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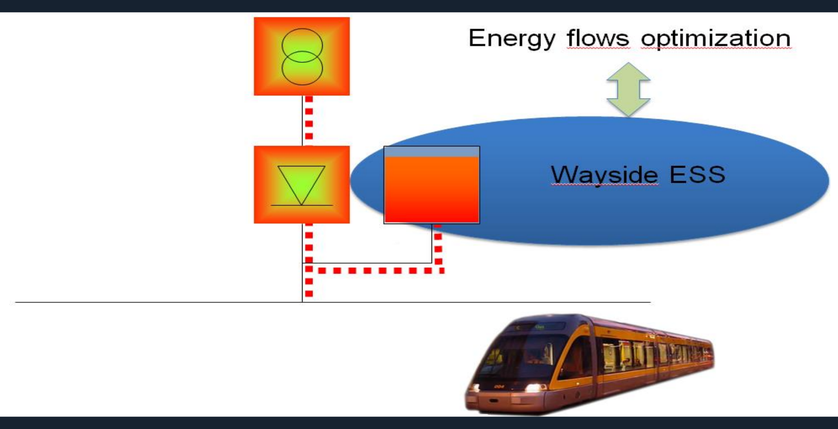
XXX Cycle - II year presentation

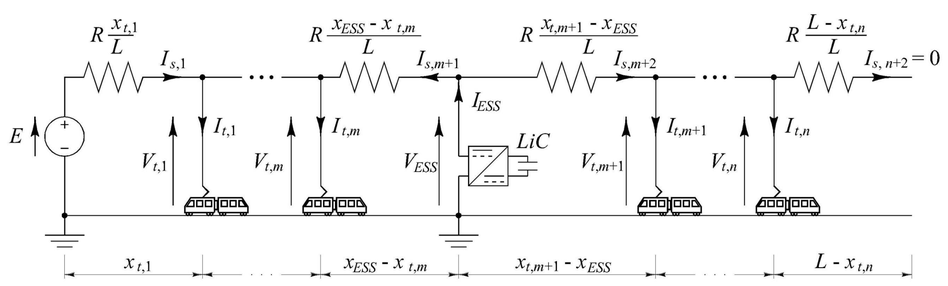
Optimal Control of Stationary SC-based Storage Device for Light Electrical Transportation Network

MOTIVATIONS OF THE RESEARCH ACTIVITY:

- **Storage systems are recognized as viable mean for improving the performances of electrified transportation.**
- **In the recent literature some noticeable results have been highlighted which allow to afford the design problem according a rationale procedure based upon optimization theory.**
- **In the research activity it is demonstrated that the storage device optimal control law can be reduced to determine a proper constant voltage over the whole traction cycle.**
- **The robustness of the control law is performed by verifying the optimal response of the controlled system against the random variations of significant traction parameters.**



Idea A stationary energy storage system is able to store the electrical braking energy that cannot be used to supply other vehicles in operation on the same line and seems to be a suitable solution fo. improving the energy efficiency of electrified light transit systems. The optimal control law and design of a stationary ESS has to be exploited by minimizing a proper objective function. while satisfying the equations of the mathematical model and a isoperimetric constraint .



$$\begin{cases} \min J(\mathbf{y}) \\ \vartheta(\mathbf{y})=0 \\ \int_0^T V_{ESS}\, I_{ESS}\, dt = 0 \end{cases}$$

$$J(\mathbf{y}) = \int_0^T f(\mathbf{y},\mathbf{y}',t)\,dt$$

$$f(\mathbf{y},\mathbf{y}',t) = f(I_s, I_{ESS}, V_t, t) = R_1 I_s^2 + R_2 I_{ESS}^2$$

Development

✓ By applying two different metodologies to a significant case study, two different solutions of the optimization problem have been found out:

SIMULATION PARAMETERS

Parameter	Unit	Quantity
Time simulation (T)	[s]	120
Track Length (L)	[Km]	1.4
Contact wire resistance (copper, cross-sectional area 150 mm²) (R)	[Ω/km]	0.125
Rail resistance	[Ω/km]	0.016
Substation internal resistance	[mΩ]	20
Rated voltage	[V]	750
Number of substations	-	1
Number of stops	-	1
Number of vehicles	-	1
Maximum Vehicle Power	[kW]	800
Maximum Braking Power	[kW]	400
Average vehicle acceleration/deceleration rate	[m/s²]	0.7 / 0.9
Vehicle mass	[kg]	60 000

SOLUTIONS

Analytical Solution

$$V_{ESS} = E - R_1 I_t + \frac{R_1 I_t (2+\gamma)}{(1+\gamma)} - \frac{\gamma E}{2(1+\gamma)}$$

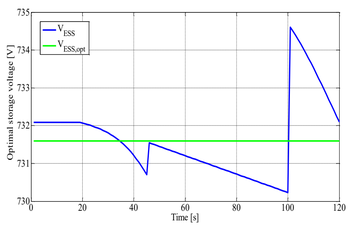
$$\gamma = a\gamma^2 + b\gamma + c$$

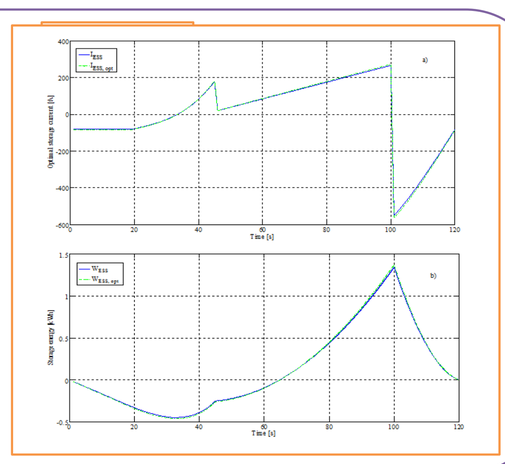
$$\begin{cases} a = \int_0^T -E^2 + 2ER_1 I_t + R_1^2 I_t^2\,dt \\ b = 2\int_0^T -E^2 + 2ER_1 I_t + R_1^2 I_t^2\,dt \\ c = \int_0^T 4ER_1 I_t\,dt \end{cases}$$

Semplified Solution

$$V_{ESS,opt} = E - \frac{1}{T}\int_0^T R_1 I_t\,dt$$

RESULTS

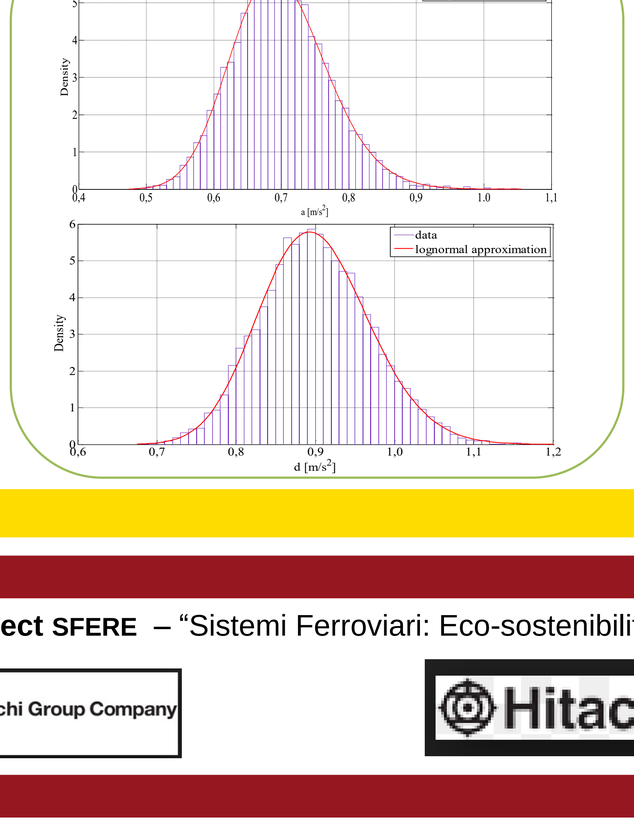


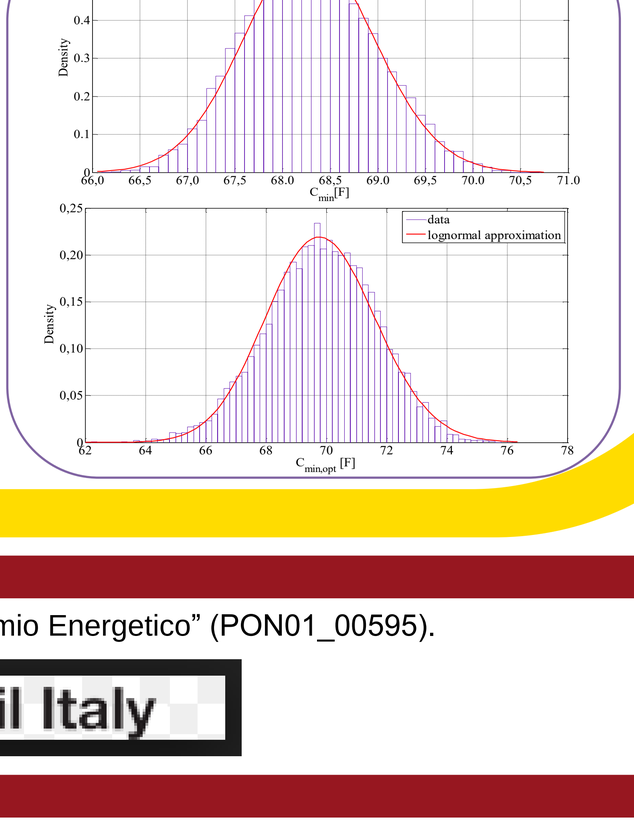


✓ The proposed control law is required to be robust against the randomness of operation conditions. At this aim, starting from the simulation parameters of the deterministic case, acceleration and deceleration have been modeled as lognormal distributions.

The stocasticity of $V_{ESS,opt}$ is demonstrated to be negligible if compared with the randomness degree of "a" and "d" . Thus it can be reasonably considered as a deterministic variable , this resulting in the possibility to properly use its mean value as control law of the DC-DC converter.

As a consequence, also the minimum requested capacitance C_{min} of the storage device becomes a stochastic variable. If the mean value of this distribution is considered as sizing parameter of the SC device, this leads to the same arrangement found out for the deterministic case study . Since such a solution can face all the perturbations considered for the system under investigation , then the robustness of the chosen control law over the variation range has been verified.





COOPERATIONS: ANSALDO STS, HITACHI RAIL ITALY – Project SFERE – "Sistemi Ferroviari: Eco-sostenibilità e Risparmio Energetico" (PON01_00595).

Ansaldo STS A Hitachi Group Company

Hitachi Rail Italy

Future developments

The effectiveness of the proposed control strategy will be proved by means of proper tests performed on a scaled simulator of the physical system set up in the Trasportation Laboratory of DIETI.