ELECTROMOBILITY TOPICS ENTERING A NEW DECADE

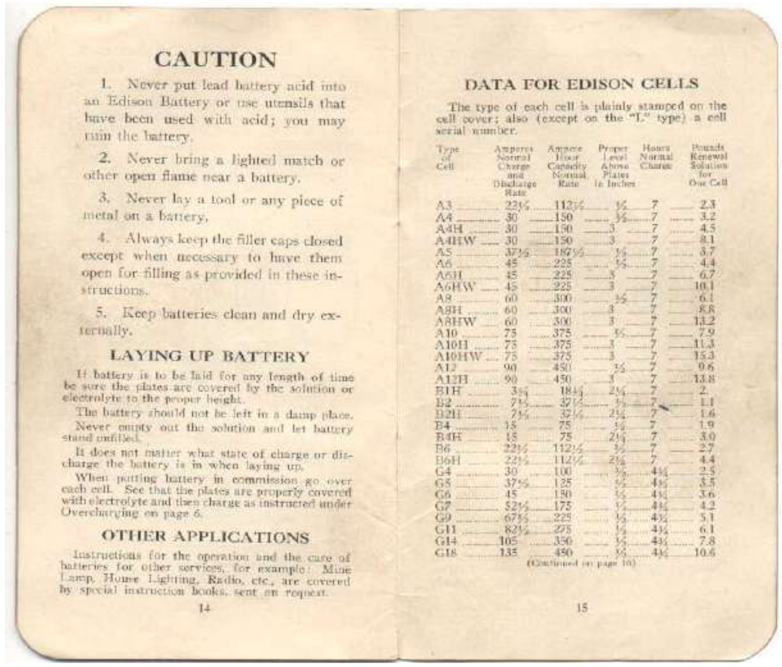
Liviu POPESCU[1]
Politehnica University of Bucharest
Doctoral School of the Faculty of Electrical Engineering
liviu_p@yahoo.com

Abstract:
During the last ten years the electric vehicles became more and more part of the daily mobility. Supported by different policies, but also by the technology advance, the electromobility is far to be an achieved topic and enters a new decade. The hybrid solutions continue to offer an alternative using the combustion engines. Latest researches and developments on fuel cells push to an alternative future, based on hydrogen. The electric batteries, as energy storage on vehicle, remain the most important way to conduct EV to the roads, with regular improvements. In fact, all these technologies are developing solutions to provide and control the energy for an electric motor. The classic solution using one engine and a kinematic chain to distribute the mechanical power to the wheels is completed by the possibility to integrate not only one, but more electric motors in the same vehicle.

1. INTRODUCTION

The beginning or 20th century, the electric vehicles were the preferred transportation mode in front of gasoline ones and started to be attractive. Between 1907 and 1939, the company Detroit Electric built 13000 units. Between the clients, Thomas Edison, Henry Ford's wife [1]. Nickel-iron batteries produced by Thomas Edison, were conceived without lead or cadmium (like lead–acid and nickel–cadmium batteries), but with water. The Figure 1 presents an extract from general information and instructions for the operation and care of Edison alkaline storage battery at this time [2]:

ISSN / ISSN-L: 1843-5912
https://www.doi.org/10.36801/apme.2020.1.13



CAUTION

1. Never put lead battery acid into an Edison Battery or use utensils that have been used with acid; you may ruin the battery.

2. Never bring a lighted match or other open flame near a battery.

3. Never lay a tool or any piece of metal on a battery.

4. Always keep the filler caps closed except when necessary to have them open for filling as provided in these instructions.

5. Keep batteries clean and dry externally.

LAYING UP BATTERY

If battery is to be laid for any length of time be sure the plates are covered by the solution or electrolyte to the proper height.

The battery should not be left in a damp place.

Never empty out the solution and let battery stand unfilled.

It does not matter what state of charge or discharge the battery is in when laying up.

When putting battery in commission go over each cell. See that the plates are properly covered with electrolyte and then charge as instructed under Overcharging on page 6.

OTHER APPLICATIONS

Instructions for the operation and the care of batteries for other services, for example: Mine Lamp, House Lighting, Radio, etc., are covered by special instruction books, sent on request.

14

DATA FOR EDISON CELLS

The type of each cell is plainly stamped on the cell cover; also (except on the "L" type) a cell serial number.

Type of Cell	Amperes Normal Charge and Discharge Rate	Ampere Hour Capacity Normal Rate	Proper Level Above Plates in Inches	Hours Normal Charge	Pounds Renewal Solution for One Cell
A3	22½	112½	½	7	2.3
A4	30	150	½	7	3.2
A4H	30	150	3	7	4.5
A4HW	30	150	3	7	8.1
A5	37½	187½	½	7	3.7
A6	45	225	½	7	4.4
A6H	45	225	3	7	6.7
A6HW	45	225	3	7	10.1
A8	60	300	½	7	6.1
A8H	60	300	3	7	8.8
A8HW	60	300	3	7	13.2
A10	75	375	½	7	7.9
A10H	75	375	3	7	11.3
A10HW	75	375	3	7	15.3
A12	90	450	½	7	9.6
A12H	90	450	3	7	13.8
B1H	3¾	18¾	2¼	7	2.
B2	7½	37½	½	7	1.1
B2H	7½	37½	2¼	7	1.6
B4	15	75	½	7	1.9
B4H	15	75	2¼	7	3.0
B6	22½	112½	½	7	2.7
B6H	22½	112½	2¼	7	4.4
G4	30	100	½	4½	2.5
G5	37½	125	½	4½	3.5
G6	45	150	½	4½	3.6
G7	52½	175	½	4½	4.2
G9	67½	225	½	4½	5.1
G11	82½	275	½	4½	6.1
G14	105	350	½	4½	7.8
G18	135	450	½	4½	10.6

(Continued on page 16)

15

Figure 1. Extract from Edison Alkaline storage battery document

The available milage offered between battery recharging was usually about 80 miles (130 km). But in one test a Detroit Electric obtained 211,3 miles (340,1 km) on a single charge. With a top speed adapted for city traffic and limits at this time, 20 mph (32 km/h), the car was considered good enough, adequate for driving and very appreciated by women [3]. To illustrate this period, the Figure 2 presents a General Electric promotional photograph of a woman charging an electric car. Image courtesy of miSci - Museum of Innovation & Science [4]:

Figure 2. Woman with rectifier and electric car

With a simple resistor for starting-off and low speed or putting the battery packs in parallel or in series, and also selecting various windings on the motor it was possible to attempt various speeds.

After 100 years of success and regular improvements for combustion engines, the restart of pure electric vehicles seems to be fragile. Would we assist to a trend reverse and an acceleration of derivatives from classic vehicles? What technologies are needed to be improved for continuing towards electromobility?

2. ELECTERIC VEHICLES EVOLUTION DURING THE LAST 10 YEARS

Different electric vehicles had been launched on the market. In 2010 about 17000 electric vehicles were on the roads. The last 10 years, with some exceptions, the typical range increased from 100 km (real driving conditions) and more than doubled.

The Figure 3 presents the xEV sales compared to total car sales in 2019 and the xEV stock. The term used for xEV represents all kind of EV (electric vehicles) which can be plugged (including battery electric vehicles, plug-in hybrid electric vehicles and passenger light-duty vehicles). Despite the percentage increase from year to year in electric vehicles sales, the global stock is attempting 7,2 million (less than 10% of global car sales in 2019 and 2,1 million xEV sold only in 2019). With the increase in transport needs, the energy for the transport sector has been provided by oil in a proportion of 92%. The same sector is responsible for 25% of carbon dioxide emissions being an important contributor to air pollution [6].

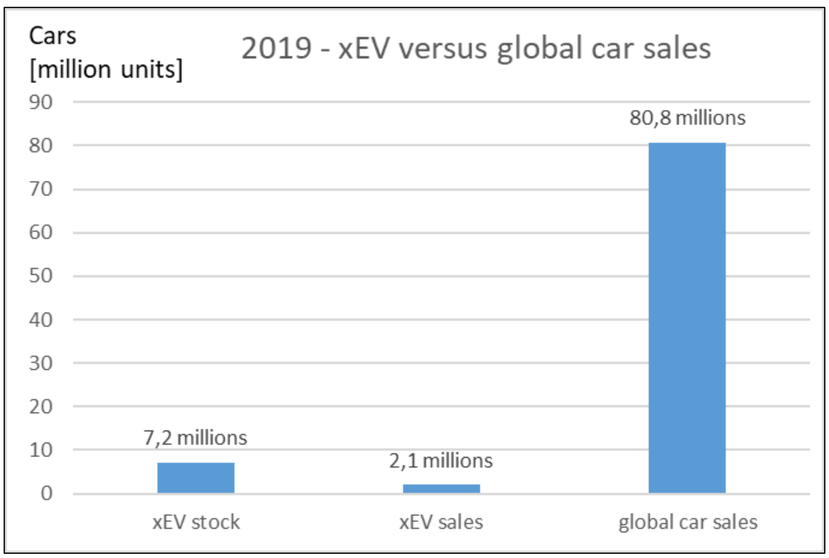


Figure 3. xEV stock and car sales in 2019

It was the period of rapid deployment for alternative fuels and powertrains and the the electrification subject became mainstream and it appears under different modes [6]:

- more durable and swappable components and batteries helped the **micromobility** industry to develop more durable electric scooters compared to previous generations;
- the **two/three wheelers** especially used in some parts of the world as an electrification subject are now available in over 600 cities across more than 50 countries;
- **low speed electric vehicles** are more present in China (low speed and small driving range) – because of safety concerns it is unclear how the specific industry will be impacted by the regulations;
- the **electric light-commercial vehicles** on the road attempted 377000 in 2019 (compared to the 7,2 million passenger electric cars);
- the battery **electric busses** are the exclusive technology for electric busses (95% of the market) – about 513000 electric buses were available in 2019 worldwide;

- concerning the **electric trucks**, the situation is similar to the busses: most of them are battery electric trucks – the sales are pulled by China with more than 12000 new electric trucks entering the roads the last decade, especially used in urban environments.
  In parallel the fuel cell technology obtained an increasing interest. But the fuel cells, on the other hand, only achieve an efficiency of 30 percent of the energy used.
  Electric vehicles confirmed again their benefits:
  - zero emissions in utilization, especially appreciated in crowded area (like city centers) but also in residential area,
  - noise reduction,
  - better efficiency than internal combustion engines (3 to 5 folds)
  - GHG emissions concerns by zero emissions in usage in association with more and more low-carbon energy generation
  - premises for relevant industrial development for clean energy transition

From micromobility to heavy duty, the electrification continued.

Table 1. Increasing sizes of main characteristics related to electrification

Electric Mobility	Total Weight	Speed	Range	Electric powertrain and control	Battery
Micromobility*	<1/4 t	25 km/h	30 km	250 W	280Wh
Two / Three wheelers					
Low speed electric vehicles		40-70 km/h			
Light-commercial electric vehicles					
Passenger cars**		200-250 km/h	500 km	100-500 kW	100 kWh
Busses***			500 km		660 hWh
Trucks					

* usual values examples for electric micromobility
**Tesla Model S
***Proterra ZX5 Electric Bus

Based on the Table 1, if we take as a reference the energy usage in a usual gasoline car (1 kWh for something more than 1 km) a passenger electric car could travel approximatively 5 folds more, and e-scooter up-to 100 folds more:

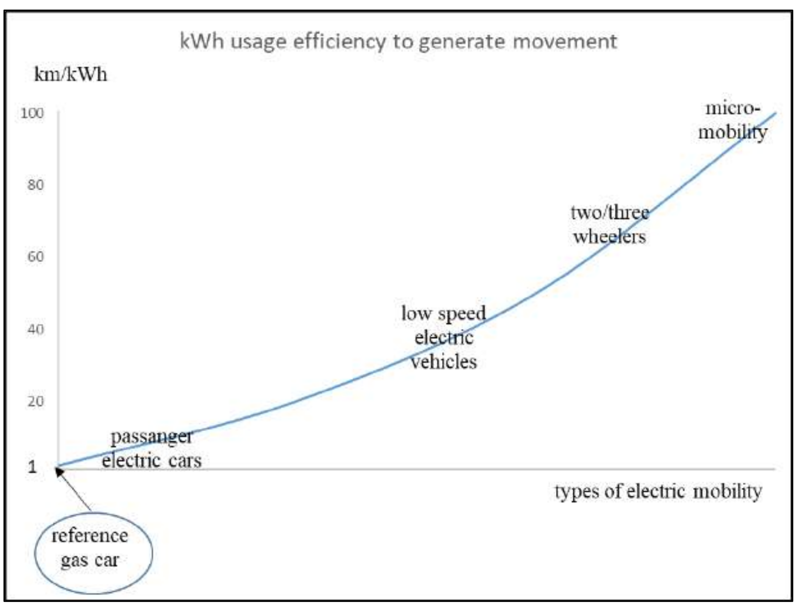


Figure 4. Energy usage efficiency for providing movement

Today the electrification is part of the present and the future. In comparison with the classic mobility, based on next three criteria of usage in cities, on highway and mixed trips, the electric mobility continues to have a handicap: **the autonomy**.

Table 2. A parallel between benefits and usage advantages in different situations for electric vehicles

Usage adv. / Benefits	**Cities**	**Highways and long distances**	**Mixed trips**
Emissions and air pollution	High / High	Low / High	High / High
Energy efficiency	High / High	High / High	High / High
Noise reduction	High / High	High / High	High / High

3. NEXT DECADE EXPECTATIONS

The actual studies show that the transport sector, especially du to electrification, will continue to have an important role in improving air quality and attempting local objectives and commitments. Even with the ongoing dominance of oil products in transport, these drivers drove rapid change.

A key technological strategy to reduce air pollution in densely populated areas is the electrification. A promising option to contribute to countries' energy diversification and greenhouse gas (GHG) emissions reduction objectives. The electric micromobility vehicles can have an important role especially in the last mile delivery in cities (as for example e-cargo vehicles). Also, the electric vehicles are expanding significantly to two/three wheelers, buses, and trucks. The heavy-duty trucks, the operations in airports and seaports offer opportunities for electrification, implying cost and emission savings.

There is another aspect related to COVID-19 and the administrations influence for electric vehicle transitions. A low oil price during this period will in fact increase the payback time for electric cars. The transition to electric vehicles will be influenced by government responses to the pandemic. The users also could change, in a post-pandemic period, their preferences for either shared or private micromobility.

Despite all barriers, the adoption of electric drivetrains accelerates. One of scenarios specifies that by 2030, the global electric vehicle stock will be 20 folds higher than the actual one. It will be sustained by the development of electric batteries, the cost reduction and deployment of batteries to all road vehicles categories. This is an essential technology for electrification. The driving range of 400 km is already possible with 80 kWh energy stored in a battery. With the battery capacity increase, the demand for materials will be higher, the technology will improve and the costs will drop. For example, in 2019 a battery pack had an average price of 156 USD/kWh (much less compared to the price in 2010 – 1100 USD / kWh). The average battery pack is actually 44 kWh / electric vehicle, up from 37 kWh in 2018, and a usual battery for an electric car has 50 to 70 kWh. It means that better batteries are available for longer ranges. Also, the demand for battery electric vehicle is rising compared to those used for plug in hybrid cars. The most common technology for batteries is Li-ion. But the trend will push the boundaries of Li-ion as new performances are searched. Some other technologies, today in development or test, might be able by 2030 (for example:

the lithium-metal solid-state battery, lithium-sulphur, sodium-ion or even lithium-air, which could represent an improvement from Li-ion on indicators such as cost, density, cycle life, and benefits from more widely available materials than Li-ion technologies). Between the development and the industrialization, a lap of time will be needed for such new technologies in order to confirm a large-scale manufacturing and usage possibilities [6].

4. RESEARCH AND DEVELOPMENT ISSUES

Globally, it is proved that the electrification of a vehicle impacts positively the vehicle capabilities:
- acceleration/deceleration – improved by the capabilities of electric motors
- braking – better braking, battery charging during the process, less usage of mechanical braking system
- cornering – efficient power distribution for each wheel during cornering

4.1 Onboard energy

As specified in the section 2, in the parallel between benefits and usage advantages in different situations for electric vehicles, one of the main technical issue for the next period would be to continue improving the autonomy (including **energy storage** capacity but also **energy harvesting** when using the electric vehicle).

4.2 Electrical power systems dimensioning and control

Between the engine and the wheels, the transmission generates frictions and inertia. The over-all performance of the system is improved by the reduction of the transmission. Instead of using a mechanical one, the use of electricity allows to have the mechanical power source (electric motor) in proximity of the wheel (also inside the wheel).

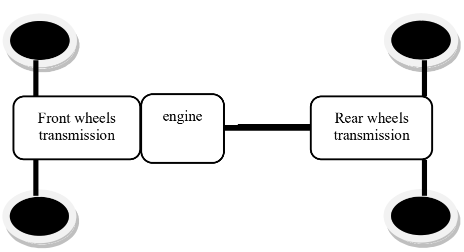


Figure 5. Classic power transmission

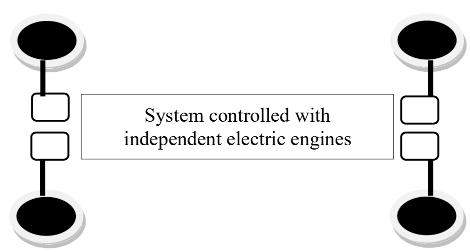


Figure 6. Dedicated electric motors for each wheel

Replacing the mechanical differential by a 100% electric control of the motors, suppresses some mechanical losses but ask for adapted transducers, sensors, and power electronics.

4.2 Electric motor development

Some general advantages of electric motors compared to internal combustion engine sustain the usage of such technology [11]:
- high efficiency,
- high instant power,
- fast torque response,
- fast power density,
- low cost,

- high acceleration,
- robustness.

We saw in the Figure 4 the efficiency of one kWh of energy used for different kind of vehicle. Even though electric motors are stronger from this point of view compared to internal combustion engines, the EV's motor and electronics efficiency directly influences the battery weight. Any loss of power needs to be compensated. Every 1% lower efficiency requires 1% more power from the battery (meaning more batteries). So, the EV's performance directly depends on the electrical motor specifications, being determined by the torque-speed and power-speed characteristic of the traction motor [5].

Different kind of electric motors could compete to provide the electric mobility [11]:

- **DC Motor**:

Robust and accepting a simple control, the DC motors have appropriate torque-speed characteristics providing high torque at low speed for EVs. On the other hand, the size is important and it has lower efficiency, lower reliability and higher maintenance. The speed is limited. In usage, there is a continuous friction between brushes and collectors.

- **Permanent magnets motors**:

For the permanent Magnets Brushless DC Motor (PM BLDC) the magnets are passed in the rotor, replacing the windings. It means their efficiency is higher and there is no rotor loses. But the presence of permanent magnets generates a short constant power operation zone, the permanent magnet field being weakened by the stator one.

Using conduction angle control, a wider constant power region can be extended by where the speed range may reach three to four times the base speed. Also, the high temperatures reduce the remnant flux density and the motor torque. The centrifugal forces at higher rotation speeds can cause safety issues. The price of the magnets could be a disadvantage of this motor.

The Permanent Magnet Synchronous Motor (PMSM) is an AC synchronous motor whose field excitation is provided by permanent magnets, and has a sinusoidal back EMF waveform. They have a simple construction, high efficiency and high-power density, thus they are suitable to be used as traction motors (common in hybrid vehicles, EVs, and buses). PMSM motors have a higher efficiency compared to IMs. But the cost of the magnets increases the total cost of the motor. At high speed, they have similar disadvantages as PM BLDC.

- **Induction Motor** (IM)

Some characteristics of this motor in EV usage: simple construction, high reliability, robustness, simple maintenance, and low cost and operation at different environmental conditions. The field-oriented vector control of IMs is industrially standardized. An important safety advantages for EVs is that the IM can be naturally de-excited if the inverter faults.
Some disadvantages: slightly lower efficiency (compared to PM motors), higher power losses (increased because of the cage losses), and a relatively low power factor. The weakening of the flux can be used to extend the speed range in the constant power operation region. This region can be extended by using dual inverters as well. Rotor losses can be also reduced by careful motor design.

- **Switched Reluctance Motor** (SRM)

For this motor, there is no windings or permanent magnets on the rotor. Their advantages in EVs include their robustness, simple control, high efficiency, wide constant power operation region, fault tolerance, and effective torque-speed characteristics. Since they do not contain brushes, collectors, or magnets, the maintenance of SRMs is very simple and effective and their price is very competitive. The absence of magnets eliminates the problem with mechanical forces, enabling the motor to operate at a high speed. Since the motor's windings are not used, there are no copper losses in the rotor ensuring the rotor temperature is lower than other motor types. Since the phases are not connected, SRM motors can continue their operation even when one of the phases disconnects. SRM rotors have a lower inertia than other motor types. The drawbacks of this motor type are increased vibration and acoustic noise. In addition, the salient-pole rotor and stator construction cause high torque ripple. The high rotor inductance ratio allows sensor-less control to perform. Proper motor design enables the wide constant power operation region, which in turn allows operation at high speeds. SRMs have a suitable torque/power speed characteristic for EV applications.

Table 3. Electric motor types of features for EV

Characteristics	**Motor type**			
	DC	**Induction Motor**	**Permanent Magnets**	**Switched Reluctance Motor**
Power density	Low	Medium	Very high	Medium
Efficiency	Low	Medium	Very high	Medium
Controllability	Very high	Very high	High	Medium
Reliability	Medium	Very high	High	Very high
Technological maturity	Very high	Very high	High	High
Cost	Low	Very low	High	Low

Some example of motor types used for EVs [11]:

- Induction Motors (IM) : Tesla
- Switched Reluctance Motors: Tesla, the SRM uses internal permanent magnets in the stator (internal permanent magnet switched reluctance motor – IPM-SRM).
- Permanent magnet synchronous motor: GM Chevrolet Bolt, with permanent magnets inside the rotor.
- Multi-motor solutions:
    - IM in the front and an IPM-SRM in the back - Tesla—the Model 3
    - IPM-SRM in the front and an IM in the back for Tesla Model S and Model X.

5. CONCLUSIONS

The promotion of electric vehicles remains an important issue to reduce pollution and GHG emissions.

Compared to classical vehicles, the autonomy will continue be in the center of the next improvements, by acting directly on the battery optimization, but also on the whole electric systems design. New technologies will try to reach industrialization phase (direct improvements on actual Li-ion technology and also new ones).

Different solutions could be adapted for different kind of mobility (from micromobility, passing by passenger cars mobility to busses and trucks).

Every manufacturer utilizes their approaches and technologies to make their propulsion as efficient as possible and produces many varieties of the same motor type. New solutions, but also different optimizations and solutions combination could be used in order to improve the characteristics of electric vehicles.

BIBLIOGRAFY

[1] J. Voelcker, "All-Electric Sports Car Coming Next Month From Detroit Startup?", Green Car Reports. Retrieved 2013-03-19.

[2] Web archive backup: "Edison Battery Booklet" original instruction book for the Edison battery.

[3] G.N. Georgano Cars: "Early and Vintage", 1886-1930. London: Grange-Universal, 1985.

[4] General Electric Photographs, miSci - Museum of Innovation and Science. "Woman with rectifier and car 1912." *New York Heritage Digital Collections*. 1912.

[5] R. Crowder, "Electric Drives and Electromechanical Systems", Butterworth-Heinemann, Second Edition, 2019.

[6] IEA (2020), "Global EV Outlook 2020", IEA, Paris, 2020.

[7] Simon Chinguwa, Wilson R. Nyemba, Charles Mbohwa, "Development of an electric drive train for cycles as a sustainable means of transportation for a green environment", Procedia Manufacturing, 2019.

[8] Ching-Lung Chu, Che-Wei Chou, Jiun-Hau Fang, "Study of an Electric Vehicle Drive Dynamic Testing System with Energy Recovery", Procedia Engineering, 2011.

[9] Milos N. Mladenovic, "Vehicle Types and Dynamics", A"Aalto University, School of Engineering, 2017.

[10] Runlin He, Ziyou Song, Jianqiu Li, Minggao Ouyang, "Optimal Torque Distribution Strategy Considering Energy Loss and Tire Adhesion for 4WD Electric Vehicles", 2017 IEEE Transportation Electrification Conference and Expo, Asia-Pacific.

[11] E. Osmanbasic, "The Many Types of EV Motors", Engineering.com, 2020.

[12] Dorrell, D.G., Popescu, M., Knight, A.M., Evans, L., Staton, D., A., "Comparison of Different Motor Design Drives for Hybrid Electric Vehicles", 2010 IEEE Energy Conversion Congress and Exposition.

[13] K.T. Chau, Wei Cui, J.Z. Jiang, Zheng Wang, "Design of permanent magnet brushless motors with asymmetric air gap, for electric vehicles", Journal of Applied Physics, April 2006.