec{v}_{dq2} \]

Power

\[ P_{motor} = P_1 - P_2 \]

How can we choose the \( \vec{v}_{dq1} \) and \( \vec{v}_{dq2} \) vectors?
Open-winding multiphase machines with two different storage sources

- Strategies of control for open-winding machine structure -

Unity Power Factor Control  [Welchko 05]

\[
\vec{v}_{dq-motor} = \vec{v}_{dq1} - \vec{v}_{dq2}
\]

Voltage

\[
P_{motor} = P_1 - P_2
\]

Power

The power (acceleration or break) of the super-capacitor is maximized

Acceleration

Regenerative breaking
Open-winding multiphase machines with two different storage sources
- Strategies of control for open-winding machine structure -

Quadrature voltage control  [Welchko 05]

\[ \mathbf{v}_{dq1} - \mathbf{v}_{dq2} = \mathbf{i}_{dq-motor} \]

\[ P_{motor} = P_1 - P_2 \]

The active power of the super-capacitor is null

Speed constant

Blue: INV2 is considered as a “capacitor”  →  High power factor of INV1

Red: INV2 is considered as a “winding”  →  Low power factor of INV1
Open-winding multiphase machines with two different storage sources

- Strategies of control for open-winding machine structure -

EMR'13, Lille, Sept. 2013

Maximum voltage control [Welchko 05]

\[ \vec{v}_{dq-motor} = \vec{v}_{dq1} - \vec{v}_{dq2} \]

Voltage

\[ P_{motor} = P_1 - P_2 \]

Power

 Maximum machine voltage

High speed
Open-winding multiphase machines with two different storage sources

- Strategies of control for open-winding machine structure -

Simulation result

1. Super-capacitor is used mainly.
2. Battery supplies and super-capacitor is charged.
3. Super-capacitor is used mainly.
4. Super-capacitor and battery are used.
5. Super-capacitor is charged (regenerative brake).
6. Battery supplies and super-capacitor is charged.
Open-winding multiphase machines with two different storage sources

- Strategies of control for open-winding machine structure -

Simulation result

Rotor speed

Battery energy

Super-capacitor energy

EMR’13, Lille, Sept. 2013
Open-winding multiphase machines with two different storage sources

« BIOGRAPHIES AND REFERENCES »
Open-winding multiphase machines with two different storage sources

- Authors -

Prof. Eric SEMAIL
Arts et Métiers ParisTech, L2EP, France
PhD in Electrical Engineering at University Lille1 (2000)
Full Professor since 2010
Research topics: Multiphase machines design and control, multi-converter modelling

Dr. Ngac Ky NGUYEN
Arts et Métiers ParisTech, L2EP, France
PhD in Electrical Engineering at University of Mulhouse (2010)
Associate Professor since 2012
Research topics: Multiphase machines control, fault tolerance systems, EMR
Open-winding multiphase machines with two different storage sources

- References -


Open-winding multiphase machines with two different storage sources

- References -
