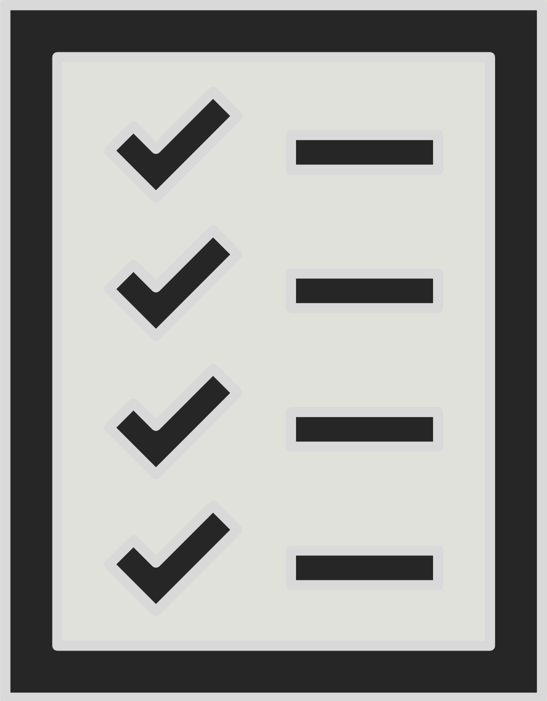
CHARGING OPTIMIZATION USING SERVICE OPERATIONAL DATA

CANDIDATO DANILO MARASCIA

RELATORE POLITO FABIO MANDRILE

RELATORE HITACHI MAURIZIO PICHIERRI



Objectives of the Thesis

Hitachi Rail wants to start a ***transition*** path ***from diesel to electric buses*** with related usage optimizations

The study of the thesis is based on the search for ***optimization of bus charging*** to reduce the consumption

The evaluations that will be carried out are three:

Economic evaluation between diesel and electric buses	Knowledge of the characteristic ***variables and parameters of a bus battery***	***Optimization of battery charging and scheduling*** of buses in depot

Total Cost: Electric and Diesel Bus

Cost items:

- Initial investment
- Operation and maintenance
- Infrastructure

Reference day ***16/12/2022***

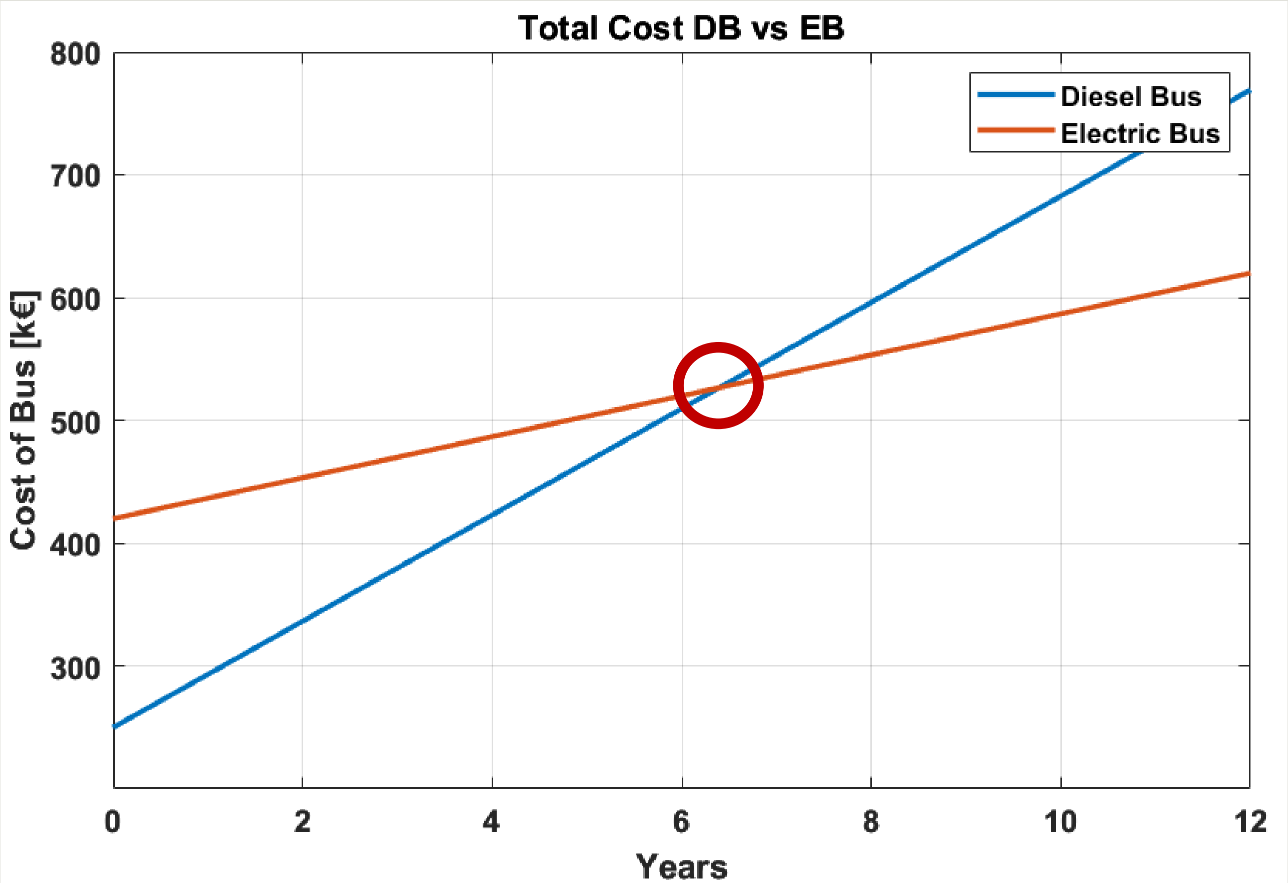
1.77 €/l cost of diesel and ***0.247 €/kWh*** cost of electricity

Equalization costs after ***6 and a half years*** approximately

Economic saving of about ***19.39%*** ***(149134 €)*** after 12 years of use compared to diesel

Lower maintenance and operational cost of the electric motor

This ***economic result*** confirms the ***feasibility of the transition***



How to study the behaviour of the battery in charge and discharge mode?

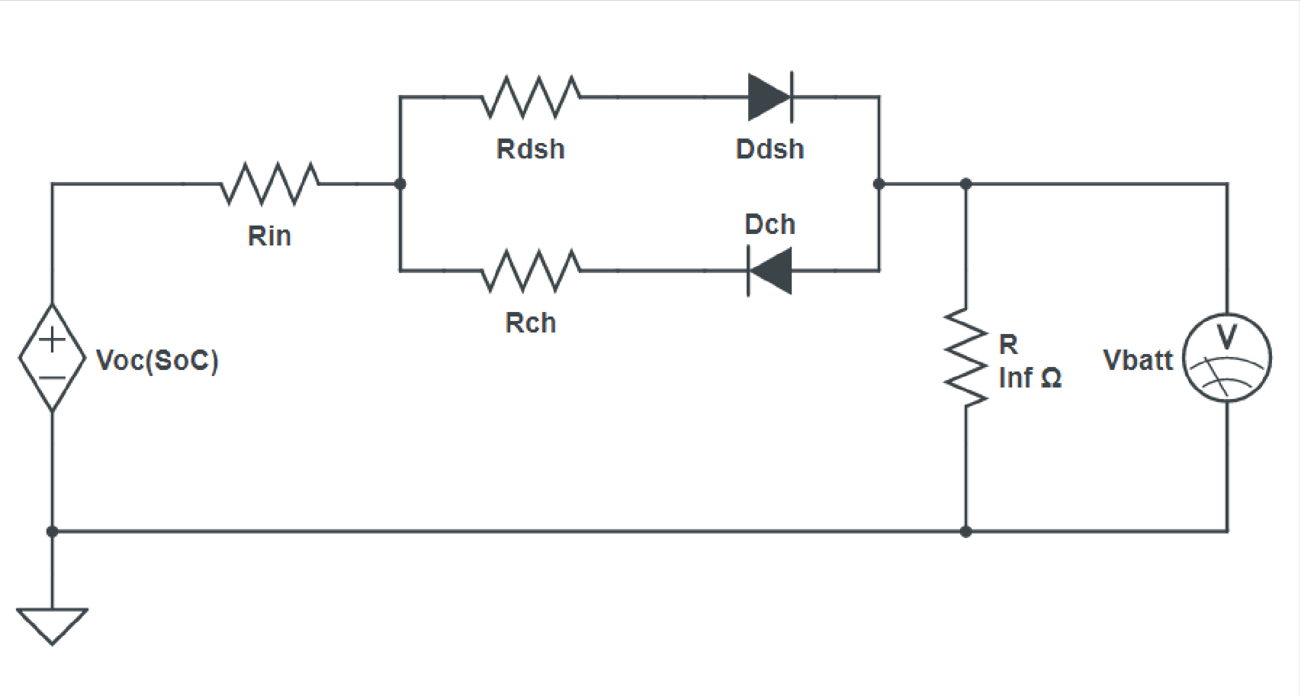
Equivalent Circuit of Battery

The Lithium-ion battery model is represented including:

- ***Open Circuit Voltage (V_{oc})***
- ***Internal resistance*** that represents the internal ***voltage drop***
- One or more ***RC parallel*** to model the ***transient polarization voltage***

All parameters and variables depends on the SoC level

R_{dsh} ***and*** R_{ch} are respectively the polarization resistance in discharge and charge condition



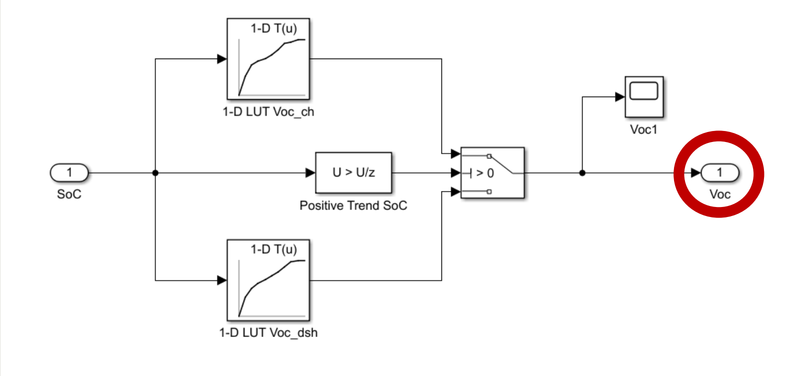
EC - Simulink

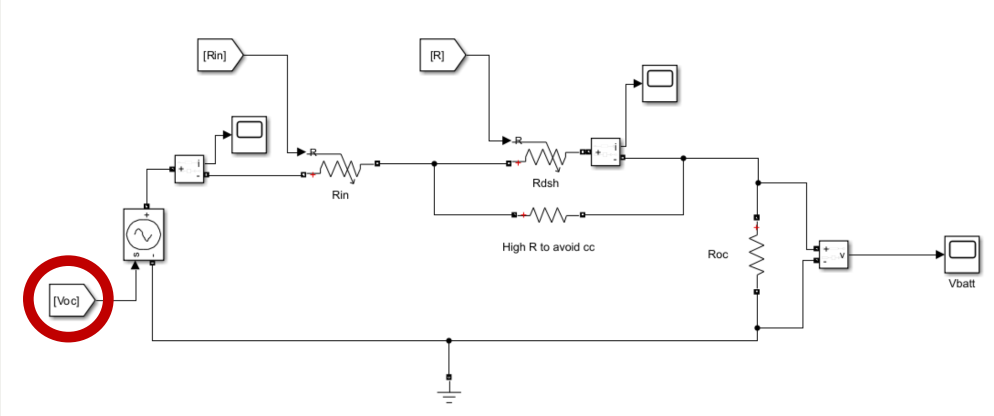
The ***HPPC test*** determine ***all elements in function of SoC level*** and with these it is possible to model the cell in Simulink

Cell data test:

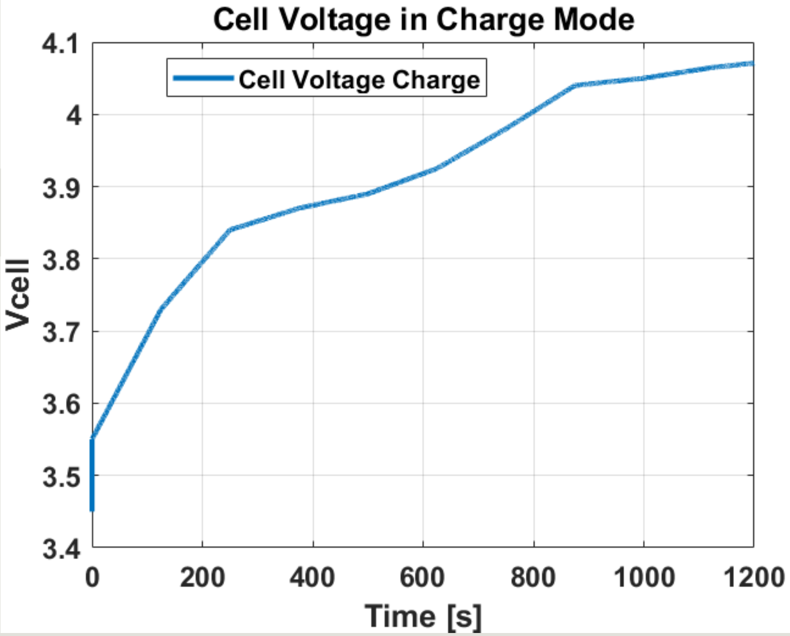
Data	Value	
Rated voltage	3.7	V
Rated capacity	4	Ah
C_{rate}	0.1	
Charge and Discharge capacities	0.2 and 0.4	Ah
Range of the Ohmic resistance	20.3	$m\Omega$

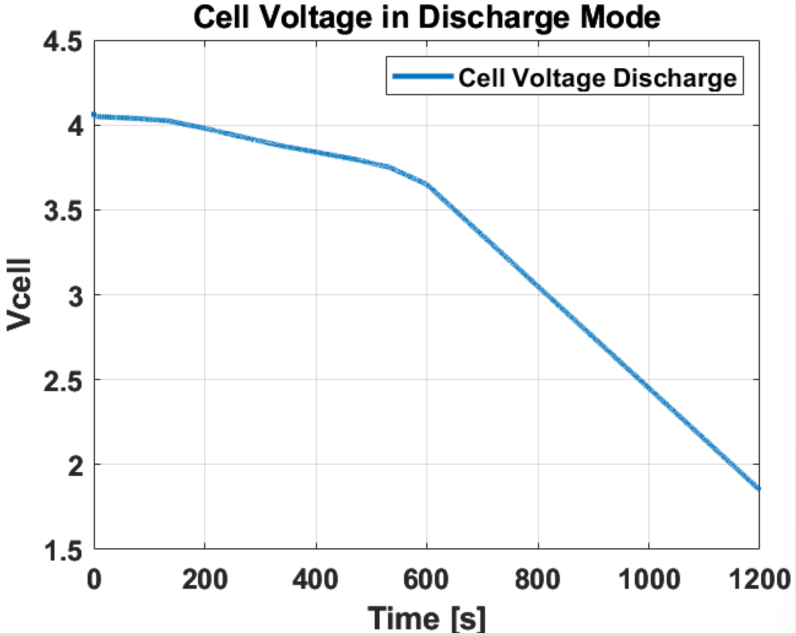
Two LUTs that represent the element in ***function of the SoC***, respectively in the ***charge and in discharge mode***. The block ***"Detect" valuates the SoC behaviours***





The output of simulation is the ***cell voltage***:



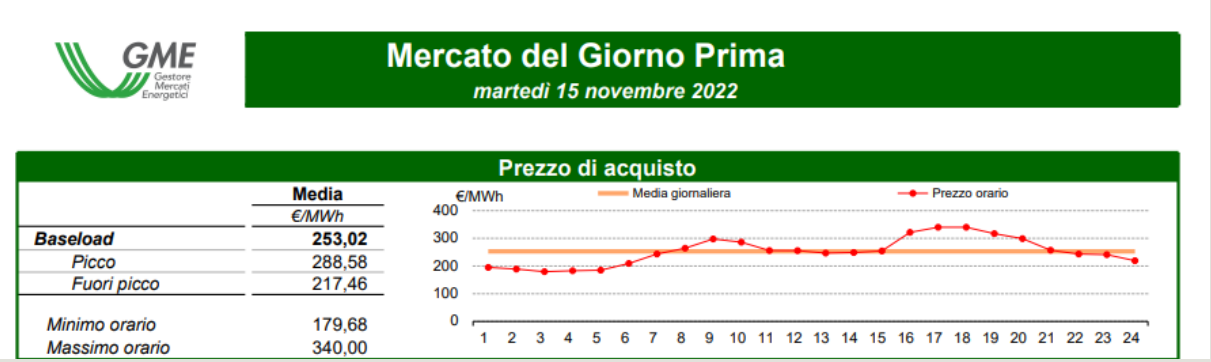


How to develop the Optimization?

Genetic Algorithm

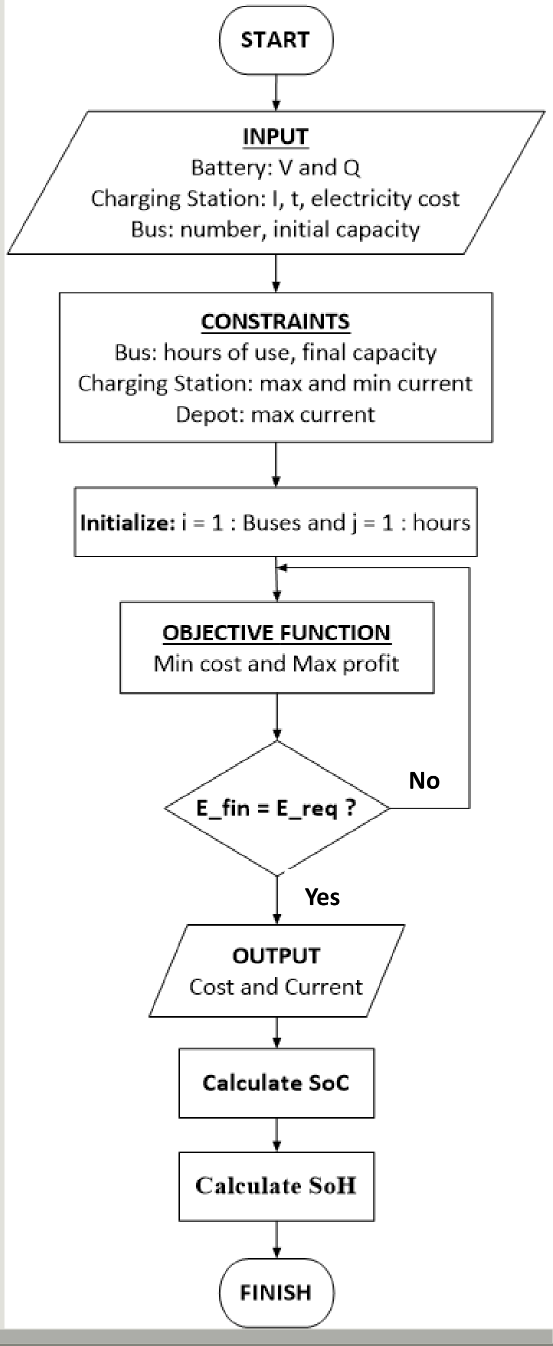
The Genetic Algorithm is applied to ***minimize charge cost or maximize energy sales profit*** when the battery is in discharge mode (***V2G Technology***). To perform this, an ***Objective Function*** is constructed in the algorithm that ***depends on*** the cost of electricity (***day-ahead market price***):

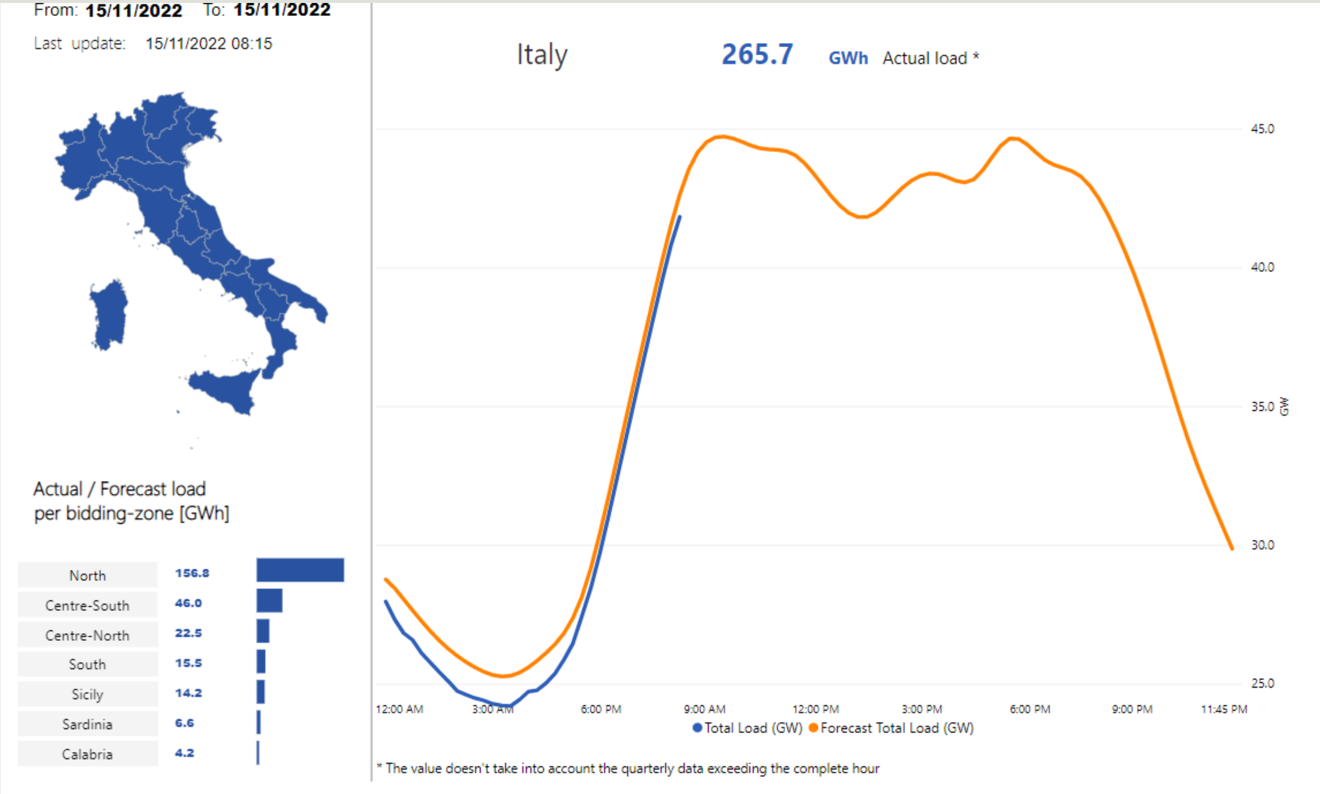
- The ***total energy cost*** → $V \cdot I(i,j) \cdot \Delta t \cdot Cost(j) \cdot \eta_{\frac{ch}{dsh}}$
- The ***cost of battery aging*** → $\left| \frac{Q_{loss\_day}}{Q_{loss\_tot}} \cdot V \cdot I(i,j) \cdot \eta_{\frac{ch}{dsh}} \cdot \Delta t \right|$



Constraints of Genetic Algorithm:

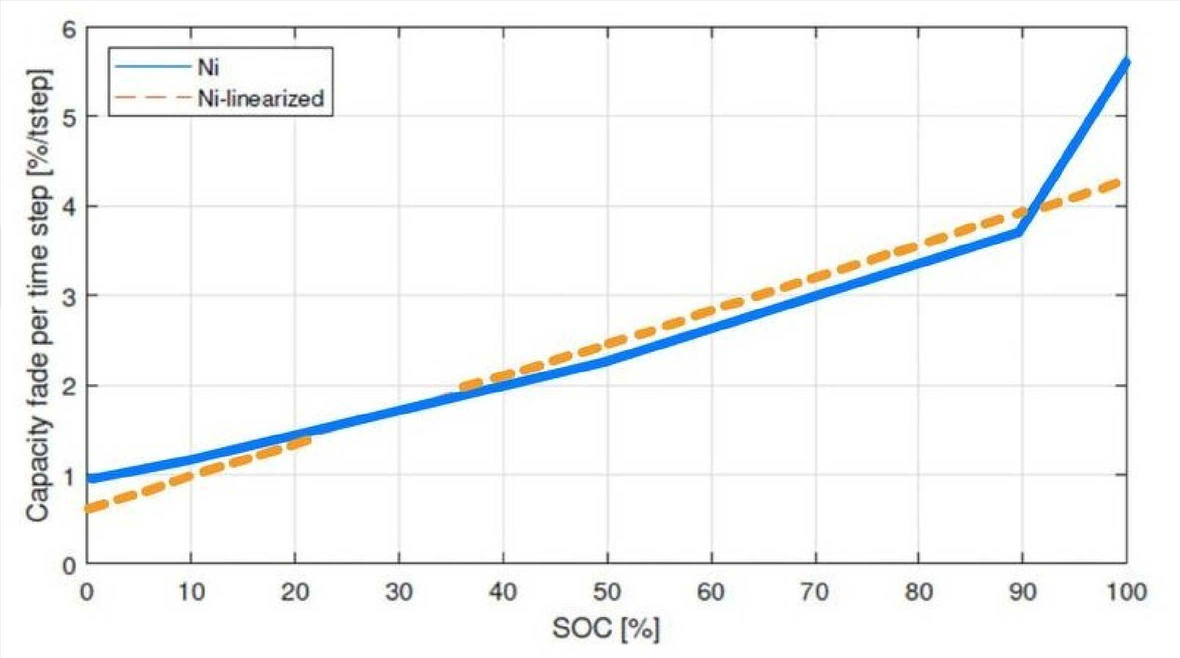
I_{cs}	$0 \le I_{cs} \le 125A$
$I_{cs,all}$	$0 \le I_{cs,all} \le 625A$
E_{fin}	$E_{fin} = E_{req}$





Why V2G Technology?

V2G to use ***each bus battery as energy storage***
In this case, ***bidirectional charging stations*** are used

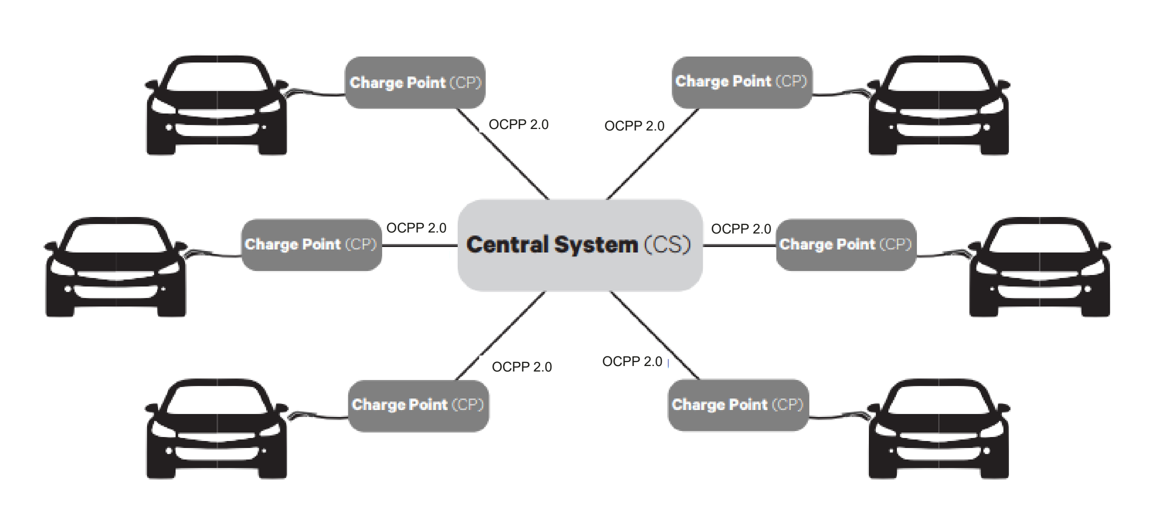


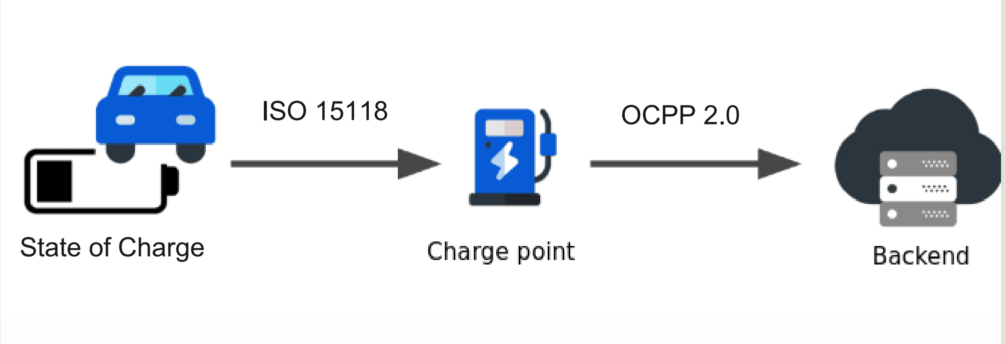
This solution also ***limits the SoC of the battery*** to a range where the ***loss of useful energy is lower***

How to Evaluate SoC_{in}?

It is necessary to evaluate SoC_{in} to consider the use of the bus with ***V2G technology*** and also an ***optimized scheduling of the bus in depot***

The protocol «***Open Charge Point Protocol 2.0***» (OCPP) makes ***independent communication between electric vehicles and a Central System*** (CS), safe (***avoids cyber attacks***), with costs and schedule time.





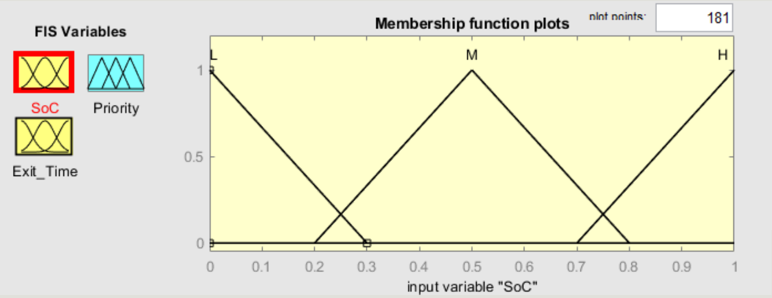
The main functions of the protocol are: ***limiting the charging current***, ***charging programming and power sharing*** (load balance) ***without human intervention***

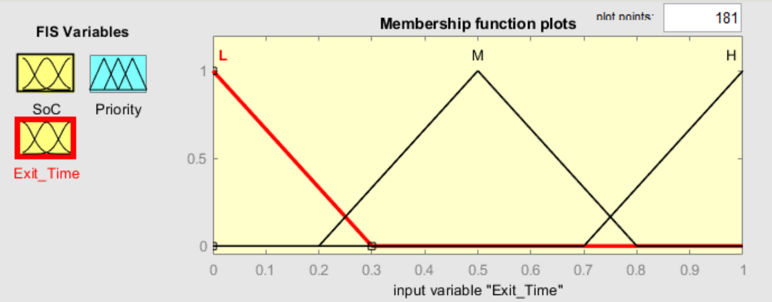
Fuzzy Logic - Matlab

Fuzzy Logic is used to ***optimize the positioning*** of the buses in depot, according to the ***SoC*** and the "***Exit Time***" (***inputs***)

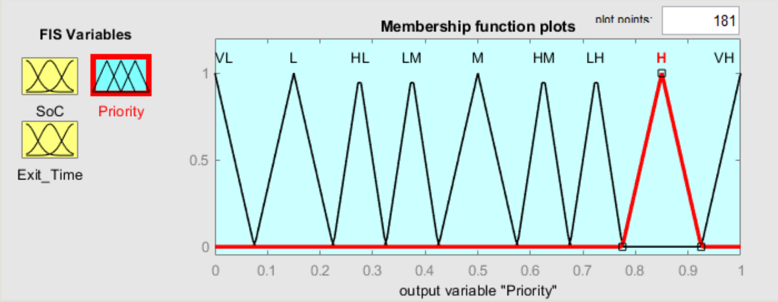
In order to use this Fuzzy logic it is necessary to insert ***fuzzy rules*** that can indicate the ***solution depending on the input/inputs***. This software ***determine the priority index to schedule buses*** in depot

The ***time to charge*** the bus battery is ***directly proportional to the priority index***





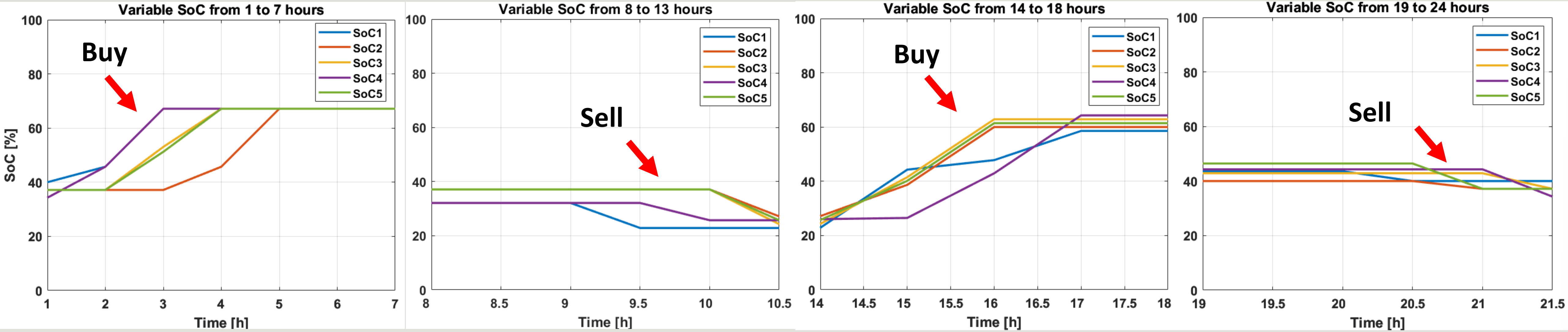
SoC_{in}	Exit time	Priority
L < 30%	Low	VH
	Medium	HM
	High	HL
30% ≤ M ≤ 70%	Low	H
	Medium	M
	High	L
H > 70%	Low	LH
	Medium	LM
	High	VL



VL – Very Low
LM – Low Medium
H – High
L – Low
M – Medium
VH – Very High
HL – High Low
HM – High Medium

SoC

- 30000 km/year
- 250 day/year
- 12 km bus ride
- 10 rides for day
- 5% of SoC lost each route



- ***From 1 to 7*** hour the generically bus is in a depot and it is available to ***charge*** its battery at ***maximum SoC with minimize condition***
- ***From 8 to 13*** the bus runs its route and returns to storage with a low SoC. The residual SoC is available for ***sale to the Grid*** and it is a ***maximize condition***
- ***From 14 to 18*** the bus follows the same steps as the first time range in ***minimize condition***
- ***From 19 to 24*** the same situation of second time range, ***maximize condition***

Average ***savings of 4.2%*** considering a ***variable electricity price*** instead of average

Economic return of ***24.28%*** compared to the ***total spent***

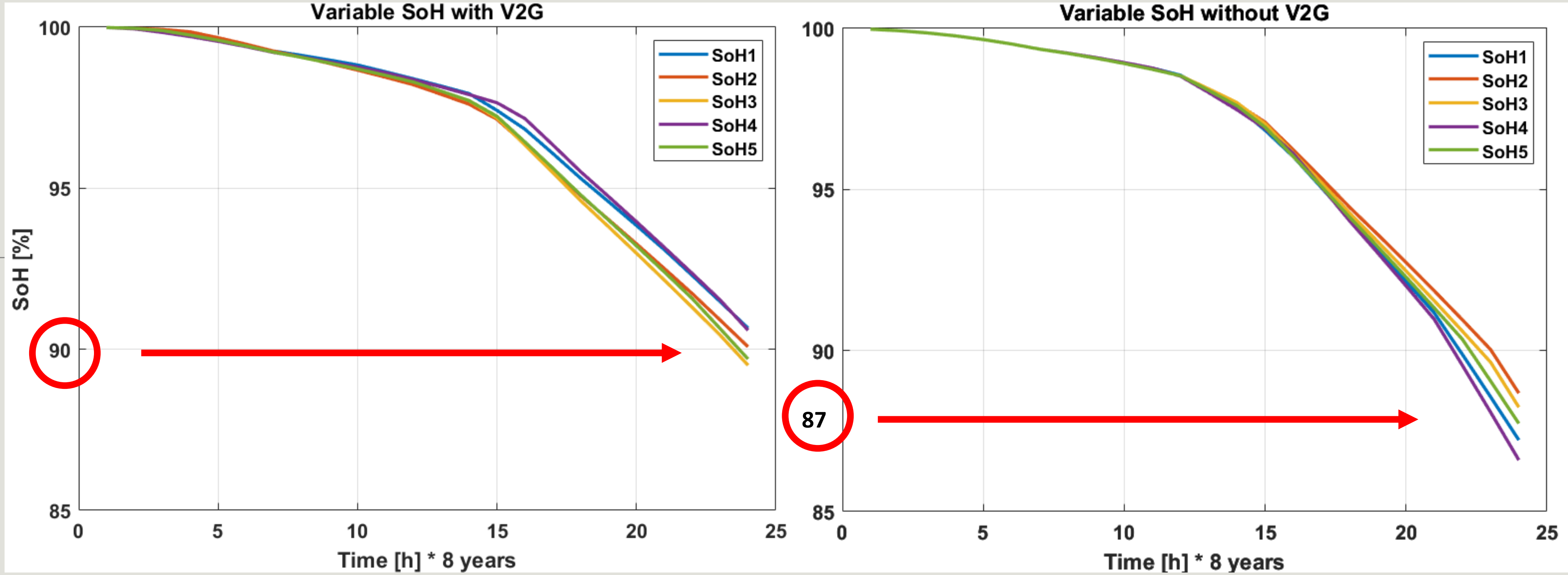
SoH

State of Health ***estimate the battery lifetime*** and it is calculated:

$$SoH_i = SoH_{i-1} - 0.2 \cdot (aging_{cal,i} + aging_{cyc,i})$$

An evaluation of SoH is necessary considering the use of a ***bidirectional or unidirectional charging station*** (***with revenue, without revenue***). It is important to ***understand*** how ***V2G affects battery life***

Bus	With Rev. [%]	Without Rev. [%]
SoH1	90.66	87.22
SoH2	90.08	88.68
SoH3	89.5	88.24
SoH4	90.59	86.6
SoH5	89.7	87.73



Conclusions

The results show that ***the transition*** from Diesel to Electric buses ***is economically viable***. Besides, ***V2G technology with an optimization reduces charging costs and increases the battery life*** depending on the time and SoC of each bus

The following actual data provided by **AMT of Genoa** were used:

- Kilometres travelled per year (***30000 km/year***)
- ***Average operating days*** per year (***250***)
- ***Capacity*** of bus batteries (***350 kWh***)
- Power (***50 kW***) and number of ***charging stations*** in depot
- ***Nominal power*** of the ***depot counter*** (***2 MW***)

Personal Contributions

- Assessment of ***all economic aspects*** related to investment, maintenance and infrastructure for ***diesel and electric buses***
- Implementation of an ***Optimization Algorithm*** using ***MATLAB code*** considering a ***variable energy cost*** in the day (day-ahead market) and V2G technology
- Evaluation with ***combinatorial logic*** of a ***priority index*** for the ***positioning of buses*** in depot
- Determine the ***trend of the SoC*** for a typical day of each bus ***knowing the percentage loss*** for each route made
- Verification of ***battery life degradation*** using ***V2G technology*** by ***SoH*** calculation

GRAZIE PER L'ATTENZIONE

Politecnico di Torino 1859

INGEGNERIA ELETTRICA

AMT Genova

PEIC Power Electronics Innovation Center

HITACHI Inspire the Next