PROYECTO FIN DE CARRERA

FINAL PROJECT

PRAXISPROJEKT

NETWORK CALCULATION IN THE LOW VOLTAGE NETWORK OF THE DÜSSELDORF UTILITY COMPANY IN RESPECT OF FUTURE ELECTROMOBILITY

Autor/Author: JOSEFINA SÁNCHEZ GARCÍA

Tutor FHD: Prof. Dr.-Ing. DETMAR ARLT

Cotutor UC3M: Prof. Dr.-Ing. HORTENSIA AMARÍS

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0. INTRO

As introduction to our project we will make some brief historical review to see the beginnings of electric car. For this, we have built this table where we can see easily the evolution of the Electric Car:

YEAR	**DESIGNER/MAKER**	**PLACE**	**FEATURES**
1828	Ányos Jedlik	Hungary	Tiny model car powered by an early type of electric motor
1834	Thomas Davenport	USA	Small model car with short circular electrified track
1835	Sibrandus Stratingh Christopher Becker	Netherlands	Small-scale EC powered by non-rechargeable primary cells
1838	Robert Davidson	Scotland	Electric locomotive that attained a speed of 6,4 Km/h
1839	Robert Anderson	Scotland	Crude Electrical carriage
1865	Gaston Plante	France	First rechargeable battery
1867	Franz Kravogl	Austria	Electric powered two-wheel cycle

1881	Gustave Trouvé	France	Working three wheeled automobile
1884	Thomas Parker	England	Innovations such as electrifying the London Underground
1899	Camille Jénatzy	Belgium	“Jamais Contente”

Figure 0: “Table of the evolution of the Electric Car”

Among the most notable of these records was the breaking of the 100 km/h (62 mph) speed barrier, by Camille Jénatzy on April 29, 1899 in his 'rocket-shaped' vehicle Jamais Contente, which reached a top speed of 105.88 km/h (65.79 mph).

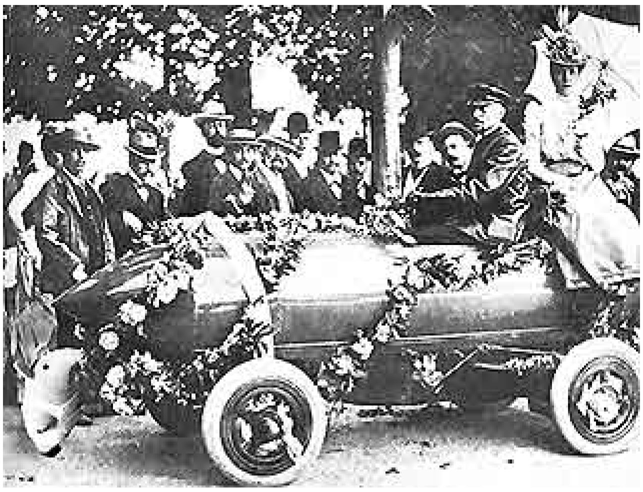


Figure 1: “La Jamais Contente”

Source: Electric and hybrid cars

On 1930 Electric Cars are extinguished because of the fall in the price of gasoline.

On 1973 General Motors developed an urban electric car with a battery charger, which was presented in USA.

The same company created in 1999 the EV1 model which was the first electric car completely modern, fast, clean, efficient, mechanically simple and with a range of 130 km.

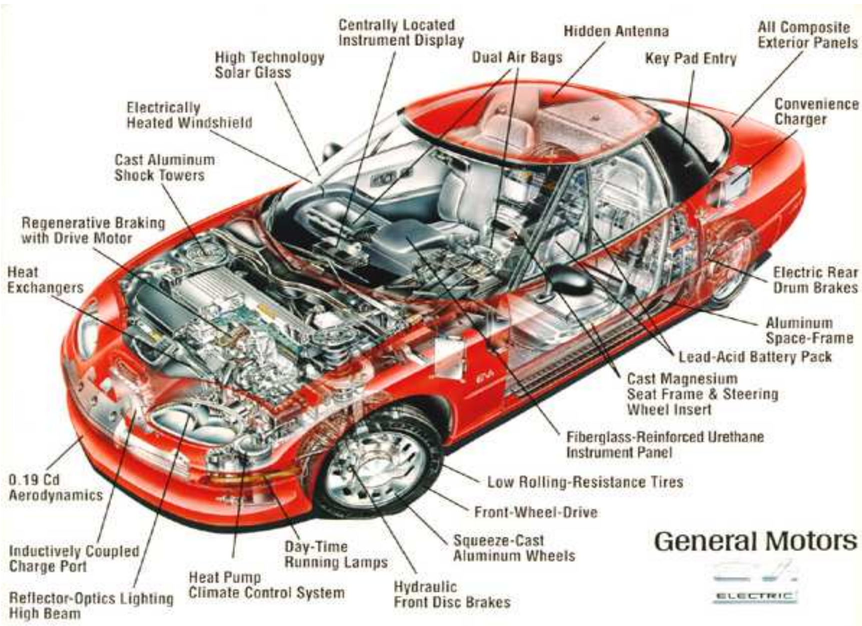


Figure 2: "EV1"

Source: General Motors

1. MOTIVATION OF THIS PROJECT

Nowadays, everybody talk about Electromobility as something revolutionary but distant. Over recent years there has been a given social awareness about global warming due to greenhouse gases. People are aware of the need of changing in order to the current situation does not harm future generations. This has resulted in policies and laws at national and European level, in addition to global agreements like the Kyoto protocol, and more recently the Copenhagen summit. In particular, in Europe, we find an increase in taxes on more polluting vehicles, restrictions on CO2 emissions of new production vehicles, subsidies for vehicles with environmentally friendly, and integration plans for electrovehicles.
Electric cars enjoyed popularity between the mid-19th century and early 20th century, when electricity was one of the preferred methods for running cars.

But the electric car was not successful because it had some severe disadvantages:

1. The need to recharge the battery. If you own an electric car need to plan at what moment it is necessary to recharge the battery. Also, if you are thinking of buying an electric car, then you must make an honest assessment of how much you will use your vehicle. An extended or unplanned trip could be problematic if you haven't had time to fully recharge the batteries.

2. The batteries of these cars are very heavy. For example, cell battery pack in a Tesla Roadster can reach up to 450 kilos. This is much weight to carry and reduces the car's efficiency.

3. Electric car price which is high. What makes electric vehicle expensive is the battery. The batteries used in electric cars are lithium-ion, which are expensive. Also keep in mind that the battery will need to be replaced, as they have a life of approximately three or four years.

4. The autonomy of the electric car. If you drive long distances the electric car may not be able to meet your needs, so you will need to consider how far you plan on driving your car. Most of the electric cars have limits on how many miles they can go before needing a recharge.

Despite these difficulties, the electric car is the car of the future and that is the reason why we consider interesting making a deep study about it.

Electric cars improve energy efficiency, reduce CO2 emissions and pollutants in the cities and also allows the reduction of oil dependence and use of energy sources indigenous (in the case of Spain involve the use of their sources CO2-free generation, especially renewable energy which already accounts 20% of electricity generation and in 2020 will involve 40%).

Electric cars have come a long way in recent years but still have to overcome a few more obstacles before becoming widely embraced as a solution for many consumers.

Currently, there is a social awareness to protect the environment and therefore the electric car is an attractive alternative for people so it is important to focus on this issue. Additionally, consumers are also interested in electric cars in the wake of the rising price of gasoline (electricity is cheaper than fuel).

Expect a great change in the automotive industry with the development of electric cars and a great success based on the reduction of pollution, rising gas prices and less dependence on oil. Governments all over the world are pledging billions to fund development of electric vehicles and their components.

It is important that the electric vehicle as a new consumer of electricity may become an advantage to operate more efficient electrical system, reducing the large differences that happen between periods of higher and lower power consumption and facilitating the integration of renewable energy. For best operation of the system is very important that the demand shifts towards the peak times, and this is where the nocturnal slow recharge electric car can play a key role in flattening the demand curve.

Also the electric car can be a reversible electric storage system. Batteries should be recharged at night when demand is smaller, and during the day may shed electricity to the network (but this point is yet to be developed).

Thus, improvements to the system by the electric car would be:

1. Contribute to flatten the demand curve and thereby improve system efficiency. For this purpose, consumers would have to recharge their vehicles during lower consumption periods (between 1:00 am and 7:00 am) to reduce the differences

in consumption between peak hours and valley hours, thus flattening the demand curve .

2. Renewable energies can easily integrate into the system with security conditions. Wind power energy generation is extremely variable and frequently increases at night, when it is not always possible to integrate this energy generated into the system if the electric energy offer is greater that the electricity demand. For this reason, recharging electric vehicles during night-time hours reduces the possible disconnection of the wind farms should their production exceed the system safety limits which have been set.

3. Thanks to the electric vehicle the countries can reduce its oil dependency for energy and CO_2 emissions, contribute to improving the air quality and reduce the noise levels in cities.

2. ELECTROMOBILITY NOWADAYS

The world of Electromobility has much yet to explore, you could say that today is beginning to "take off". Lots of plans are being developed by the goverments all over the world but in this chapter we will focus in the main strategics plans of Spain and Germany. It is interesting to know that in the Electromobility Guide "Wegweiser Elektromobilität" there is an overview of 150 projects that have been identified in Germany, Europe and on an international scale in the first six months of 2010.

2.1 Electromobility in Spain.

Electric cars are new consumers which come to represent over the next decade 2% of current demand.

According to studies by Red Eléctrica España could be integrated in the coming years to six and a half million electric cars without additional investment in generation or in the transmission if we make a nocturnal slow recharge.

However, we need to develop intelligent charge systems that allow a communication network-vehicle **(**intelligent networks) and install meters with time discrimination to help users make intelligent recharging. We will see this point deeply in another chapter.

Comprehensive Strategy for the Promotion of Electric Vehicles in Spain

At the beginning of 2010, some working groups formed by various Spanish companies and institutions gathered for the elaboration of this strategy. These associations are as follows:

MOTOR GROUP: Ministry of Industry, Tourism and Trade, Foundation Institute for Sustainable Technology auto-FITSA, Institute for Diversification and Saving Energy – IDEA.

DEMAND AND PROMOTING GROUP: Acciona, ACS, Asociación Española Renting, Berge Automoción, Citroën, Endesa, EON, FCC, Gas Natural /Unión Fenosa, HC / EDP, Iberdrola, Iveco, Mercedes, Mitsubishi, Nissan, Peugeot, Race, Renault, Reva, Seat, Tata, Toyota, Vaesa.

INDUSTRIALIZATION, RESEARCH, DEVELOPMENT AND INNOVATION GROUP: ANFAC, Ford, Grupo PSA, Iveco, Mercedes, Nissan, Opel/General Motors , España, Renault, Seat, Sernauto, Volkswagen.

INSTITUTIONAL GROUP: Heads of Government, Home Office, Ministry of Economy and Finance, Ministry of Environment, ministry of Development, Ministry of Science and Innovation, Spanish Federation of Municipalities and Provinces, Autonomous Communities.

The quantitative objective of the Comprehensive Strategy to promote Electric Vehicles is to facilitate the introduction of Electric cars or plug-in, until in 2014 there will be 250000 units of these vehicles in Spain.

In order to achieve this goal, the promotion of Electric Vehicle has to go through four lines of action, in accordance with this strategy.

Inside of these four areas there are programs that define the actions to be taken.

Here is a brief summary of them:

I) Boost demand and the promotion of electric vehicle use:

I.1)Program to boost demand:

It is estimated that if there are 250000 Electric Vehicles in 2014 , 85% will belong to companies and public institutions and the remainig 15% will be vehicles por personal use. It aims to provide economic aid to the users of this kind of vehicles and develop plans for this reason (an example is the MOVELE PLAN, which will provide between 750 and 20000 Euros, depending on the type of vehicle, managing to give up to 7000 Euros in case of the electric cars).

I.2)Urban benefits program:

It is intended to give the electric vehicle urban advantages compared to internal combustion vehicles:
-Preferred parking and circulation on public roads.
-Allow the movement of Electric Vehicles in restricted areas of cities.
-Extended hours loading / unloading.
-Reduce Tax Disc.
-Reserve space for quick reloads for emergency vehicles urban fleets serving sensitive areas: medical, police, etc.
-Reserve space for taxi fleets refills when autonomy EV is sufficient to provide this service.

II) The promotion of industrialization and the research, development and innovation for electric vehicle:

II.1) *Promotion program of development and industrialization of electric vehicles in Spain, its components and equipment environment:*

The purpose of this program is maximize the industrialization of specific components and modules for electric vehicles and plug-in hybrid, both elements characteristic of ElectricVehicle associated with Electric Vehicle (Electric Vehicle communication, infrastructure charging, etc..) and establish production lines of these vehicles on Spanish plants to satisfy, in large measure, the demand will strengthen, not losing, likewise, position as the third European country in the manufacture of automobiles.

II.2) *Program of research, development and innovation:*

This program aims to provide specific and explicit support in:
-Lines of research, development and innovation priority to improve the supply of builders and specific components of electric vehicles, and specifically the batteries and battery management systems and control.

-Lines of research, development and innovation for the development of energy supply infrastructure and load management: intelligent charging, control and communications equipment, etc.

-Lines of research, development and innovation for the problems related to the life of the vehicle: security, vehicles out of use (recycled from batteries, motors, etc.).

-Promote centers of excellence for research, development and innovation special for Electric Vehicles capable of doing research, testing, standardization, training, etc.

III) The development of freight infrastructure and energetic management:

III.1) *Deployment program of burden infrastructure:*

About charging points, this program provides that on the horizon of 2014 there will be 62000 points private households, 263000 car fleet points, 12150 points in public parks and 6200 on public roads. It also provides the installation in 2011 of fast-loading point for every 400 vehicle charging points individuals, so that on the horizon 2014, reach 160 stations.

III.2) *Management Program of Energy Demand:*

The program aims to provide adequate assurance that the cost of electric vehicle energy is significantly lower than cost of thecombustion energy. Along with incentives to purchase electric vehicle, this economy makes the market introduction of this new propulsion technology easier.

Ministry of Industry, Tourism and Trade will promote the existence of power deals with the kWh price ranges and articulate legal provisions that promote demand management to take advantage of the benefits when electric vehicle is recharging in times of low electrical consumption.

IV) Horizontal Programs

IV.1) *Actions of communication and strategic marketing:*

This program focuses on the implementation of communication plans and strategic marketing reporting what is an electric vehicle, its features, its advantages,charging different rates, optimal load times, etc. Implementation, coordination and management of strategic marketing and their communications will be carried out by the Ministry of Industry,Tourism and Trade.

IV.2) *Regulatory Activity and Suppression of Legal Barriers:*

The aim is to identify and overcome legal barriers that hinder the momentum of demand and the deployment of charging infrastructure. The Directorate General of Industry, Ministry of Industry, Tourism and Trade, with the associated organization of this Technological Institute Foundation Sustainability Motor-Fits-and with the involvement of two groups of work or specific interest (Manufacturers and energy services industry) identify the needs to amend the regulations and laws that are apply to these vehicles, and charging infrastructure.

IV.3) *Promotion of Specific and Specialized vocational Training*

This section will attempt to identify and propose a catalog of courses required for development and manufacture of electric vehicles, and for maintenance, repair and recycling and for those professionals who, for their safety, will require minimum knowledge. The ongoing identification of these specific needs and knowledges will be conducted by training, business and technology organizations.

In order to continuously monitor the objectives achieved and try to solve the problems encountered, a group of Monitoring will be created and managed by the Ministry of Industry, Tourism and Trade and will be formed by the Ministry of Energy and the General Secretariat Industry through the DGs that they designate, and may part of the same institutions and companies that are considered necessary for it. They are invited by the Ministry of Industry, Tourism and Trade for this purpose and the Ministry of Environment and the Ministry of Science and Innovation support participating in the development of the Comprehensive Strategy Impetus to electric vehicle.

Also there will be a specific follow-up to Promote Electric Vehicle with Autonomous Communities in the framework of the Conference and Industry Sector Energy (C.S.I.E).

2.2 Electromobility in Germany.

An strategic plan was created in August 2009 and claims that Germany is a leader in Electromobility and that in 2020 a million of these electric vehicles will be circulating in Germany. Let's see a brief summary of this plan in accordance with the information extracted directly from the German Federal Government's National Development Plan Electromobility:

German Federal Government´s National Electromobility Development Plan

The German Federal Government’s Integrated Energy and Climate Programme cites electromobility as a major component and its implementation report calls for drafting a National Electromobility Development Plan.

Electromobility is therefore an issue of major strategic importance for the German Federal Government, as stipulated in the Integrated Energy and Climate Programme in combination with energy supply from renewable sources. The responsible ministries, the Federal Ministry of Economics and Technology (BMWi), the Federal Ministry of Transport, Building and Urban Affairs (BMVBS), the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Federal Ministry of Education and Research (BMBF) entered into intensive joint dialogue with the business and science community to discuss the challenges and opportunities and draft guidelines for implementing the ten-year plan to achieve its electromobility goals.

The activities and measures of the German Federal Government are based on a variety of ongoing programmes and activities, which are outlined here. Assistance to date has concentrated on the following priorities:

-Research and development.

- Enabling framework.

- Markets.

Likewise, the activities will be carried out in three phases:

I) ***Phase 1 (2009- 2011) Market preparation***

I.1) *Research and Development:*

Research and development as well as start-up of production of first generation Li-ion batteries and second generation Li-ion batteries and double layer capacitors.
Production of PHEV (plug-in hybrid electric vehicle) and BEV (battery electric vehicle) based on existing vehicle platforms and prototypes.
Drive technologies (engines/converters) adapted to performance category, installation space, safety and reliability.Research and development for electrical, electronic and mechanical vehicle components for PHEV and BEV.

I.2) *Enabling Framework:*

Research and development of new components in the infrastructure. Testing and simulation facilities for grid integration trials . First public charging stations. Studies and demonstrations for coupling with renewable energies . Safety standards. Regulatory framework. Standardisation of interfaces.

I.3) *Market Development:*

Application in fleet tests.

II) ***Phase 2 (2011-2016) Market escalation***

II.1) *Research and Development:*

Demonstration and field tests of Li-ion batteries and double layer capacitors. Mass production of first generation Li-ion batteries . Production start-up of second generation Li-ion batteries and double layer capacitors .Research and development on third and fourth generation Li-ion batteries.
Production of PHEV and BEV based on existing platforms by all OEMs (original equipment manufacturer) in small lots . Serial production maturity of second generation PHEV /BEV platform . Research and development for economical drive technologies and vehicle components for second generation platforms.

II.2) *Enabling Framework:*

Charging infrastructure in many towns and regions . Research, development and initial trials for grid integration (load management).Coupling with renewable energies . Development of advanced charging and energy transmission systems .
Use of procurement guidelines for the public sector. Appraising systems of incentives.

II.3) *Market Development:*

First private users. Business models for charging, feedback and batteries.

III) Phase 3 (2017-2020) Mass market (aim: lead market in electromobility)

III.1) *Research and Development:*

Mass production of second generation of Li-ion batteries and double layer capacitors. Production start-up of third generation Li-ion batteries. Continuation of research and development on Li-ion batteries and alternative storage technologies. Mass production of second generation PHEV/BEV. Production of higher performance BEV/PHEV.

III.2) *Enabling Framework:*

Field tests on complete systems under realistic conditions. Full-coverage charging infrastructure. Grid integration and feedback. Initial trials of fast loading, contactless energy transfer.

III.3) *Market Development:*

One million electric vehicles on Germany's roads in 2020. Germany is the lead market for electromobility .

2.3 Brief comparison between the two types of plans

The German Electromobility Federal Government's National Development Plan (GEFGNDP) was launched in August 2009 while the Comprehensive Strategy for the Promotion of Electric Vehicles in Spain(CSPEVS) started at the beginning of 2010.

The first major difference we found between the two plans is that both have different aims: whereas in Spain the aim is to facilitate the introduction of electric vehicles in 2014 so that there is 250000 pieces of these vehicles, in Germany they want to be leaders in Electromobility market so that in 2020 there will be a million electric cars on the roads in Germany.

The structure of the plans is also different: in Germany is structured in phases which are defined in dates in which to achieve their short-term objectives and actions in Spain to carry out are not dated.

Both plans give utmost importance to the research, development and innovation in the electric vehicle industry and aim to facilitate as far as possible the acquisition of an electric vehicle by consumers.

There are currently circulating in Germany about 1600 electric vehicles while in Spain there are only about 680.

In Spain today has 356 public charging points of which 82 are in Madrid. In Germany there are about 900 public charging points of which about 80 are in Berlin and 5 are located in Düsseldorf.

These figures are reflected in major breakthrough in Germany with respect to Spain in terms of electro-referred.

3. TECHNICAL DETAILS OF ELECTRIC CARS

The battery of an electric car is the most important part of it and perhaps the greatest handicap. Therefore we will start this chapter talking about them. They come in various types and are in constant development and study as it seeks to increase its capacity while reducing their size and weight.

As we know, a battery is the device that stores electrical energy using electrochemical methods and then returns almost entirely. Let's look carefully at the different types of batteries that we can find.

A)TYPES OF BATTERIES

I. Lead-acid

Flooded lead-acid batteries are the cheapest and most used in thermals vehicles for boot them because these types of batteries can provide high current levels in short periods of time. However because of their poor autonomy, short life and their long period of load (between 10 and 16 hours), the utility in electric vehicles is limited to auxiliary systems as radio, lights… These batteries also require inspection of electrolyte level and replacement of water.

The advantages of lead-acid batteries are their mature technology, high availability and low cost.

Like all batteries, they have significantly lower energy density than petroleum fuels, in this case 30-40Wh/kg. The efficiency is between 70-80% and the power around 180 W/kg. These types of batteries can work 500 cycles of load and can support overloads. The average value in each cell voltage is 2V and the appropriate range of temperatures is between -20ºC and 60ºC. The monthly self-discharge rate is 5%. Inside takes place the following chemical reaction:

$$PbO_2 + Pb + 2H_2SO_4 \leftrightarrow 2PbSO_4 + 2H_2O$$

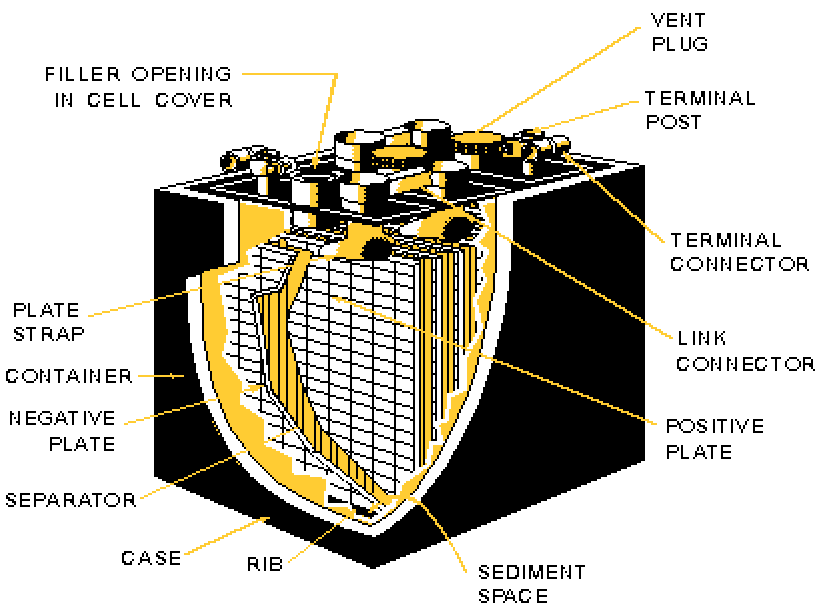


Figure 3: "Lead-acid battery construction"

Source:Tpub

II. Nickel-Cadmium (NiCd)

The endurance of the Nickel-Cadmium batteries is higher respect the Lead-Acid batteries, but a European rule limited its used for been the Cadmium a heavy metal with problems for the environment.

The reaction that takes place inside the battery is as follow:

$$Cd + 2H_2O + 2NiOOH \leftrightarrow 2Ni(OH)_2 + Cd(OH)_2$$

One advantage of this kind of battery is that it can provide high current level with reduced voltage. On the other hand these batteries have memory effect, this means that if the battery is recharged before losing the entire charged, for example when the battery is at 50% of its capacity, it will appear Cadmium crystals causing that the next time it is recharged it will assume that the new level 0 of charged is 50%.

Its energy density is 60 Wh/kg and 50-150 Wh/liter. They have a moderate overload tolerance and the range of temperatures for their correct operation is between -40ºC and

60ºC. The average voltage in each cell is 1,25 V and the monthly self-discharge rate is 20%.

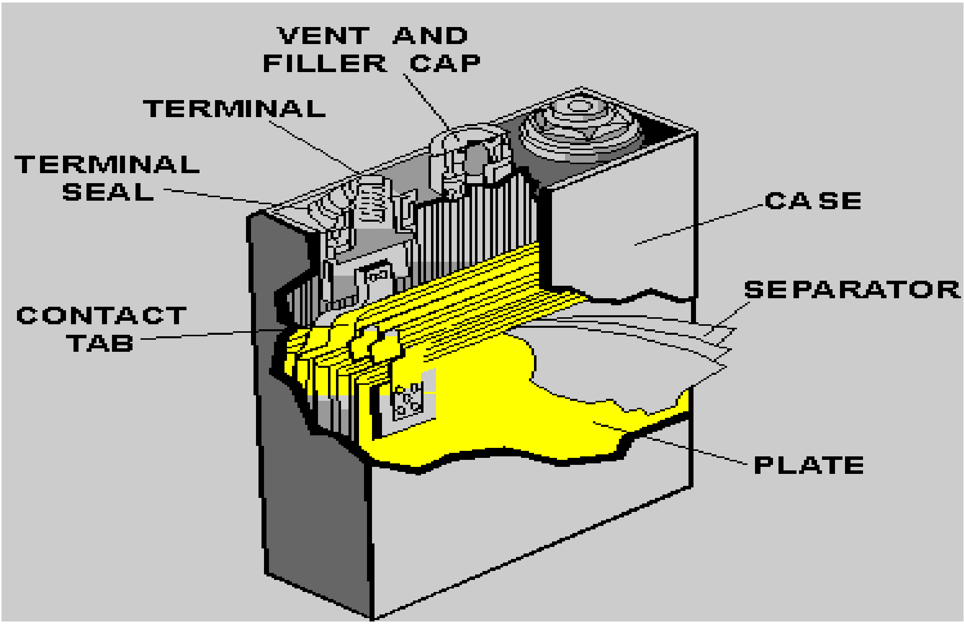


Figure 4: "Nickel-cadmium cell"

Source: Tpub

III. Nickel metal hydride (NiMH)

Nickel-metal hydride batteries are now considered a relatively mature technology. While they are less efficient (60-70%) in charging and discharging than even lead-acid, they boast an energy density of 70Wh/kg and 143-300 Wh/liter, far higher than lead-acid.

When they are used properly, nickel-metal hydride batteries can have exceptionally long lives (approximately 1000 recharge cycles, ten times longer than the Nickel-Cadmium batteries), it has been demonstrated in their use in hybrid cars like the Toyota Prius or RAV4EV that still operate well after 100,000 miles (160,000 km) and over a decade of service. With this technology the problem of memory effect due to Cadmium, disappear.

Downsides include the poor efficiency, high self-discharge (30% per month), very finicky charge cycles, poor performance in cold weather and the low resistance to overload. These batteries also are more expensive than the previous and the average voltage in each cell is low (1,25V). GM Ovonic produced the NiMH battery used in the second generation EV-1, and Cobasys makes a nearly identical battery (ten 1.2V 85Ah NiMH cells in series in contrast with eleven cells for Ovonic battery). This worked very well in the EV-1.

Figure 5: " Toyota hybrid car equipped with NiMH"

Source: Powerpulse

IV. Lithium -Ion

Lithium-ion batteries, widely known through their use in laptops and consumer electronics, dominate the most recent group of EVs in development. The traditional lithium-ion chemistry involves a lithium cobalt oxide cathode and a graphite anode. The energy density is one of the advantages of this type of batteries that is around 200 Wh/kg as well as 80 to 90% charge/discharge efficiency and high autonomy. They are also recyclable and have not memory effect in addiction to a low weight and a low monthly self-discharge (10%).

The disadvantages of traditional lithium-ion batteries include a not very long life (hundreds or thousands charge cycles) and significant degradation with age. The cathode is somewhat toxic. Also, traditional lithium-ion batteries can pose a fire safety risk if punctured or charged improperly. Nowadays the maturity of this technology is improving so much.

But the most important problem of these batteries is the poor resources of lithium.

According to a study by William Tahil, the director of Research of Meridian International, if all thermal vehicles (900 millons) were replace for electrical vehicles equipped with ion-lithium batteries of 20 kWh, would be necessary to spend the 50% of the current resources of lithium. For this and because of would be necessary 75 years for building all of those batteries, currently the industry is focusing on dvelopment of battery technologies more viable loke Zebra or Zinc-Air batteries.

Now we see in the following diagrams the percentage of resources metal allocated to electrify 900 million vehicles equipped with 10 kWh batteries and the time necessary for making batteries for these vehicles:

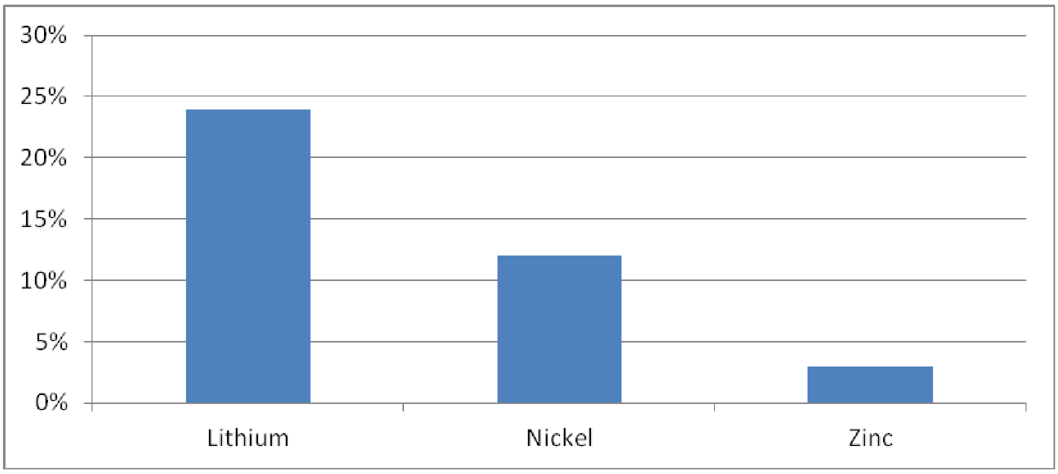


Figure 6: "Percentage of resources metal"

Source: Meridian International Research

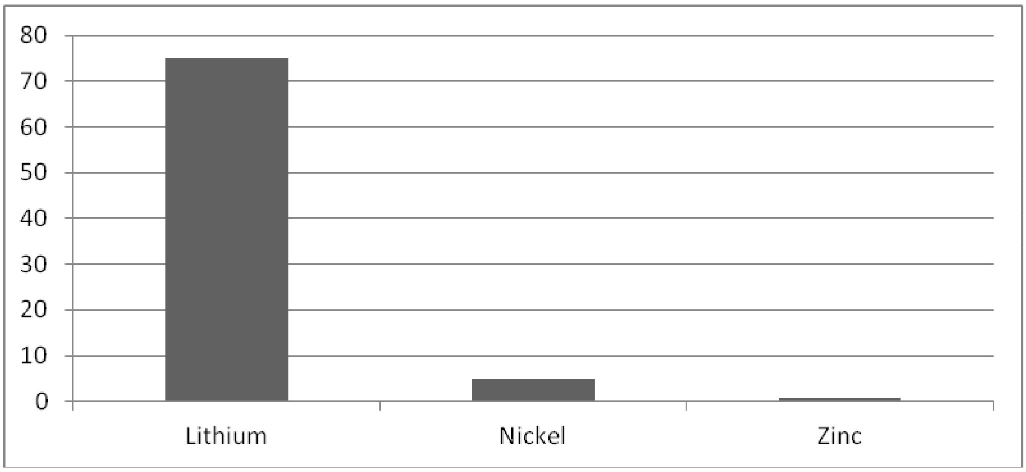


Figure 7: "Years needed to make batteries for 900 million vehicles"

Source: Meridian International Research

The Tesla Roadster uses "blades" of traditional lithium-ion "laptop battery" cells that can be replaced individually as needed.

Mostly other EVs are utilizing new variations on lithium-ion chemistry that sacrifice energy density to provide extreme power density, fire resistance, environmental friendliness, very rapid charges (as low as a few minutes), and very long lifespans. These variants (phosphates, titanates, spinels, etc.) have been shown to have a much longer lifetime, with A123 expecting their lithium iron phosphate batteries to last for at least 10 years and 7000 charge cycles, and LG Chem expecting their lithium manganese spinel batteries to last up to 40 years.

Much work is being done on lithium ion batteries in the lab. Lithium vanadium oxide has already made its way into the Subaru prototype G4e, doubling energy density. Silicon nanowires, silicon nanoparticles, and tin nanoparticles promise several times the energy density in the anode, while composite and superlattice cathodes also promise significant density improvements.

In 2009 Mitsubishi (i-MiEV) and Subaru (Stella) introduced electric vehicles offered for fleet then public sale.

The next picture shows us a comparison of production, reserves and requirements metal for electrify 900 million vehicles with 10 kWh battery:

The vertical axis values are given in million tonnes:

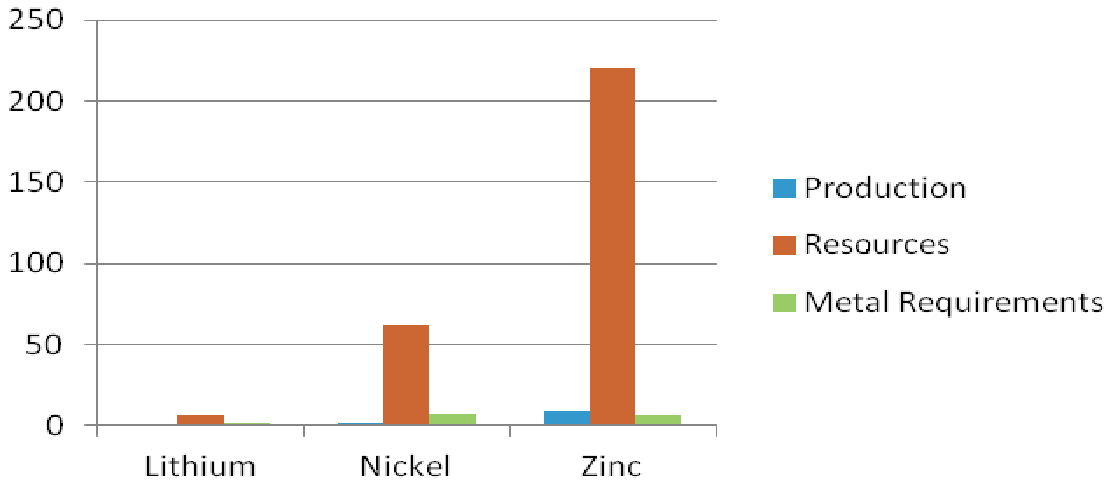


Figure 8: "Comparison of production, resources and requirements"

Source: Meridian International Research

V. Lithium Polymer

These kind of batteries are characterized for have a plastic electrolyte so they don´t need metallic coating and they can take many forms as well as they are safer than ion-lithium ones.

Although they can provide good energy density (200 Wh/kg) and also a high power (3000W/kg), they are just used in some devices types very thin because their features are similar or worse than the ion-lithium batteries.

VI. Zebra

The sodium or "zebra" battery uses a molten chloroaluminate ($NaAlCl_4$) sodium as electrolyte. This chemistry is also occasionally referred to as "hot salt". This relatively mature technology, hasn´t a high energy density, this is around of 120Wh/kg. They must be heated for use because these batteries operate at a high temperature range (270ºC-350ºC), but cold weather doesn't strongly affect for the operation except for increasing heating costs and spending much energy. Their performance is very high near of 100% and they have a long life besides can support short circuits very well. The nominal capacity is 38 Ah and 20 kWh.

They have been used in several EVs, for example in the Modec vehicle since it entered production in 2006, or the Think City which is equipped with Zebra batteries of 28,3 kWh.

The only company that manufactures this type of batteries is Mes-Dea from Switzerland.

Figure 9: "Zebra Battery"

Source: Vehiculos verdes

VII. Zinc-Air

According to investigations, the future of electromobility is linked to Zinc-Air batteries for their high energy density (370Wh/kg, 3 times higher than lithium), their long life because they can be recharged and recycled as many times as you want, and also for the low cost of this kind of technology. Another advantages are the low weight, high safety and zero CO2 emissions.

Unlike the situation with lithium, there are available resources of Zinc for produce billions of these batteries as mentioned in White Book of Meridian International Research, which also says that world production of zinc in 21 months would be sufficient to produce a billion of electric vehicles equipped with 10 kWh batteries zinc_air, while it would take 180 years to produce enough lithium for the same number of batteries.

The downside is that for recharging these batteries, you have to extract the Zinc from inside of the batterie, for being recharged outside. But this is not a big problem because this process can be quickly made in a station service, replacing the old Zinc for another one new or recycled.

Nowadays these batteries are used for hearing aids and portable electronic systems, but all researching talk about Zinc like the electric fuel future.

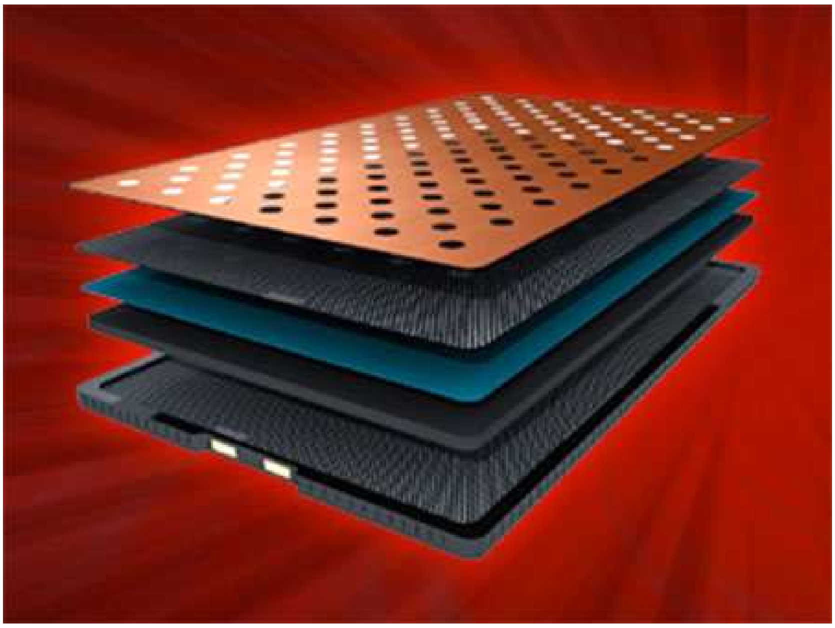


Figure 10: "Zinc-Air batterie"

Source: Treehuger

In accordance with Green Car, we constructed the following comparative table in which we can see the main characteristics of each battery:

Type of battery	Energy (Wh/kg)	Energy/Volume (Wh/liter)	Power/Weight (W/kg)	Life (Cycles)	Energy efficiency %
Lead-Acid	30-40	60-75	180	500	70-80
Nickel-Cadmium	60	60-150	180	500	82
NiMH	70	143-300	250	1000	60-70
Li-ion	200	270	1800	1000	80-90
Lithium Polymer	200	300	3000	1000	90
Zebra	120	300	nd	1000	99
Zinc-Air	370	750	nd	1000	99

Figure 11: "Comparative table"

According with Meridian International Research the cost to manufacture a battery of 30 kWh with the differences view technologies is:

Li-ion: $$30\ kWh \cdot 240 \frac{€}{kWh} = 7200€$$

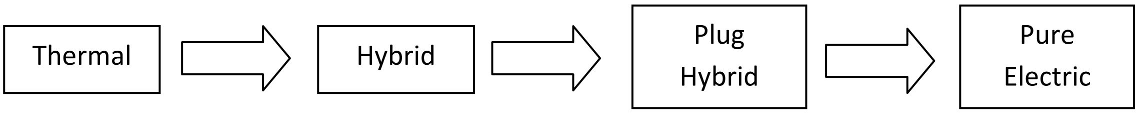
Zebra: $$30\ kWh \cdot 100 \frac{€}{kWh} = 3000€$$

Zinc-Air: $$30\ kWh \cdot 70 \frac{€}{kWh} = 2100€$$

B) CONSTRUCTIVE ASPECTS

In this chapter we will try to give an overview of the different possible configuration that enables the transition from thermal cars to pure electric cars, through hybrids.

We will see the most important characteristics of these available configurations which are Hybrid, Plug-in Hybrid and Pure Electric.



I. Hybrid Electric Vehicle (HEVs)

This kind of car has two engines, the thermal one and the electric one, and there are three different configurations for propel the car. In all the cases the car cannot be plugged to the net, and the batteries for feed the electric engine are recharged by the thermal engine which move a generator and also by the regenerative braking. So these cars do not have the problem of autonomy like the pure electric cars, they are more efficient and their price is not much higher than the thermal cars. This is the first step to the pure electric cars.

The three types of settings that we can distinguish are as follows:

PARALLEL CONFIGURATION: The most usual configuration is both engines can traction the wheels (parallel connection). The electric engine works alone below 30 km/h so the noise is zero and also CO_2 emissions. Honda Civic Hibrid uses this configuration.

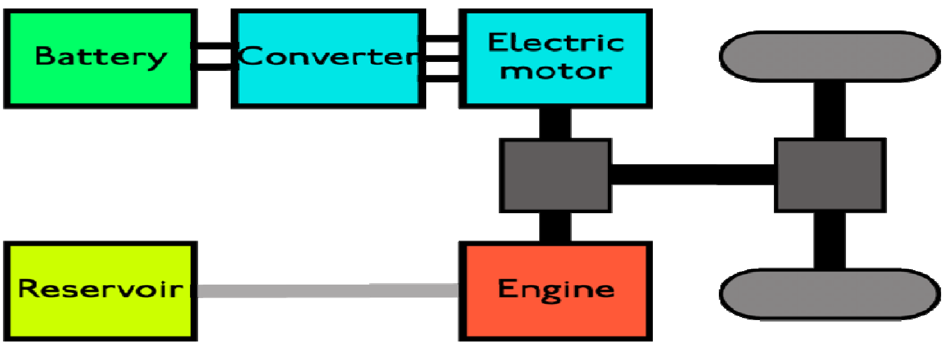


Figure 12: "Parallel configuration scheme"

Source: Sport car buzz

The batteries of these cars must have more capacity than the batteries from the cars equipped with conventional combustion engine and the auxiliary systems like air conditioning or power steering are fed from the electric engine for improve the car performance because these systems can work to constant speed regardless the speed that you are driving.

Nowadays the most commercial car of this technology is the Toyota Prius. It has NiMH batteries of 28 modules with a consumption of 6,5 Ah and a nominal voltage of 201,6V. Include its low consumption and low CO_2 emissions.

Figure 13: "Toyota Prius"

Source: Motor pasion

The thermal engine always operates at peak efficiency and whether it generates more energy than necessary electric motor acts as generator to charge batteries.

Another technological advancement is being introduced even in vehicles with internal combustion engine is called Start-Stop, which is responsible for turning off the engine when you make a stop (traffic lights, pedestrian crossing) for reduce CO_2 emissions.

SERIAL CONFIGURATION: The internal combustion engine does not directly move the wheels, only is used to generate electricity. Thermal Engine operates at an optimal capacity and recharges the battery until it is fully filled. The wheels are powered completely by electric energy from the battery. The thermal engine is turned on again when the battery is nearly depleted. E-REV is another name for series hybrid car, also defined as an electric (not hybrid) car that uses a gasoline engine as internal recharger. Chevrolet Volt uses this configuration.

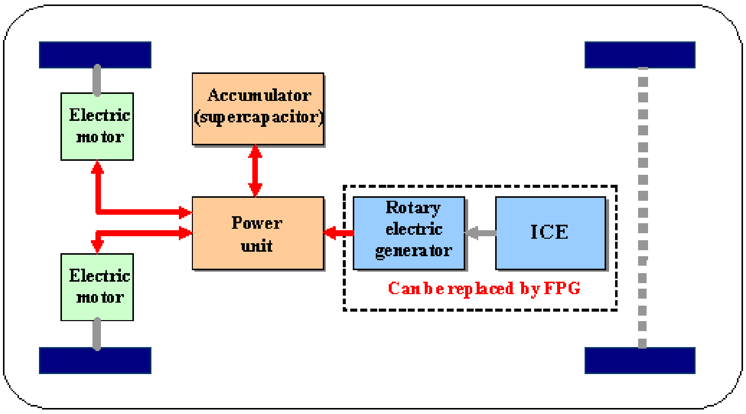


Figure 14: "Serial configuration scheme"

Source: Reviewcar

As the combustion engine is not connected to the vehicle's transmission, it can rotate at a constant speed, so its performance is quite close to theoretical, about 37%.

Energy produced by the combustion engine must flow through the generator, batteries and electric motor, which reduces performance. In long distances most of the energy is provided by the internal combustion engine as its yield is reduced compared to the parallel model.

For reduce the losses on items such as transmissions and differentials, the option is put an electric motor on each wheel.

COMBINED HYBRID: It is an hybrid car that uses both series and parallel configuration. Series hybrid is more efficient in low speed and parallel hybrid at high speed. Toyota Lexus uses combined configuration.

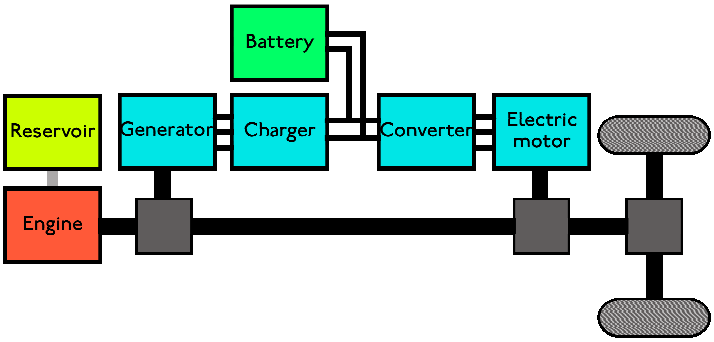


Figure 15: "Combined Hybrid"

Source: Reviewcar

II. Plug-in Hybrid Electric Vehicle (PHEVs)

The PHEV (Plug-in Hybrid Electric Vehicle) is postulated as the precursor to pure electric vehicles.

It offers all the benefits of HEVs (Hybrid Electric Vehicles) because it has a combustion engine and a electric engine but it can be connected to the network for recharge the batteries.

This kind of vehicles also solves the problem exists today because of poor infrastructure to recharge the batteries through the network because if you cannot connect the vehicles to the net it can be recharged through the combustion engine.

As in the case of HEV, PHEV has two different configurations. Parallel configuration that both engines can give traction to the wheels, and serial connection that the combustion engine can only provide energy to the electric engine.

Nowadays the vehicles that are available are Toyota Prius Plug-in and the Chevrolet Volt which has an autonomy of 64 km using just the electric engine. This distance is higher than the average distance traveled by the majority of the population, so throughout the year most of the miles would be made with the electric engine and thermal engine is only used to recharge the batteries on long trips.

According to studies by General Motors, if you drive the Chevrolet Volt with the batteries energy you will spend two cents per kilometer compared with the eight cents that you will spend driving a car equipped with thermal engine. Driving a average distance of 22.000 km per year, the difference on the price would be 2.200 euros (per year) between use a conventional car or use a electric car.

Most of these cars are equipped with Li-ion batteries. As mentioned above, these batteries present a risk of overheating and explosion so the investigations focus on other technologies based on Zinc or NaCl.

Figure 16: "Toyota Prius Plug In"

Source: Coches *eco*

III. Pure Electric (EVs)

Pure Electric refers a vehicle powered exclusively by electricity but has a combustion engine that operates as a generator. As stated above, the Electromobility has many advantages but it still has some barriers to break down as the development of batteries and the infrastructure to recharge them.

The current projects like the Movele Project from Spain focus on the development of the recharge points in public and private places and also on the development of recharge stations where users of electric cars can replace in a few minutes the empty battery for another recharged (Project Better Place). These last projects are been developed specially in Israel and Denmark due to their small size.

The electrification of transport is also important for producers of current vehicles, because they can stay in business due to this new concept of mobility.

Because of the limited current infrastructure of charging points, presents works focuses on vehicles designed for short trips within the city with sufficient autonomy to cover the distance average daily users. This will reduce local emissions of CO2 and noise level in urban areas.

Electric cars have fewer mechanical parts than combustion cars, because these haven´t clutch, gearbox so the maintenance will lower too.

These vehicles can be equipped with one or more electric motor. The single engine configuration is more suitable for big vehicles that need more power. On the other hand, the arrangement of some engines placed in each wheel is more appropriate for small vehicles eliminating transmission losses.

Therefore is necessary to develop batteries for being able to provide more autonomy, as well as reduce the price of these. For it, the Movele Project from Spain proposes that the customer buys the car withour batteries, and then pay a monthly fee for having the battery recharged at any point of recharge. The client will be paying a fee for service including batteries, electricity and infrastructure available, so the initial cost of the electric car does not differ much with a petrol car. But also it is necessary to expand the recharge infrastructure points and the efficiency of these for recharge the batteries quickly.

At low speeds, electric cars produced less roadway noise as compared to vehicles propelled by a internal combustion engine. Blind people or the visually impaired consider the noise of combustion engines a helpful aid while crossing streets, hence electric cars and hybrids could pose an unexpected hazard. Tests have shown that this is a valid concern, as vehicles operating in electric mode can be particularly hard to hear below 20 mph (30 km/h) for all types of road users and not only the visually impaired. At higher speeds the sound created by tire friction and the air displaced by the vehicle start to make sufficient audible noise.

The US Congress, the European Commission and the Government of Japan are exploring legislation to establish a minimum level of sound for hybrids and plug-in electric vehicles when operating in electric mode, so that blind people and other pedestrians and cyclists can hear them coming and detect from which direction they are approaching. The Nissan Leaf is the first electric car to include Nissan's Vehicle Sound for Pedestrians system, which will include one sound for forward motion and another for reverse.

C) SOME AVAILABLE ELECTRIC CARS NOWADAYS

Model	**Top speed**	**Acceleration**	**Capacity Adults+kids**	**Charging time**	**Nominal range**	**Market release date**
Wheego Whip LiFe	105 km/h (65 mph)		2		161 km (100 mi)	Dec 2010
CODA Sedan	129 km/h (80 mph)	0–60 mi/h in 11 seconds	4	full charge in approx. 6 hours	193 km (120 mi)	Q3 2011
REVA NXR	104 km/h (65 mph)		4		160 km (99 mi)	2011
Renault Fluence Z.E.	135 km/h (84 mph)	0-62 mph: 9.0 seconds (est)	5	6–8 hours with standard AC power; 30 minute rapid charge to 80%	161 km (100 mi)	Early 2011
Tata Indica Vista EV	105 km/h (65 mph)	0-62 mph: 10.0 seconds (est)	4		241 km (150 mi)	Q1 2011
Ford Focus Electric	137 km/h (85 mph)		5	approx 6 to 8 hours, 230 V/16A	160 km (99 mi)	Late 2011
Hyundai BlueOn	130 km/h (81 mph)	0–100 km/h in 13.1	4	6 hours with 220 V power; 25 minute rapid charge to 80%	140 km (87 mi)	Late 2012
Tesla Model S	193 km/h (120 mph)	0 to 97 km/h (0 to 60 mph) in 5.6 s	5+2	Full charge 3.5 hours using the High Power Connector or 45 minute QuickCharge	483 km (300 mi)	2012

Figure 17: "Table of some cars available nowadays"

4. COMPARISON OF THE MEDIUM/LOW VOLTAGE NETWORK STRUCTURE OF DÜSSELDORF AND MADRID

4.1. MEDIUM/LOW VOLTAGE NETWORK STRUCTURE OF MADRID

Madrid is the capital and largest city of Spain. The population of the city is roughly 3.3 million (as of December 2009); the entire population of the metropolitan area (urban area and suburbs) is calculated to be nearly 6.5 million. Iberdrola provides power to approximately 4.200.000 inhabitants in Madrid, according to data provided by the company itself so that it will be the number we take into account in our study.The city is located on the river Manzanares in the centre of both the country and the Community of Madrid.

Firstly, we are going to proceed to describe how energy is distributed in the present case.

We can see how energy is generated in hydraulic power, nuclear power stations, conventional thermal powerplants and renewables such as wind, photovoltaic, solar, etc.

The energy obtained is transformed to very high voltage, 400 kV (to minimize energy loss) for transport. Red Eléctrica de España is the manager of the transmission grid and acts as the sole transmissioner on an exclusive basis.

As we can see in the following picture, when energy gets into the transformer substation, it goes from having a value of 220 kV to another between 66 and 45 kV (being previously transformed from 400 kV into 220 kV) so we are in high voltage area.

This energy is transported through the distribution lines to reach the substation distribution transformer. There becomes medium voltage, 20 kV and 15 kV.

Finally, low voltage conversion occurs in the processing centers where we get the 400-230 V to supplied in urban area.

We can see and fully understand the whole process in the following figure:

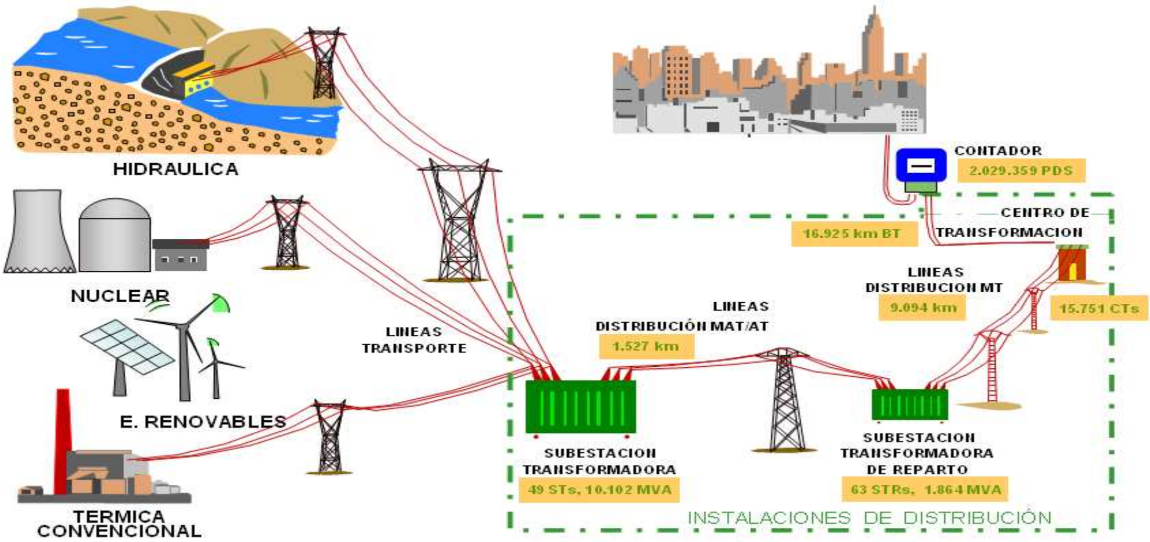
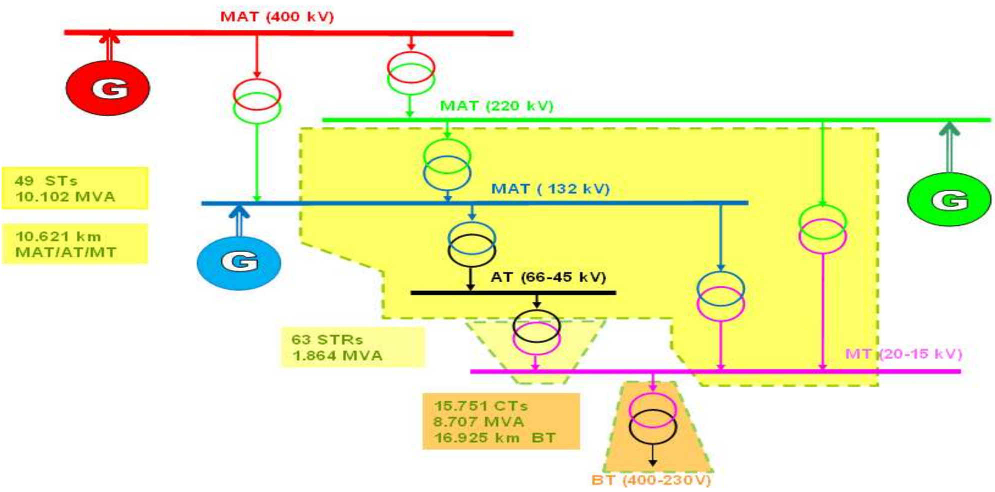


Figure 18: "Electricity path Madrid"

Source: Iberdrola Distribution

In that picture, also we can see the lengh of the lines, the power in MVA and how many of each type centers there are.

Below we see a line diagram of the network in Madrid:



MAT=Very High Voltage; AT=High Voltage; MT=Medium Voltage, BT=Low Voltage

Figure 19: "Network in Madrid"

Source: Iberdrola Distribution

There are 49 transformer substations with an installed processing capacity of 10102 MVA in total (about 206 MVA per substation).

The total length of very high voltage lines, high voltage lines and medium voltage lines is 10621 km.

The length of the lines of 132 kV, 66 kV, 45 kV (very high voltage and high voltage) is 1527 km so that the remaining 9094 km are medium voltage lines of 15kV and 20 kV.

In medium voltage, we can find 112 substations with an installed processing capacity of 6193 MVA in total.

There are 63 distribution transformer substation with an installed processing capacity of 1864 MVA in total (about 30 MVA per substation).

Finally, there are 15751 processing centers with an installed processing capacity of 8707 MVA in total and the total length of low voltage lines is 16925 km.

5212 of these Distribution and Processing Centers are particular.

Below are the types of transformers used for each voltage:

a)VERY HIGH VOLTAGE INTO HIGH VOLTAGE:

These transformers convert 400 kV to 220 kV. They are property of Red Eléctrica de España. It consist of two transformers of 450 MVA each.

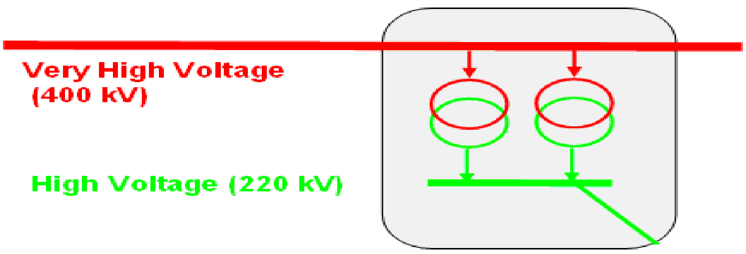


Figure 20: "VHV/HV TRANSFORMER"

Source: Iberdrola Distribution

b)HIGH VOLTAGE INTO MEDIUM VOLTAGE:

These transformers convert 220 kV to 20 kV. There are three transformers of 50 MVA each so the configuration is as follow:

-For 220 kV the system is GIS (encapsulated) double bar which tend to have three lines of 220 kV.

-For 20 kV the system is GIS (encapsulated) double bar with 3X10 outputs. There is also a longitudinal coupling between bars of 20 kV.

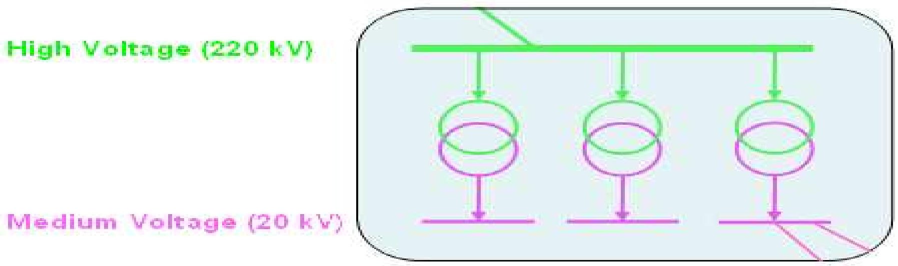


Figure 21: "HV/MV TRANSFORMER"

Source: Iberdrola Distribution

c) MEDIUM VOLTAGE INTO LOW VOLTAGE:

These transformers convert 20 kV to 0,4 kV. In a typical Transformation Center we have two transformers of 630 KVA of power each. They have two line breakers and two fuses for transformers and two low voltage boxes, with three or five outputs each.

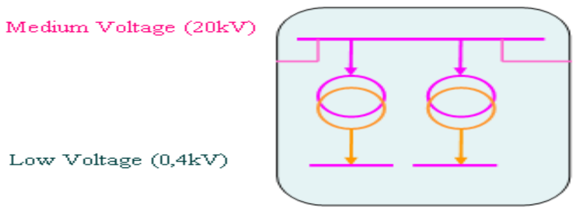


Figure 22: "MV/LV TRANSFORMER"

Source: Iberdrola Distribution

In urban networks tend to avoid intermediate transformations between transport (220 kV) and medium voltage (15 or 20 kV).

In Madrid city substation typical configuration are as follow:
-ST 132/15 kV transformers with three 40 MVA 132/15 kV

-ST 220/15 kV transformers with three 50 MVA 220/15 kV.

Although in Iberdrola the preference voltage for the MV network is 20 KV, there are some areas with others voltage levels like Madrid city where is supplied with 15 KV.

In Madrid is so common the "Distribution Center" which is a switching center that provides protections in its outletstand, usually feeds 2 or 3 large section cables (AL400) from the station. It allows reducing outputs number of the Substations and also this way downstream failures don´t affect the entire substation feeder.

In MV the most used cables for urban areas are AL240 for distribution and AL400 for connecting the Subestation to Distribution Centers.

The MV network has a big number of interconnections, which allows a very important support power between substations. The tendency is to support even the complete failure of a substation with the help of support from other substations. In older networks the design of the MT network doesn't follow a clear structure

In modern networks (urban and rural) the trend of the loads is based on two complementary systems:

> -From the substation feeding Distribution Centers located near major consumption areas, from these Distribution Centers out cables that connect with the Transformation Centers and finish in another Distribution Center (or Substation)

> -Loads closer to the substation are feeded directly from the substation with distribution cables which finish in another substation or other Distribution Center.

The low voltage that coming out of each TC run through the streets connecting the points of low voltage supply in so-called CGPs (General Protection), which basically allow the referral to the client is protected by a fuse. In Spain are the property line between the distributor and low voltage supplies.

Now we are going to see some examples with photos.

The following picture shows a typical Medium Voltage Network in the center of Madrid:

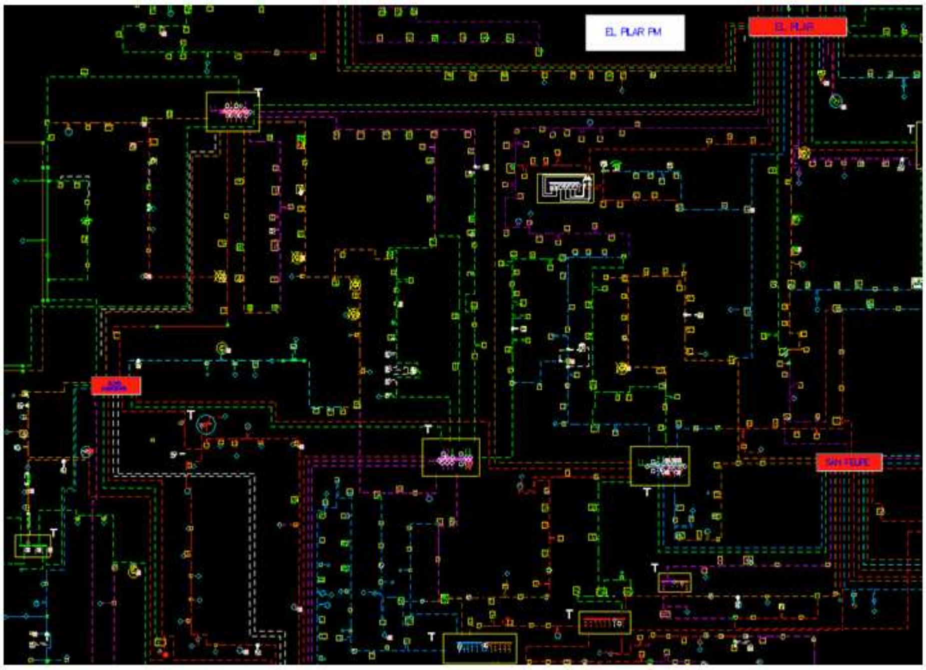


Figure 23: "Medium Voltage Network"

Source: Iberdrola Distribution

Now, an example of a Low Voltage Network:

Figure 24: "Low voltage Network"

Source: Iberdrola Distribution

Finally, the last picture shows the interior of two processing centers, namely CT Crial and CT Comandante Fortea:

Figure 25: "Processing Centers"

Source: Iberdrola Distribution

4.2. MEDIUM/LOW VOLTAGE NETWORK STRUCTURE OF DÜSSELDORF

Düsseldorf is the capital city of the German state of North Rhine-Westphalia and centre of the Rhine-Ruhr metropolitan region. The population of the city is nearly 586200. Düsseldorf is in the middle of the lower Rhine basin on the delta of the Düssel River where it flows into the Rhine.

Energy landscape in Düsseldorf roughly as follows:

About 20% of the energy of the city is imported from the company RWE in Essen, such transport is carried at very high voltage, 400 kV. The remaining 80% is generated in Düsseldorf, where substations are approximately 3800 and 2700 which belong to Stadtwerke Düsseldorf. Add that they are able to cover 90% of demand in the city.

Within the city there is a conventional gas turbine that works with a generator and has a capacity of 90 MW (Heizkraftwerk Flingern, it was the first big power plant in Düsseldorf). The more powerful central is Lausward Power Station which has three generators and a power of 580 MW. Lausward cogeneration plant is a combined cycle power plant (CCPP), and since 1957 the largest power plant in North Rhine-Westphalia's capital Düsseldorf. It is located in the port of Düsseldorf and its tall chimneys are visible from far away.

This power station was originally a hard coal power station.Since 1998 the gradual conversion of the power station to natural gas followed. The power station produced also long-distance heating.

Schematically, the distribution of energy in Düsseldorf would be as follows:

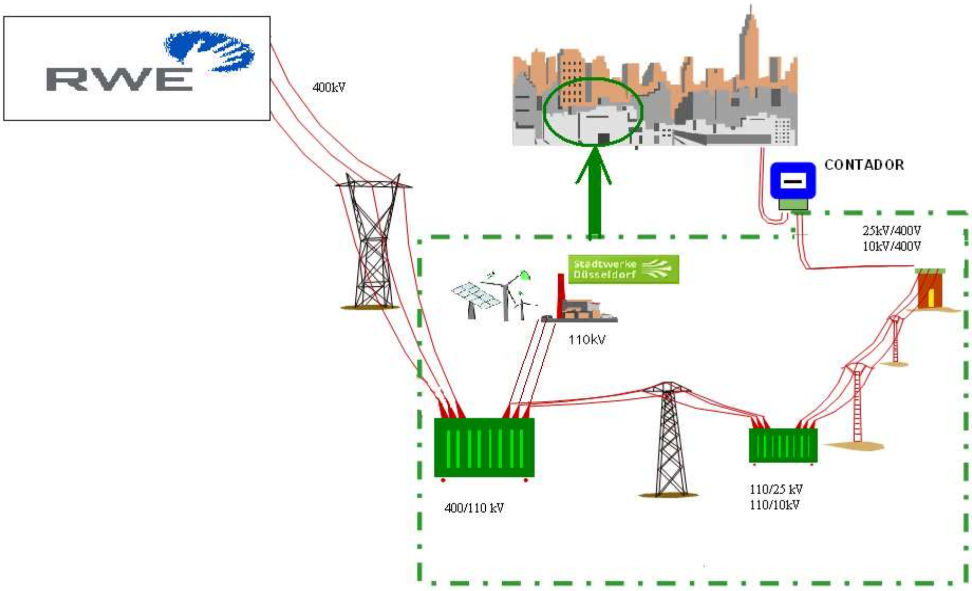
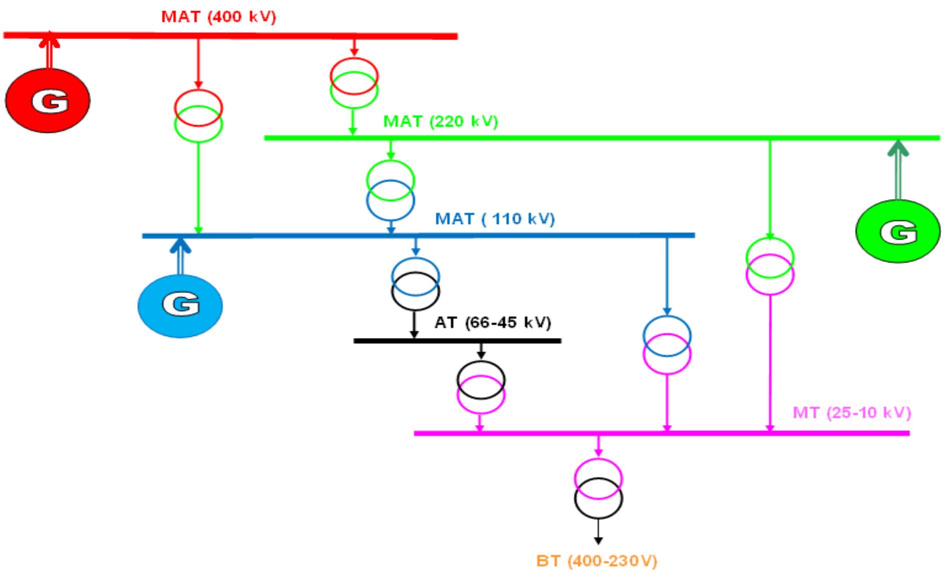


Figure 26: "Electricity path Düsseldorf"

Below we see a line diagram of the network in Düsseldorf:



MAT=Very High Voltage; AT=High Voltage; MT=Medium Voltage, BT=Low Voltage

Figure 27: "Network in Düsseldorf"

The data discussed below date from 2009 and are the lengths of the lines. The source of information has been STADTWERKE DÜSSELDORF:

The length of the network without connections (System) is 9819 km.

High voltage network (110 kV) is 130 km long.

Medium voltage network (10 to 25 kV) is 3383 km long.

Low voltage network (0.4 kV) is 3462 km long.

Also, there are 89623 house connections, 46116 street lighting units and 433701 counters.

2700 stations belong to StadtwerkeDüsseldorf and transformers are about 2800 so, in most substations there is only one transformer. 1500 transformers have power of 630 kVA and the rest are rated at 500 kVA.The remaining stations (1100) are owned by the customers themselves.

Now we are going to see some examples of the Düsseldorf network structure with pictures.

The first image shows an example of very high voltage network that goes from 400 kV to 110 kV:

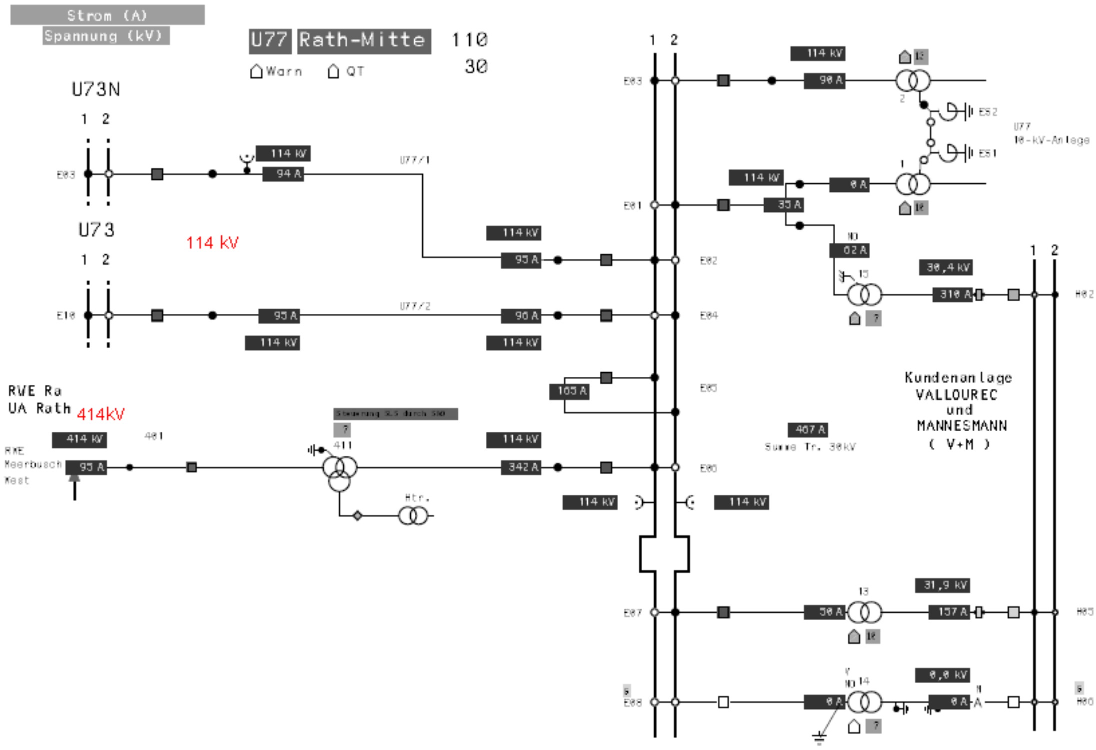


Figure 28: "VH Network Düsseldorf"

Source: Stadtwerke Düsseldorf

The second image shows an example of the network when takes place the conversion of 220 kV to 110 kV:

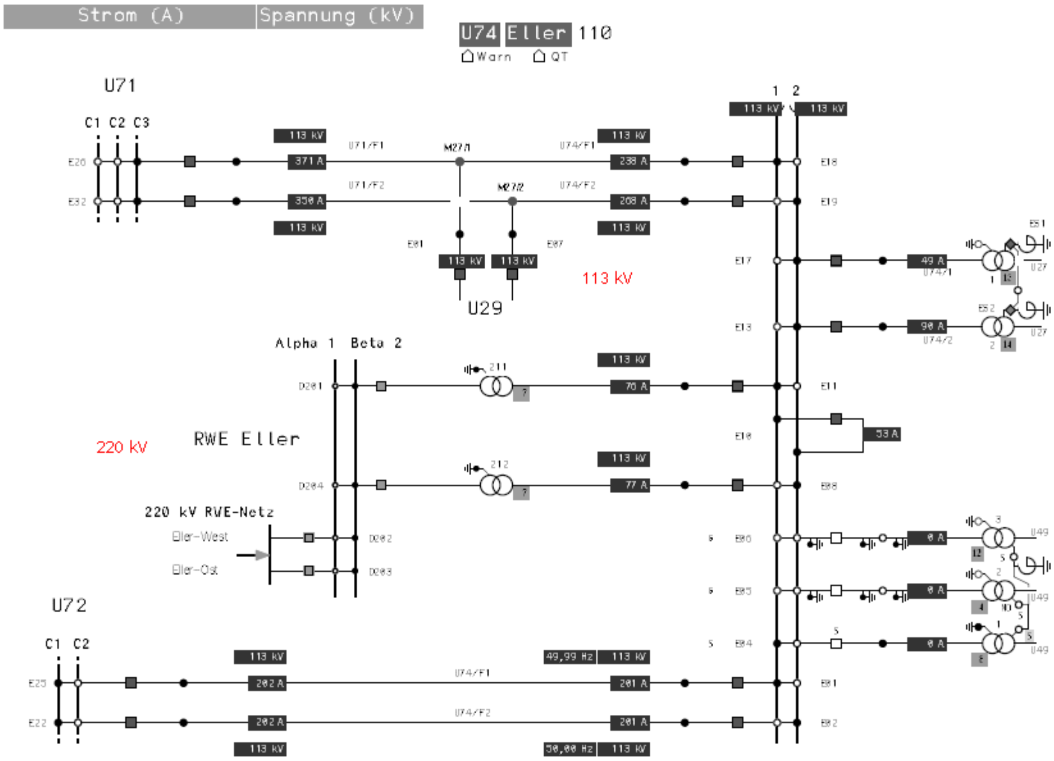


Figure 29: "220kV/110kV Network"

Source: Stadtwerke Düsseldorf

Now we can see an example of the 10000 volts grid in the following picture:

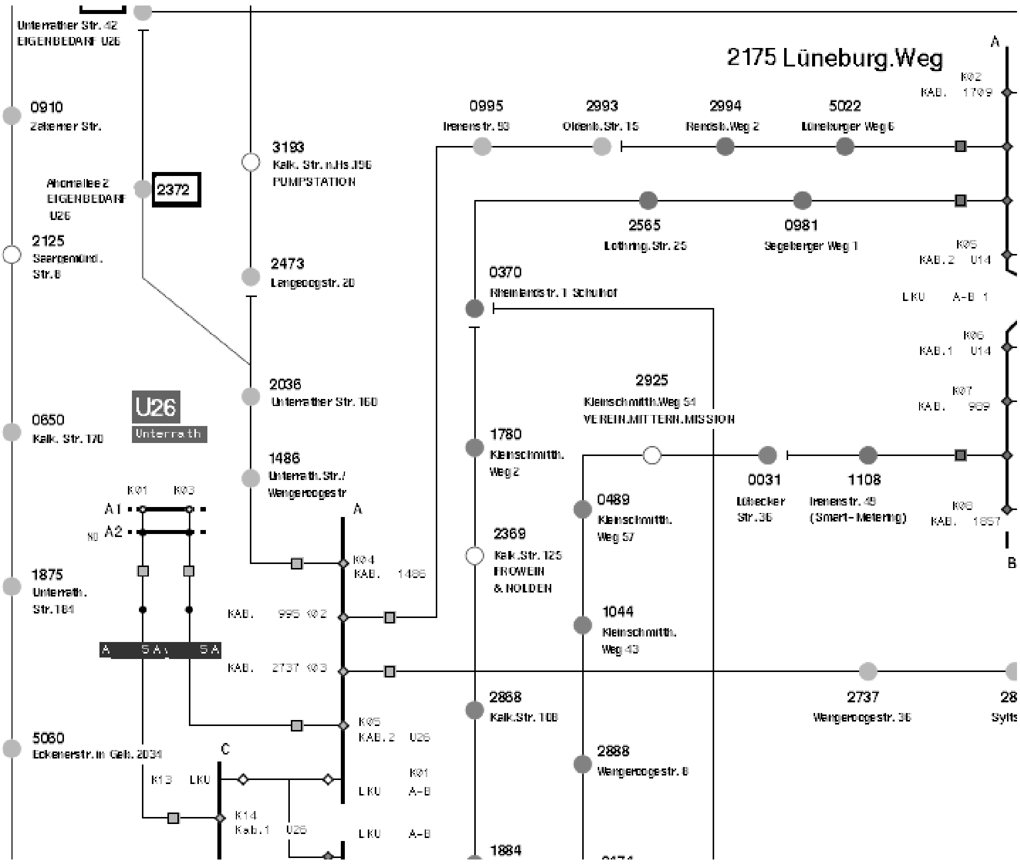


Figure 30: "10kV Grid"

Source: Stadtwerke Düsseldorf

Now let's get into the inside of a typical transformer station.

Firstly we can see the low voltage part with a voltage of 400V:

Figure 31: "Substation Low Voltage part"

Source: Stadtwerke Düsseldorf

It is interesting also the medium voltage part (10000 volts), this figure shows the location of the switches:

Figure 32: "Substation Medium Voltage part"

Source: Stadtwerke Düsseldorf

Finally we see the picture of the transformer which produces the decrease in tension of 10 kV to 400 V:

Figure 33: "MV/LV TRANSFORMER"

Source: Stadtwerke Düsseldorf

4.3. COMPARISON OF MEDIUM/LOW VOLTAGE NETWORK STRUCTURE OF DÜSSELDORF AND MADRID

The first thing to note is that the number of inhabitants is significantly higher in Madrid than in Düsseldorf (4.2 million versus 586.200) and therefore all figures will be higher in relation to demand, production, infrastructure, etc.

Once reviewed this, we proceed to list the features to compare:

1. **VOLTAGES**

We can see in the following picture how the voltages are not exactly the same between both cities:

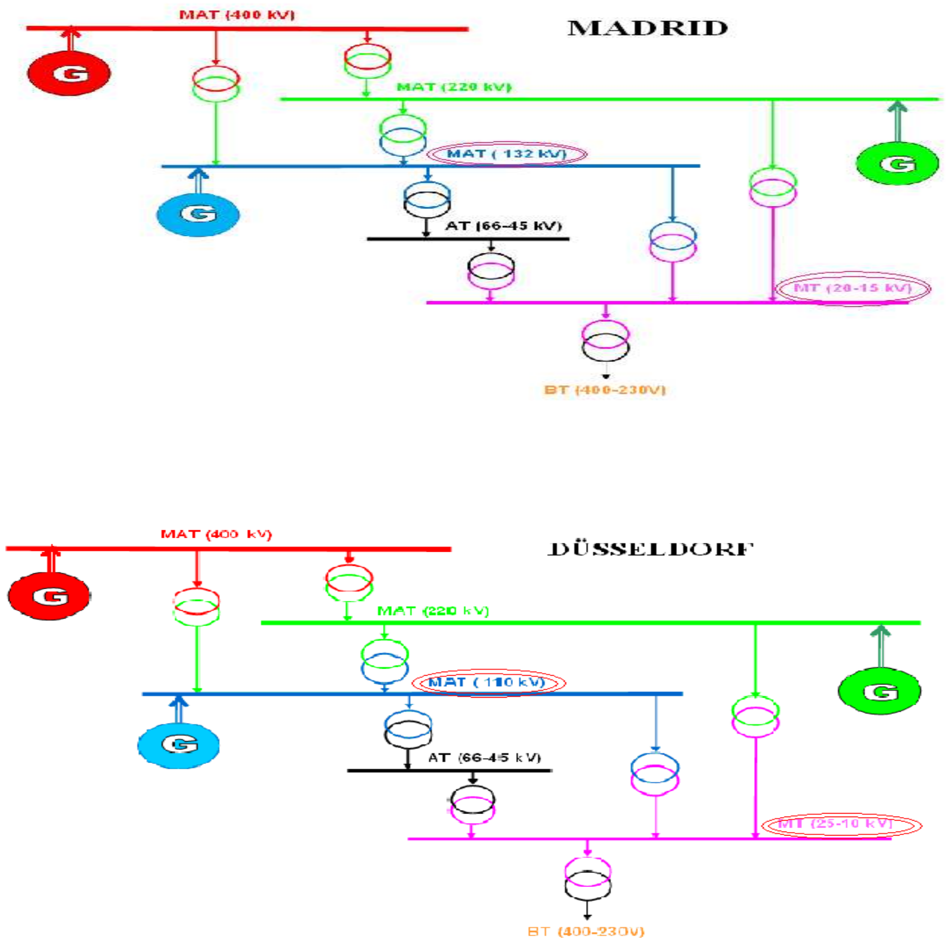


Figure 34: "Comparison Düsseldorf/Madrid Network"

As we can see, the first major difference is that while in Madrid transport of energy at very high voltage is performed at 132 kV, in Düsseldorf occurs at 110 kV.

This can be justified as they need to transport the high voltage power over long distances while minimizing losses and maximizing the power transported.

A voltage increase means a decrease in current through the line to carry the same power and therefore heat losses of the conductors and electromagnetic effects. A higher voltage, lower intensity and, consequently, lower energy loss, which is very important if we take into consideration the fact that power lines are often long distances.

In addition, a greater intensity requires more drivers section, and therefore a higher weight per unit length.

For all these factors, it raises voltage´s transport, reducing the intensity and lowering transport costs.

We appreciate that in Madrid this voltage is greater because, as we will see, the lines are longer and require more transportation energy as demand increases.

In medium voltage the values are also differents, while in Madrid distribution lines are to a tension between 15-20 kV in Düsseldorf they are at a voltage between 10-25 kV.

In relation to this, we can say that the capability to distribute energy is higher in Düsseldorf than in Madrid despite being a smaller city.

2. LENGTH OF THE LINES

We see clearly in the following comparative table as electrical lines are longer in Madrid than in Düsseldorf as the energy in the first city is transported from longer distances and in greater proportion.

MADRID	**DÜSSELDORF**	
1.527 km	130 km	**HIGH VOLTAGE**
9.094 km	3.383 km	**MEDIUM VOLTAGE**
16.925 km	3.462 km	**LOW VOLTAGE**

Figure 35: Table length lines. Source: Stadtwerke Düsseldorf and Iberdrola

3. SUBSTATIONS

Here also we see as the number of substations is higher in Madrid than in Düsseldorf, of course, because of having a higher energy management. According to data provided by Stadtwerke Düsseldorf and Iberdrola Distribución we know that:

In Madrid there are 15.751 centers of energy transformation (processing centers) of medium to low voltage and 5.212 particular or private substations. There are also 2.029.359 counters.

In Düsseldorf there are 2.700 centers of energy transformation (processing centers) which belong to Stadtwerke Düsseldorf and 1100 particular or private substations. There are also 433.701 counters.

4. TRANSFORMERS

Here we find similarities between the two cities because both use transformers of 630 KVA for the most part though each city has its peculiarities:

MADRID:

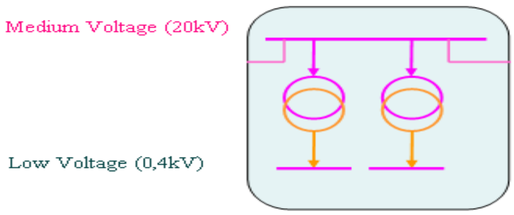


Figure 36: "MV/LV Transformer in Madrid"

Source: Iberdrola Distribution

As we saw in the previous description, the typical configuration is two transformers per substation with a capacity of 630 kVA each.

DÜSSELDORF:

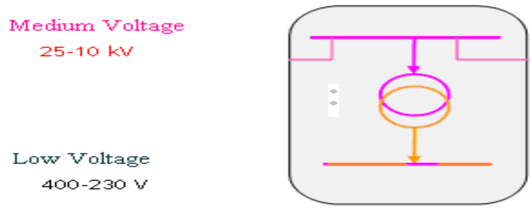


Figure 37: "MV/LV Transformer in Düsseldorf"

Source: Stadtwerke Düsseldorf

The typical configuration in this case is a transformer per substation as there are 2800 transformers for 2700 substations. 1500 of these transformers are rated at 630 kVA and the other nearly all have a capacity of 500 kVA.

5. ENERGY MANAGEMENT

In **Madrid** the energy demand is covered as follows (according to REE):

35.6% Renewable Energies.

16.6% Nuclear.

47.8% Fossile and other energy forms.

According to the Aragonese Institute of Statistics (data for 2009), in the same city 36 GWh is generated by Hydropower and 1677 GWh in special regime (Combinated Heat and Power, waste treatment, biomass, solar energy and wind power).

In **Düsseldorf** the energy demand is covered as follows (according to Stadtwerke Düsseldorf):

27.7% Renewable Energies.

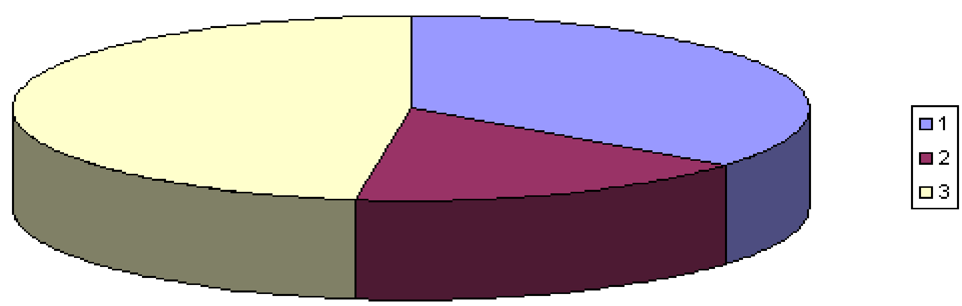
19.8% Nuclear.

52.5% Fossile and other energy forms.

According to Stadtwerke Düsseldorf (data for 2009), 1553704 MWh were generated in the city itself, particularly in Lausward production plant and Flingern power plant.

The following graph shows visually the proportion of each energy used to meet demand:

MADRID



DÜSSELDORF

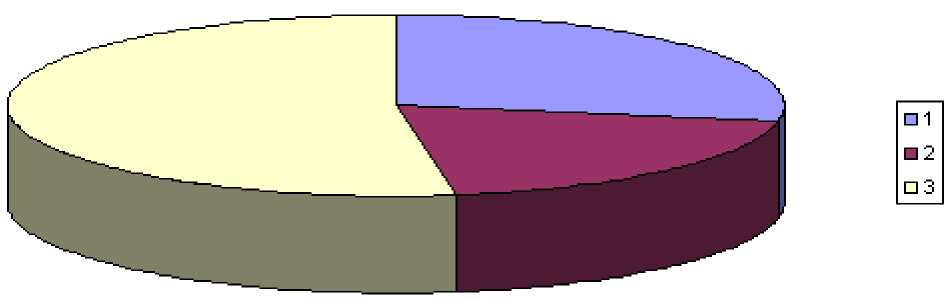


Figure 38: "Graph of energy sources"

Where number **one** in blue is for Renewable Energy, number **two** in maroon corresponds to Nuclear Energy and number **three** in beige color corresponds to Fossil and other forms of energy.

Düsseldorf note that the percentage of energy produced by Fossil fuels and Nuclear energy is higher than in Madrid while the percentage of energy produced by Renewable Energy is higher in Madrid. Both, in this order, produce more energy from Fossil fuels, followed by Renewable Energy and Nuclear Energy finally. We see that although the percentages are different, they are close.

Let us focus now on demand. According to the Aragonese Institute of Statistics, the total demand in Madrid in 2009 was 30.528 GWh while in Düsseldorf, according to Stadtwerke Düsseldorf, the total demand in 2009 was 2.657.250 MWh.

These data are logical to be considerably more numerous population Madrid than Düsseldorf. But if we make a more thorough analysis, such as calculating the consumption per capita per year will get the following results:

MADRID: $$\frac{30528 \cdot 10^6 \, kWh}{4{,}2 \cdot 10^6 \, hab} = 7.269 kWh / hab$$

DÜSSELDORF: $$\frac{2657250 \cdot 10^3 \, kWh}{586200 hab} = 4.533 kWh / hab$$

(Although data provided by Stadtwerke Düsseldorf told us that the average consumption per capita and year is 4.528 kWh in Düsseldorf, to be exact.)

It is curious that, according to UNESA (Spanish association of electric industry), as seen in the table below, the consumption per capita in Germany is higher than in Spain:

Consumo de electricidad "per capita" de los países de la Unión Europea

	Consumo "per capita" (kWh/hab)
Luxemburgo	13.703
Bélgica	8.313
Francia	7.965
Austria	7.698
Holanda	7.032
Alemania	6.744
Eslovenia	6.391
República Checa	6.131
España	**5.721**
Italia	5.629
Eslovaquia	4.881
Grecia	4.774
Portugal	4.736
Hungría	3.893
Polonia	3.422
Media	**6.149**

Fuente: UNESA.

Figure 39: "Per capita consumption table"

Source: UNESA

But if we focus our attention on our subject, which is the comparison between Düsseldorf and Madrid, we note that a resident of Madrid consume about 1.6 times more than an inhabitant of Düsseldorf, which is a big plus for the city Düsseldorf because it is an indicative of the social consciousness of the importance of saving energy.

5.NEPLAN SIMULATIONS OF POWER SYSTEMS WITH ELECTROMOBILITY

With the program called Neplan and with data supplied by the company Stadtwerke Düsseldorf concerning the network architecture of this city, we will study the results of the load flows on a small part of the Düsseldorf network located in the south of the city (Haberstrasse Wersten) with the massive influx of electric cars.

For this study we assume a standard battery of 30 kWh which is the most usual used in the available electric cars nowadays. The instantaneous power consumed depends on the recharge time, so we will see five different cases that are a slow recharge of 8 hours, the intermediate recharges (4 hours and 2 hours) and two fast recharges of 1 hour and 20 minutes.

Because we only have a demo version of Neplan, we cannot study the most real case according with the data from Stadtwerke that would be 3 lines for each transformer, each line with 10 loads for the houses and 10 loads more for the electric vehicles in the case that each house had just one electric vehicle. So we have decided to study a single line with 20 loads, 10 for houses and 10 for the electric vehicles, for each kind of recharge.

However, to show that the transformer could support the 3 lines with all electric vehicles connected with the fast recharge at the same time, we have also done a study with 3 lines but with half elements and the double load, due to the demo version doesn´t allow put more than 30 elements. This is the most real case that we could simulate with this program. We will see this section at the end of this chapter.

We will start seeing the flow load of this part of the Düsseldorf network **without electric cars**, with an average consumption per household of 6 kW. The result is as follow:

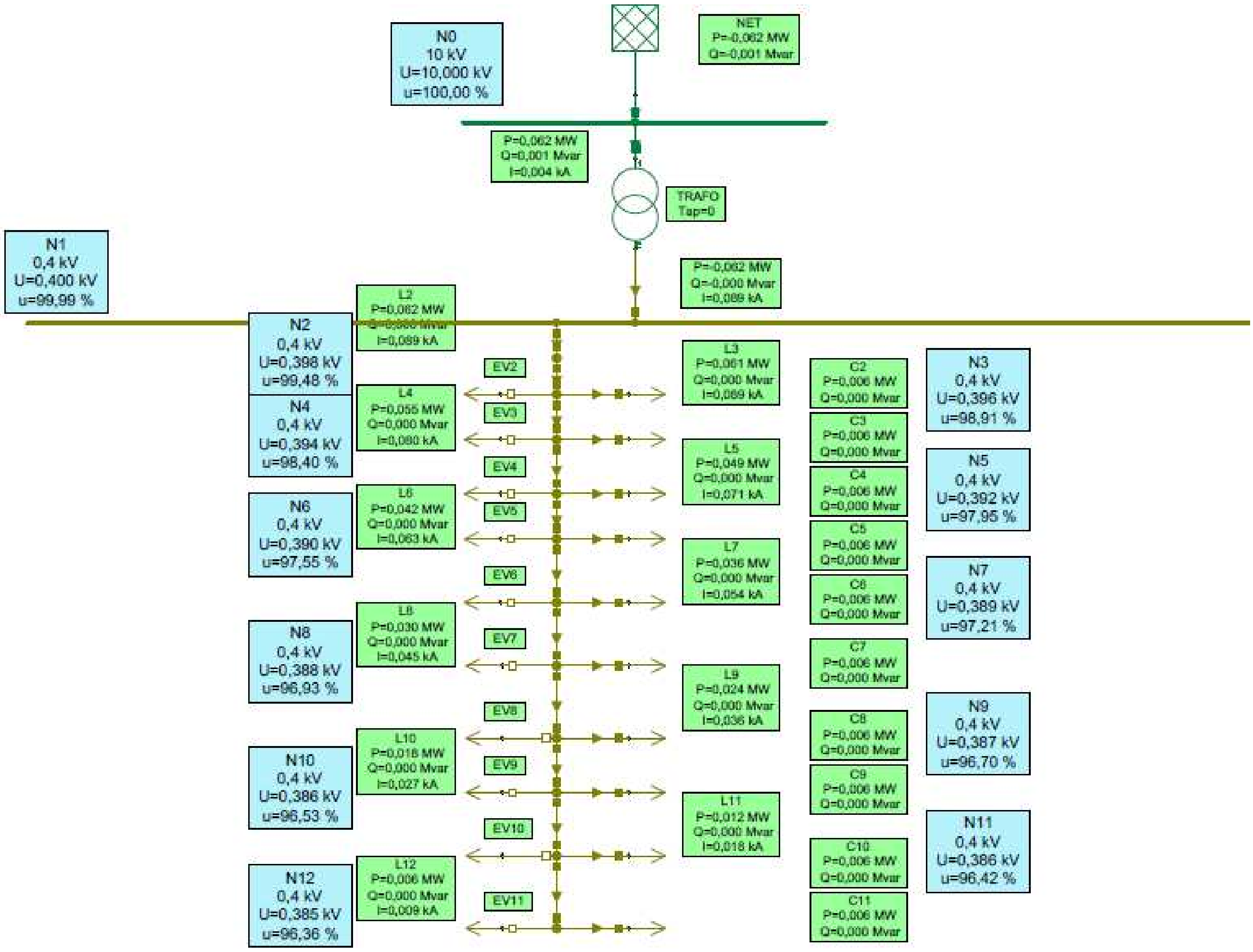


Figure 40: "Load flow without Electromobility"

All parameters are within limits, as well as the voltage in the last node (more than 90%) and the supported current of the cables.

Then we will see the results of the **slowest recharge** which during **8 hours**. To calculate the instantaneous power consumed for the battery we have done the follow calculation:

$$\frac{30kWh}{8h} = \mathbf{3,75kW}$$

So according to there is only one electrovehicle in each home, we have 10 loads of 6 kW for the houses and 10 loads more of 3,75kW for each car.

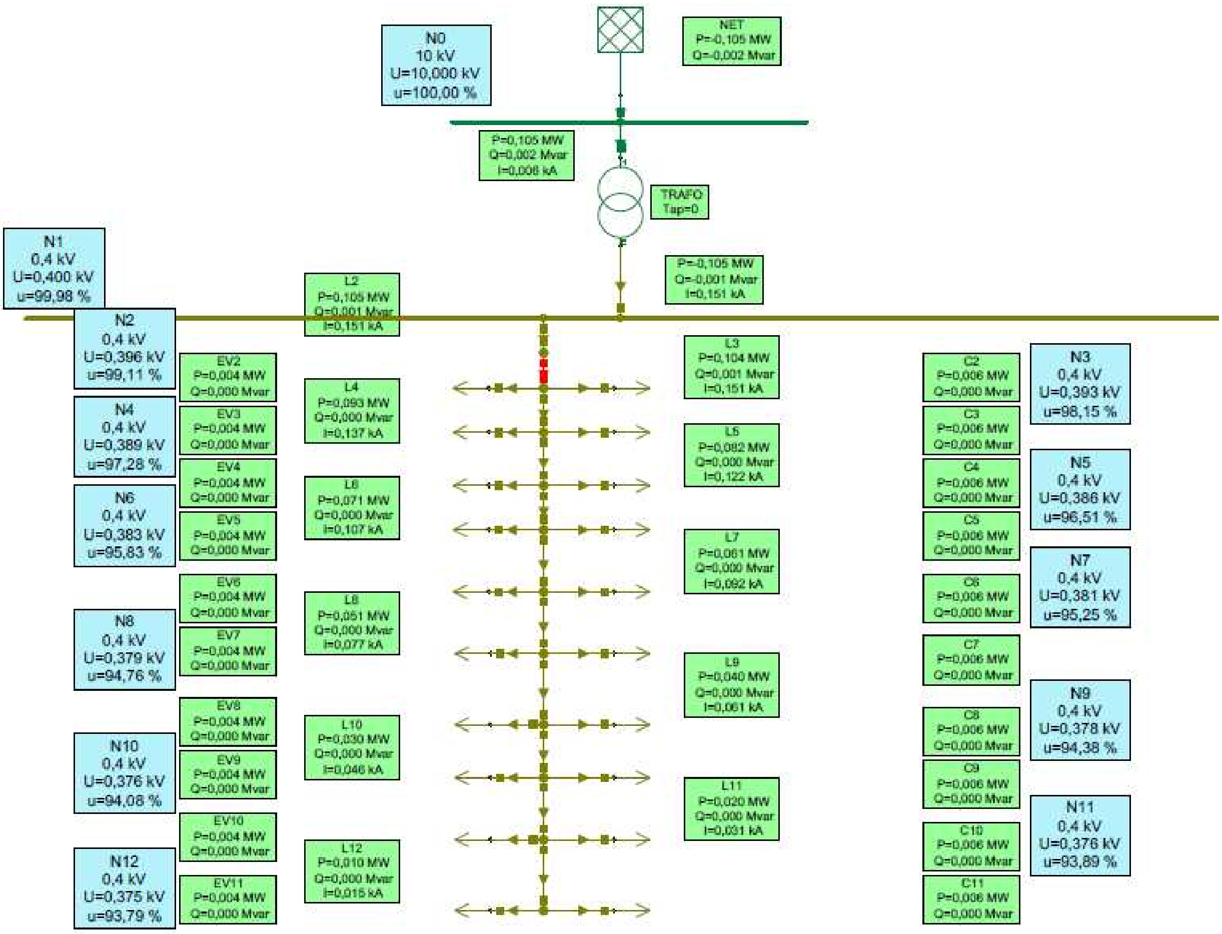


Figure 41: "Load Flow with slow recharge"

We can see the voltage on the last node is within the limits too, but a section of the line cannot support the current flowing. We will see the possible solutions to this problem in the next chapter.

The next case is with a recharge of **4 hours**:

$$\frac{30kWh}{4h} = \mathbf{7,5\ kW}$$

So changing the value of the electric cars loads, we get the following results:

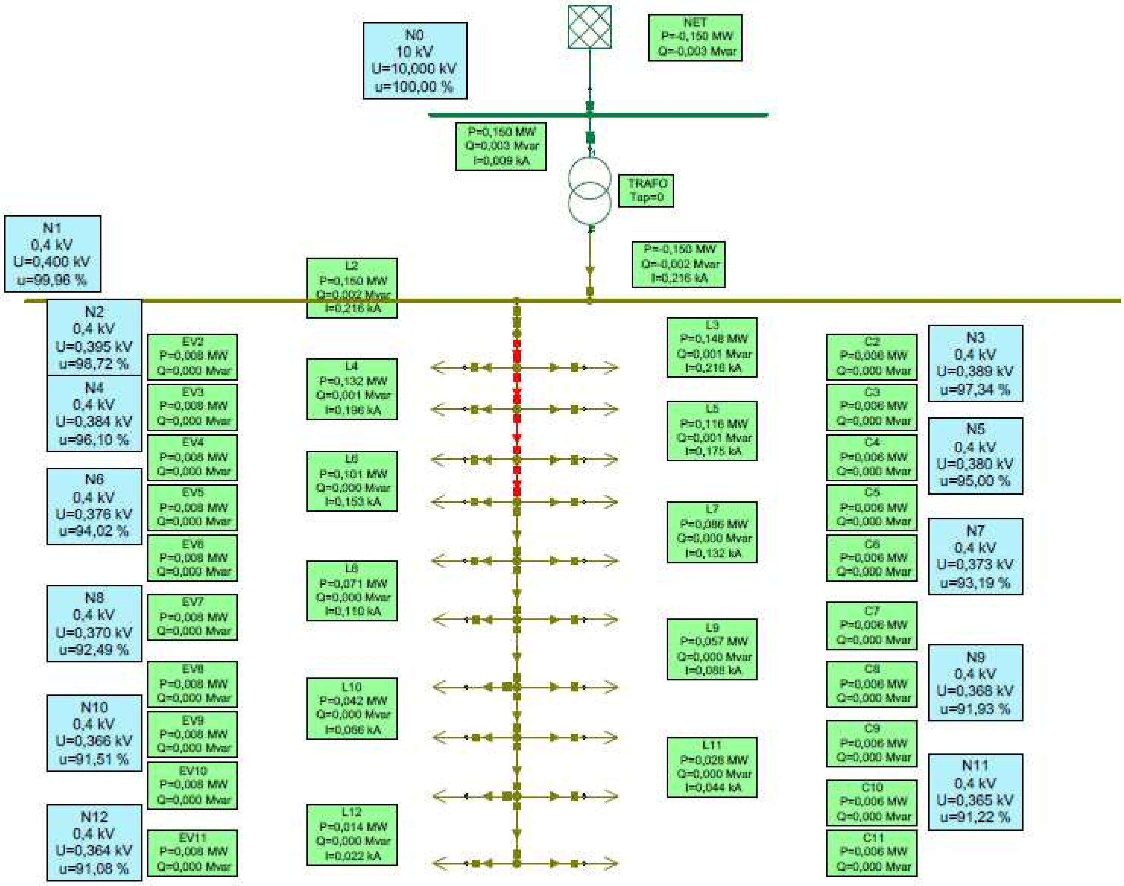


Figure 42: "Load Flow with 4 hours recharge"

With this kind of recharge the voltage level on the last node is also within the limits (bigger than 90%), but we have problems in four parts of the line, because if the power demand increase keeping the same voltage level, the current will be bigger so some parts of the line couldn´t support that current.

So as we said previously, we will see possible solutions in the next chapter.

If we want to recharge cars with this type of battery in **2 hours**, the demand of each car will be:

$$\frac{30kWh}{2h} = 15\ kW$$

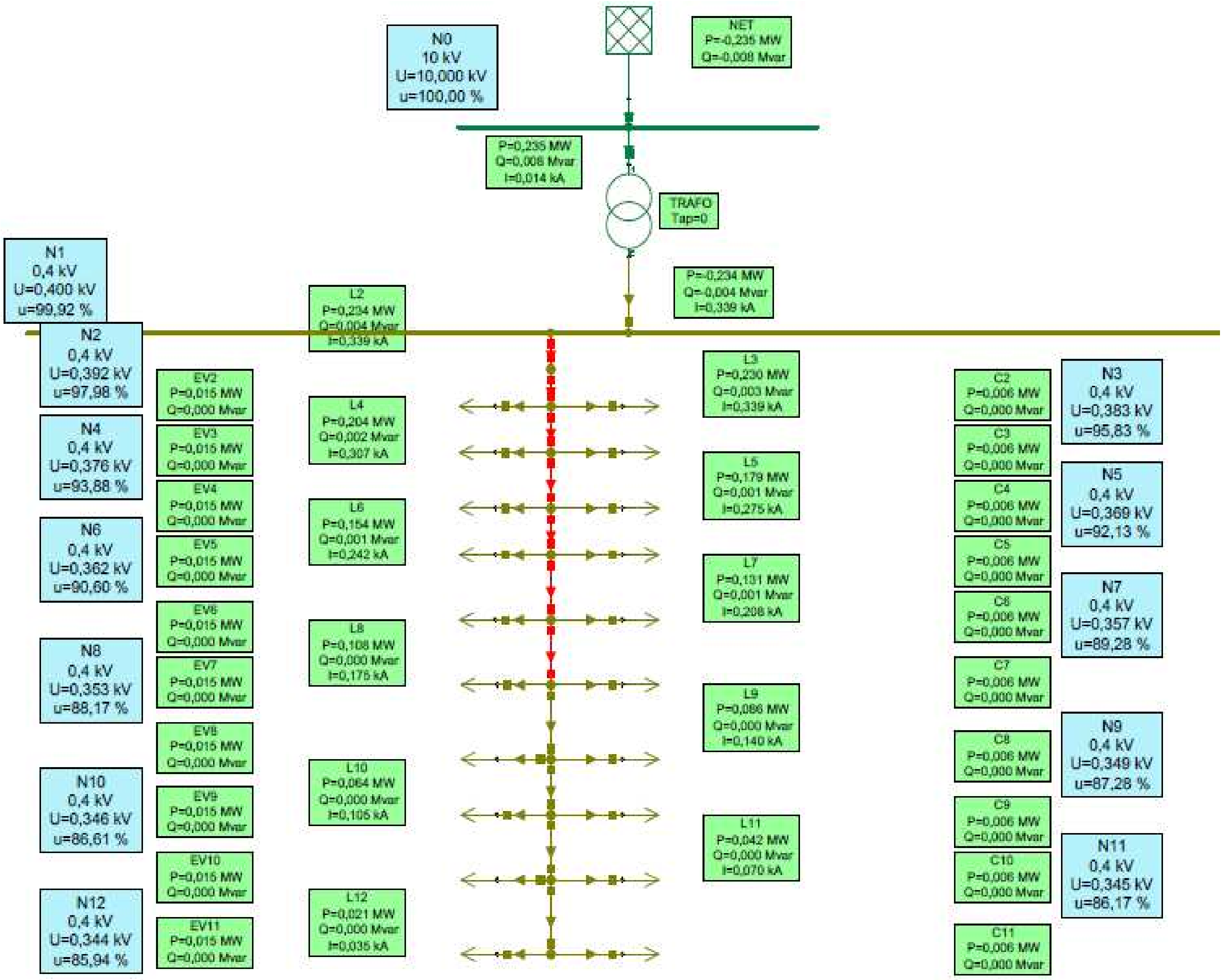


Figure 43: "Load Flow with 2 hours recharge"

As we can see, in this case there are 7 parts of the line where is flowing more current than the cables can support and also the voltage on the last node falls bellow 90% that is a problem for the company that distributes the electricity because they have to ensure a voltage level 90% above the nominal value for all consumers.

Can previse that with a faster recharge, the voltage level will fall more and the line current will be higher. We can see it in the results for a recharge of **1 hour** and 30 kW:

$$\frac{30kWh}{1h} = 30\ kW$$

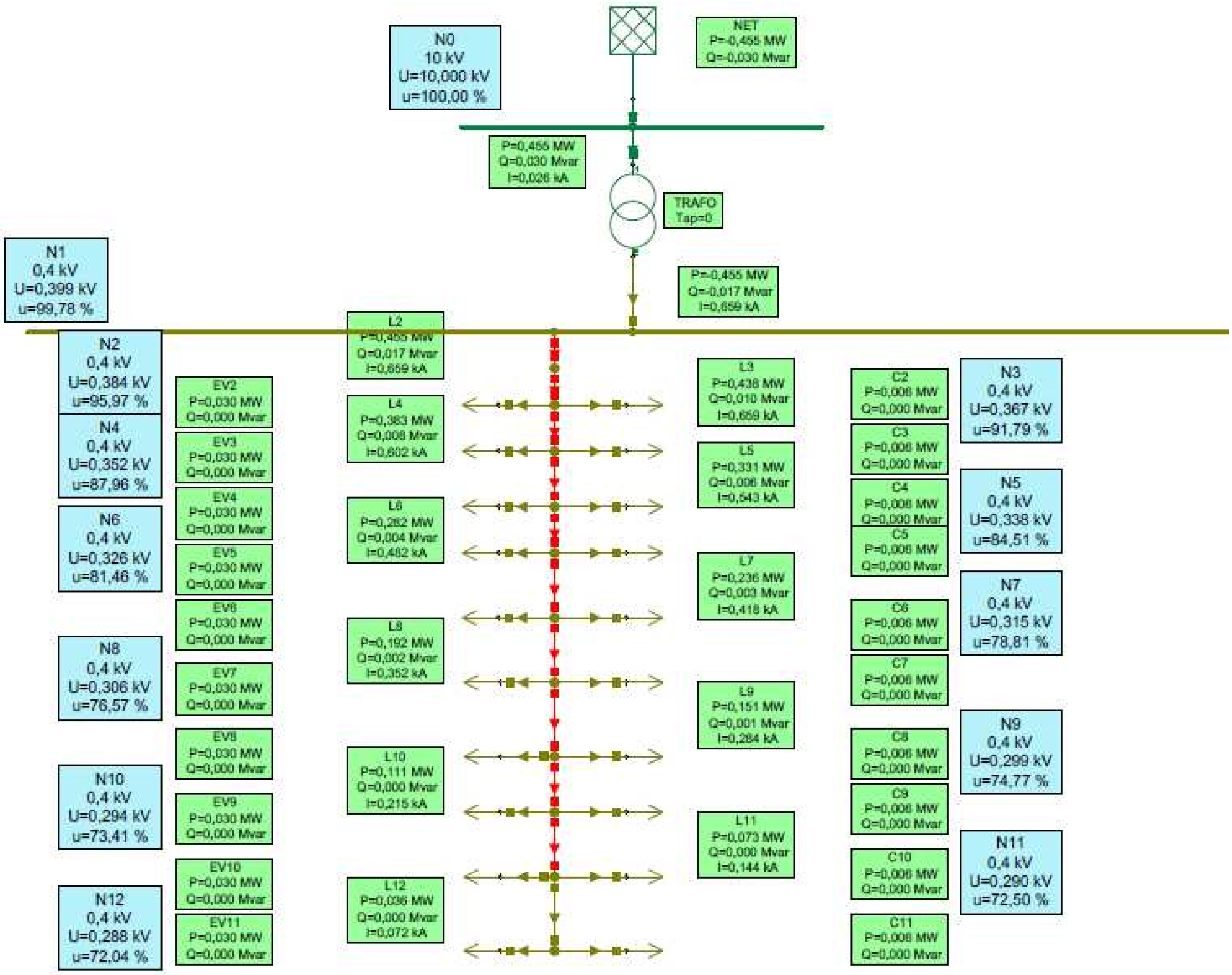


Figure 44: "Load Flow with 1 hour recharge"

In this case the voltage level fall until 72,04% on the last node and only one section of the line can support the flow current, so we need real solutions for make possible the fast recharges of the electric vehicles.

The last recharge example is the fastest one which during only **20 minutes** but cause serious problems to the network.

$$\frac{30kWh}{1/3h} = \mathbf{90\ kW}$$

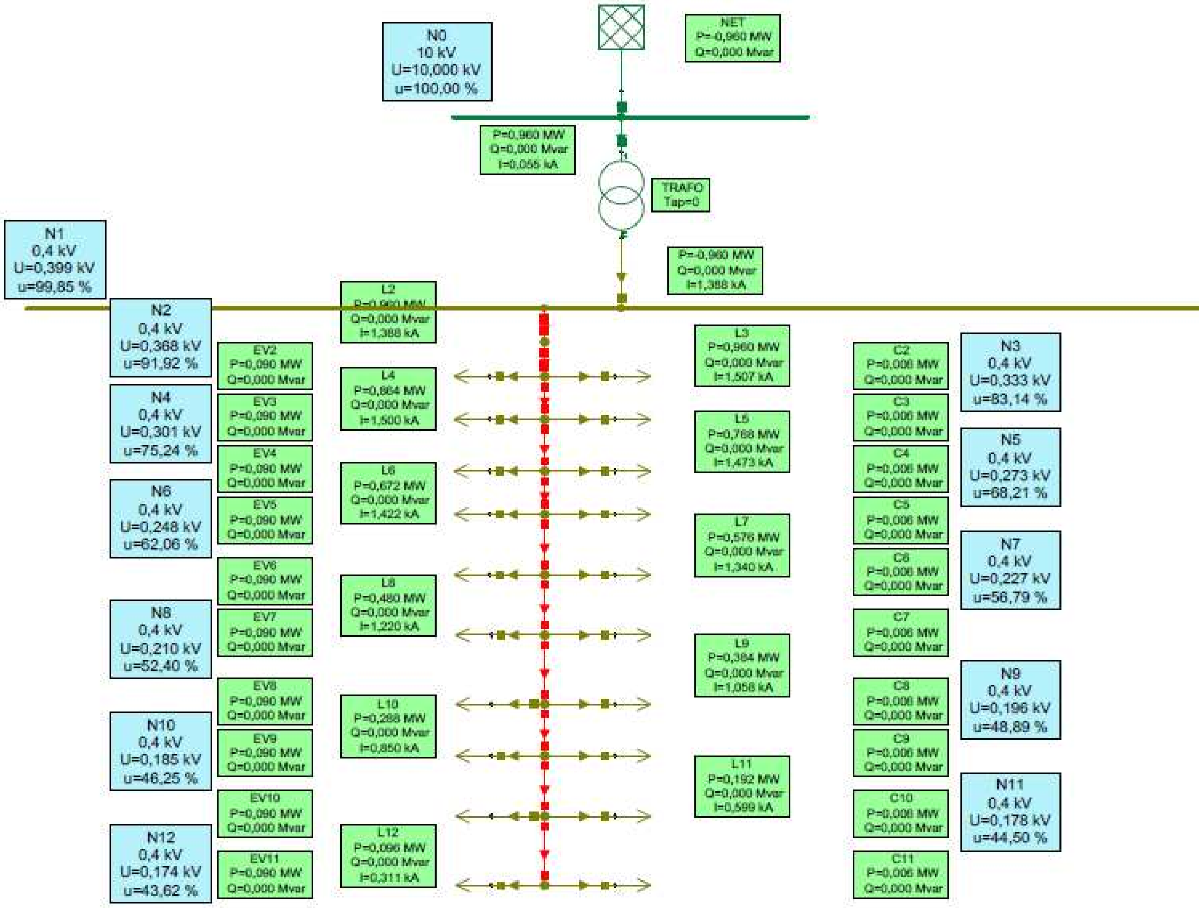


Figure 45: "Load Flow with 20 minutes recharge"

In this case the program gave problems because the voltage on the last node is completely and wildly out of the limits (43,62%) and also the current is very high for these type of cables.

Before go to study the solutions for the problems in the network that we have got with the program and could make possible the integration of the electric cars in the net, we will see if the transformers could support the actual configuration with 3 lines for each transformer, or they should be replaced for another bigger if there was an electric car in every houses and every people wanted to recharge it at the same time.

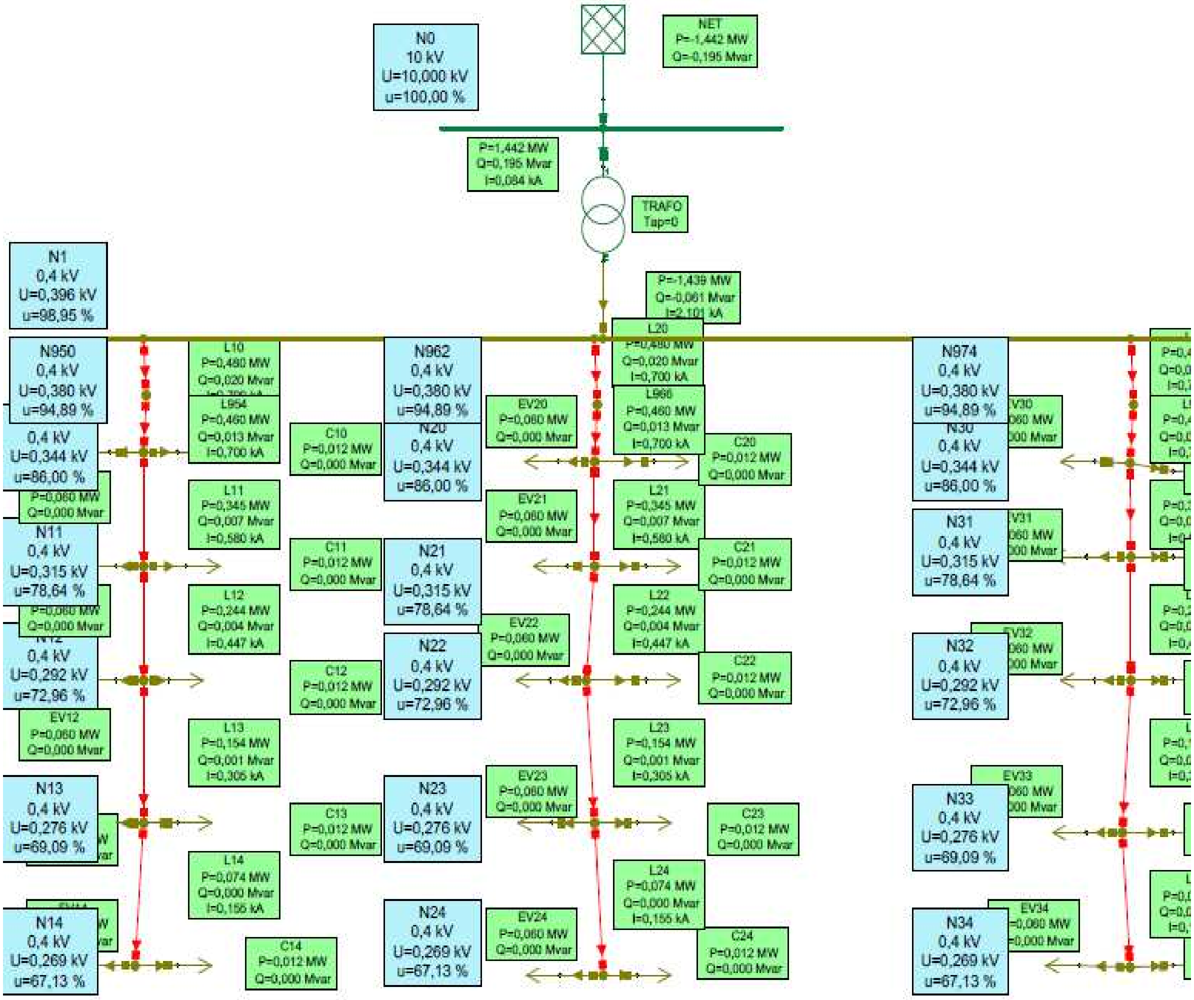


Figure 46: "Power System with Electromobility"

As we can see, the voltage on the last node is lower than with only one line for the same recharge (1h, 30kW) because each part of the line is longer, so there will be more voltage drop in each part.

We can see again that the flow current is higher than the current the cables can support, but the transformer doesn´t have any problem with all the loads connected. It can provide the total power but maybe it would need more cooling than without electric cars.

6.TECHNICAL REQUIREMENTS OF THE NETWORK AS A RESULT OF ELECTRIC CARS

As we saw in the results with Neplan, we have problems in the cables because if all electric cars are connected at same time the current flowing through the cables will be higher than it can support, even with the slowest recharge (8 hours).

Also the electricity distribution company (in this case Stadtwerke Düsseldorf) would have problems to ensure a voltage level higher than 90% to the consumer on the last point of the line as law required.

For find possible solutions, we are going to see the results of each recharged with more detail.

If all cars do a **slow recharge of 8 hours**, only would be necessary change the second cable of the line for another one bigger that could handle the current that flow. It can support 142 amperes and with this kind of recharge flow would be 151 A, so change just this part wouldn´t be so expensive because all of the others cables can support the current that is flowing and also the voltage level on the last node is within the limits (93,79%).

With a **recharge of 4 hours** the first cable can support the current but not the following four. The voltage level on the last node is 91,08% so it is within the limits, so this type of recharge could be viable changing the four cables for others bigger but do this operation would be expensive for the companies and as result the consumers could suffer a rise in the electricity price.

The three **quickest recharges** studied are not viable for the current urban infrastructure because in all the cases the voltage on the last node is out of limits and the flow current is so much higher than in the previous recharges, so it would need change mostly of cables for others bigger for support the current and with less impedance for reduce the voltage drop.

This work would be expensive so the better solution for can make possible the fast recharges is build special charging points in public places, like supermarkets or garages of workplaces, with the infrastructure appropriate for supply the necessary power. So slow recharges may be make in the garages of the houses and fast recharges only may be make in the recharges points enabled for that use.

As for the slow recharges as for the fast recharges is necessary the implementation of a smart system in the recharges points that can make possible the connection between the electric vehicle and the net for a better energy management. This topic will discuss on the next chapter.

7. POSSIBLE FINAL SOLUTIONS FOR THE OPERATION OF THE ELECTRIC CARS

As we have seen, electric power systems are facing a major new challenge: the future integration into the grid of massive electric vehicle (EV).

In terms of the electric power system, EV can be considered as:

-Simple loads, when their owners simply define that the batteries must be charged at a certain rate;

- Dynamic loads/storage devices, if their owners define a time interval for the charging to take place, allowing some EV management structure to control that process.

If we understand EV as a simple load, it represents a large amount of consumed power, which easily can approach half the power consumed in a typical domestic household at peak load. Therefore, it is easy to foresee major problems of congestion on already heavily loaded networks and problems of tension in predominantly radial profile networks, especially if the peak periods coincide with EV charging periods.

There are two ways of adapting the presence of EV battery charging on distribution networks. The first is to plan for new networks in a way that can be handled completely new charges, regardless of the control scheme, which requires heavy investment in network reinforcement to do so. The second is to create an intelligent management system that fully integrates EV in the power system, the exploitation of the potential also to store energy and thus optimizing network investments. The latter is, of course, the way it should be done:

I. V2G networks. Intelligent Networks and Smart Grids:

V2G is an acronym for “Vehicle To Grid”.
Nowadays this type of networks are under consideration but if the electric car reaches the expected popularity, these intelligent networks are the next step to develop.
This technology allows energy´s storage in the valley hours and recovery of electricity at peak times from batteries of electric vehicles to the network.
V2G can charge the batteries during valley hours, when the kWh is cheaper, and sell to the grid at peak hours, when kWh is more expensive.
So, with the V2G everyone wins: the owners of the vehicles, electricity companies, society and the planet, although this requires creating an entire infrastructure no longer exists.

Figure 47: "Vehicle to Grid"

The charging of electric vehicles can be conductive or inductive. The conductive system is the direct connection to the network as simple as plugging vehicle through special high capacity cables with connectors that protect the high voltage conductor. Inductive coupling has the advantage of preclude any shock, but is more expensive and less efficient than the first. Inductive charging consists in that a few electric cars could be adapted to recharge simply by parking on a plate transmitting on the road. Citroën electric cars are already equipped with receiving plates under the car, allowing the vehicle to automatically recharge wirelessly.

Figure 48: "Conductive System"
Source: Chinadaily

Figure 49: "Inductive System"
Source: Blog de Ingeniería en Redes y Tecnología Digital

Network provides power to the vehicle in AC mode. Normally, the charger converts AC mode into DC mode and provides energy properly to the batteries (from here is supplied to the engine and the wheels).
Some engines operate in AC mode, so that an investor must convert the DC of the battery.

As the price of energy is lower in valley periods, it would be usual to recharge the batteries at night. A Smart Grid with a large number of charging points in roads and parking areas with appropiate software would tell the car when to recharge, stop and even shed electricity to the network.

On average 95 percent of all cars are parked in a particular time, being used on average an hour a day. It would be desiderable economic incentive (as we saw in the Chapter of Electromobility nowadays) for making the recharges in the valley hours and allow to use the enery stored in the batteries in case of need paying for that energy a higher price.

The intelligent load management, how to make the interconnection of charging points with the system supplier and a tariff model that is in line with the new demand, are the main challenges facing industry to make the electric car can also perform the function of regulator.

That is why electric vehicles can play a key role to start better manage the network, flattening the load curve, use the active reserve much of which is wasted (the amount of electricity available to ensure the immediate availability when needed by an unexpected increase in the demand) and permit an increase in the contribution of wind and other energy renewable, and may involve a restructuring of the electric and transport leading to new specialized companies.

An electric vehicle type, which runs some 17,000 miles a year, and makes recharge by 80% night rate, would spend about 800 euros a year in electricity. Travel the same distance with gasoline or diesel cost around 2,000 or 2,500 euros in fuel, given normal driving patterns.

The Californian company AC Propulsion has been the first to develop electric vehicles with two-way communication with the network, the eBox, which incorporates TZero patented technology. This system allows bidirectional power flow for 50 or 60 Hz, allowing the vehicle's own battery provides power even to a house. It also allows the connection between vehicles (V2V, vehicle to vehicle) thus enabling to perform a roadside assistance to an electric vehicle that have run out of battery power by applying a fast charge.

When EV are required to make long trips, battery replacement stations will start appearing outside city areas, perhaps nearby main roads. The concept of “Electrolinera” born in the company Better Place, which has its headquarters in California. The idea is to have a service station for electric cars where they recharge batteries in about a minute through the exchange of their batteries.

II. Electric Car Battery Swap Station (ECBSS):

Such stations would consist of a robotic device completely change the car battery for a full load.

Explaining the process is entering a rail car wash type which will accommodate on a mechanism to remove the battery that is below the car and then mount the new one to go down a ramp as if nothing in no time.

Figure 50: "Better Place ECBSS"

Source: Noticias.coches

Better Place has the idea that all the infrastructure necessary for the operation of the station is installed underground, and that the same store about 12 batteries with electrical connection to the network, to load all the stock within one hour. In the future we will see in California, Israel, Denmark and the main cities of Spain.

Undoubtedly it is an interesting idea but not very useful unless it is for a specific sector such as the carriers with fleets of cars as a normal user is not generally end up charging the car battery in a day, can get home and plug or relying on charging ports in public parking lots, shopping centers or their own offices.

The biggest problem is that all automakers would have to make their batteries and containers of them in a standard way to perform well throughout, but as we know the consensus between the marks seems impossible.

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9. ACRONYMS

EV: Electric Vehicle

DGs: Dirección General de Seguros (General Insurance)

C.S.I.E.: Conference and Industry Sector Energy

PHEV: Plug-in Hybrid Electric Vehicle

BEV: Battery Electric Vehicle

GEFGNDP: German Electromobility Federal Government's National Development Plan

CSPEVS: Comprehensive Strategy for the Promotion of Electric Vehicles in Spain

HEV: Hybrid Electric Vehicle

GIS: Gas Insulated Switchgear

ST: Substation

TC: Transformation Center

CGP: Cuadro General de Protección (General Protection Box)

UNESA: Asociación Española de la Industria Eléctrica (Spanish Association of the Electricity Industry)

AC: Alternating Current

DC: Direct Current

V2G: Vehicle To Grid

ECBSS: Electric Car Battery Swap Station