A complex modular technique based on a full library of modeling of automotive components implemented on SABER and MATLAB environment and aided by a software platform that manage all the developed routines in a unique framework is proposed to evaluate the electric service quality of a power bus system for automotive applications. The suggested technique gives the steady-state and the transient analysis of the overall on-board electrical system and by means of a multicriteria analysis evaluates the electric service quality index of the analyzed power-buses. This index takes in account the following items: state of charge of the batteries in a drive cycle, bus voltage profile and voltage sags and dips and power bus efficiency. Thanks to this tool it is possible to compare different power bus architectures under the aspect of the electrical quality obtaining interesting information about the performance of the examined power-buses and their adaptability to the requests of the operative conditions. This tool represents a suitable decision support technique during the phase of the design of the architecture of a power bus for automotive application. In the paper after a full analysis of the proposed tool some numerical results are presented in order to prove the goodness of the proposal.

Keywords: Modeling of automotive subsystem; expert systems applications; automotive electrical power system.

1. Introduction

In recent years, the number of electrical subsystems in cars has steadily increased. These subsystems include the well-known loads, such as electrically assisted power steering, electrically driven air conditioner compressor, electromechanical valve control, electrically controlled suspension and vehicle dynamics, and electrically heated catalytic converter. Due to the increasing of electrical subsystems, the adaptability of the conventional electrical system to the needs of near future and present electrical components is very small therefore alternative architectures of power-bus have been developed [1]-[2]. Consequently it is always stronger the need to develop techniques that help in the design and in the choice of the power-bus architecture. The goal of this paper is to present a decision support technique in the evaluation of the performances of the power bus under the profile of the electrical quality. The suggested technique gives the steady-state and the transient analysis of the overall on-board electrical system and by means of a multicriteria analysis evaluates the electric service quality index of the analyzed power-buses. This index takes in account the following items: state of charge of the batteries in a drive cycle, bus voltage profile and voltage sags and dips and power bus efficiency. Thanks to this tool it is possible to compare different power bus architectures under the profile of the electrical quality determining which can meet the requirements imposed by the operative conditions.
In the next sections preliminarily an overview on the trend of technologies for advanced vehicles are briefly summarized, then the proposed decision support technique will be presented and some results proving the goodness of the solution are shown and discussed. The suggested techniques has been developed tanks to many years of cooperation with FIAT automobile and is protected by copyright.

2. Actual technologies in advanced vehicles

The electrical loads of modern cars have increased dramatically over the last 10 or 15 years. Luxury cars - especially - are huge consumers of electrical power [1] (Fig. 1).

![Fig. 1. Electrical loads in the MEV power systems](image)

Vehicle manufacturers are seeking ways to reduce substantially vehicle weight, because lower weight means less fuel consumption, which in turn means lower emissions. Electronic systems have helped manufacturers toward this goal because these are often lighter than the mechanical systems that they replace. Additionally, electronic systems have proven to be precise in their functioning, reliable, with low need of maintenance and to have best performances, in terms of dynamic response and their natural integration in the electrical system respect to the hydraulic or mechanical actuators. Thus, engines, transmissions, airbags, brakes, and many other systems are now controlled electronically on many vehicles. Another important issue is that the automobile industry is always concerned with safety related issues. It is always trying to develop methods that keep increasing the safety standards, for example, intelligent driver assistance. However, such systems need to be computer controlled to deliver maximum efficiency.

With this comes the need to replace all the mechanic or hydraulic backup with electric/electronic components (X-by-wire technologies). This can be done only when it has been ascertained that the systems that are replacing the mechanical or hydraulic backups are very safe.

X-by-wire technologies refer right to the electric/electronic controls that are replacing traditional automotive mechanical or hydraulic systems such as steering, braking,
suspension and throttle control. By placing electronic controls (a computer) between the driver and the system, automakers can gain design flexibility, shave weight and decrease the manufacturing complexity of both system components and vehicle assembly.

In the Fig. 2 are reported some of x-by-wire applications that can be actually found on board of few prototype cars.

Fig. 2. X-by-wire technologies’ applications (Source: Frost & Sullivan)

As it can be easily supposed, x-by-wire systems must be powered taking into account safety, reliability, availability, and maintainability aspects. Some electric loads in a x-by-wire vehicle are mission and safety-critical. They require uninterruptible power availability at all times, therefore the design of the power bus is fundamental in this case because the voltage level and the adopted architecture for the power bus are very important for the cited aspects of safety and availability.

3. ESQI software tool for the evaluation of electrical service quality of automotive electrical systems

The proposed technique compares different power bus architectures and identifies which of them has higher performances respect to the electric service quality. This technique automates two critical functions: system analysis and comparative evaluation and it can be used to quantitatively compare a large number of architectural alternatives in a relatively short time. The first function gives the steady-state and the transient analysis of the overall on-board electrical system. The second function gives a global electric service quality index (ESQI) that defines the adaptability of analyzed architecture to the specific automotive application. The electric service quality index is evaluated employing a further multicriteria analysis, which take in account the following indexes: state of charge of the batteries in a drive cycle, bus voltage profile and consequently voltage sags and dips and power-bus efficiency.

The following Fig. 3(a) show the functional chart of the main steps previewed by the software tool. Fig. 3(b) shows the front-end of the proposed tool.

With the first step the designer composes the power bus architecture selecting by a suitable library all the components of the power-bus (ICE, energy storages, electric motor, alternator, electric loads and so on).

Several architectures of electrical power system can be implemented by means of a graphical user-friendly tool, with a graphical user interface that consents to assembly an
architecture topology simply by selecting the desired components (generation set, loads set, converters set, etc.) and the wires of the power bus from an internal database.

1. Power-bus architecture composition
   (Energy storage, electric motors, electric loads, etc)

2. Selection of:
   (2.1 Critical loads activation sequence
   2.2 Drive cycle)

3. Transient and steady state analysis of the power-bus and ESQI evaluation

Fig. 3(a). Functional-chart of the proposed tool

Fig. 3(b). Front-end of the proposed software tool

Figs. 4, 5 and 6 show some examples of the implemented architectures available in the library of the software tool. In Fig. 4 a classical two voltage levels power bus oriented for electric vehicles is shown. It presents a 12V DC bus with the loads being controlled by manually or electronically actuated switches and relays.

This type of configuration is a very simple and robust point-to-point topology but it leads to expensive, complex and heavy wiring circuits.

Some improvement to this architecture, for cars of medium or high range is obtained using multiplexed architectures [3], with separate power and communication buses. The interconnections among remote modules with communication buses determine possibility to have a power management system on-board, which can comprise battery and charging
management, load management (strategies of load-activation sequence) and energy management.

Fig. 4. Point-to-point 12V DC architecture

In Fig. 5 an example of this type of architecture oriented for an advanced vehicles is shown. It is a multi-voltage hybrid (DC and AC) electrical power distribution system with a main high voltage (e.g., 300V or higher) DC bus providing power for all the loads. Conventional loads as well as new electrical ancillary and luxury loads associated with the more electric environment are fed by the main bus via different DC/DC and DC/AC power electronic converters. Fig. 6 shows a different solution based on an AC power bus distribution system [4].

Moreover, in the library of the proposed tool, several models have been developed for the devices which compose the power system. All these models are the result of different research activities developed for many years by the Federico II University [5]-[31], often with the cooperation of automotive manufacturers. This library contains many components used in automotive applications as:

1. Energy management strategies [5]-[7];
2. Power bus architectures [8]-[9];
3. Energy storage systems [10];
4. Electrical machines (particularly induction motor, dc-motor and Permanent-magnet synchronous motor and brushless machines) under normal operating conditions or fault conditions [11]-[19];
5. Electrical drives controlled with different techniques (generally F.O.C. or direct torque control) [20]-[26];
6. Power converters controlled with different algorithms [27]-[30] particularly oriented for automotive applications;
7. Antiskid systems [31].

Suitable algorithms for the generation system (battery, electrical machines and dc/dc converters) and for several automotive electrical drives have been implemented in MAST language [32] and in MATLAB language, for the simulation in SABER® DESIGNER environment and in MATLAB® environment.
F. Esposito: A new software tool for evaluating the electric service quality...

Fig. 5. Advanced electric vehicles electrical power distribution system architecture

The accuracy and the performances of the models have been proved by means of experimental tests on effective automotive components provided by the ELASIS Research Center of FIAT Group (Italy). For all the electrical drives, the simulated results have been obtained by developing an adequate model of the actuator and by identifying, with numerical identification techniques, the value of the electrical and mechanical parameters in the equations of the theoretical models.

Fig. 6. AC automotive power bus distribution system

Figs. 7 show an example of the modelled electro-mechanical loads (dc actuator for rear electric windscreen wiper).
With the second step on the basis of the electrical loads selected in the phase 1, a critical sequence activation of these loads is found. The critical operative conditions are evaluated respect to the power bus and to the power source system. Then a drive cycle is selected among the many cycles available in the library.

3.1. Critical Loads Activation Sequences Maker

This module gives information about electrical stress of the power bus. The critical operative conditions are evaluated respect to the power bus and to the power source system.

The inputs to the software are some known data such as the min and max load activation duration for every load, the activation rates on a whole drive cycle, the on-board loads currents and so on.

The software tool generates, by means of a stochastic approach, different sequences of loads activation and it gives, by means of Montecarlo technique, the probability distribution of the maximum values of the bus current $I_{\text{bus}}$ and the probability distribution of the maximum values of product $I_{\text{bus}} \times T$ ($T$ is the time while $I_{\text{bus}}$ is greater than the rated alternator current in a drive cycle for a traditional car or the time while $I_{\text{bus}}$ is greater than the rated battery current) for each sequence. This tool considers only sequences which give
an $I_{\text{max}}$ value greater than the rated alternator current value in order to consider the sequences more complicated to handle for the previewed load management strategies.

The first output represents a set of critical operative conditions suitable for testing the power source system while the second output is a set of critical operative conditions suitable for testing the power bus.

In Fig. 8(a) is shown a histogram of the maximum values of the bus current (in A) and in Fig. 8(b) histogram of the maximum values of $I\times t$ (in As) in a Montecarlo simulation.

![Fig. 8(a). Histogram of the maximum values of the bus current in a Montecarlo simulation (occurrences as function of $I_{\text{max}}$, in A)](image)

![Fig. 8(b). Histogram of the maximum values of $I\times t$ in a Montecarlo simulation (occurrences as function of $I\times t$, in Ah)](image)

The step 3 gives the transient and the steady state analysis of the power bus. The inputs, determined by the steps 1 and 2, are: topology of the chosen architecture of the power bus; advanced models of the main loads; critical loads activation sequence and drive cycle. All the computational routines have been implemented in MAST language [28] and in MATLAB language, for the simulation in SABER® DESIGNER environment and in MATLAB® environment. Once a system has been analyzed, the software tool calculates the performances indexes that are of interest for the multicriteria analysis: cost, weight, efficiency, reliability and electric service quality.
The cost index is broken down into “parts cost” and “assembly cost”; efficiency is measured in terms of the average mechanical power consumption of the electrical system. These indexes are generally calculated from the data residing in the internal archive.

The power bus reliability index depends on the topology of power network, so it can be evaluated with classical schemes (series, parallel, etc.).

The electric service quality index is evaluated employing a further multicriteria analysis, which take in account the following indexes: state of charge of the batteries in a drive cycle, bus voltage profile and consequently voltage sags and dips. The indexes used for the evaluation of the quality of service have been obtained simulating the selected architecture in a full SABER schema.

The step 4 starting from the following system indexes: size, weight, cost, efficiency, electric service quality, reliability of every components and of the whole system, gives a global index that defines – by means of a multicriteria analysis- the adaptability of analyzed architecture to the specific automotive application.

4. Numerical Results

Two families of power bus architectures (conventional and dual voltage) have been analyzed under different aspects: energetic, systemic and of reliability (Figs. 9 (a)-(c)).

(a) - 14V DC supply concentrated architecture

(b) - 42-14V DC dual voltage supply concentrated architecture
For each topology the same set of loads and the same alternator have been adopted. N. 30 loads (electrical window winders, radiator and air conditioner fans, electrical windscreen wipers, electrical assisted power steering, lamps and so on) have been considered. The parameters of the simulated alternators (at 14V and 42V) have been reported in Tables 1, 2.

Table 1: Parameters of the simulated 14V alternator

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rs - 25°C [mΩ]</td>
<td>Armature resistance</td>
<td>25</td>
</tr>
<tr>
<td>Ls [μH]</td>
<td>Armature inductance</td>
<td>120</td>
</tr>
<tr>
<td>Re - 25°C [Ω]</td>
<td>Field resistance</td>
<td>2.75</td>
</tr>
<tr>
<td>p</td>
<td>Pole pairs</td>
<td>6</td>
</tr>
<tr>
<td>V [V]</td>
<td>Rating voltage</td>
<td>14</td>
</tr>
<tr>
<td>P [kW]</td>
<td>Rating power</td>
<td>3</td>
</tr>
<tr>
<td>W [kg]</td>
<td>Weight</td>
<td>7.5</td>
</tr>
<tr>
<td>S [dm³]</td>
<td>Size</td>
<td>1.8</td>
</tr>
<tr>
<td>C [€]</td>
<td>Cost</td>
<td>320</td>
</tr>
</tbody>
</table>

Table 2: Parameters of the simulated 42V alternator

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rs - 25°C [mΩ]</td>
<td>Armature resistance</td>
<td>44</td>
</tr>
<tr>
<td>Ls [μH]</td>
<td>Armature inductance</td>
<td>494</td>
</tr>
<tr>
<td>Re - 25°C [Ω]</td>
<td>Field resistance</td>
<td>14</td>
</tr>
<tr>
<td>p</td>
<td>Pole pairs</td>
<td>8</td>
</tr>
<tr>
<td>V [V]</td>
<td>Rating voltage</td>
<td>42</td>
</tr>
<tr>
<td>P [kW]</td>
<td>Rating power</td>
<td>3</td>
</tr>
<tr>
<td>W [kg]</td>
<td>Weight</td>
<td>7</td>
</tr>
<tr>
<td>S [dm³]</td>
<td>Size</td>
<td>1.4</td>
</tr>
<tr>
<td>C [€]</td>
<td>Cost</td>
<td>400</td>
</tr>
</tbody>
</table>
A 12 V – 60 Ah battery has been adopted.

Fig. 10 shows the drive cycle adopted for all the simulations. Fig. 11 shows, as example, some results given by the step 3 when the power bus solution reported in Fig. 9(a) is considered. Fig. 12 shows, as example, some results given by the step 3 when the power bus solution reported in Fig. 9(b) is considered.

![Fig. 10. Considered power bus architectures for the analysis](image)

![Fig. 11. Bus voltage, battery current, alternator current, S.O.C., total load current vs. time, for a critical loads activation sequence applied to the arch. (a)](image)
Table 3 reports the ESQI computed by the step 3 by means of the multicriteria analysis. As can be noted the performances of the compared architectures are different respect to the considered indexes. The architecture a) presents the best performance respects to the weight, power bus size and the cost but has the lower performance respects to the indexes that have main importance for the efficiency, reliability and electric service quality.

Considering adequately all the performances indexes instead the best performance have been obtained with the solution (c) (42-14 V DC dual voltage supply distributed architecture).

Table 3: Comparison Among Three Different Simulated Architectures

<table>
<thead>
<tr>
<th>POWERBUS INDEX</th>
<th>Arch. (a)</th>
<th>Arch. (b)</th>
<th>Arch. (c)</th>
<th>Index weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{avg}$ [V]</td>
<td>13.52</td>
<td>13.97</td>
<td>13.99</td>
<td>3</td>
</tr>
<tr>
<td>$\Delta V$ [V]</td>
<td>3.44</td>
<td>3.61</td>
<td>2.59</td>
<td>4</td>
</tr>
<tr>
<td>$\Delta S.O.C.$</td>
<td>0.05</td>
<td>0.09</td>
<td>0.1</td>
<td>5</td>
</tr>
<tr>
<td>Power bus efficiency</td>
<td>0.53</td>
<td>0.60</td>
<td>0.60</td>
<td>3</td>
</tr>
<tr>
<td><strong>Global ESQI</strong></td>
<td><strong>0.72</strong></td>
<td><strong>0.87</strong></td>
<td><strong>0.92</strong></td>
<td></td>
</tr>
</tbody>
</table>
5. Conclusion

In this paper a new computer aided technique for analysis of power-bus of different vehicles has been proposed. The suggested technique gives the steady-state and the transient analysis of the overall on-board electrical system and by means of a multicriteria analysis evaluates the electric service quality index of the analyzed power-buses. As example, different facilities of the software tool are presented, then a comparison among different power bus architectures has been conducted and the results have been reported. The results prove that presented technique can be employed either as aid to choice, to analyze and to design different architectures, or to validate the adaptability of existing ones under the profile of the electric service quality. This criteria is not the unique that can orient the choice therefore the next step of research will be to extend such technique to the evaluation of a global index of adaptability that should be taken in to account many other aspects, as for example cost, encumbrance and weight of each component, reliability of the power bus and electrical consumptions.

References


