«FAULT-OPERATION MODES OF A HIGHLY REDUNDANT MILITARY HEV»

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Why using hybrid or electric technologies in military vehicles?

- Objectives of the study -

- Autonomy
- Stealth (noise, heat, infrared)
- Mobility
- Flexible architecture
- Degraded mode

Energy management in case of failure

Consequences of a power axle failure on the vehicle behavior (several strategy tested)
1. Presentation of the vehicle
2. Previous works
3. System behavior in case of failure
4. Driver abilities for fault compensation
« Presentation of the Vehicle »
The DPE 6x6

*(Electric Propulsion Demonstrator)*

- Hybrid Electric Drive Demonstrator
- Armored Soldier transport Vehicle (20t)
- 6 driving wheels
- Electric mode (Stealth mode)

**Performances**

- Max Speed: 105km/h (65miles/h)
- Specific power 30hp/t
- Range (tank capacity: 400L)
  - 750km in hybrid mode
  - 15km in stealth mode
Series Hybrid

Diesel / Batteries (Ni-Mh)

6 driving wheels

Redundancy of the electric part

- Double electric machines – Generator and wheel motors (Permanent Magnet Synchronous Machine)
- 2 DC buses et 2 battery packs
Double machines: 2 stators, 1 rotors

3 inverter legs and 1 chopper on each stator

Fix mechanical reductor gear
Previous works
Today
Focus on the traction part
- Traction part EMR and inversion based control-

- EMR of a wheel
  2 electric machines (map)
  common rotation speed
  control input = torque ref.

- Vectorial representation
  Only 1 wheel is represented
  Each variable is a vector (6)
  Scalar are independents

- Inversion based control structure
  Distribution criteria appear

- Strategy
  Set the distribution criteria
System behavior in case of failure
- System behavior in case of failure -

➤ An strong acceleration with a constant force is simulated
   The driver equivalent control part is removed

➤ A complete axle failure is simulated
   a switch is open in the model part of the simulation

➤ Energy management
   Re-organisation of the strategy if the fault is detected
System behavior in case of failure – No fault

- Equi-distribution of the total requested force between the wheels

\[
k_{d6} = \begin{pmatrix} 1/6 \\ 1/6 \\ 1/6 \\ 1/6 \\ 1/6 \\ 1/6 \end{pmatrix}
\]

\[\sum k_{d6} = 1\]

\[\sum F_{tract} = \sum F_{tract \, ref}\]

- Good Behavior

- Constant force ref = constant torque ref (blue curve)

- Limit torque of a machine vs. the rotation speed (green curve)
- System behavior in case of failure – Powered axle

- Non detected failure at $t=15\text{s}$ –

No strategy reconfiguration

$$k_{d6} = \begin{pmatrix} 1/6 \\ 1/6 \\ 1/6 \\ 1/6 \\ 1/6 \\ 1/6 \end{pmatrix}$$

$$\sum k_{d6} = 1$$

Because of the failure, the forces requested on wheels 5 & 6 are not applied.

$$\sum F_{\text{tract}} \neq \sum F_{\text{tract \ ref}}$$

$$F_{\text{tot}} \neq F_{\text{tot \ ref}} \quad \text{Lower acceleration}$$
Detected failure at t=15s – Strategy reconfiguration

\[ k_{d6} = \begin{pmatrix} 1/4 \\ 1/4 \\ 1/4 \\ 1/4 \\ 0 \\ 0 \end{pmatrix} \]

\[ \sum k_{d6} = 1 \]

The requested force on wheel 1 to 4 is increased.

\[ \sum F_{tract} = \sum F_{tract \, ref} \]

\[ F_{tot} = F_{tot \, ref} \rightarrow \text{Good behavior} \]

The acceleration duration is longer because the torque limit is reached before
«Driver abilities for fault compensation»
Previous tests have been realized with a constant requested force.

In real vehicle operation, the driver can compensate the fault by acting on the throttle pedal…

On DPE 6x6: driver request is a ratio of the full power:

\[
\begin{align*}
\text{Previous test} & : P_{\text{ref}} = 0 \\
\text{Driver request} & : P_{\text{ref}} = 0.5 \, P_{\text{max}} \\
\text{Full power} & : P_{\text{ref}} = 1 \, P_{\text{max}}
\end{align*}
\]

In the case of the non detected fault, we can assume the driver will push on the throttle… Does the driver can compensate the fault?

Study on torque limitations
Power axle failure is simulated at $t=0s$

The driver requests $P_{max}$

For the specific case of the DPE 6x6, the reference torque is always over the limitation (even without failure)

The driver can compensate any fault by acting on the throttle pedal

Nevertheless, the re-configuration is useful if the system reaction time is under the driver reaction time
«Conclusion & Future Works...»
Thanks to EMR, it is possible to dissociate the modeling, the control and the energy management studies of a complex system. With only one control structure, we can design many strategies and energy management.

This work is a first study of fault-operation modes of DPE 6x6. Future works will study several other failure like generator or DC bus losses.
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