12V/14V TO 36V/42V THE AUTOMOTIVE CHANGE TO ACCOMMODATE THE NEW TECHNOLOGIES

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Abstract – This paper shows some aspects of the automotive voltage energy system level shift from 14 to 42 Volts. New features and prospective emissions/fuel economy requirements are creating electrical power needs in future automobiles, which today's conventional system cannot adequately supply at 14 Vdc (nominal, with a 12 Volt battery). This requires new architectures and offers opportunities for further system improvements. It will be necessary to provide electric motors, DC/DC converters, inverters, battery management, and other electronic controls to meet higher voltage requirements. These new demands challenge the suppliers capacity to innovate. Suppliers must now include 42 Volt components and systems within their product range and make these new components as light, small, and cost efficient as possible. Finally, before the decision for series production is made, these components and systems must be validated for functionality and product life. What will the new electrical system architecture look like? What effects will this new system complexity have on components? This paper intends to explain what is happening with the new 42V automotive energy supply level.

I INTRODUCTION

The increasing power demand in the vehicle electrical system of passenger cars requires a new vehicle electrical system concept. Fig. 1 shows the historical and anticipated average electrical load in high-end automobile [1].

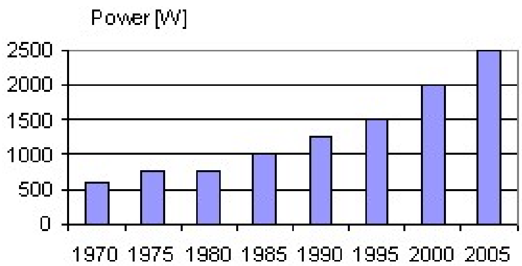


Fig. 1 - Electrical load in high-end automobile Power x Model Year

This figure shows year over year the contribution of the ancillaries and accessories on the automobile energy system, with reflexes on the growth in wiring harness. The increasing of electrical loads such as engine valve actuators, active suspensions, all electric steering, braking, pumps, fans and compressors are pressuring the change to the generation voltage to 42V. With the 42-Volt system, technologies that were previously impractical or impossible are now feasible, like x-by-wire systems (for example: ride control, brake-by-wire, steer-by-wire, electromagnetic valve control), integrated starter-generator and active suspension.

A. The history of the 42V

"By 1994 Mercedez Benz realized that they would need higher voltage to support the electrical system they were envisioning for their future production vehicles. Mercedez Benz also realized that they could not unilaterally decide which voltage to use, but needed buy-in by the international auto industry. MIT - USA, which had already been doing electrical systems research for Mercedez Benz, was organize a working group of automotive OEMs (Original Equipment Manufacturers) and suppliers to see if agreement could be reached on a new voltage. This group of 7 companies met regularly for a year and a half, considering issues of safety, reliability, infrastructure and transition costs. The result was proposal for 42 V, which would be the engine-on voltage of 36 V lead acid battery. These were made public through an article in August 1996 issue of IEEE Spectrum [2]. From there up to now the group has been expanded to include all European OEM and many suppliers, and is "known" as the "Forum Bordnetz". Its work is organized and facilitated by a German company named SICAN, and it has assumed principal responsibility for refining the recommendations and turning then into ISO standards. The MIT group has been transformed into the MIT/Industry Consortium on Advanced Automotive Electrical/Electronic Components and Systems, and is membership expanded to 34 companies including 10 in Japan [3]. Thus there is now comprehensive international acceptance of 42 V as the system voltage of the future" [1].

Fig. 2 illustrates a "logo" and "mark" designed by the consortium and used by manufacturers and suppliers of components and other products specifically for new 42V power network ("PowerNet").

Fig. 2 a) 42V logo

Fig. 2 b) 42V product mark

II THE PRESENT 14V ELECTRICAL SYSTEM

The present electrical system employs a 12 V lead-acid battery energy storage and power capability, thus creating a network with a nominal voltage of 14,4 V with the engine on. A conceptual diagram of the system is shown in Figure 3. Not shown in this figure are details of the loads like lamps, electronics, motors, heater system, Electronic Control Units (ECU's) comprising microprocessors and power MOSFET's switches to control de engine, transmission, etc.

A. Summary for 14 V nominal voltage

The 14V system would have to carry too much current, with thick wires, more weight with installation problems. However, if the voltage is increased by the factor x, then the current required for the same amount of power consumption is reduced by the factor 1/x. Less current comes with additional benefits such as reduced cable cross-sections, a reduction in the relative voltage drop and earth offset, easier use of semiconductor switches, plug instead of screw connectors etc. An increase in the vehicle electrical system voltage presents itself virtually as a necessity. A reduction in current is of particular advantage for the use of silicon modules for the power electronics. Current, rather than voltage, is the main source of problems. High currents require a large area, and since the formula 'chip area = cost' applies in the semiconductor industry. Smaller currrent means that these components can be offered at much lower prices despite increasing functionality.

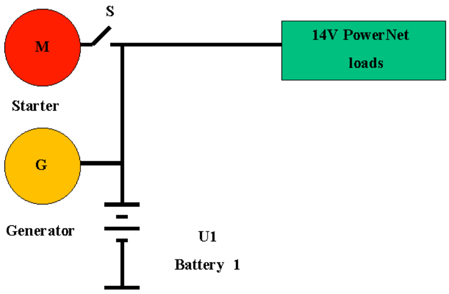


Fig. 3 Present single 14V voltage system

III The Future Vehicle Electrical System

The structure of the 42 V electrical system is still in discussion, and it is not clear what will be an industry standard. Two practical alternatives are being seriously considered by OEMs [3-8]. Figure 4 shows a dual battery system and the other alternativehas a single battery only on the 42 V side. In this new vehicle electrical system, the heavy-load consumers will be kept separated from the remainder of the vehicle electrical system. The voltage level of the heavy-load consumers will be raised to three times the present-day 14 V level. Each of the two networks will be buffered with an energy storage device. The generator feeds the 42V network for the heavy-load consumers. The 14V branch is supplied by a DC/DC converter.

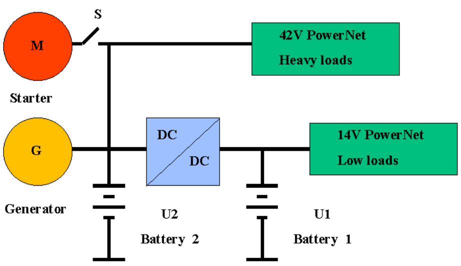
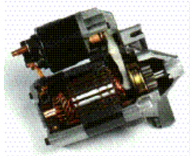


Fig. 4 - 42V/14V dual voltage with two batteries system

IV Integrated Starter Motor/Generator for Future 42-Volt System

The mechanical-to-electrical conversion efficiency of today's 14V Lundell alternator – Claw Pole alternator - (including the integrated rectifiers) is about 50%. The practical maximum rating limit for Lundell alternator is generally considered to be approximately 3 kW (200A at 14 V) [10].

The proposed higher-voltage architectures constitute an opportunity to revisit the idea of combining the starter and generator functions into a single drive. Then, instead of the belt-driven alternator (generator) used in conventional engines, powered by a 36V battery, the starter-motor/generator acts either as a motor or generator, switching between functions according to driving conditions. The single unit could be designed to generate higher power levels than the conventional Lundell alternators, and would be capable of providing smooth starts thus making it possible to turn the engine off at idle. Some alternatives are being investigated for starter/generator automotive applications including Induction [16], Permanent Magnet [5], and Switched Reluctance Motors [12,15]. Figure 5 shows the conventional DC starter motor, the Claw-Pole alternator used in the present system, and the Switched Reluctance Motor/Generator – SRM/G with the power electronic converter prototype developed at UNICSUL for traction and automotive motor/generation studies [13,14,19].



Conventional DC starter motor

Conventional Claw-Pole alternator

SRM/G Starter-Motor/Generator and Converter

Fig. 5 Conventional starter motor, alternator and the new Switched Reluctance Integrated starter/generator system

A. The integrated SRM/G operation

The switched reluctance machine is basically a doubly salient structure in which there are concentric coils mounted around the stator poles and the rotor has neither windings nor permanent magnets. Fig. 6 shows the cross-section of the machine, that has 3 phases, 6 stator poles and 4 rotor poles, and the flux density distribution. The stator and the rotor are assembled with ferromagnetic laminations. Some constructions may use solid ferromagnetic materials in the rotor. The coils of opposite stator poles are connected in series or in parallel with convenient polarities to create, when electric current flows in them, the N and S pole pairs of a phase. This machine configuration is the simplest one that enables full starting torque and operation in both directions [20-22].

The base speed of the machine prototype is 3000 rpm, the maximum speed is 10000 rpm, the maximum torque is 3.8 Nm and the maximum power is 1200 W. Fig. 7 shows the Asymmetric Half-Bridge Converter scheme used in this work and it allows four quadrant operations of the drive. In this scheme the phases are independent from each other and if a failure in one phase occurs, the machine may continue the operation within a limited power range.

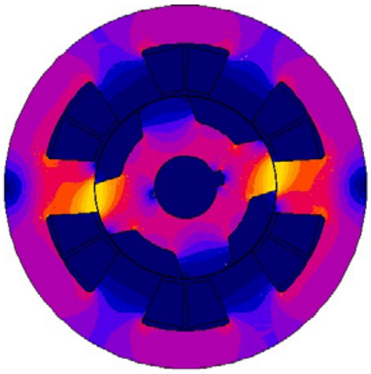


Fig. 6 – Machine cross-section and Flux Density obtained using FLUX2D Simulation Software [27]

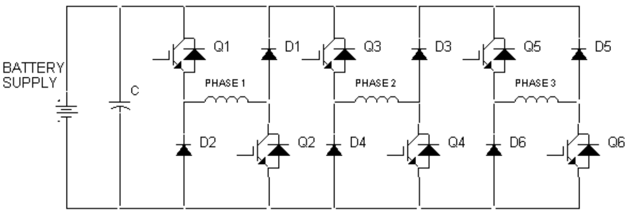


Fig. 7 Asymmetric Half-Bridge Power Electronic Converter

B. Switched reluctance motor operation

The development of torque is due to the tendency of the poles of the rotor to align with the axis of an excited pair of coils. The polarity of the current makes no difference and the direction of the motion depends only on the relative positions between the axis of the poles of the rotor and of the excited stator coils. From these facts derives the possibility of motion in both directions. Fig. 8 shows an idealized waveform of the inductance versus angular position of one phase. To depict this figure it is assumed that the saturation and the fringing effects are negligible.

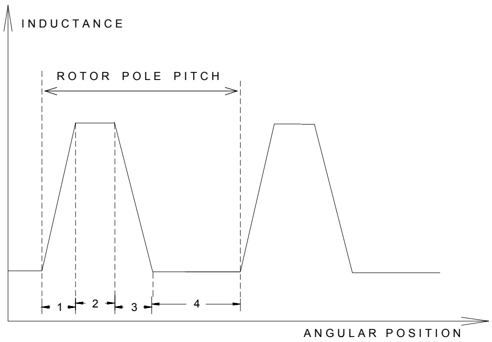


Fig. 8 - Inductance x angular position

Suppose that the rotor is running and at a certain instant of time the edges of two rotor poles meet the edges of two stator poles pertaining to one phase. It corresponds to the beginning of the part number 1 of the curve. Before this instant, the inductance is at its minimum value. If the rotor continues to run the inductance starts a linear increase until the beginning of the part 2 where the rotor and stator poles are fully overlapped and the inductance value comes up to its maximum value. This maximum value is maintained during the part 2 and this part corresponds to the angular difference between the stator and rotor pole arcs. From the beginning of part 3, the inductance starts a linear decrease until the beginning of part 4 where the poles are not overlapped and the inductance remains constant at its minimum value.

To take into account the saturation and fringing effects the torque must be calculated by using the concept of the co-energy Wc, i.e.,

$$T(\theta,i)=\frac{\partial W_c(\theta,i)}{\partial\theta} \qquad (01)$$

where θ is the angular position and *i* is the current in the coils. A first approach to the design may be conducted considering the curve of Fig. 8 [20-22], i.e.,

$$T(\theta,i)=\frac{i^2 dL}{2d\theta} \qquad (02)$$

where L is the self-inductance of the coil as a function of the angular position. Considering the equation (02), the Fig. 8 and a constant current flowing in the coils of one phase, we may depict the Fig. 9 and get the following conclusions:

a) during the part 1 the torque is a positive constant and this is a motoring region; b) during the part 2 the torque is zero, then the inductance is constant at its maximum value; c) during the part 3 the torque is a negative constant and this is a generating or braking region; d) during the part 4 the torque is zero again, then the inductance is constant at its minimum value.

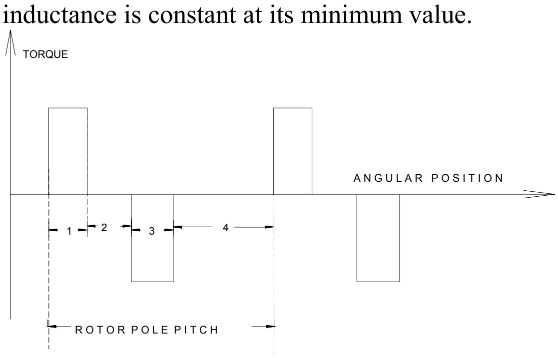


Fig. 9 Torque x angular position

The parts 1 and 3 correspond to the pole arc of the smaller angle between the pole arcs of the stator and rotor. From the above figures one may also conclude that for our prototype to be able to start at any position in any direction the parts 1 and 3 must have at least 30 mechanical degrees. For the rotor to run by an angle corresponding to the rotor pole pitch, each phase must contribute with one stroke of torque. As our motor has 3 phases and the rotor pole pitch is 90 mechanical degrees it becomes apparent the minimum angle statement. The converter is of the asymmetric half-bridge type. From the explanation about the nature of torque production we may see that it is necessary to establish the electric current in each coil, sequentially, with the switching control signals derived from the angular position sensor. There are 2 operation modes for this prototype converter: the single-pulse voltage and the chopping-voltage. Referring to Fig. 8, in the chopping-voltage mode, at the beginning of the conduction period of one phase, e.g., phase 1, the switches T1 and T2 are turned on and the current flows through the switches and the coils of the phase. During this period, by using a reference value and a current feedback, the current peak value is limited by turning on and off one of these switches, e.g., T1. When T1 is turned off the current flows through the phase, T2 and D2. At the end of the conduction period both switches are turned off and the current flows through the phase and the diodes D1 and D2 returning to the supply. Pulse width modulation (PWM) is suitable for controlling the current and this operation mode is used for low and medium speeds and Figure 10 is an illustration of this mode of operation.

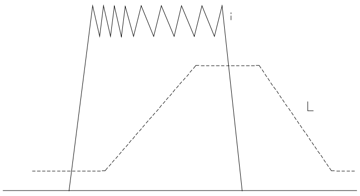


Fig. 10 - Current supply x inductance waveform m

As the speed increases, the time required for the rotor to travel an angle equivalent to the conduction angle of one phase becomes smaller. In this way the conduction time will be such that the current is switched on and off only once in each conduction period. Than we have the so-called voltage-fed or single-pulse mode which is used in the upper speed range. Fig. 11 is an illustration of this mode of operation.

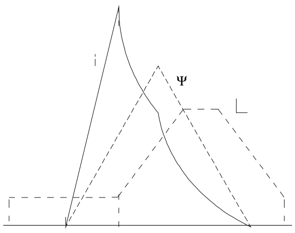


Fig. 11 Current, flux and inductance

C. Generator or regenerative braking operation

Referring to figures 8 and 9, one may notice that if there is current flowing in the phase while the rotor traverses angular positions corresponding to the part 3 of these figures, the developed torque becomes negative (sense opposite to the speed). This characterizes the generating or braking operation and the operation point is inside a region in the fourth quadrant. As may be seen in figures 8 and 9, the operation in the fourth quadrant is achieved delaying properly the conduction angles of the power switches, imposing current in the phase winding while the rotor traverses angular positions corresponding to the decreasing of the inductances of the phase. In this way, equation (02) shows that the torque is negative and this is only a matter of developing a suitable control strategy. This operation mode is considered in this work to study the possibility of recovering the energy during the braking of the system. The analysis to make a decision if the energy recovered will be dissipated in a braking resistor or it will be stored in a battery is being conducted. The generator or regenerative braking operation presented in this paper regards the single-pulse operating mode. This kind of generator has been studied for applications where a wide speed range, robustness and fault tolerance are the main requirements to achieve. The generator supplies the DC link through the same converter used for the motor operation and a suitable angle and speed control is necessary to establish this operation [21,23-32].

The generator presented in this paper is self-excited and it needs an initial charge of magnetic energy supplied from an external power source. During the conduction period of the power switches, it draws energy from the DC link and this is the excitation period. At the end of this period, both power switches are turned off and the current flows to DC link through the diodes and this is the generating period. The generating current is sustained while the rotor displacement causes a variation in the phase inductance. The generating current is shared between the next phase to be excited, the bus capacitor and the load. Notice that the polarity of the phase current never changes. The generator phase terminals voltage equation represented as an electrical coil with resistance R can be written as:

$$u(t) = R.i(t) + \frac{d\Psi(t)}{dt} \qquad (03)$$

$$\Psi(t) = L[i(t), \theta(t)].i(t) \text{ and } \frac{d\theta}{dt} = \omega_m \qquad (04)$$

where w_m is the rotational speed of the rotor and θ the rotor angular position.

Arranging the equations (3) and (4) and neglecting R, results in the following expression:

$$u(t) = L\frac{di(t)}{dt} + i.\frac{dL(\theta)}{d\theta}.w_m \qquad (05)$$

The first term of (05) represents the inductance voltage drop; the second term represents the motional or back-emf of the switched reluctance machine. Notice that this emf depends on the current in the phase, the derivative of the inductance and the speed. The nature of torque production is dependent on the gradient of the phase inductance, which varies periodically with the rotor angle, as shown in Figure 12 and equation (02). A negative torque can be generated during the negative slope of inductance

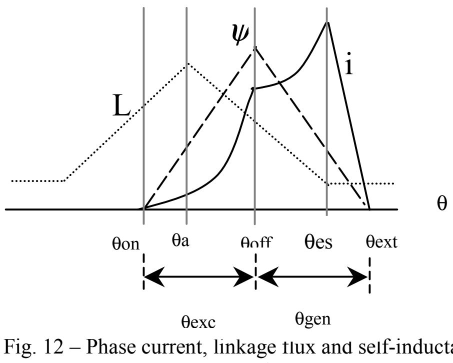


Fig. 12 – Phase current, linkage flux and self-inductance during generation

The symbols in Fig. 12 mean: θon, turn-on angle; θa, alignment angle of the rotor and stator poles; θoff, turn-off angle; θes, end of superposition angle; θext, extinction angle; θexc, excitation angle; and θgen - generation angle.

An outstanding characteristic of the switched reluctance machines is that there are not steady-state rms or average values of the currents and voltages in the phases like the conventional AC and DC machines. The current waveform depends on the rotor speed, DC link voltage and switching angles. This generator operates in a succession of electrical transients imposed by the control circuits of the converter. At the beginning of each electrical cycle of each phase (θon) both power switches are turned on and the current flows in the coils to excite the machine. The current is showed in Fig. 12 and this period is the excitation period, θexc. At the end of the excitation period both power switches are turned off and electrical power is delivered to the DC bus through the diodes. This is the generating period, θgen and if R is negligible, θexc =θgen. This process is repeated indefinitely in a frequency proportional to the rotor speed. The speed is imposed by the prime mover.

Each electrical cycle of each phase begins when the power switches are turned on in an angular position of the rotor pole axis, which is approaching the stator pole axis of the phase to be excited. From the second term of (05), since the inductance derivative is positive, the back emf polarity is such that it opposes the DC link voltage, limiting the rate of rise of the phase current. After the alignment position, the inductance derivative becomes negative and the polarities of the back emf and the DC link voltage are the same, increasing the rate of rise of the phase current. The current always increases during the excitation period and this shows that it is necessary to limit θexc in order to preclude excessive values of current (and torque). At θoff , both power switches are turned off and the current is delivered to the DC bus through the freewheeling diodes and the generating period begins. During this period, the back emf opposes again the DC link voltage (Vdc) and, depending on the relative values of these voltages, the current waveform can increase if emf >Vdc (as showed in Figure 12); maintain the value of the beginning of θgen if emf = Vdc; or diminish from the beginning of θgen if emf < Vdc. In the excitation period, the phase absorbs electrical energy from the DC link and in the generating period, the mechanical energy supplied by the prime mover is converted into electrical energy. Continuous generating action is achieved provided that the mechanical energy converted into electrical energy exceeds the electrical energy absorbed during the excitation period. Fig. 13 shows a set of flux linkages versus phase current for several rotor positions. The area enclosed by the solid line represents the energy available for conversion per electrical cycle of each phase, W. As showed in [1], the average torque and mechanical power are

$$T_{avg} = \frac{mN_r}{2\pi}W \qquad (06)$$

$$P = T_{avg}w_m \qquad (07)$$

where m is the number of phases and Nr is the number of rotor poles.

We have concluded that for achieving continuous generating action, the control parameters should be adjusted to balance the mechanical power with the power absorbed by the DC link load and the losses of the machine and converter [21].

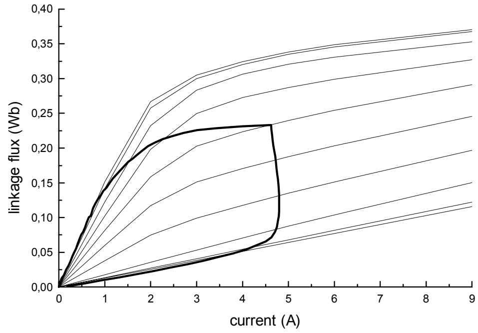


Fig. 13 - i - ψ plain

D. Conceptual 42V system adopting the SRM/G Starter/generator

A conceptual diagram of the integrated starter/generator for the 42V System applying the SRM/G is illustrated in Fig. 14.

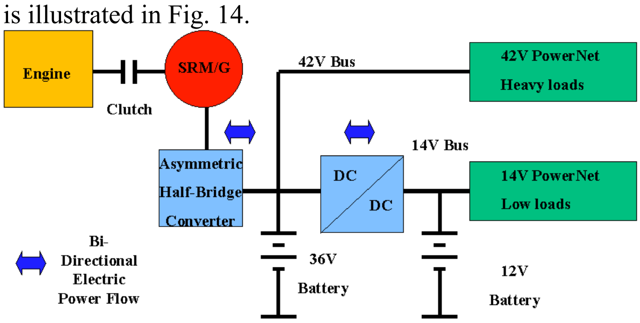


Fig. 14 Integrated SRM/G Starter/Generator for 42V System

The conceptual motor/generator system proposed will have the following functions: a) restarts engine from "idling stop" mode; b) starts vehicle moving before engine kicks in after "idling stop" mode; c) charges battery (as needed) during engine operation; d) regenerates energy during vehicle deceleration and braking; e) supplies accessories when in "idling stop" mode.

E. Preliminary SRM/G tests results

The assembling of the system prototype is in the final process and the equipment will be ready for tests very soon. The operation of this machine depends on the signals of a rotor position sensor and a controller is used to perform the control functions of the drive. For generation of drive and the interface signals we used an 8-bit microcontroller. The algorithms to control the switched reluctance motor and generator drive will be summarized in a future paper.

Simulations are being developed to study the integration of the electric machine and its converter. Next figure is included as illustration of the preliminary result. Fig. 15 shows an example of test result for the motor operation at constant speed and feeding a resistive load.

V Electrical, Electronics and Electro-Mechanical Requirements for 42V Applications

A. Switches and Power Semiconductors Characteristics For Future Automotive Electrical Systems

After discussing the advantages and the implications of introducing a new automotive electrical system in general terms, we will need to address the specific question of how future power semiconductors are actually to be defined if they are to meet the new voltage requirements [9-11]. Fig. 16 a) and b) shows the required net and semiconductor operating voltages for both 14V and 42V systems, respectively.

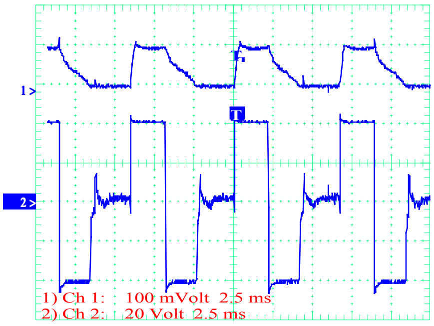


Fig. 15 Ch 1- Phase current and Ch 2 - voltage waveforms, motor operation

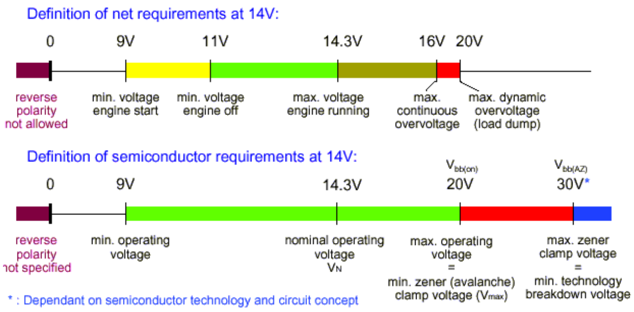


Fig 16 a): Voltage definition of present 14V PowerNet

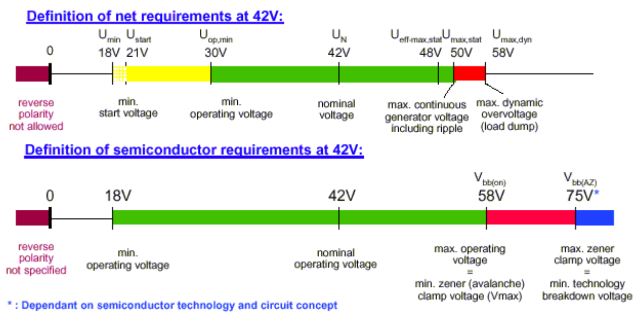


Fig. 16 b): Voltage definition of future 42V PowerNet system

B. Power storage system Battery requirements

For most dual voltage 14/42V systems, a 36V battery will be required, mainly for starting, and a 12V battery will be used as a storage unit and backup for the 14V applications (such as lighting) [18]. In general, the 36V battery will need similar attributes to the current 12V unit. It must be designed for power, and its parameters will be mainly defined by torque demand for cold starts. In this respect lead-acid technology would be acceptable. A 36V battery with similar characteristics to current 12V units would be much the same shape and weight, although a little larger to accommodate connections between 24 cells instead of 8. There will be a problem of finding space for two batteries (12 and 36V) instead one, but the 12V unit could probably be much smaller as it does not have to offer high power. The industry view is that the lead-acid battery will have to be replaced by some alternative to get the most out of 42 Volt systems, and the current favorite is the Lithium Polymer or Lithium Ion battery. Lithium batteries, which are already in production, but not for general automotive applications, appear to be capable of meeting the future needs. They have a good combination of specific energy and specific power, and are capable of many more (1 million) charge/discharge cycles. Although more expensive than lead-acid units, they offer greater performance and life, and can also be provided in a variety of shapes including flat units which could be under-floor mounted and offer real packaging benefits. Nickel-metal-hydride (NiMH) batteries also look promising in meeting 42 Volt demands, but are even more expensive. Although unlikely to be used on early 42 Volt systems because of their large size and high cost, ultracapacitors or Flywheel Energy Storage Systems – FESS are eventually likely to play an important part in 42 Volt systems.

C. 14V/42V DC-DC converter topology

One possibility of DC-DC converter applied for 14V/42V system is the Multi-Stage Interlaced Buck-Boost DC-DC Converter [33], whose basic structure is shown in Fig. 17. The Multi-Stage converter is derived from the conventional single-stage Buck-Boost converter and allows also bi-directional current flow. This multi-stage configuration, allows the decreasing of current ripple at low voltage level, the increasing of the average current at high voltage level and thus get an improvement of the converter efficiency and reliability on faults.

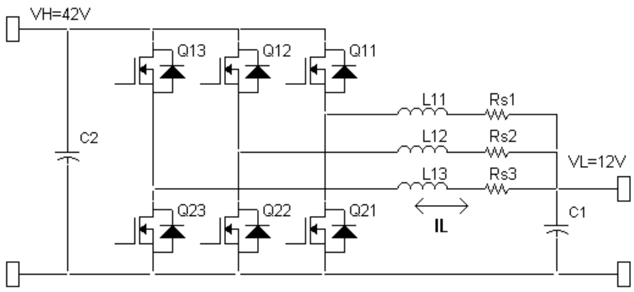


Fig. 17 Triple stage Buck- Boost DC-DC Converter topology for 14V/42V systems

The switching time for a single stage Buck Converter in continuous operation mode is:

$$\frac{VL}{VH} = \frac{Ton_{Q1}}{T} \tag{08}$$

And for a single stage Boost Converter continuous operation mode is:

$$\frac{VH}{VL} = \frac{Ton_{Q1}}{1 - \frac{Ton_{Q2}}{T}} = \frac{Toff_{Q1}}{T} \tag{09}$$

These expressions establishes the following switching times values for Q1 and Q2 for the 14V/42V system:

$$Ton_{Q1} = \frac{12V}{42V} = 0.286T \quad \text{And} \quad Ton_{Q2} = \frac{42V - 12V}{42V} = 0.714T$$

A single stage Buck-Boost bi-directional current profile is illustrated in Fig. 18.

D. Other automotive electrical and electronics components considerations

1)Electric Motors: What can be observed is that currently more than 100 electric motors can be found in a well equipped luxury vehicle, which supports the increase in electric voltage system [15]. However, electric motors usually follow other custom guidelines like: frame size, cost, quantities, noise, lifetime, and ambient conditions. Therefore, in most cases simply adjusting the motor windings is not sufficient.

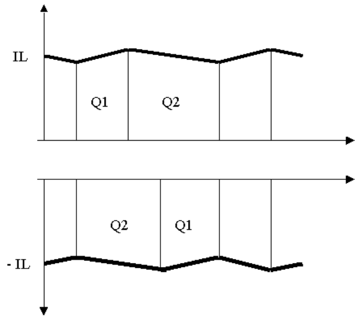


Fig. 18 Single stage Buck- Boost DC-DC Converter current flow

2) Fuses and smart power semiconductors: Fuses are the main automotive devices for wiring and circuitry protection. The establishment of new standards of circuit protection for upcoming high voltage 42V system requirements has obliged the fuse manufacturers to develop a new fuse series to ensure safe opening characteristics and predictable time/current characteristics for the high voltage requirement. Today, new smart power semiconductor devices can be used as an alternative to replace relays and guarantee disconnection. The PROFET [33], and the IPS – Intelligent Power Switch [34] are examples of smart power semiconductor switches that offer low order on resistance and greater functionality such as diagnostics and PWM control.

3) Lamps: Other existing components such as incandescent lightbulbs prefer lower bus voltages, which is one of the reasons for retaining 14V in the new dual-voltage system.

4) Influence on embedded products: With the adoption of the 42V system more new embedded electronics will be enabling to the vehicle. Fig. 19 shows the embedded product areas of focus.

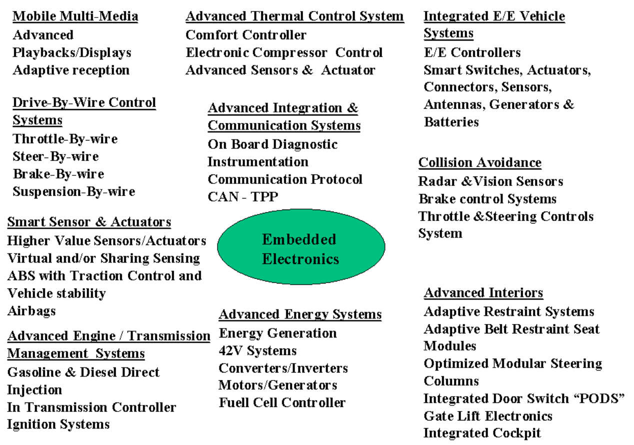


Fig. 19 Embedded product areas of focus

VI THE STANDARDIZATION PROCESS

The establishment of the general technical conditions for the introduction of the new voltage level and of the corresponding electric components requires international standardization processes [3,11,35] and the steps to regulate all the subjects for the 42V system is depicted in Figure 20.

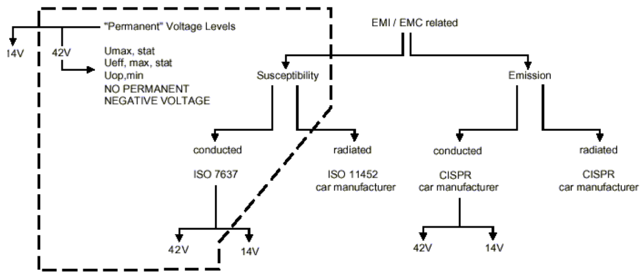


Fig. 20 Schematic of the standardization scope

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42V POWERNET INTERNET RESOURSES

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http://www.sae.org
http://www.batteriesinternational.com
http://www.42v.org
http://www.sican.de
http://auto.mit.edu/consortium/ -

Internet URL of Automotive OEMs

Acura	http://www.acura.com/
Alfa Romeo	http://www.alfaromeo.de/
Aston Martin	http://www.ford.com/
Audi	http://www.audi.com/
BMW AG	http://www.bmw.com/
Citroen	http://www.citroen.com/
Daewoo	http://www.dm.co.kr/
Daihatsu Motor	http://www.daihatus.co.jp/
DaimlerChrysler	http://www.daimlerchrysler.com/
Dodge	http://www.daimlerchrysler.com/
Fiat	http://www.fiat.com/
Ford	http://www.ford.com/
General Motors	http://www.gm.com/
Honda	http://www.honda.co.jp/
Hyundai	http://www.hmc.co.kr/
Isuzu	http://www.isuzu.co.jp/
Iveco	http://www.iveco.com/
Jaguar	http://www.ford.com/
Jeep	http://www.daimlerchrysler.com/
Kia	http://www.kia.co.kr/
Lancia	http://www.lancia.de/
Land Rover	http://www.ford.com/
Lexus	http://www.lexus.com/
Lotus	http://www.lotuscars.co.uk/
McLaren	http://www.mclarencars.com/
Nissan	http://www.nissan.co.jp/
Opel	http://www.gm.com/
Peugeot	http://www.peugeot.com/
Porsche	http://www.porsche.com/
Proton	http://www.proton.com/
Renault	http://www.renault.com/
Rolls-Royce Motor Cars	http://www.rolls-royceandbentley.co.uk/
Rover	http://www.rover.co.uk/
Saab	http://www.gm.com/
SEAT	http://www.seat.com/
Skoda	http://www.skoda-auto.cz/
Toyota	http://www.toyota.co.jp/
TVR	http://www.tvr-eng.co.uk/
Vauxhall	http://www.gm.com/
Volkswagen	http://www.vw.com/
Volvo	http://www.ford.com/
Yamaha	http://www.yamahausa.com/