Smart Energy Management of Auxiliary Load for Electric Vehicles

Lorenzo Berzi
dept. of Industrial Engineering
University of Florence
Florence Italy

David Delichristov
Virtual Vehicle Research GmbH
Graz, Austria

Tommaso Favilli
dept. of Industrial Engineering
line 3: *University of Florence*
Florence Italy

Marco Pierini
dept. of Industrial Engineering
University of Florence
Florence Italy

Luca Pugi
dept. of Industrial Engineering
University of Florence
Florence Italy
Luca .Pugi@Unifi.it
https://orcid.org/0000-0001-7385-9471

Albi Qehajaj
dept. of Industrial Engineering
University of Florence
Florence Italy

***Abstract*—Energy Consumption of Auxiliary Systems on electric vehicles has an important role in reducing the overall autonomy since their contribution, especially for what concern HVAC Systems, is often not negligible and not correlated to vehicle kinematics. In this work authors propose a quite simple architecture to adopt an intelligent management of on board loads in order to increase the level of correlation between vehicle dynamics and applied auxiliary loads whit the aim to smooth the overall power demand for vehicle storage system, which should be stressed by transients in which both traction and auxiliary loads are applied at the same time.**

Keywords*—*Smart Energy Management, HVAC, Electric Vehicles

I. Introduction

Auxiliary loads represent an important source of energy consumption [1] which is weakly correlated to vehicle kinematics. As a consequence, an optimization of mission profile in term of vehicle kinematics, the so-called Eco-Driving [2], can take count of these loads but has limited possibilities of intervention. In a mid-term scenario this problem is going more and more important since electric vehicles cannot harvest the thermal power of the internal combustion engine for energy consuming systems such as HVAC (Heating, Ventilation and Air Conditioning), as for conventional Internal Combustion Engine (ICE) vehicles ones, so the whole power demand has to be satisfied by on board energy storage. Even considering the increasing efficiency of electronic devices, the number of on board auxiliary systems will increase on autonomous or semi-autonomous vehicles, contributing to further increase these problems. In this work authors propose a simple decentralized power management strategy that can be easily implemented to almost every vehicle starting with few interventions on involved systems. Aim of the proposed system is force an increased statistical correlation between regenerative braking and

System is applied to a benchmark simplified vehicle model whose main parameters are inspired to FCA 500 E car that was previously developed [3] as a part of the European project OBELICS.

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II. Proposed Solution

Proposed system is based on following assumptions:

- There is a wide variety of possible vehicle subsystems with different load profiles and different levels of priority; also considering the wide variety of optional and possible configuration of a commercial vehicle it's almost unrealistic to manage a centralized control for every subsystem.
- BMS (Battery Management System) plays a key role in protecting the battery from misuse and overloads and, thanks to an high level of installed intelligence (sensors and control units), is able to identify the state of the storage.
- Since the electric Powertrain is still the most important load of the vehicle, it's fundamental to correlate as much as possible the application of auxiliary loads to vehicle kinematics.
- All power limitations can be approximately treated as equivalent constraints of corresponding delivered currents on a common voltage bus shared by electric power train, storage system and more generally all the power converters that provide energy to connected vehicle auxiliary systems, according the general scheme of fig. 1.

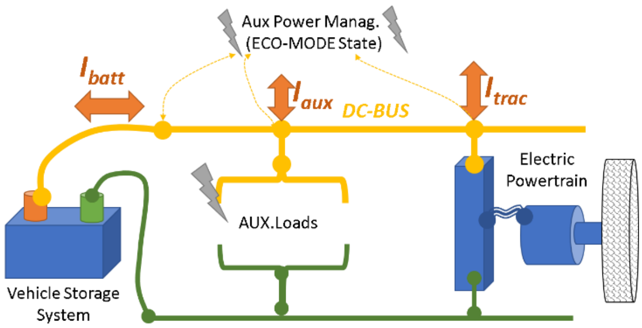

Fig. 1. Proposed Energy Management For Auxiliary Loads

As visible in the scheme of fig.2 proposed system performs the following operation: Power and current delivered from battery (W_{batt}, I_{batt}) and required by the powertrain (W_{trac}, I_{trac}). According the sign of I_{trac} is possible to determine the quadrant in which is operating the traction system. Current SOC (State of Charge) of the battery is estimated through the BMS, which also estimates current charge I_{CL} and discharge I_{DCL} limitations, according battery state.

According the value of I_{trac} respect to I_{CL} and I_{DCL} and SOC, it is decided the way in which auxiliary loads are managed in order to preserve battery against power overloads, especially for extreme value of the state of charge where the battery is tendentially more sensitive to this kind of troubles.

In particular it's defined a binary state briefly called ECOMODE, which is sent and shared with the electronic control units of various auxiliary system. According the state of ECOMODE, each connected subsystem will define its own energy management policy, privileging performance (ECOMODE 'OFF') or energy saving (ECOMODE 'ON').

In this way proposed system simply indicates to connected system the opportunity of privileging a more aggressive or conservative power strategy, but the way in which this choice is implemented is strictly customized in each connected sub-system Control Unit (CU).

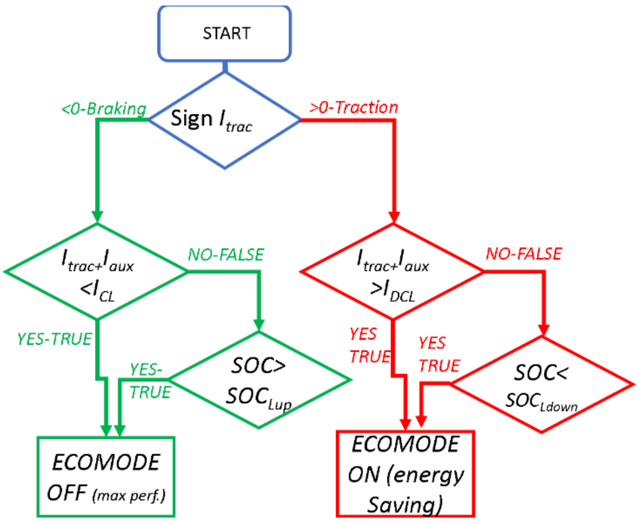

Fig. 2. Proposed Energy Management For Auxiliary Loads

The only exception respect to this policy is represented by the electric powertrain: current limits I_{limit} depurated of estimated consumption of auxiliary system I_{aux} is used as limiting constrain $I_{limited}$ for traction current I_{trac}.

For what concern connected subsystems, highest consumptions are statistically related to the HVAC [4] system, also considering additional loads related to battery thermal management which can be relatively important, even for safety and reliability consideration of the overall vehicle system. In order to preliminary explore and investigate the possibilities offered by the proposed approach, authors exploited a simplified general model developed within the OBELICS project which is briefly described in following sections.

III. Reference System/Vehicle Model

Main features of the chosen benchmark vehicle (FCA 500e) are shown in table I and in figure 3.

The model, as visible in figure 3 composed by the following elements:

- A planar vehicle model developed using Siemens Simcenter as a part of previous research activities;
- A lumped model of HVAC that was provided by the Siemens (a partner of the project) after a calibration performed with FCA;
- A simplified model of the NMC battery developed using standard Simcenter sub-models;
- A co-simulation interface between Matlab-Simulink™ which allows the implementation of controllers developed by the authors; in particular authors inserted the new controller on a Simulink Model that was originally developed to manage optimal, traction control, brake blending between regenerative and conventional braking [5], simulation of safety related to on board systems [6],[7] such as ABS, ESP etc. Running frequency of the control logic is supposed to be 100Hz, which is quite far high enough respect vehicle longitudinal behaviour.
- Additional blocks modelling many other onboard secondary systems that are supposed to be not regulated in this preliminary simulation.

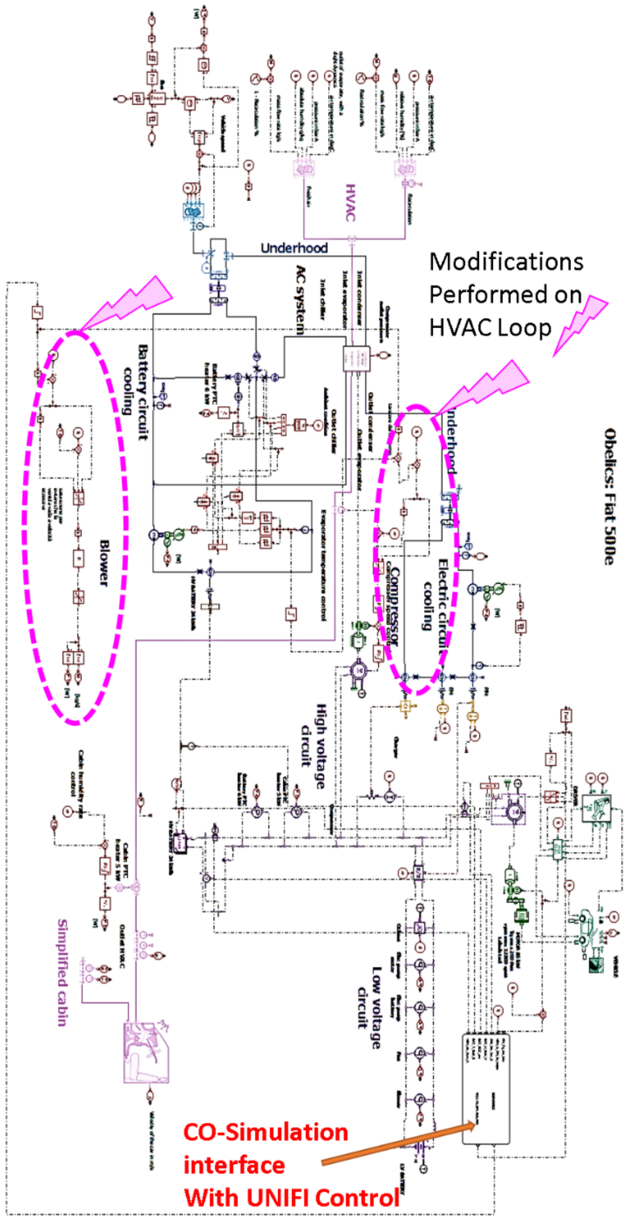

Fig. 3. Proposed Energy Management For Auxiliary Loads

TABLE I. MAIN FEAUTURES OF SIMULATED VEHICLE

FCA 500e Main Features	
Mass	1320[kg]
Front/Rear Track	1407/1397[mm]
Distance of Center of Mass respect to front //rear axle	989/1311[mm]
Heigh of Center of Mass	650[mm]
PM Traction Motor Power//Nominal Speed//Max Speed	85[kW]// 4000[rpm]//12800[rpm]
Storage System battery voltage nominal//max	364 [V]- 400 [V]
Battery Power//Weight	24[kWh]/275[kg]
HVAC Blower and Compressor Power	ALBI me lo ricordi?

For what concern the implementation of co-simulation, the Amesim Simcenter model is implemented with its proprietary variable step solver, data are exchanged with the Simulink controller with a communication interval of 100 Hz, which is the same adopted by the fixed step solver adopted in Simulink.

IV. CUSTOMIZATION OF HVAC SYSTEM

As visible in the general scheme of figure 3, HVAC plant is composed by a single refrigeration loop with a single compressor that provide the coolant, or more generally the fluid used for thermal exchange to two different temperature loops: a first one devoted to cabin, in which heat is exchanged with inlet air of the cabin and a second one devoted to the control of battery temperature and a third one devoted to some underwood power equipment.

In order to implement the proposed control strategy authors, introduce in HVAC system the modifications described respectively in figures 4 and 5: speed of the compressor of the chiller/heat pump is regulated to maintain the temperature of the processed air to a known reference temperature (see figure 4). So by adjusting this processed air temperature T_{evap} is fundamentally regulated the specific heat/enthalpy flow that is transferred to incoming air, which have a different inlet temperature T_{inlet}. Therefore, the heat flow that is exchanged with inlet air to refresh the cabin is roughly proportional to the mass flow $\dot{m}$ multiplied for the specific thermal coefficient c_p.

$$Q \approx \dot{m} c_p \left(T_{evap} - T_{inlet} \right) \tag{1}$$

Value of T_{inlet} depends from cabin and external temperatures (T_{cabin}, T_{ext}) according the fraction k_{rec} of recirculating air from the cabin (2)

$$T_{inlet} \approx k_{rec} T_{cabin} + \left(1 - k_{rec}\right) T_{ext} \tag{2}$$

$$0 \le k_{rec} \le 1$$

Air mass flow $\dot{m}$ is regulated through a speed controlled blower; blower speed reference is generated by a temperature loop aiming to regulate the internal temperature of the cabin (as visible in figure 5). So a higher temperature error in the cabin correspond to a greater performance in terms of exchanged heat flows.

Respect to the original controller authors introduce the following modifications: both regulators are supposed to be proportional and not controlled by a discrete state logic; also it's introduced a variable deadband on the evaluation of both Temperature Loop Errors. This deadband is a function of the ECOMODE state: if ECOMODE state is "ON" (system need to safe energy) dead band is increased, otherwise is near to null and performances of both loops are higher.

In order to further protect battery safety, if the temperature of the battery is over a cautious threshold T_{warn} the application of the ECOMODE On state to the compressor loop is avoided assuring that maximum performances are still available: this last protection has limited consequences in terms of energy saving since much of the exchanged heat Q depends from the value of flow $\dot{m}$ and only marginally from T_{evap}.

However

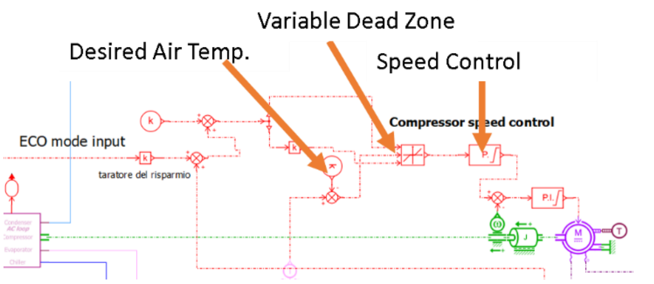

Fig. 4. Modified Compressor Control Loop (detail of modified Siemens Simcenter Model)

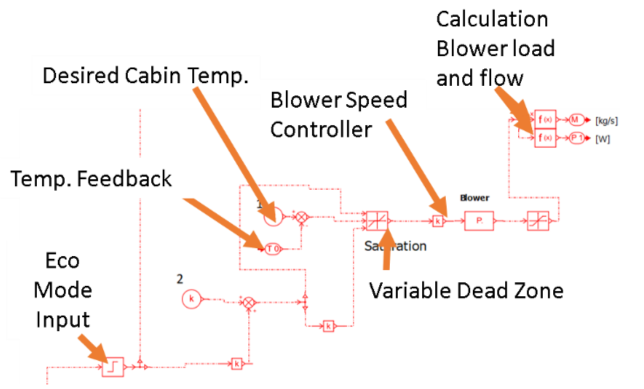

Fig. 5. Modified Blower Control Loop

V. Simulation Results

Overdescribed model was used .

TABLE II. TABLE TYPE STYLES

	Application of ECO MODE	Conventional	Difference%
Blower Energy Cons.	25.8[Wh]	25.6[Wh]	0.8%
Compressor Energy Cons.	134[Wh]	193[Wh]	-30%

TABLE III. TABLE TYPE STYLES

	Application of ECO MODE	Conventional	Difference%
Distance	7264[m]	6682[m]	9%
ΔSOC	1.82	1.64	11%

TABLE IV. TABLE TYPE STYLES

	Application of ECO MODE	Conventional	Difference%
Distance	7264[m]	6682[m]	9%
ΔSOC	1.82	1.64	11%

TABLE V. TABLE TYPE STYLES

Table Head	**Table Column Head**		
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TABLE VI. TABLE TYPE STYLES

Table Head	**Table Column Head**		
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For what concern cabin forced thermal convection with incoming air is adjusted by working

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Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

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Number equations consecutively. Equation numbers, within parentheses, are to position flush right, as in (1), using a right tab stop. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

$$a + b = \gamma \quad (1)$$

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D. Some Common Mistakes

- The word "data" is plural, not singular.
- The subscript for the permeability of vacuum μ_0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter "o".
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- Be aware of the different meanings of the homophones "affect" and "effect", "complement" and "compliment", "discreet" and "discrete", "principal" and "principle".
- Do not confuse "imply" and "infer".
- The prefix "non" is not a word; it should be joined to the word it modifies, usually without a hyphen.
- There is no period after the "et" in the Latin abbreviation "et al.".
- The abbreviation "i.e." means "that is", and the abbreviation "e.g." means "for example".

An excellent style manual for science writers is [7].

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After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

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The template is designed for, but not limited to, six authors. A minimum of one author is required for all conference articles. Author names should be listed starting from left to right and then moving down to the next line. This is the author sequence that will be used in future citations and by indexing services. Names should not be listed in columns nor group by affiliation. Please keep your affiliations as succinct as possible (for example, do not differentiate among departments of the same organization).

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a) *Positioning Figures and Tables:* Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation "Fig. 1", even at the beginning of a sentence.

TABLE VII. Table Type Styles

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***
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[a.] Sample of a Table footnote. (*Table footnote*)

Fig. 6. Example of a figure caption. (*figure caption*)

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity “Magnetization”, or “Magnetization, M”, not just “M”. If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write “Magnetization (A/m)” or “Magnetization {A[m(1)]}”, not just “A/m”. Do not label axes with a ratio of quantities and units. For example, write “Temperature (K)”, not “Temperature/K”.

Acknowledgment

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