INITIATE GREEN HOME CHARGING FOR ELECTRIC VEHICLES

Adrian PÎSLĂ, Lorand KACSO-VIDREAN, Daniela Corina JUCAN

Technical University of Cluj-Napoca, Cluj-Napoca, Romania
(adrian.pisla@muri.utcluj.ro)

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Abstract: *The research presented in the paper revolves around the electromobility concept, connected with photovoltaic energy and the electricity conversion efficiency. The solar energy feeds the photovoltaic panel, generating electricity that is further transmitted through cables to a battery bank to be stored. From this point the electric current will be redirected to an electric car charging station where finally will reach the electromobile.*

In practice there are not only different types of photovoltaic panels and different structural combinations but also multiple variants of electric charging stations as well as different types of sockets.

A less considered problem, presented in the last chapter of the paper, is the loss of energy due to the wiring components. In the mentioned chapter is highlighted the effects of using improper cable for a certain type of electric car charging station leading to high energy losses or to the uses of oversized cables. The effects determinations is made based on a new developed automated calculation model, on a Microsoft Excel software platform, to detect the power losses and/or achieve a correct sizing of the electric installation to increase the investment efficiency is in line with the expected energy harvesting.

Keywords: *electromobility, solar panel, AC, DC, voltage drop and energy losses*

1. ELECTROMOBILITY

An electric vehicle (EV) is a vehicle powered by an electric motor, instead of an internal combustion engine (ICE) or a hybrid one that runs exclusively with the energy stored in its batteries. EV's have been in continual use, starting with Porsche electric vehicle since 1900s. New advances in battery technology, system integration, aerodynamics, safety and energy management constantly increase the role of electric vehicles.

The EV still presents five major problems: the batteries have to be charged frequently (relatively poor storage capacity) equal if is the long lasting (up to 8 hours, at any main inlet AC 120V or 240V) or swift method (30 minutes); the high costs of the swift chargers (regardless the manufacturer); the missing of the swift charger network; batteries are sensitive to cold temperatures (the range could be reduced by as much as 50% or more); Maintenance, due to high number of components, connectors, batteries mass and the reliability of the electric circuits and the missing of a service network for EV, all are increasing the maintenance costs. Electric vehicles are considered as zero emission vehicles (ZEVs), but how is produced the electricity that is stored in the batteries, how pollute the batteries manufacturing and the batteries recycling.

Generally the EV range and the possible rechargeable cycles are considered knowing that the ordinary range is about 100 km, considering two impact cars the city car BMWi3 (~180km) and SUV EV Kona (~450km).

2. CHARGING THE PROPULSION

Within the doctoral studies attention is given to all 5 aspects with focus on charging management and optimization. The standard SAE J1772 defines six charging levels. Around the world, but only three are currently accepted and frequently used, Table 1 [1].

The Level 1 addresses to the slow charging that operates at 120 VAC, while Level 2 addresses to the slow charger that operates at 208VAC/ 240VAC and to the fast chargers that operates at 200VDC/ 450VDC. The only standards that currently set out specifications for swift charging are the SAE J1772 and CHAdeMO. In parallel, Tesla has developed its own DC fast-charge system, “Supercharger”, which can be used only by Tesla [2].

Table 1 – Summary comparison of charging connectivity

	Level 1	Level 2	Fast charge
Voltage	120 V	208V or 240V	200 to 500 V
Current type	AC	AC	DC
Power	1.4 kW	7.2 kW	50 kW
Maximum output	1.9 kW	19.2 kW	150 kW
Charging time	12 h	3 h	20 min
Connector type	J1772	J1772	J1772 Combo CHAdeMO (Supercharger)

EVs are equipped with an on-board Level 1 charger that can be plugged into an ordinary power outlet (CSA 5-15R). For the Level 2 charging stations, the charging time can be limited by the on-board charger specifications and the battery charging state. Tesla offers already on-board 10kW and 20kW chargers.

DC fast charging is governed by the North American SAE J1772 Combo standard (mounted on EV models such as: Opel Ampera, Nissan Leaf and ENV200, Mitsubishi Outlander and iMiev, Peugeot iON, Citröen C-Zero, Renault Kangoo ZE (type 1), Ford Focus, Toyota Prius Plug in and KIA SOUL EV [8]). The Japanese JEVS G105-1993 standard. DC fast-charge stations generally support both standards. All carmakers adopted one of these standards, except Tesla that offers optional a CHAdeMO adapter(developed by a Japanese association: Tokyo Electric Power Company (TEPCO), Nissan, Mitsubishi, Fuji Heavy Industries (Subaru) and Toyota.

Since external device manages the correct charging, it takes into account the battery parameters, transfer functions and communication protocols. The maximum charging power, CHAdeMO standard, is 62 kW (125A at 500VDC), while the J1772 Combo standard sets the maximum power at 100 kW (200A at 500VDC). In practice, very few batteries support 500V, and charging stations are commonly equipped with both standard connectors and limit the rated power to 50kW in contrast with Tesla Supercharger stations rated at 120kW[5]. For comparison it is useful to establish charging times considering 100km range at 80% of the battery capacity, using a feasible output of 40kW.

EVSE (Electric Vehicle Supply Equipment) is an expanding network of public (or private) charging stations but most EV owners want the convenience of a “home” charging option at 3.3 kW or 6.6 kW, but the home wiring and vehicle-charging equipment must be compatible.

3. PHOTOVOLTAIC TEHNOLOGY

Photovoltaics are best known as a method for generating electric power by using solar cells to convert energy from the sun into a flow of electrons by the photovoltaic effect.

Electricity is produced in solar cells which, the most common material for the production of solar cells is silicon. Solar cell manufacturing technologies are:

- Monocrystalline; Polycrystalline; Ribbon- crystalline silicon; thin- film technology

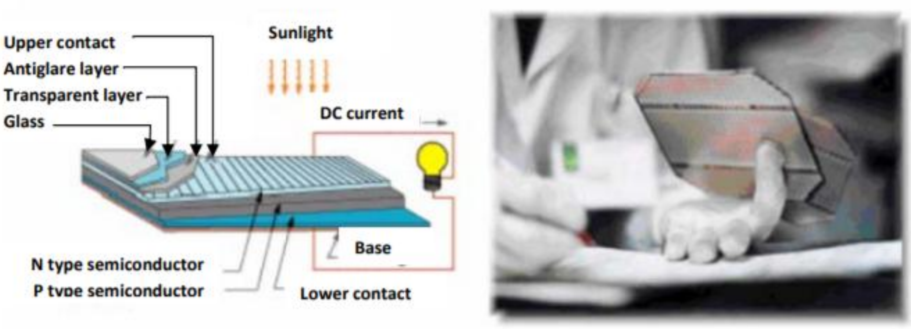


FIG. 1. Typical monocristalline cells

Monocrystalline Si cells, shows conversion efficiency from 13% to 17%, and can generally be said to be in wide commercial use, with an expected lifespan of 25- 30 years.

Multicrystalline Si cells convert solar radiation of 1.000 W/m^2 to 130W of electricity with the cell surface of 1m2, shows conversion efficiency from 10% to 14%, at the same lifespan.

Ribbon silicon has production advantages with an efficiency around 11%[9].

In the thin- film technology the modules are manufactured by piling extremely thin layers of photosensitive materials on a cheap substrate such as glass, stainless steel or plastic. Today's price advantage in the production of a thin- film is balanced with the crystalline silicon due to lower efficiency of the thin- film, which ranges from 5% to 13%. The share of thin- film technology on the market is 15% and constantly increasing, and the lifespan is around 15- 20 years. There are four types of thin- film modules (depending on the active material) that are now in commercial use: Amorphous Si Cells; Cadmium tellurium (CdTe) cells; Cooper Indium Gallium Selenide (Cis, Cigs); Thermosensitives Solar Cells and Other Organ Cells (DSC).

3.1 PHOTOVOLTAIC SYSTEM TYPES

Photovoltaic systems (PV) can be generally divided into two basic groups:

- Photovoltaic systems not connected to the network, stand- alone systems (off- grid)
- Photovoltaic systems connected to public electricity network (on- grid), Fig. 2.

The main components of PV systems are photovoltaic modules, photovoltaic inverter, mounting subframes and measuring cabinet with protective equipment and installation.

Photovoltaic modules convert solar energy into DC current, while photovoltaic inverter adjusts the produced energy in a form which can be submitted to the public grid. The AC voltage is supplied to the electricity network through the protection and measuring equipment.

Photovoltaic inverter is usually located indoors, although there are inverters for outdoor installation.

Inverters produce high- quality AC current of corresponding voltage and are suitable for a network- connected photovoltaic system to deliver the electricity to the electrical network.

Electrical connection is usually located in the electrical control box, which is located in a separate room, but can also be placed in the measurement and terminal box.

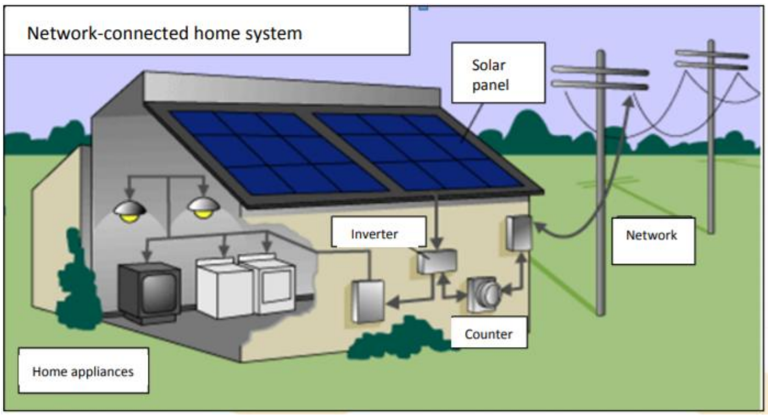


FIG. 2. Network-connected photovoltaic system

3.2 SOLAR POWER PLANTS (FARMS)

These systems are generating large amounts of electricity by a photovoltaic installation on a localized area being connected to an electric network,. The power of such photovoltaic power ranges from several hundred kilowatts to hundred megawatts. Some of these installations can be located on large industrial facilities and terminals, but more often on large barren land surfaces, exploiting existing facilities to produce electricity at the location.

FIG 3. Solar farm

4. AC AND DC ELECTRICAL WIRE VOLTAGE DROP AND ENERGY LOSSES

The developed studies identified two issues that affect the electric vehicles charging:

- Loss of energy recorded in the cable due to overheating
- Loss of energy due to DC-AC and AC-DC transformation

Voltage drop describes how the energy supplied by a voltage source is reduced as electric current moves through the passive. The voltage drop across the internal resistance of the source, conductors, contacts and connectors is undesirable because some of the energy supplied is lost (dissipated). The voltage drop across the electrical load and across other active circuit elements is essential for supply of energy and so is not undesirable. National and local electrical codes may set guidelines for the maximum voltage drop allowed in electrical wiring to ensure efficiency of distribution and proper operation of electrical equipment.

In electronic design and power transmission, various techniques are employed to compensate the effect of voltage drop on long circuits or where voltage levels must be accurately maintained. The simplest way to reduce voltage drop is to increase the diameter of the conductors. In power distribution systems, a given amount of power can be transmitted with less voltage drop if a higher voltage is used. More sophisticated techniques use active elements to compensate for excessive voltage drop.

4.1 Computing voltage drop and energy losses in a wire

Losses in solar PV wires must be limited, DC losses in strings of solar panels, and AC losses at the output of inverters. A way to limit these losses is to minimize the voltage drop in cables. A drop voltage less than 1% is suitable and in any case it must not exceed 3%.

Voltage drop is given by following formula:

$$\Delta V = b\left(\rho_1 \frac{L}{S} cos\varphi + \lambda L sin\varphi\right) \cdot I_B \qquad (1)$$

This is phase-phase voltage for 3-phase system, phase-neutral voltage for single-phase system. (Example: for European countries a 3-phase circuit will usually have a voltage of 400 V, and single-phase 230V. In North America, a typical three-phase system voltage is 208 volts and single phase voltage is 120 volts).

Note: DC voltage drop, the system voltage U = Umpp of 1 panel x number of panels.

ΔU = voltage drop in Volt (V)

b = lenght cable factor, b=2 for single phase wiring, b=1 for three-phased wiring

L = simple lenght of the cable (distance between the source and the appliance), in meters

S = cross section of the cable in mm^2

$\cos\varphi$ = power factor

$\cos\varphi = 1$ for pure resistive load, $\cos\varphi < 1$ for inductive charge, (usually 0.8)

λ = reactance per lenght unit (default value 0.00008 ohm/m)

$\sin\varphi = \sin(\mathrm{acos}(\cos\varphi))$

I_b = current in Ampere (A)

Note: For DC circuit, $\cos\varphi=1$, so $\sin\varphi=0$

ρ_1 = resistivity in ohm.mm^2/m of the material conductor for a given temperature. At 20 celcius degree (°C) the resistivity value is 0.017 for copper and 0.0265 for aluminium

Note: resistivity increases with temperature. Resistivity of copper reaches around 0.023 ohm.mm^2/m at 100 °C and resistivity of copper reaches around 0.037 ohm.mm^2/m at 100°C. Usually for voltage drop calculation according to electrical standards it is the resistivity at 100°C that is used (for example NF C15-100).

$$\rho_1 = \rho_0 \cdot (1 + \alpha(T_1 - T_0)) \tag{2}$$

Where:
ρ_0 = resistivity at 20°C
T_0 and α = Temperature coefficient per degree C
T_1 = temperature of the cable (default value = 100°C)
Note: the experiments shows that a wire with a correct sizing should not have an external temperature over 50°C, but it can correspond to an internal temperature of around 100°C
Voltage drop in percent:

$$\Delta U(\%) = 100 \cdot \Delta U / U_0 \tag{3}$$

Where:
ΔU = voltage drop in V
U_0 = voltage between phase and neutral (example : 230 V in 3-phase 400 V system)
Energy losses in a cable is mainly due to resistive heating of the cable. It is given by the following formula:

$$E = a \cdot R \cdot I_b^2 \tag{4}$$

Where:
E = energy losses in wires, Watt (W)
a = number of line coefficient, a=1 for single line, a=3 for 3-phase circuit
R = resistance of one active line
I_b = current in Ampere (A)
R is given by formula:

$$R = b \cdot \rho_1 \cdot \frac{L}{S} \tag{5}$$

Where:
b = length cable factor, b=2 for single phase wiring, b=1 for three-phased wiring
ρ_1 = resistivity of the material conductor, 0.017 for copper and 0.0265 for aluminium (temperature of the wire of 20°C) in ohm.mm^2/m
L = simple length of the cable (distance between the source and the appliance), in meters
S = cross section of the cable in mm^2
Note: for direct current the energy losses in percent is equal to the voltage drop in percent.

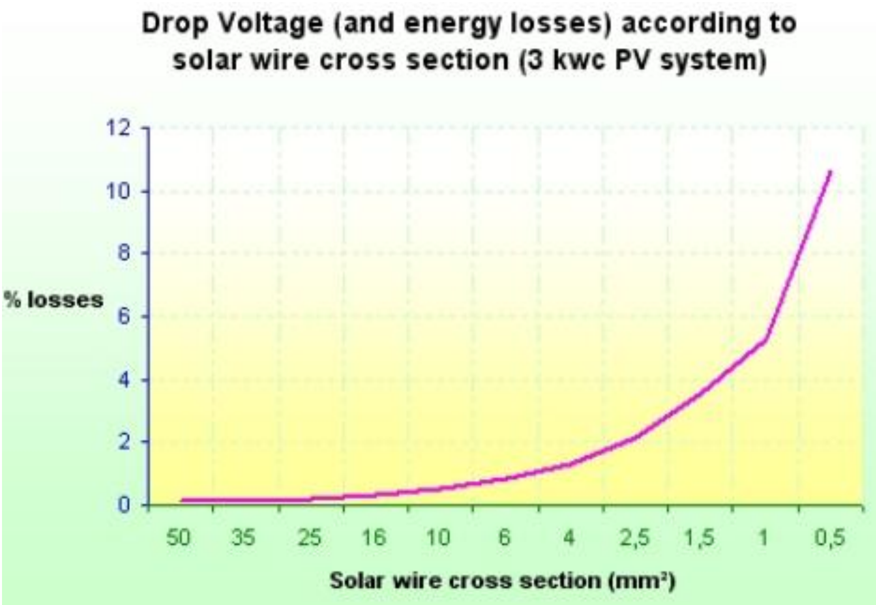


FIG. 4. Voltage drop losses according to wire cross section for a PV system of 3 kWp with 50 m of solar DC string cable.

4.2. AC voltage drop and energy losses calculator

In order to determine AC drop voltage and AC energy losses, a calculation system has been implemented using the Microsoft Excel software. As can be seen in the following figures, only the red color parameters must be pasted/selected. The calculation steps are:

AC POWER		
Type	Single-phase	1
Voltage (U) of the system	Level 1	120
Power factor (PF)	Cosφ	0.9
AC Current	Amper	12
AC Power	Watt	1296

FIG. 5. Determining AC Power

1. Choosing the single-phase or three-phase current type, Fig.5, for one-phase corresponds to a value of 1, for the three-phase corresponds to a value of 1,732, Fig.6.

AC POWER		
Type	Three-phase	1.732
Voltage (U) of the system	Single-phase Three-phase	120
Power factor (PF)	Cosφ	0.9

FIG. 6. Choosing the type of current (single-phase or three-phase)

2. The second step consists in choosing the type of desired charging station (EV Charger Level 1 or EV Charger Level 2). In Fig. 7 automatically switching between EV Charger Level 1 type on EV Charger Level 2 type is represented, switch the amperage (correspondent for Level 1 being 12A or Level 2 being 30A)

AC POWER		
Type	Single-phase	1
Voltage (U) of the system	Level 2	120
Power factor (PF)	Level 1	0.9
AC Current	Level 2 Amper	30

FIG. 7. Selecting type of EV Charger

3. The calculation program will directly display the AC Power output in watt, as can be seen in Fig. 5.

4. The next step is to determine AC drop voltage (both in volts and in %), by selecting the cable material (Cu, value = 0.017 or Al, value = 0.0265), Fig. 8.

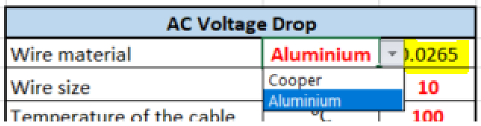


FIG. 8. Cable material selection

5. After selecting the cable material the cable diameter is selected Fig. 9.

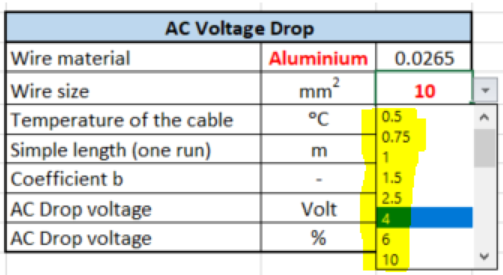


FIG. 9. Cable size selection

6. The made selections, are folod by the input of the cable temperature and the cable total length, resulting the automatic drop voltage calculation (V and %), Fig. 10.

AC Voltage Drop		
Wire material	Cooper	0.017
Wire size	mm^2	10
Temperature of the cable	°C	100
Simple length (one run)	m	50
Coefficient b	-	2
AC Drop voltage	Volt	2.47
AC Drop voltage	%	2.47

FIG. 10. Parameters selection and AC drop voltage presented

7. Performing all the previouse steps, automatically is generated a third table with AC Energy losses (W and %), Fig. 11**.**

AC Energy losses		
Coeffiecient a	-	1
AC Energy losses	W	32.3136
AC Energy losses	%	2.49

FIG 11. AC energy losses in watt and percent

By using this calculation method, the cable diameter that leads to minimizing the power losses can be determined.

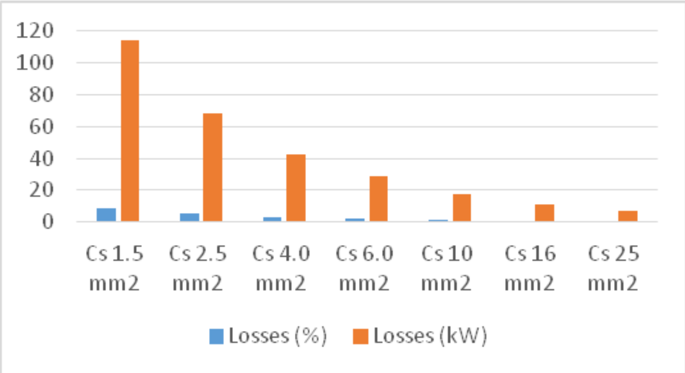
Calculation example: single-phase, with EV level 1 charging station, the cable material copper, maximum temperature 120°C, cable length of 25 m.

In Graph 1 is demonstrated the connection between cable diameter and the loss of electricity.

Tabular calculations rendered the following values:

- Cable diameter of 1.5 mm^2, AC power energy loss of 8.81% (114.24 watts)
- Cable diameter of 2.5 mm^2, AC power energy loss of 5.29% (68,544 watts)

- Cable diameter of 4.0 mm^2, AC power energy loss of 3.31% (42.84 watts)
- Cable diameter of 6.0 mm^2, AC power energy loss of 2.20% (28.56 watts)
- Cable diameter of 10 mm^2, AC power energy loss of 1.32% (17,136 watts)
- Cable diameter of 16 mm^2, AC power energy loss of 0.83% (10.71 watts)
- Cable diameter of 25 mm^2, AC power energy loss of 0.53% (6.8544 watts)



Graph 1. Energy losses according to solar wire cross section (for a 1.3 kW solar installation)

4.3 DC voltage drop and energy losses calculator

To determine DC drop voltage and DC energy losses, a calculation system has been implemented using the Microsoft Excel software. As can be seen in the following figures, only the red color parameters must be pasted / selected. The calculation steps are:

DC POWER		
DC Voltage (U)	SuperCharger (V)	500
DC Current (I_b)	Amper	125
DC Power (P)	Watt	62500

FIG. 12. Determining DC Power

1. The first step is choosing the SuperCharge EV station ampere (as can be seen in Fig. 12). This station type works at a voltage of 500V.

DC POWER		
DC Voltage (U)	SuperCharger (V)	500
DC Current (I_b)	Amper	125
DC Power (P)	Watt	125 200

FIG. 13. Amper selection for the Supercharger EV Station

2. By selecting the type of amperage, an automatic calculation of DC Power expressed in watts will be made, as can be seen in Fig. 13.
3. The next step is to determine DC drop voltage (both in volts and in %), by selecting the cable material (Cu, value = 0.017 or Al, value = 0.0265), Fig. 14.

DC Voltage Drop		
Wire material	Cooper	0.017
Wire size	Cooper Aluminium	0.5
Temperature of the cable	°C	100

FIG. 14. Cable material selection

4. After selecting the cable material, choose the diameter of the cable through which the desired current passes as shown in Fig. 15.

DC Voltage Drop		
Wire material	Cooper	0.017
Wire size	mm^2	0.5
Temperature of the cable	°C	
Simple lenght (one run)	m	
DC Drop voltage	V	
DC Drop voltage	%	

0.5
0.75
1
1.5
2.5
4
6
10

FIG. 15. Cable diameter selection

5. The made selections, are folod by the input of the cable temperature and the cable total length, resulting the automatic drop voltage calculation (V and %), Fig. 16.

DC Voltage Drop		
Wire material	Cooper	0.017
Wire size	mm^2	0.5
Temperature of the cable	°C	100
Simple lenght (one run)	m	50
DC Drop voltage	V	561
DC Drop voltage	%	112.2

FIG 16. Parameters selection and DC drop voltage presented

1. Performing all the previouse steps, automatically is generated a third table with DC Energy losses (W and %), Fig. 17**.**

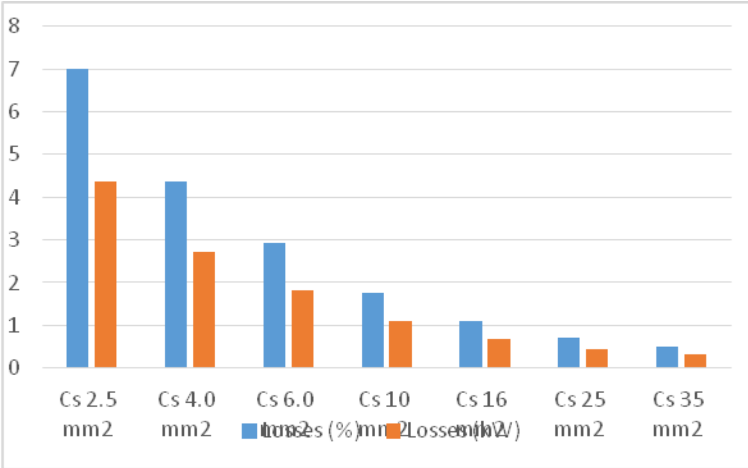
DC Energy losses		
DC Energy losses	W	70125
DC Energy losses	%	112.2

FIG 17. DC Energy losses

By using this calculation method, the cable diameter that leads to minimizing the power losses can be determined.

In the following, a sizing for a 62500W system in which the amperage is 125A, the material of the cable is made up of aluminum with a maximum temperature of 100°C and a length of 10 m. It will be shown in Graph 2 the importance of choosing the thickness the cable and how it affects the loss of electricity. Tabular calculations rendered the following values:

- Cable diameter of 2.5 mm^2, DC power energy loss of 6,996% (4372.5 watts)
- Cable diameter of 4.0 mm^2, DC power energy loss of 4.37% (2732.82 watts)
- Cable diameter of 6.0 mm^2, DC power energy loss of 2.92% (1821.88 watts)
- Cable diameter of 10 mm^2, DC power energy loss of 1.75% (1093,125 watts)
- Cable diameter of 16 mm^2, DC power energy loss of 1.09% (683.20 watts)
- Cable diameter of 25 mm^2, DC power energy loss of 0.7% (437.25 watts)
- Cable diameter of 35 mm^2, DC power energy loss of 0.5% (312.32 watts)



Graph 2. Energy losses according to solar wire cross section (for a 62.5 kW solar installation)

5. CONCLUSIONS

For increasing the efficiency of electric cars charging in the paper are presented the premises for photovoltaic electric current generation and two calculators, for AC and DC current solutions that are helping in optimal dimensioning of the charging cables. The technical optimization will be followed by the management of COTS (commercially available off-the-shelf) solution in order to ensure also the economic efficiency.

By presenting this method of supplying electric vehicles, we offer a solution to a detected problem: the loss of energy due to the electric cables used for both AC and DC.

From a technical point of view, cables that fits and falls within the tolerance of 1-3% for an AC are:

- 6 mm^2, recording energy losses of 2.20%
- 10 mm^2, recording energy losses of 1.32%

From a technical point of view, cables that matches and falls within the tolerance of 1-3% for a DC system are:

- 6 mm^2, recording energy losses of 2.92%
- 10 mm^2, recording energy losses of 1.75%
- 16 mm^2, recording energy losses of 1.09%

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