Open-winding multiphase machines with two different storage sources

Dr. Ngac Ky NGUYEN, Prof. Eric SEMAIL, 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
4. Conclusion
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 and for optimization
• Increasing the functional fault tolerance capacities
Open-winding multiphase machines with two different storage sources

- EMR for open-winding multiphase machines -
Open-winding multiphase machines with two different storage sources

- EMR for open-winding multiphase machines -
« 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: \( \vec{v}_{ev} \rightarrow \vec{v}_{motor} \) (dimension 3)

Tuning variables: \( \vec{S}_{INV1} \) and \( \vec{S}_{INV2} \) (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 -

Note:

P_{bat} > 0 : **Battery feeds** the motor and vice-versa

P_{SC} < 0 : **Supercap. feeds** the motor and vice-versa

\[ P_{motor} = P_{bat} - P_{SC} \]
Open-winding multiphase machines with two different storage sources

- Strategies of control for open-winding machine structure -

Power flow

\[ \overrightarrow{v}_{dq \text{-motor}} \rightarrow \overrightarrow{i}_{dq \text{-motor}} \]

\[ P_{\text{motor}} = P_{\text{bat.}} - P_{SC} \]

Battery Supercap.

**MAIN objective of SC:**

Smooth the current of the battery, it means SC will be used in accelerations and braking.
Open-winding multiphase machines with two different storage sources

- Strategies of control for open-winding machine structure -

Unity Power Factor Control  [Welchko 05]

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

\[ \text{Power} \quad P_{motor} = P_1 - P_2 \]

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 -

Others
(constant speed, low speed, high speed)

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

Power
\[ P_{motor} = P_{bat} - P_{SC} \]

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 -

Quadrature voltage control [Welchko 05]

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

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

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 -

Maximum voltage control [Welchko 05]

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

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

Voltage

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
Open-winding multiphase machines with two different storage sources

- Strategies of control for open-winding machine structure -

Simulation result (Artemis Cycle)

**Speed Vs Time**

![Graph showing speed vs time](image)

**Powers**

![Graph showing powers vs time](image)

**States of charge Vs Time**

![Graph showing states of charge vs time](image)

Note:
- for SC, 0% corresponds to 50% SoC
- EMR is a tool for representation and inversion-based control.

Performances of the whole system depend on the designer (Chosen Strategies and Topology (Parameters) Design)
An open-end three-phase winding structure has been modeled and controlled by using EMR.

EMR is a tool for representation and inversion-based control. Performances of the whole system depend on the designer (Chosen Strategies and Topology (Parameters) Design).
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 -
