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AN OPTIMIZATION TECHNIQUE FOR THE CHOICE OF ADVANCED AUTOMOTIVE ELECTRICAL SYSTEMS

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ABSTRACT
In the last years, the on-board electric power requirement is likely to increase from 1kW to 5kW for non-propulsion loads. Since the adaptability of the conventional electrical system to the needs of near future and actual electrical loads is very little, alternative architectures of powernet are required, particularly in applications x-by-wire based, where it is important to improve some of characteristics of power supply, such as reliability, uninterruptible power feed, fault-tolerant components, autonomous control. For these reasons, different architectures have been presented in literature, in order to overshot the problems of the traditional powernet. Although a large number of alternative architectures have been suggested, they have not been rigorously evaluated. Hence, it isn't still clear how to detect the best architecture for a fixed automotive application.
The goal of this paper is to introduce an optimization technique for the choice of advanced electrical systems for automotive applications.

KEY WORDS
Optimization techniques, expert systems applications.

1. Introduction

The goal of this paper is to present a new optimization technique for the choice of a functional automotive powernet architecture. The suggested technique can be successfully adopted for any automotive applications. As will be shown in the following, it is only necessary to calculate adequately the weight of the indexes that are of interest for the particular application and that are to the base of the proposed technique. The paper compares different powernet architectures in order to identify those having better performances and competitive costs. Three different architectures will be compared in terms of cost, weight, efficiency, reliability of every component and of the whole system, electric service quality. The paper is organized as follows: at first, the new trends in the architectures topologies are presented; then, the suggested technique with the relevant routines are presented. At end, the results are shown and discussed in order to prove the goodness of the proposal.

2. Overview on Automotive Powernet Architectures

Existing vehicle electrical powernet comprises six main components [1]: generator, battery, electrical loads, starting motor, supercaps, dc/dc converters.
How the electric power is topologically distributed determine the particular architecture of the powernet [2].
Actually most of conventional powernet architectures for vehicles have a single voltage level 12V DC, with the loads being controlled by manually or electronically actuated switches and relays (fig. 1).

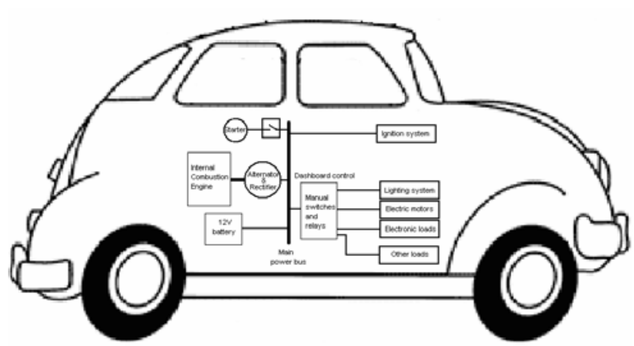


Figure 1. Conventional automotive powernet topology

These configurations are point-to-point topologies in which all the electrical wiring are distributed from the single main bus to different loads through relays and switches of the dashboard control.
This kind of network architecture leads to expensive, complicated and heavy wiring circuits. In this conventional electrical system, bus voltage is comprised between 9V (overall loaded system) and 16V (no-load system), with results in overrating the loads at nominal system voltage. Other disadvantages are related to the load dump transient, where a voltage spike is caused by sudden load loss on a fully loaded alternator, and considering that DC motors at 12V produce high losses in brushes, connectors have high rate of failure. Moreover, with the increase in electrical/electronic components in vehicles, the on-board electric power requirement is likely to increase from 1kW to 5kW for non-propulsion loads. Since the adaptability of the conventional architecture to

the needs of near future and actual electrical loads is very little, new conceptions of electrical powernet architecture in automotive sector are required, particularly in applications x-by-wire based, where is important to improve some of characteristics of power supply such as reliability, uninterruptible power feed, fault-tolerant components, autonomous control.

The actual powernet architecture can be improved using multiplexed architecture (fig. 2) with separate power and communication buses.

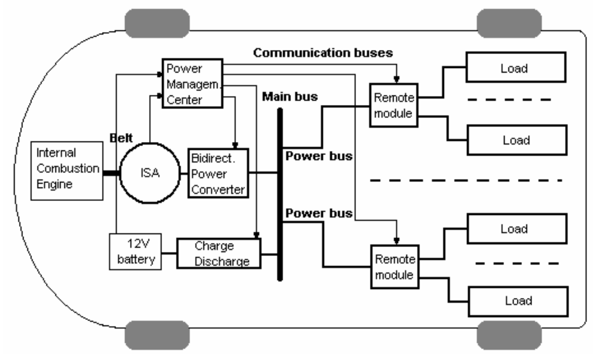


Figure 2. Advanced multiplexed power system architecture with power and communication buses

The loads are controlled by intelligent remote modules, so number and length of wires in the harness are reduced. Then, interconnections between 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), management of alternator and regulator too, control of a high integrity supply system.

To migrate from a conventional point-to-point to a multiplexed powernet architecture with separated power and communication buses can simplify vehicle design and assembly process and offers additional benefits such as the following:

- all loads are under intelligent control, this means possibility to integrate power management into existing control;
- power management strategy can help to optimize the size of the batteries and alternator;
- vehicle economy can be improved using the knowledge of battery SOC in a networked system.

Other innovative architectures proposed in last few years [2], [3], [4], are depicted in following figures.

In fig. 3 is shown a powernet based on distributed and multiplexing architecture. The load boxes include the interface circuits, load selector switches, load drivers and loads.

This type of architecture comprises a single powernet, a single control bus and a single ground bus for the whole vehicle, therefore it simplifies and minimizes harness complexity, cost and weight. The powernet is distributed around the vehicle and electrical loads are connected directly to this bus at load points.

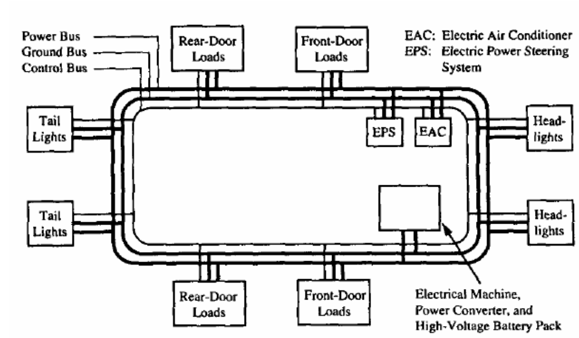


Figure 3. A closed-ring power system topology with separated power and control buses

At last, fig. 4 shows a wholly power system architecture which comprises two buses at different level of voltage and power (42V/14V), communication connections between every component, PCU units, DC/DC converters, redundancy battery units at every level of bus voltages, an Integrated Starter Alternator (ISA) and various alternative sources of electrical energy [5].

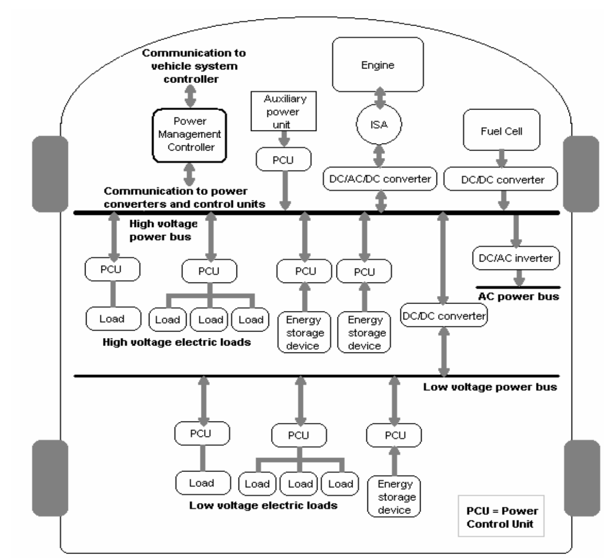


Figure 4. Generic automotive power/energy management and distribution system

A higher voltage level such as the recently proposed 42V will reduce the weight and volume of wiring harness, among several other vantages.

Because automobile engineers are currently introducing many new electronic developments such as electric power steering, braking, suspension, accelerator, electronically actuated engine valves etc., in some large cars the 12V charging systems are already struggling to cope, as they are compromised by bulky wiring harnesses, heavy motors, and electronics that are subject to voltage irregularities. These new electronic developments require

the higher system voltage provided by the 42V PowerNet. This development is expected to proceed in 2 stages with a dual voltage system initially (42V/14V), followed after a few years by a single 42V system in which lower voltages e.g. for lighting, are achieved by a low cost dc-dc converter.
For first, increasing voltage level consent to cope with increasing electrical power request on board. The most important advantages that can be reached using a 42V powernet architecture are the following [1], [6]:

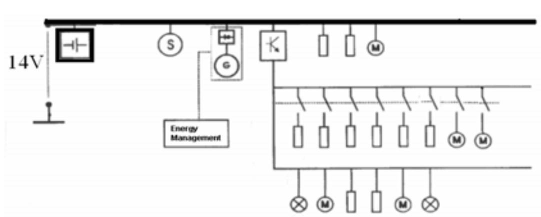
- lower currents,
- reduction of power semiconductor costs,
- cable cross section reduction,
- efficiency increase (particularly for alternator, distribution system, switching devices),
- cost reduction due to new specifications (overvoltage, reverse battery load dump, jump start),
- new power application can be realized on board (e.g. x-by-wire),
- enables reduction of fuel and emission,
- enables electrification of accessory drives.

On the other hand, in a system such this, some loads need for source at lowest level of voltage (such as lamps and electronic equipments) so a dual voltage system is actually necessary.

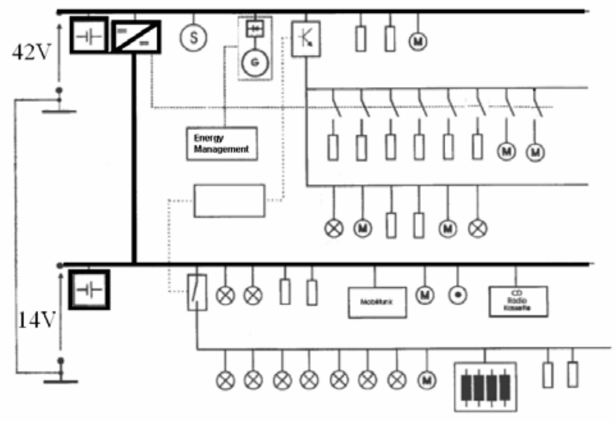
3. Description of the Suggested Technique

3.1 Analyzed Powernet Architecture Families

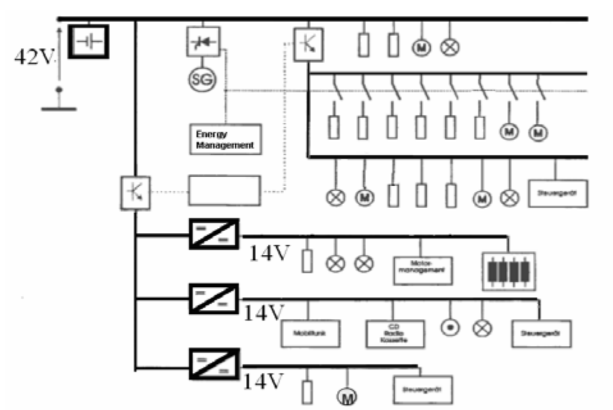
The optimization technique is formulated by means of stochastic and expert system approaches, and is specifically oriented for the analysis of automotive electrical systems. The proposed technique has been developed for the ELASIS Center of Research of FIAT. It is covered from industrial secret and therefore it cannot be described in detail.
Since it automates two critical functions: system analysis and comparative evaluation, it can be used to quantitatively compare a large number of architectural alternatives in a relatively short time.
Two families of powernet architectures (traditional and dual voltage) have been analyzed under different aspects: energetic, systemic and of reliability [7] (figs. 5(a) – (c)).



(a) - 14V DC supply concentrated architecture



(b) - 42-14V DC dual voltage supply concentrated architecture



(c) - 42-14V DC dual voltage supply distributed architecture

Figures 5. Considered powernet architectures for analysis

3.2 Flow-Chart of the Proposed Technique

The proposed technique, starting from the following system indexes: size, weight, cost, efficiency and reliability of every components and of the whole system, electric service quality, gives a global index that defines the adaptability of analyzed architecture to the specific automotive application.
Fig. 6 shows a flow-chart of the suggested technique.
The evaluator module compares different architectures adopting a multicriteria analysis [8];
To find some of these multicriteria analysis indexes (S.O.C., supply continuity, etc.) it is necessary to simulate the powernet configuration running under a well defined vehicle drive cycle and an adequate activation sequence of loads.
For these reasons, a modular software tool named POWERNET SIMULATOR has been developed.

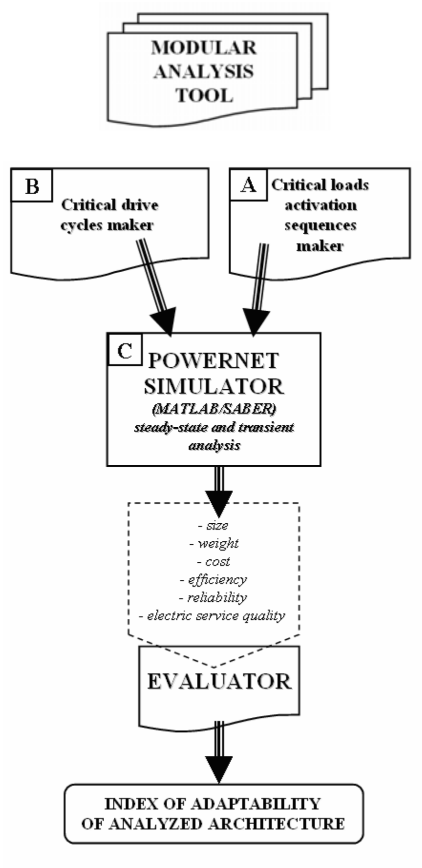


Figure 6. Schema of the realized modular tool

3.3 Powernet Simulator (C)

This tool gives the steady-state and the transient analysis of the overall on-board electrical system. Inputs are: topology of chosen architecture for powernet; models of all the loads in the automotive electrical system; critical loads activation sequence (found with module A) and critical drive cycle (found with module B).

Several models have been developed for the devices which compose the power network. Appropriate algorithms for each model have been realized, implemented in MAST language, in way to be simulated in SABER DESIGNER environment; particularly, battery, alternator, supercaps, dc/dc converters, electrical window winders, radiator and air conditioner fans, electrical windscreen wipers templates have been realized. Then, every realized model has been validated with a comparison among simulated and experimental data, these last obtained at the same conditions by employing effective automotive components.

Once a system has been analyzed, POWERNET SIMULATOR calculates the system indexes that are of interest for the multicriteria analysis: cost, weight, efficiency, reliability, etc. Cost is broken down into parts cost and assembly cost; efficiency is measured in terms of the average mechanical power consumption of the electrical system as measured at the crank-shaft of the engine. These indexes are generally calculated from the data residing in the part database. However, if an appropriate part was not found in the database and a virtual component was created, POWER SIMULATOR calculates the component indexes using physically based component properties models.

Powernet reliability depends on the topology of power network, so it can be evaluated with classical schemes (series, parallel, etc.). Electric service quality is evaluated employing a further multicriteria analysis, which take in account the following indexes: supply continuity, state of charge of the batteries in a drive cycle, bus voltage profile and consequently voltage sags and dips.

The indexes employed for the evaluation of service quality have been obtained simulating the selected architecture in a full SABER schema.

Every type of the selected architecture has been simulated considering the same loads set, the same drive cycle and the same loads activation sequence.

Drive cycle and loads activation sequence are the output of two other techniques (as shown in fig. 6), that are of fundamental importance because they identify the opportune operative conditions on which the powernet must be tested.

3.4 Critical Loads Activation Sequences Maker (A)

This technique gives informations about electrical stress of powernet. The critical operative conditions are evaluated respect to the powernet and respect to the power source system.

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

The technique generates, by means of a stochastic approach, different sequences of loads activation. The output represents a set of critical operative conditions suitable for testing the power source system.

3.5 Critical Drive Cycles Maker (B)

This technique starts from a set of data (i.e. limit of speed for every gear change or compatibility condition for every change) and gives, by means of a stochastic approach, different drive cycles and the relevant probability distribution of the average speed values. The outputs represent a set of operative conditions with the relevant degree of criticity for the power source system.

4. Numerical Results

Two families of powernet architectures (traditional and dual voltage) have been analyzed under different aspects: energetic, systemic and of reliability. For each topology the same loads and the same alternator have been adopted.

N. 30 loads (electrical window winders, radiator and air conditioner fans, electrical windscreen wipers, lamps and so on) have been considered. The parameters of the simulated alternator has been reported in Tab. I. A 12 V – 60 Ah battery has been adopted.

TABLE I.

PARAMETERS OF THE SIMULATED ALTERNATOR

Rs - 25°C [mΩ]	25
Ls [μH]	120
Re - 25°C [Ω]	2.75
Pole pairs	6
Rating voltage [V]	14
Rating power [kW]	3
Weight [kg]	7,5
Size [dm³]	1,8
Cost [€]	320

Fig. 7 shows the drive cycle adopted for all the simulations.

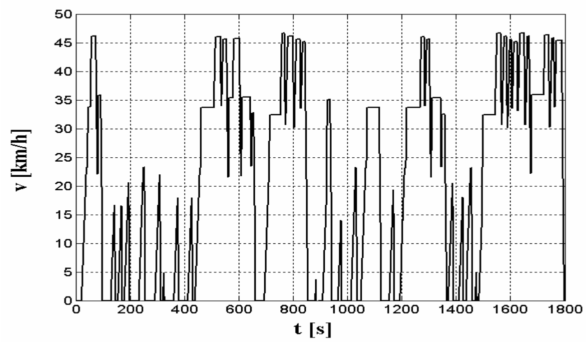


Figure 7. Adopted drive cycle

Figg. 8 show some results given by powernet simulator when the powernet solution reported in fig. 5(a) is considered.
Figg. 9 show some results given by powernet simulator when the powernet solution reported in fig. 5(b) is considered.
Table II reports the powernet indexes computed from the POWERNET SIMULATOR and the global index result given from the multicriteria analysis.
As can be noted, the best performances have been obtained with the solution (c) (42-14V DC dual voltage supply distributed architecture). Naturally, the result significantly depends on the values assumed for the indexes weight. Therefore it’s very important to define adequately these values.
Table III reports as example the same results when different values are fixed for the indexes weight. In both the tables it has been fixed as maximum of indexes weight a value of 5.
Results reported in both the tables confirm that good performances in terms of ΔS.O.C. and ΔV are obtained with powernet architectures (b) and (c), even if the choice of the weight fixed for the “cost” item significantly influences the result.

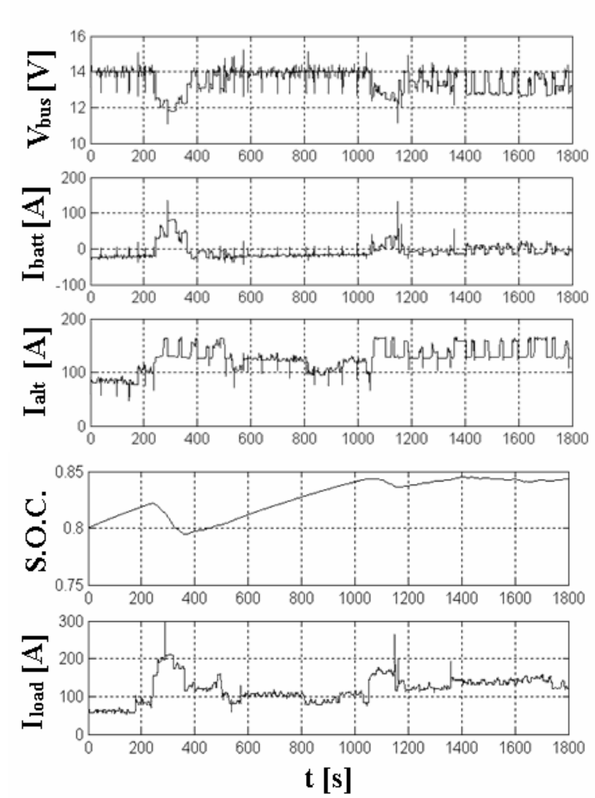


Figure 8. Bus voltage, battery current, alternator current, S.O.C., total load current vs. time, for a critical loads activation sequence applied to arch. (a)

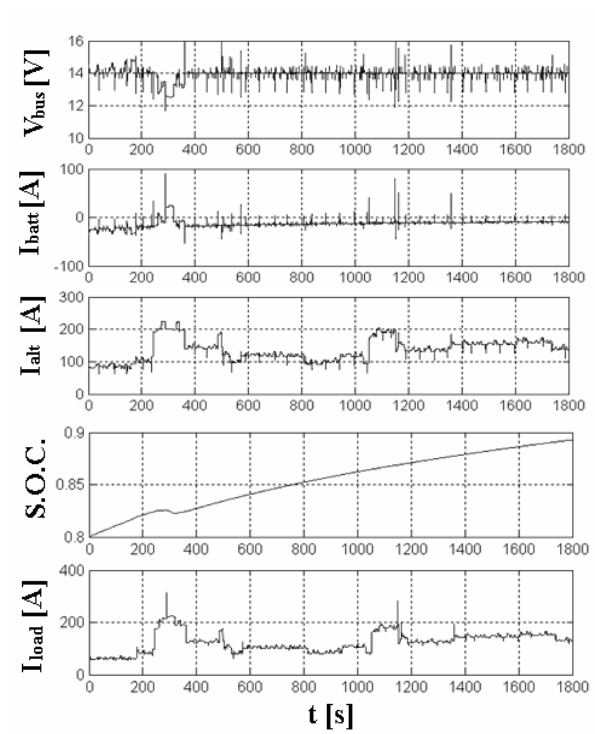


Figure 9. Bus voltage, battery current, alternator current, S.O.C., total load current vs. time, for a critical loads activation sequence applied to arch. (b)

TABLE II.

COMPARISON AMONG THREE DIFFERENT SIMULATED ARCHTECTURES: CASE A

POWERNET INDEX	Arch. (a)	Arch. (b)	Arch. (c)	Index weight
V_{avg} [V]	13.52	13.97	13.99	3
ΔV [V]	3.44	3.61	2.59	4
ΔS.O.C.	0.05	0.09	0.1	5
Weight [kg]	82	100	93	2
Powernet size [dm^3]	12	32	38	4
Cost [€]	1525	1626	2050	3
Powernet efficiency	0.53	0.60	0.60	3
Powernet reliability	0.850	0.890	0.910	5
Global index result	0.5128	0.5052	**0.5169**	

TABLE III.

COMPARISON AMONG THREE DIFFERENT SIMULATED ARCHTECTURES: CASE B

POWERNET INDEX	Arch. (a)	Arch. (b)	Arch. (c)	Index weight
V_{avg} [V]	13.52	13.97	13.99	2
ΔV [V]	3.44	3.61	2.59	0
ΔS.O.C.	0.05	0.09	0.1	5
Weight [kg]	82	100	93	0
Powernet size [dm^3]	12	32	38	1
Cost [€]	1525	1626	2050	5
Powernet efficiency	0.53	0.60	0.60	2
Powernet reliability	0.850	0.890	0.910	5
Global index result	0.4977	**0.5549**	0.5348	

5. Conclusions

In this paper a new computer aided technique has been introduced for the choice of a functional architecture for evoluted automotive powernet. New trends in architectures topologies have been presented and 42V technology applications have been depicted.

Then, in the paper an optimization technique has been presented which has the aim to compare different powernet architectures and to identify which of them have superior performance and are economically competitive.

A comparison among three different powernet architectures has been conducted and results of the comparison realized with the multicriteria analysis have been reported. This comparison evidences the goodness of dual voltage solutions, with the same loads set and drive cycle for every considered powernet, with respect to the traditional architecture.

The presented technique can be employed whether as aid to choice, to analyze and to design different architecture, or to validate the adaptability of existing ones.

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