The Mobility Scenario vs Green Deal Objectives

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***Abstract*—To achieve the objectives indicated in the new Green Deal of July 2021 for year 2030 (- 55% GHG emissions) and finally year 2050 (Getting closer to zero emissions)), an important role will be played by mobility. In fact, electric vehicles, such as trains, trams, and subways, have always been the most energy efficient and environmentally sustainable solutions**

Keywords— mobility, EV, WBG

I. INTRODUCTION

An interesting overview of the objectives for Europe at 2030 was given in SFM (Shaping Future of Mobility) Congress held in Lisbon last November 2021 [1].

Looking at terrestrial mobility by 2030, there are several objectives to reach:

- Minimum 30 Mu zero-emission cars and 80 ku zero-emission trucks in operation;
- Scheduled collective travel under 500 km should be carbon-neutral within the EU;
- Doubled high-speed rail traffic, rail freight traffic increased by 50%;
- Rail & waterborne-based intermodal will be able to compete on equal footing with road-only transport in the EU;
- Automated mobility deployed at a large scale;
- Operational multimodal Trans-European Transport Network equipped for sustainable and smart transport with high speed connectivity (core network).

There is a clear interest in Europe in electric vehicles (EVs) and Rail mobility. In both cases the introduction of new cars and trains equipped with more and more efficient technologies is foreseen.

Railway is the most electrified sector among all transport modes, with electricity accounting for over 40% of energy consumption in 2020. In the APS (Announced Pledges Scenario) the share of electricity reaches almost 60% in 2030, compared with nearly 65% in the NZE (Net Zero Emission). Plans for further electrification of railways are planned in several countries (e.g. Germany, India and United Kingdom), involving in some projects hydrogen powered trains too (e.g. Germany) [2].

Some of the transport modes are already fully electric (trains, trams, subways), undergoing a rapid transformation from internal combustion engine (ICE) to hybrid and fully electric (EV) cars. So looking at 2030 objectives, in both cases it will be a question of optimizing the efficiency of the transport system (trains, trams, subways) or of accelerating the transition to electric cars [3].

II. ELECTRONICS FOR MOBILITY

In this work we analyze the case of terrestrial mobility: electric vehicles, trams, and trains, representing a mean of private and collective mobility. Thanks to new technologies they can benefit for efficiency and reliability.

In Figure1 the area of application of power semiconductors technologies, as a function of power rating and frequency range, is represented. Table 1 lists the required breakdown voltage for a given end application and semiconductor technology.

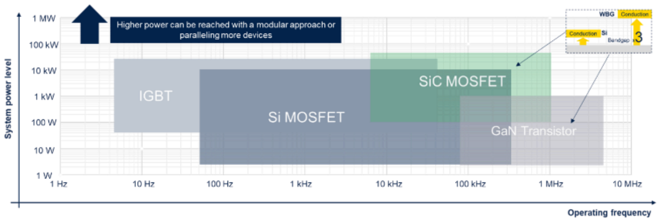

Fig.1 Power technologies (source STMicroelectronics).

Table 1: SUMMARY OF DEVICES BY APPLICATION (source Yole)

	Voltage required	Rail	EV / HEV and automotive auxiliaries
IGBT	250V-900V		**SiC**
	1.2kV-1.7kV	**SiC**	**SiC**
	>3.3kV	🟩	
MOSFET	<40V		🟩
	60V-100V		🟩
	150V-400V		🟩
	>500V		🟩

Silicon IGBT vs SiC MOSFET

Substantial improvements in the performance of power electronics systems are due to power electronic devices based on wide bandgap semiconductors. They offer higher blocking voltages, improved efficiency, and reliability (higher performance/cost ratio), easier paralleling, and reduced thermal requirements, thus leading to the realization of more efficient green electronic systems.

Anyway IGBT devices with high breakdown voltage like 3.3kV are available while SiC counterpart is still under development. In Table II, a comparison between two devices at 1.7kV is provided in terms of Rdson and chip area. Similar performances and advantages already get for 1.7kV and 2.2kV and are expected for next 3.3kV generation.

Table II: key power devices parameters for IGBT and SiC.

Parameter	***Si IGBT 1.7kV***	***SiC MOSFET 1.7kV***	***SiC MOSFET 2.2kV***	***SiC MOSFET 3.3kV***
Operating Voltage	1700 V	1700 V	2200 V	3300 V
Rdson		60 mΩ	30 mΩ	80 mΩ *
Normalized active chip area	100	20		

* *prototype*

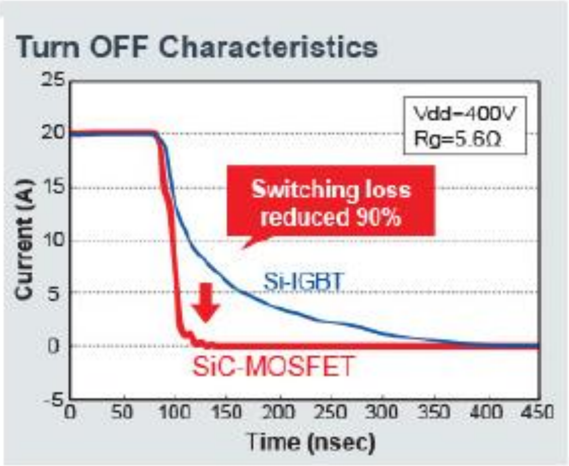

Fig. 2 Turn OFF characteristics IGBT vs SiC MOSFET.

Comparing the turn-off behavior of silicon IGBT and SiC MOSFET shown in Fig. 2, it is easy to conclude that, thanks to SiC MOSFETs higher efficiency values can be obtained when the switching frequency increases.

III. MOBILITY

Mobility in general has to be considered collective as well as private, in order to define the specific characteristics in the Green Deal scenario.

A. Colletive mobility

A train is ideal in the range between 500km to 800km distance. The earliest high-speed rail line built in Europe was the Italian "Direttissima", the Florence–Rome high-speed railway (254 km/158 mi) in 1978, which used FS Class E444 3 kV DC locomotives. Italy pioneered the use of the Pendolino tilting train technology. The Italian “Treno Alta Velocità” (High Speed Train) has been adding to the high-speed network in Italy, with some lines already opened. The Italian operator NTV is the first open access high-speed rail operator in Europe, since 2011, using AGV ETR 575 multiple units.

In March 2011, a contract for the second phase of construction on the Milan–Verona high-speed line was signed. This section will be 39 km. Originally planned to be completed by 2015, it was open to Brescia late 2016.

The Italian high-speed railway network consists of 1342 km of lines, which allows speed of up to 300 km/h. The safety system adopted for the network is the ERMTS/ETCS II, the best existing solution in terms of railway signaling and safety. The power supply follows the European standard of 25 kV AC 50 Hz single-phase current. The Direttissima segment is still supplied with 3 kV DC current, but it is planned that this will be conformed to the rest of the network. [1] In particular, the 3kV technology is of interest for the recent very high voltage power semiconductor which is the 3.3kV Silicon Carbide MOSFET.

B. An example of railway performances

It is interesting to give a look at some characteristics of a high speed train. This is the case of “Frecciarossa 1000”, shown in Fig. 3, with related power level and electronics.

Fig. 3: Frecciarossa 1000 train.

“Frecciarossa” is the high-speed service launched by Trenitalia in 2009 that connects the major Italian cities from North to South:

- Turin-Milan-Bologna-Florence: 25 kV - 300 km / h;
- Florence-Rome: 3 kV - 250 km/h;
- Rome-Naples: 25 kV - 300 km/h.

The fleet of 59 trains travels 20 million km/year.

The train introduces many technological innovations in all its parts.

The aerodynamic profile has been optimized to contain resistance to motion and noise at high speeds. Any external appendages that could create turbulence have been eliminated.

The pantograph is positioned directly in electrical continuity on the roof of the train with no isolators. The galvanic isolation from ground was achieved by inserting a structural insulator in the lower arm of the pantograph, which is a novelty in the field of railway traction.

The effect is that the noise requirements are met even at maximum speeds not fully covered by TSI [1].

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[1] The TSI Energy specifies the following power systems: AC 25 kV 50 Hz system, AC 15 kV 16,7 Hz system, DC 3 kV system and 1,5 kV system.

The most extreme performances required are for the 3 kV pantograph which has to pick up about 3000 A from a single heavy catenary pantograph (4 wires).
For this reason, special contact strips have been developed to guarantee a good tradeoff between achieving a low resistivity while maintaining a low weight to not compromise the dynamic characteristics of the pantograph head.
The traction system is characterized by high modularity as it consists of 16 independently driven motors with the possibility of single isolation and overload of the rest to compensate for the loss of power and strength. The adhesion committed is always less than half of that required by the TSI. All the logic of the redundancies and related management has been made to guarantee the availability of force and power to obtained even very aggressive schedules. The power converter is based on IGBT power switches.

C. *Private mobility*

In the scenario of private mobility, hybrid electric vehicle (HEV) and electric vehicle (EV) must be considered. A hybrid electric vehicle (HEV) is a type of hybrid vehicle that combines a conventional internal combustion engine (ICE) system with an electric propulsion system (hybrid vehicle drivetrain). The presence of the electric powertrain is intended to achieve either better fuel economy than a conventional vehicle or better performance. There is a variety of HEV types and the degree to which each function as an electric vehicle (EV) also varies. The most common form of HEV is the hybrid electric car, although hybrid electric trucks (pickups and tractors), buses, boats and aircraft also exist.

A pure-electric vehicle or all-electric vehicle (EV) is powered exclusively through electric motors. The electricity may come from a battery (battery electric vehicle), solar panel (solar vehicle) or fuel cell (fuel cell vehicle).

Obviously, all the electronics connected to the electric vehicle from photovoltaic systems, to charge stations for domestic and public use, can be optimized to have a low impact in CO2 emissions.

Dedicated electronics is used for HEV and EV to convert energy and drive the motor, as shown in Fig. 4.

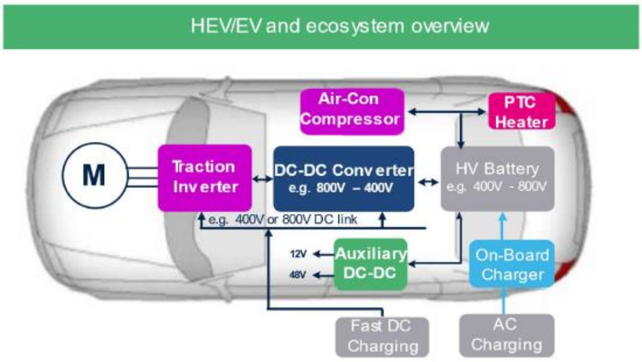

Fig. 4: Schematic of Power Electronics in HEV and EV vehicle [4].

Looking at each block, the most suitable technology must be identified. A schematization is listed in Table III.

Table III: key power technologies vs. application.

Material	**Technology vs. application**	
	Technology	***Focus applications***
Si	IGBT	Traction, OBC, DC-DC, PTC heater and aircon
	HV MOSFET	OBC, DC-DC converter and exploring traction inverter
SiC	SiC MOSFET	Traction, OBC and DC-DC converter
GaN	Power GaN	OBC and DC-DC converter
	PM and IPM	Traction, OBC, DCDC converter and aicon

[a] PM Power Module, IPM Intelligent Power Module

All the identified technologies can be used equally in each application: so that a DC-DC converter or an On-Board Charger (OBC) can be realized with any of them. Of course, different specifications and use case for OBCs may require SiC or GaN instead of Si.

IV. SMARTSYSTEM FOR MOBILITY

To successfully pursue the electric way for mobility some smart systems are needed. Just considering the EV these smart systems are crucial to achieve efficiency, reliability and be competitive with railway for medium distances:

1. ELECTRIC MOTOR CONTROL
2. DC/AC CONVERTER
   (Energy from the battery to the motor and vice versa)
3. SUPERFAST CHARGER
4. On Board Battery Charger
5. KERS (Kinetic Energy transformation system into Electrical)

A key system that for us is key are the superfast charger and On Board Battery Charger; with his performances users can be ready for medium distances travels with EV.

A. *Super fast charger 300kW*

The spread of charging infrastructures is a determining factor for the development of sustainable mobility. The availability of recharging is therefore a decision-making element for the passage and diffusion of electric vehicles.

Charging stations for electric cars represent a fundamental element for “Car Electrification”.

A wide spread of charging stations will have an impact on the network infrastructure and management, especially in the Smart Grid area with the V2G application.

The fundamental factors for the development of a charging station are: Power Quality, efficiency, size and cost!

In the fig.5 the main blocks that make up the high-power charging columns, highlighting how the new technologies improve the performance of charging systems. In addition to the charging stations available on the road, there are also new ones so called 350kW superchargers. These are built using a modular approach.

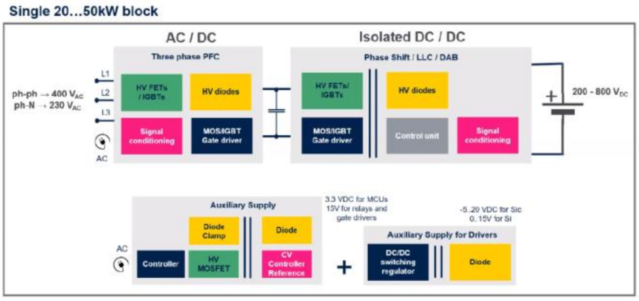

Fig.5 Single 50kW block of battery charger

Instead in the Fig.6 it shown the positioning of the Charging station and main Smart Systems cited in the technologies scenario including WBG.

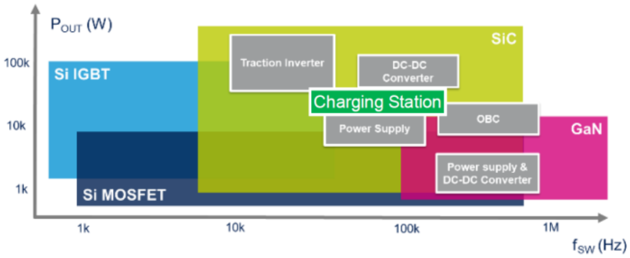

Fig.6 Applications in technologies scenario [Source: STMicroelectronics].

In the AEIT Automotive 2019 some numbers were presented by Bender and charging time span from few hours for AC charging to 30mn for DC fast charging.

B. *On-Board Battery Charger*

The on-board battery charger, OBC, is the direct link with the Grid, charges the battery of plug-in HEVs and EVs from the single-phase or 3-phase power grid. In Fig. 7 is shown a basic single phase solution for 400V battery system.

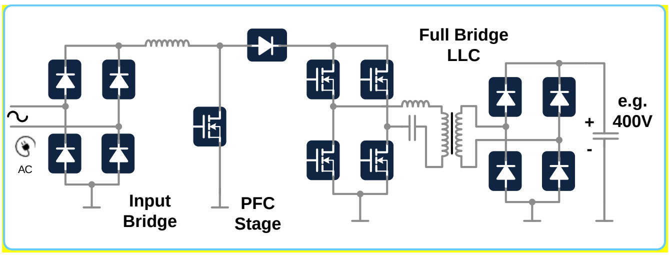

Fig. 7: Schematic of On-Board Battery Charger for EV vehicle [Source: STMicroelectronics]

Further optimization in terms of efficiency can be introduced with higher performance topologies for PFC stage with bridge-less architectures as well as synchronous rectification on the output of the DC/DC stage. Such improvements are made possible thanks to WBG device characteristics.

Different architectures and topologies in automotive are required to support scalable solutions. The availability of different power semiconductor technology helps in finding the best trade-off between performance and cost.

In addition to Si and SiC based power components, there is the introduction of the "newcomer" GaN power transistor. The advantage of such new technology is highlighted in Fig. 7, where the efficiency evaluation of a DC-DC converter in Boost topology is shown using different power semiconductor technology in the 650V voltage class.

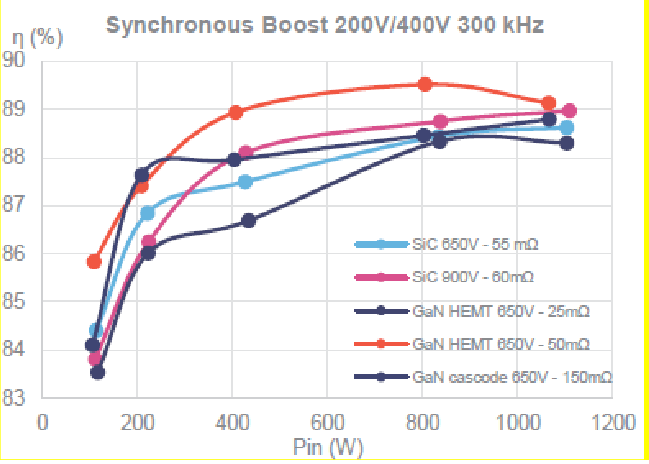

Fig. 8: Synchronous Boost 200V/400V 300 kHz
[source STMicroelectronics]

The efficiency of GaN transistors is superior compared to SiC, so it may be used in OBC developments with promising perspectives in terms of overall performance.

C. *Electric Veichole as a challange*

An important step for SiC adoption for power electronics happened in 2018 when Tesla decided to adopt this technology for its traction inverter. After two years and almost 1 million cars on the road, SiC demonstrated its ability to support high current and high voltage with very low electrical losses, high thermal and electrical conductivity and reliability.

SiC added value for electrical vehicles, at a nominal installed power, are:

▪ Extended range or smaller battery size (5 to 10% range) by improved partial load efficiency, leading to significant system level savings (-400$ to -800$)

▪ Less cooling needs: -60% size of cooling system

▪ Higher power density: Size reduction by 40 to 50% at same power output

▪ Increased charging speed at 800V battery voltage: down to 15 min.

▪ Extended current carrying capability due to higher thermal limits 200°C (vs. 175°C for silicon).

Therefore, SiC material is firstly identified as a material of choice to replace silicon in the traction inverter to drive the electric motor, bringing increased performance, lower losses and decreasing battery size which impacts vehicle weight, cost and overall reliability. With its ability to work at very high power, SiC also enables increased charging speed, a major argument for the massive adoption of electrical vehicles, and could be used with on board as well as off board chargers.

With SiC device costs still being three times higher than the traditional Si insulated-gate bipolar transistor (IGBT) we need to consider the total cost of ownership (TCO) at system level. With benefits at system level, lower system weight and volume and user-oriented benefits, SiC technology is already addressing the high-end markets as of today. The funded Project TRANSFORM aims to reduce component and system cost of ownership further to address an even broader accessible market, by introducing newly engineered substrates, accelerating the introduction of 200 mm SiC wafer to reduce cost efforts further, and implement design innovations at device and system levels.

D. Abbreviations and Acronyms

GaN Gallium nitride

IGBT insulated-gate bipolar transistor

EV Electric Vehicle

HEV Hybrid Electric Vehicle

HV High Voltage

OBC On Board Battery Charger

PFC Power Factor Correction

SiC Silicon Carbide

TOC total cost of ownership

WBG Wide Band Gap

V. CONCLUSION

Next generation very high voltage power devices have been introduced and discussed in order to highlight the benefits of the mobility in the Green Deal scenario. In particular, silicon IGBT and Silicon Carbide MOSFETs have been considered for this purpose.

Two examples of mobility have been illustrated, railway and automotive, which are used respectively - for medium and short distances respectively.

It has been considered also main Smart System that take benefits form new technologies looking at 300kW Super chargers and On-Board Battery Charger.

Thanks to the intrinsic characteristics of the WBG materials, the next generation power devices will allow to increase the efficiency of the applications and consequently the working temperature. This will bring benefits by reducing CO_2 emissions: Train 25, Auto 68, Airplane 113 kg of CO_2 for passenger.

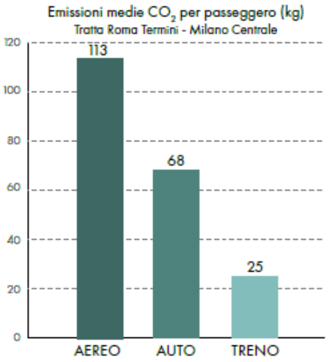

Fig. 9 - CO2 emission example from Sustainability report 2020 Ferrovie Italiane.

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