STUDY OF THE ELECTRIC VEHICLE IMPLEMENTATION ON THE SMART GRID

Electric engineering final year project
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<th>Full Form</th>
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<tbody>
<tr>
<td>BC</td>
<td>Battery Charger</td>
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<tr>
<td>BFEF</td>
<td>Building Feeder Energy Flow</td>
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<tr>
<td>BMA</td>
<td>Barcelona's Metropolitan Area</td>
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<td>CB</td>
<td>Cars Batteries</td>
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<tr>
<td>C/I</td>
<td>Cars/Inhabitant ratio</td>
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<td>CU</td>
<td>Coefficient of Use</td>
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<tr>
<td>DG</td>
<td>Distributed Generation</td>
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<tr>
<td>DOE</td>
<td>Department Of Energy (US)</td>
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<tr>
<td>DOD</td>
<td>Depth Of Discharge</td>
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<tr>
<td>DSO</td>
<td>Distribution System Operator</td>
</tr>
<tr>
<td>EDSO</td>
<td>European Distribution System Operators</td>
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<tr>
<td>ENTSO</td>
<td>European Network of Transmission System Operators</td>
</tr>
<tr>
<td>ES</td>
<td>Electric Substation</td>
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<tr>
<td>ESEF</td>
<td>Electric Substation Energy Flow</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
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<tr>
<td>EV</td>
<td>Electric Vehicle</td>
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<tr>
<td>FC</td>
<td>Flow Control</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>HV</td>
<td>High Voltage</td>
</tr>
<tr>
<td>HVEF</td>
<td>High Voltage line Energy Flow</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating, Ventilating and Air Conditioning</td>
</tr>
<tr>
<td>IB</td>
<td>Inertia Battery</td>
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<td>IEA</td>
<td>International Energy Agency</td>
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<tr>
<td>IFCS</td>
<td>Intelligent Flight Control System</td>
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<td>JRC</td>
<td>Joint Research Center</td>
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<tr>
<td>LHV</td>
<td>Lower Heating Value</td>
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<td>LV</td>
<td>Low Voltage</td>
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<tr>
<td>MV</td>
<td>Medium Voltage</td>
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<tr>
<td>MVEF</td>
<td>Medium Voltage line Energy Flow</td>
</tr>
<tr>
<td>M2M</td>
<td>Machine To Machine</td>
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<tr>
<td>NPV</td>
<td>Net Present Value</td>
</tr>
<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicle</td>
</tr>
<tr>
<td>REN</td>
<td>Red Eléctrica de España</td>
</tr>
<tr>
<td>SAR</td>
<td>Sistema de Ayuda a la Reposición del Servicio</td>
</tr>
<tr>
<td>SEACON</td>
<td>Sistema Experto de Análisis de Contingencias</td>
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<tr>
<td>SG</td>
<td>Smart Grid</td>
</tr>
<tr>
<td>SOC</td>
<td>State Of Chrage</td>
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<tr>
<td>TC</td>
<td>Transformation Centre</td>
</tr>
<tr>
<td>TCEF</td>
<td>Transformation Centre Energy Flow</td>
</tr>
<tr>
<td>TCO</td>
<td>Total Cost of Ownership</td>
</tr>
<tr>
<td>TSO</td>
<td>Transmission System Operator</td>
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<tr>
<td>US</td>
<td>United States</td>
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<tr>
<td>V2G</td>
<td>Vehicle To Grid</td>
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<tr>
<td>VAC</td>
<td>Vehicle Availability Coefficient</td>
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Summary

Since some years ago the electric vehicle popularity, and so the pluggable hybrid, notably increased although it's not a brand new development. To understand it, together with the oil prices rise, another factors are to be considered like the CO2 emissions reduction or the fossil fuels dependence.

This work is devoted to the study of the electric vehicle integration on the Smart Grid exploring the synergies and the challenges of it. Geographically the study illustrates the Spanish case using as a main data inputs the International Energy Agency forecasts for western Europe together with some highly valuable European Union studies, especially those issued by the JRC.

On a first step an electric vehicle market penetration investigation shows that, on year 2030, a 21% of the cars running trough the Spanish roads will be electrically powered. The impact of such a presence of electric vehicles could be assumed, disregarding power grid meshing requirements, by the Spanish electric generation pool and transport infrastructures even if no improvement on them takes place on the next 15 years. The bottleneck will then be found on the low voltage distribution systems and their associated medium voltage lines, that will not be able to hold the electric vehicle deployment forecast unless their capacities are increased or the users car availability is impaired. A solution must be found to this fix this issue that should also explore all the possible synergies with the rest of the electrical system.

As a result two countermeasures arise preserving as much as possible the cars availability to their owners. One is to size up all the low voltage and related medium voltage systems to accommodate bigger power flows solving the main problem but doing nothing to integrate the steadily increasing renewal energy that should be consumed when is produced or stored on expensive, environmentally harmful, hydropower pumping stations. The other countermeasure, the main outcome of the next pages, derives from the functionalities of the Smart Grid and is in fact a reviewed version of the, yet popular, Vehicle To Grid (V2G) strategy. Its about to add an inertia battery emulating the inertia tanks in central sanitary water production facilities. Such a kind of proposal is possible because the grid-wide information share and distributed control that lies on the Smart Grid concept. The countermeasure will allow not only a 21% presence of the electric vehicle but even a 100% with almost no cost for the owners, will greatly help the renewables integration as offers a big energy storage capacity on valley hours without compromising the electric vehicles batteries life and also could prevent outages acting as a grid energy supplier in some cases.
1 SMART GRID CONCEPTS AND HISTORICAL BACKGROUND

A short but clarifying definitions adopted by the United States (US), the European Union (EU) and the International Energy Agency (IEA) together with a background review is to be shown through the next points.

Out of this pages there are another countries as Japan, China or India, who is facing a very strong need of adding smartness to his electric power infrastructure, that also do have special programs to drive the transition to the Smart Grid (SG). Only a matter of time and space, not relevance, justifies that they do not appear in this study.

1.1 EARLY TIMES

It was as far as middle of eighty’s [’] when, during a flight, two Israeli F-15 fighters collided in the air resulting in serious damage of one of them that loosed lifting and control planes, even if such a picture usually ends by a pilot ejection and airplane crash something was different this time. The pilot decided, by means of acting on the remaining control planes and engine thrust, to try to land the aircraft and he succeeded. He successfully managed to sense by himself the airplane stability trends and to react according it keeping the flight stable enough to land it even under such a critical condition.

![Fig. 1 Israeli F15 fighter](image)

The following investigations done on the damaged aircraft were the starting point of something new called IFCS, Intelligent Flight Control System. It was the first
step to a self-healing system designed at the time to provide pilots with additional
control functionalities based on adding more intelligence to the flight controls in
order to help them to wave predictable and unpredictable difficulties and/or
damages.

Today's Smart Grid (SG) definitions are depicting it, among other capabilities, as
a self-healing system able to automatically, without or with very little human
intervention, react and recover the grid functionalities after a failure keeping the
service quality and trying to avoid outages as much as possible.

1.2 SMART GRID DEFINITION, US VISION

Since the SG concept and first technology deployment of it were born in the US
their definitions and concerns have a special relevance.

According to an US Department Of Energy document, the SG is to meet the
following requirements, literally,

*Intelligent – capable of sensing system overloads and re-routing power to
prevent or minimize a potential outage; of working autonomously when
conditions require resolution faster than humans can respond…and
cooperatively in aligning the goals of utilities, consumers and regulators.*

*Efficient – capable of meeting increased consumer demand without adding
infrastructure.*

*Accommodating – accepting energy from virtually any fuel source
including solar and wind as easily and transparently as coal and natural
gas; capable of integrating any and all better ideas and technologies –
energy storage technologies, for example – as they are market-proven and
ready to come online.*

*Motivating – enabling real-time communication between the consumer and
utility so consumers can tailor their energy consumption based on
individual preferences, like price and/or environmental concerns*

*Opportunistic – creating new opportunities and markets by means of its
ability to capitalize on plug-and-play innovation wherever and whenever
appropriate.*
Quality-focused – capable of delivering the power quality necessary – free of sags, spikes, disturbances and interruptions – to power our increasingly digital economy and the data centers, computers and electronics necessary to make it run.

Resilient – increasingly resistant to attack and natural disasters as it becomes more decentralized and reinforced with Smart Grid security protocols.

“Green” – slowing the advance of global climate change and offering a genuine path toward significant environmental improvement.

Moreover, focusing to the Electric Vehicle (EV), the same document states next lines,

**Preparation for the future:**

A smarter grid is also a necessity for plugging in the next generation of automotive vehicles – including plug-in hybrid electric vehicles (PHEVs) – to provide services supporting grid operation. Such ancillary services hold the potential for storing power and selling it back to the grid when the grid requires it.

Thus looking at the EV full possibilities, as a load and as a storage element, when it comes to integrate it on the power grid. Complete studies on it were already carried on in the US ranging from hardware devices [3] to overall grid impact [4].

### 1.3 SMART GRID DEFINITION, EU VISION

In the EU the SG description was charged to the **EU Commission Task Force for Smart Grids**. Below there's an abstract of the EU main requirements [5],

* A smart grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies in order to:[…]
  A. Enabling the network to integrate users with new requirements […]
  1. Facilitate connections at all voltages/locations for all existing and future devices with SG solutions through the availability of technical data
and additional grid information to:

- Facilitate connection of new load types, particularly EV;

B. Enhancing efficiency in day-to-day grid operation [...]
C. Ensuring network security, system control and quality of supply [...]
D. Better planning of future network investment

17. Better models of DG, storage, flexible loads (including EV), and the ancillary services provided by them for an improvement of infrastructure planning. [...] 

E. Improving market functioning and customer service [...] 

F. Enabling and encouraging stronger and more direct involvement of consumers in their energy usage and management 

1.4 SMART GRID DEFINITION, IEA VISION

The IEA vision is of paramount relevance as it could lead a world-wide standardization of the SG, being a basis where many countries could refer to. Literally the IEA [6] defines the SG as follows, 

The smart grid is a generic concept of modernising power grids, including activation of demand based on instantaneous, two-way, interactive information and communication technologies. Features of a smart grid include grid monitoring and management, advanced maintenance, advanced metering infrastructure, demand response, renewables integration, EV integration, and V2G. As electric infrastructures age worldwide, there is increasing interest in smart grid technologies that: 

- self-heal*
- motivate and include the consumer in energy decisions
- resists attack
- provide power quality (PQ) for 21st century needs
- accommodate all generation and storage options
- enable markets
- optimise assets and operate efficiently.
*(IEA note) self-healing refers to an engineering design that enables the problematic elements of a system to be isolated and, ideally, restored to normal operations with little or no human intervention. The modern, self-healing grid will perform continuous, online self-assessments and initiate corrective responses.

1.5 COMPARISON

First of all a rough inspection tells that the main functionalities are very similar from definition to definition and an educated guess suggest that the earlier US one inspired the others. There's a common agreement about,

- Self-healing systems able to keep the customer service even under unpredictable events.

- Attack-resistant systems, cyber-security concerns.

- Efficiency in terms of energy savings and operation expenses.

- Integration of all technologies on the SG, including renewables, storage and EV.

- Power quality, an optimal electric energy delivery to the customers.

- Demand management, involving and encouraging the customers into the grid management.

Only some differences arise when it's about to consider the business opportunities that can derive from the SG introduction. In case of the US version it must be a clear economic profit delivered from the new opportunities that the SG is going to promote, in the other two such a profit will not be immediate and could be found in savings on infrastructure investments reducing them and having an efficient planning of the new ones and also savings in the maintenance and service areas.

From the EV side, the target of this study, similar interest can be seen on his full deployment as a SG load and storage agent in every case. Unfortunately this first statement, in case of the EU, suddenly jeopardizes when all of these concepts have to move to actual, real, funded R&D programs [7] and standardization rules
In both cases the use of EV batteries as a massive storage system, the so-called Vehicle to Grid (V2G) functionality, is not going to be considered by now in the EU and thus delayed for decades because it could compromise the life of them.

2 MAIN PLAYERS

The process of the EV progressive integration on the future SG will not be easy but time linked as not a significant amount of EV could be deployed without a SG and, at the same time, probably no real SG could exist without EV. Following there's a review of the main players that are going to be involved on it and where are they today regarding the huge task coming ahead: the utility companies, the oil companies, the car makers, the battery makers, the administrations and the customers.

2.1 UTILITY COMPANIES

The electrical delivery infrastructure is divided in two main areas, transmission and distribution. In each one different companies are ruling the services under the Spanish country regulations, some of them transposing EU directives.

Following both are going to be evaluated as a power grid operators under the six common concepts found through the three SG definitions and exposed on point 1.5. In case of transmission lines the published daily load profiles could be in help when determining infrastructure capacity in front of the new-coming EV's.

2.1.1 TRANSMISSION

In Spain the high voltage, mainly 400 and 220 kV, transmission service from the big generation to large consumption areas is under a single, 90% public shared company named Red Eléctrica de España (REE), the Spanish Transmission System Operator (TSO). Additional references to the Spanish regulations, many of them transposing EU directives, could not be avoided as the electrical sector is a strongly regulated one.

Additionally the ENTSO platform proposals as the “ENTSO-E Draft Load Frequency Control & Reserves Network Code” have to be taken into account by REE as far as they will be working papers for future EU plans and directives.
Regarding the agreed SG definition and the EV, despite some R&D programs that will be roughly described, today's REE smartness could be described as follows,

-Self-healing.

As far as could be known is not yet implemented but REE started, as earlier as beginning of ninety's \cite{9} \cite{10}, introducing Artificial Intelligence Expert Systems to its control centre \cite{11}. The so called SEACON and SAR systems were developed by REE and Iberdrola in order to help engineers of central control to take decisions when there's an incident on the grid. Their basic functionality is, by thriving on a data base containing the grid description and a set of pre-evaluated faults/symptoms/corrections on overloads, faults and over-voltages, to give to the operators the chance to react against a fault in a matter of few minutes and also to correct situations that may deploy to a fault in a preventing way.

In any case the system, as far as can be known from the available information, behind the pure protection devices, is not ready to take and apply decisions by himself and it can hardly provide information if an unforeseen fault, out of pre-calculation tables, takes place.

-Attack-resistant systems, cyber-security concerns.

According to the REE their control systems are based on their own communications grid and thus not connected to the Internet. On the other hand only processed data is available on their web site thus a high security level against cyber-attacks could be expected from REE.

-Efficiency in terms of energy savings and operation expenses.

In Spain there's not any legal requirement regarding total energy loses in a transmission/distribution line or ancillary equipment. Only equipment thermal limit is to be considered both for continuous and short-circuit cases.

More on efficiency is that REE, and all the other TSO in EU, operates transmission lines at a 400 kV max. voltage except some pilot facilities. This is a limiting factor to reduce joule losses and thus to improve efficiency. In the US 765 kV lines are already in service with thousands of miles of circuits.
-Integration of all technologies on the SG, including renewables, storage and EV.

The Spanish transmission infrastructure development, in terms of new circuits, transformer capacity, meshing improvement and ancillary systems, is to follow a five years plans stated by law after evaluation of technical proposals made by the most relevant public and private agents involved on it.

The global economic meltdown, driving a industrial consumption attenuation, the progressive connection of more Distributed Generation (DG) coming from renewables, the EV penetration forecasts and changes on residential consumption profiles forced the Spanish government to stop the previous plan, from may 2008 [13], and start evaluating a new one that now is under study.

Regarding the EV, REE has a R&D program, called “Verde”, focused in 100 EV connection, no more information is available about it but due to the limited amount of units also a limited result can be expected from it in terms of statistically representative data.

- Power quality, an optimal electric energy delivery to the customers.

The Spanish government is asking for a minimum quality on the electric power supply, measured by three coefficients: not delivered energy due to outages, average outage time and total power availability.

- Demand management, involving and encouraging the customers into the grid management.

Till now REE follows a Spanish law [14] that allows them to cut energy supply to a big customers that agree to do so when needed. To encourage big consumers to join this option there's a special contract that gives discounts on the energy price every time that their supply is reduced. Since REE is not working directly with the small, residential low dimension industry, they couldn't go further in this direction.

Finally, In this sense, REE has also some R&D programs focused on demand management by aggregating electric demand in valley hours.
2.1.2 DISTRIBUTION

The Spanish distribution network is owned and managed by different companies. We'll concentrate on Endesa-Enel, the biggest distribution company among them, and try to expose their concerns regarding the SG requirements as we did with REE.

As previously stated for REE, also distribution companies operate under a very closer control from the Spanish government and the laws promoted by him and by the EU. In this case distribution companies are associated to the EDSO group instead of the transmission ENTSO and there's a constant technical and regulation discussion between them related to the fact that they operate around the common frontier of high to medium voltage. In the present situation the ENTSO association proposes the future rules for the electric grid development and operation while the EDSO responds with their objections [15]

-Self-healing.

Endesa owns expert systems as those of REE aiming to help the control engineers when its to take a decision against a grid disturbance or fault. Even if its a first step on Artificial Intelligence no self-healing technology is existing as far as can be stated from their public information.

-Attack-resistant systems, cyber-security concerns.

According to the Endesa a wide M2M IP addressing grid has been deployed between the control centres and the grid elements. As the IP technology relays on the internet addressing protocol there's a potential weakness against cyber-attacks.

-Efficiency in terms of energy savings and operation expenses.

As already pointed for REE in Spain there's not any legal requirement regarding total energy loses in a transmission/distribution line or ancillary equipment. Only equipment thermal limit is to be considered both for continuous and short-circuit cases.

-Integration of all technologies on the SG, including renewables, storage and EV.

Regarding this point a project named ZEM2All [16] is to simulate a
real penetration of the EV in the Spanish city of Malaga including fast charging stations and V2G technology over a 200 fleet of EV on a limited area of the mentioned city. Endesa, together with Mitsubishi, Hitachi and the Spanish government is going to study through this project usage patterns, low voltage (LV) congestion problems, smart metering applications and others. Even if this have to be seen as a very positive activity and will deliver a highly valuable information there are some matters, as usage patterns, that may need a much more larger and statistically controlled measurements if they are to be representative.

- Power quality, an optimal electric energy delivery to the customers.

In Spain, specially for household users and after some long outages and over-voltage related damages, the government forced the distribution companies to immediately compensate any damage. Such a policy should tend to improve the service quality.

On the other hand small industry service, both medium and low voltage, is also improving but at a different speed and some uncertainties about it still exist. When it comes to assess the electric supply continuity to some critical facilities many customers still rely on emergency generators.

-Demand management, involving and encouraging the customers into the grid management.

The first step on the way of involving customers in reducing energy consumption and being more efficient when doing it is to let them to know and understand how many energy are they consuming on a given time at easy.

As a part of the company Enel, Endesa share the knowledge coming from the largest smart metering initiative in the world. In Italy Enel [17] deployed 32 million smart meters that users can read and check through the internet by using personal computers or smart phones and where they can change their contract or cut the energy supply through a remote operated switch. A stunning experience of a real Demand-side Management that will give an insight to the rest and that is being deployed in Spain with already more than 3 million of such a smart meters installed heading to a total of 13 million in 2015 [18].

17
2.2 THE OIL COMPANIES

As today main players in terms of transportation energy suppliers it's important to know how they are facing the coming future and which plans are already on the way taking into account their very strong technical and financial muscle. To do so it will be useful to concentrate in two of the biggest ones that are not only extracting oil but also selling refined fuel to the final car owner, Exxon-Mobil and British Petroleum (BP).

In case on BP his technology head, Mr. David Eyton [19], said,

“For example, everybody would like to have batteries that are more cost-effective and smaller, because then electric cars would be viable and renewable power could be stored more cost effectively. Therefore, there's a vast amount of effort going into nanotechnology for batteries. It's a long way off from being solved, but it is a potentially disruptive technology for our industry, so we keep a very close eye on it.”

From this words its clear that BP is or will be involved in one of the critical points of the EV technology, the nano-batteries, that will make it a substitute of actual thermal engine cars and also a new energy storage agent. It's a fact that batteries and the future fast charging stations will be linked to the present fuel stations, they rule the market today and will try to do so in the future by migrating from fuel pipes to electric wires.

In case of Exxon-Mobil they, as a founding sponsor of the Global Climate and Energy Project (GCEP) at the Stanford University, concentrated their investigations in, among others,

- Fuel-cells driven by H2 or natural gas for EV.
- Increasing the capacity of Li-ion batteries for hybrid and EV.

Thus the same target seen at BP. As today market leaders on automotive fuel distribution, they are making efforts to stay there in the future looking in this case for a wider range of technology to achieve it, batteries but also fuel-cells.

All of these companies, still today strongly linked to the fossil fuels market, will play a major role in the future of electric mobility and will try to lead the future services (fast charging stations, battery replacement stations, hydrogen/methane
filling stations) needed to make the EV a real option.

2.3 CAR MAKERS

Their implication in the EV introduction into the SG relays mainly on two main technical items,

-Related to the car warranties. Their concern could be the batteries life span in case of V2G usage. As the V2G strategy means more charge/discharge cycles per year, even if some of them are only partial, the estimated life of the batteries will be affected and thus some warranty problems may arise from it.

-Related to the charging equipment. Till now a vast majority of the commercially available EV incorporate an onboard battery charger being the dominant trend together with DC connectors for fast DC charging on electro-charging stations. In the future, if a V2G strategy is to be followed, they do need to consider using a bidirectional systems or give to an external charger a battery access. Global standardization is of paramount importance but today there are three different connection and charging standards, the US one, the EU one and the Japanese one.

Even if the previous technical issues, together with others like HVAC systems tailored for the EV energy availability, are all of them of paramount importance, the marketing policies and strategies that the car makers decide to start will be probably one of the greatest contributions that can be done to the EV penetration.

Additionally, as one of the main items to clear is the EV average usage patterns, it will be desirable that they enrol, even with the present petrol/diesel/hybrid cars, into a wide market research to unveil such a very valuable and extensive information. Its a real key point to successfully integrate the EV into the SG.

2.4 BATTERY MAKERS

As a basic element named to replace the fuel tank the batteries will be on the edge of the EV introduction on the SG as they will be the heart of a new consumption/storage element in to the grid. Their ability to withstand more and more cycles and to store more and more energy per kilogram are going to be
critical for the EV future.

It has been a long journey since the early lead-acid batteries where used to power-up the GM EV1. Since then the last decade electronic portable devices like laptops or cellular phones pushed to the market new generations of lithium batteries that can offer five times more energy density halving the weight of the lead-acid ones at the same time. The origin of this new batteries, the electronic industry, and the more and more sophisticated technology linked mainly to the nano structures development, make the difference and a set of new battery companies showed into the market with high-tech revolutionary products. The future for the traditional battery makers is thus not clear unless they are a part of big companies that could buy technology from outside or develop it by themselves in a very fast way.

Looking at the new players, almost all of them from the US, they are offering very competitive, commercially available, products with an impressive 16,000 cycles life span as the AltairNano 24v 60Ah modules or with an energy density over 130 Wh/kg as the A123 systems AMP20M1HD-A modules.

2.5 ADMINISTRATIONS

Public authorities in Spain, despite some special promotion programs like Movele that accounts for 590 M€ in direct subsidies for the EV introduction, do follow the EU regulations and directives transposing them in to the Spanish law corps.

Next lines will show the most relevant directives, regulations and reports issued by the EU, by the Joint Research Center (JRC) and by the European Platform Smartgrids related to the EV and its implementation into the SG.

-“Regulation 443/2009 of 23 April 2009” [20], European Parliament. Intended to be applied to the passenger cars sets a maximum of 95 gCO2/km as full production range average emissions level for car manufacturers from 2020 onwards. Considering that today's, 2012 data, best in class is Fiat with an average consumption of 119,8 gCO2/km (all-brands average for the same period is more than 132 gCO2/km) and expecting a small improvement in terms of combustion engines efficiency within the next 6 years, hybrid and EV are to be widely introduced by every car maker that plans to sell in Europe something more
than small cars. On point 3.2.1.4 there’s a detailed argumentation regarding such a forecast.

On Figure 2 [21] there’s a background of the passenger car CO2 emissions improvement through the last decade and a trend showing where it can be on 2020, a bit far from the regulation target. Note that the trend line was forced to pass the 2015 target of 130 gr CO2/km.

Further calculations based on the above data will be performed when dealing with EV penetration scenarios in following pages.


Herewith enclosed there’s a mandatory evaluation of the cost of the CO2 emitted by every vehicle able to be purchased by public authorities. The CO2 cost is to be added to the other vehicle costs in order to define the final price to compare with other competitors in every public purchasing process so in this sense the EV do have a clear advantage.

-Resolution of the European Parliament of May 6th 2010 on electric cars.

The European Parliament states, among many others related to the EV promotion, the following point,

4. Calls on the Commission and the Council to take joint action on:
(iii) improvement of electric networks by introducing smart grids, and the introduction of sustainable generation capacity with low carbon intensity, particularly through renewable energy sources,

"SmartGrids SRA 2035 Strategic Research Agenda" [7], European Platform Smartgrids, 2012

This document describes which are the EU official research priorities regarding the SG development toward year 2035. Among them, and regarding the EV integration into the SG its written that,

**The second driver is the introduction of electric vehicles. The electric vehicle constitutes a very elastic load because it remains connected long time to the grid and the battery of electric vehicles as load could be very easily managed. The electric vehicle is an attractive application in order to introduce demand response in the residential level.**

**Although bidirectional energy flows from the grid to the EV are in principle already possible (V2G, Vehicle to Grid), it is foreseen that before 2020 the batteries of electric vehicles will only be connected as a load, i.e. controlled charging. However, by 2035 some V2G services, i.e. injecting battery power into the grid, will appear.**

Thus not considering, as already exposed on point 1.5, the EV as a mass storage facility to smooth the demand curves and store renewable energy when produced with no demand.

"Driving and parking patterns of European car drivers, a mobility survey."[23] EU JRC, 2012.

A comprehensive full study aimed to identify and explore the european driving and parking patterns in order to provide valuable data for the future EV and biofuel vehicles future implementation.

"Projections for Electric Vehicle Load Profiles in Europe Based on Travel Survey Data"[24]. EU JRC, 2012.
An exhaustive report focused on the car usage patterns and their translation to electric energy demand when some of them became by Evs.


A very valuable market survey regarding the Europeans willingness of adopting the EV sliced into many different items as by country, by gender, by age, etc. The sample population was of 3723 individuals distributed between three European countries as follows,

<table>
<thead>
<tr>
<th>Country</th>
<th>France</th>
<th>Germany</th>
<th>Italy</th>
<th>Poland</th>
<th>Spain</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviews</td>
<td>623</td>
<td>606</td>
<td>613</td>
<td>548</td>
<td>617</td>
<td>716</td>
</tr>
</tbody>
</table>

Tab.1 Number of interviews by country [25]

Finally about administrations is to point that an extensive deployment of the EV will be not possible without their decided commitment in terms of new laws and codes that would pave the road to an effective and massive transport decarbonization.

2.6 CUSTOMERS

Last but not least the customers are likely to be the most important factor into the equation. Their car usage patterns and their willingness on adopting EV as their mobility solution are to be first priorities to start dealing with. Without this data becomes almost impossible to determine neither the grid stress brought by the EV penetration nor the strategy to follow as a SG to manage it including the renewable sources and distributed generation to better shape the demand figures and make all of this possible.

More in detail the customers information and the driving patterns in particular will be the basis for the calculations of the energy demand amount and profile that the EV implementation is going to add to the electric grid.

2.6.1 USAGE PATTERNS

There are four critical factors to consider on it that are directly related to the EV integration on the SG.

1- Daily average driven distance.
2- Parking time. How many time to charge the battery.

3- Parking place. Where can be charged the EV battery.

4- Hour-by-hour car usage.

Regarding all of this data many information is already available through EU reports,

- Points 1, 2 and 3 are fully deployed on the already mentioned report “Driving and parking patterns of European car drivers, a mobility survey” [23].

- Point 4 graphs can be found on the already mentioned report “Projections for Electric Vehicle Load Profiles in Europe Based on Travel Survey Data” from JRC, a huge and fundamental approach to the European driving patterns done over an extensive sample of Europeans of different countries. There some very interesting data is included as the following sample of a hour-by-hour driving pattern,

![Hourly total power consumed by engines of EV on travel](image)

**Fig.3 Hourly total power consumed by engines of EV on travel** [24]

Here it can be found, on an hourly basis of an average Monday, how much electrical power is consumed by EV cars that are running and, thus, which will be the parking times where the battery charge can be done.

Further analysis including some kinds of filtering will be performed over this data source in order to extract some Spanish-only graphs suitable for more detailed study and calculations. In this sense representatives of the JRC kindly gave to
the author the fully databases that allowed such a investigations and, by doing this, made this job possible.

In the US also such a kind of data is available as this for the city of Seattle [26], taken from a GPS survey of more than 100,000 single runs done by a fleet of 429 thermal engine cars between years 2004 and 2006.

![Fig.4 Hourly vehicles use in per-unit scale [26]](image)

Where, in terms of number of vehicles running on a given hour divided by the total number of vehicles on the study, the car usage pattern on an hourly basis and on a weekday/weekend day can be seen. The parking times could be also extracted from the same data as they are times where the cars doesn't run.

At a first sight from the above showed Figures 3 and 4 can be stated that the hour-by-hour profiles in Spain are quite different from those collected beyond the Atlantic Sea but further analysis done over the already mentioned data source didn't show such a big differences and make the results quite similar as it will be shown further in this job.. Anyway such a deviation is more likely to come from the nature of the data itself than from any other factor. While in the US case real travelling input is used trough GPS devices, the European study relies on a market survey based on panelists interviews, maybe not as accurate as GPS data.

Special effort is to be done by the EU in order to get more real, accurate, driving patterns that allow deeper power grid demand prediction and storage capabilities
to effectively plan the EV arrival and integration into the European countries power grids.

### 2.6.2 DRIVERS ATTITUDE VS THE EV

This is a must when forecasting the future degree of penetration of the EV in to the European car market. The EU, as said on point 2.5 and trough the JRC, already issued a market survey report on it, the so called “Attitude of European car drivers towards electric vehicles: a survey.” [25] from 2012.

Within this document important customer trends are unveiled together with a clear picture of today's EV knowledge among the EU citizens. The following aspects are taken into account,

- Familiarity with the EV. Quite low among the countries on the report, a little big more than 50% and closer to 60% in case of Spain.

![Fig.5 Familiarity with the electric car [25]](image)

- Probability of buying an EV. The study presents two options. The first one, whose results are shown below, consists in the probability that, if a new car is to be purchased by the panelist today, it could be an EV. The result is surprisingly high taken into account the previous result of low awareness about EV. The second one considers that the EV available at the purchasing time has some technical and cost improvements, with this the purchasing probability increased a 20% so we can conclude that customers do consider that EV is not yet ready for massive introduction into the market.
Where 26% of the total Spanish sample shows a 70% probability of buying an EV in the next 10 years if its performance is at least the present one.

-Quality Function Deployment on EV. Here customers evaluate which areas on the EV should be improved regarding the present condition of it. The results can be seen below and from it becomes clear that the main worries are those related to the charge, thus the possibility of running out of battery which is the EV nightmare, and the cost, being the power-speed of residual interest.

-EV penetration expectations. Here the European customers showed a highly optimistic criteria, with an average forecast of more that 26% market share for the EV in the next 10 years.
Where a real optimistic position is with the 25% of the Spanish sample pointing more than 40% of EV penetration.

After all of this points and the related data there are two main conclusions that must be considered regarding the target of this study.

1- The customers average likelihood of being an EV owner is higher that expected in some studies regarding the EV future market share. Among today's available forecasts [27] the most optimistic one is waving a 12% market share for pure EV [28].

2- Beyond the average data, and despite the deep economic recession in their countries, the southern Europe customers are more inclined to adopt the EV than the northern ones. It must be carefully considered as this pages are devoted to the Spanish case.

3 ENERGY BALANCE AND VEHICLE AVAILABILITY

A significant introduction of the EV in a 15 years horizon will be a big defy to deal with in many ways, among them the electrical energy transport and distribution infrastructure could be critical. Next titles will focus on how the EV needs will affect to the total energy demand and compare it with today's power grids capabilities in order to unveil where the weak points will be and the strategies or
countermeasures that can be applied to overcome them.

Another important point regarding a key players, the final users, will be the vehicle availability due to the batteries charging times and it must be seriously taken into account when evaluating the new power demand as shorter charging times give higher power needs.

Next points will introduce the criteria that will drive this study, the basic data to start from, and the resulting energy balance focused on three main ranges, continental, regional and local.

3.1 ANALYSIS CRITERIA

Two main items will be taken into account as a priorities through this study,

-Regarding the VAC coefficient

One of the most significant achievements of the engineering progress is mobility. This freedom of travelling from one part to the other brought to the human civilisation the desired availability of task force, knowledge and freedom where it was needed and at the time that it was needed.

The author of this study considers then the mobility as a capability of paramount importance and will focus his work in keeping it as closer as possible to the one provided by the thermal engines the passenger cars. No other restrictions on the use of the EV are going to be accepted but some waiting time to reload the batteries that should be minimized to assure as much as possible the maximum vehicle availability. In order to evaluate it the vehicle availability coefficient (VAC) will be described showing in percent the daily vehicle availability regardless maintenances and inspections, in particular the VAC of thermal engine cars will be considered 100% as refuelling only takes a few minutes. The formula to calculate the VAC will be,

\[ VAC = \frac{24 - \text{Charging time}}{24} \]

Exp. 1

As an example, 8 hours of charging time will mean a VAC of 66%, quite poor as the car owner could not use his vehicle with his whole operating range during one third of the day.
-Regarding the power and energy demand.

The energy efficiency will be the main concern through this study together with the need of exploring solutions and proposals that could exhibit a high degree of synergy between the different stakeholders involved into the process of transport electrification.

In addition, as many of the terrestrial public transportation is already electrically driven as for the train, subway and city railways in Spain, no any further contribution to the demand calculations will be considered due to the remaining, thermal powered, bus lines.

3.2 BASIC DATA

The basic input data to proceed with the energy balance evaluation will be integrated by two main parameters,

- EV penetration forecast for year 2030. A forecast will be performed to conclude with the total amount of EV running on the Spanish roads on year 2030 beside this an EU report regarding this data will be discussed and compared.

- EV energy demand. The other basic input, together with the EV market penetration is the amount of energy that those newcomers will demand from the power supply infrastructures. To perform such a calculation an elementary value of energy drained from the electric company to run a single kilometre will be the target to find.

3.2.1 EV PENETRATION FORECAST FOR YEAR 2030

Next titles will deploy two different ways of predicting the EV penetration on the Spanish passenger car fleet for year 2030.

The first one is achieved by calculations done over a range of complementary official data as demography or car per inhabitant (C/I) ratio in Spain The second will go right to an existing study whose results, intended for the whole EU, will be translated to the Spanish case.
3.2.1.1 CALCULATED EV PENETRATION FORECAST FOR YEAR 2030

Following the EV penetration on the next 16 years will be calculated based on the information introduced on chapter 2. There are four many inputs to define it,

- Total amount of passenger cars forecast. Today's Spanish passenger car fleet, estimated on more than 22 million of vehicles [29] could be used as a starting calculation point together with Spanish demographic data. Correlation between both sources is to be established.

- Administration activity. From today's already enforced regulations a calculation basis is to be exposed to show which will be the minimal EV penetration.

- Customer perceptions. Paying attention on market surveys a trend can be identified and used as a complementary information.

- Practical limitations. That could arise from the impossibility of settling on time the required equipments and infrastructures. This would happen if not enough resources are committed today to perform a evaluation of what's coming and to prepare the countermeasure program that will help to wave it. In this sense this study tries to be in help on identifying future issues and planning actions against it.

3.2.1.1.1 TOTAL AMOUNT OF PASSENGER CAR FORECAST

As previously stated the Spanish passenger car fleet on 2012 accounts for a little bit more than 22 million units according to the Spanish national car makers association, ANFAC [29]. Additionally when it comes to forecast how the future fleet volume will be more information is to be compiled, in detail demographic data forecast and the cars/inhabitant ratio will be needed.


- Cars/inhabitant ratio. Regarding this point it will be assumed that Spain's today ratio [31] of 0,48 Cars/Inhabitant (C/I) will steadily increase till the European's today average of 0,54 [31] in 2030. No further evolution on today's European average of 0,54 C/I ratio will be considered for the coming years as the
EU automotive markets are quite mature and public transportation is to be promoted more and more.

As a result of the above data the total amount of cars in Spain on 2030 could be estimated on 28,436,940 passenger cars.

3.2.1.1.2 ADMINISTRATION ACTIVITY

On point 2.5 the European "Regulation 443/2009 of 23 April 2009" [20] was described showing that in 2020, a new CO\(_2\) limit of 95 grams of CO\(_2\)/km for passenger cars will be in force. As a sign of the EU authorities determination a law redefinition was asked by the car industry in order to increase this limits but the finally issued code didn't change it.

As a result of such a new law, together with the thermal engines efficiency trend shown on Fig.2, EV will be a must on the car makers product portfolios if they are to follow the new regulation. In this sense, as early as 2020, they will face the following situation.

- Maximum CO\(_2\) emission level, 95 g CO\(_2\) /km.
- Maximum attainable technological level by using thermal engines, 120 g CO\(_2\) /km average. Although even today some cars are exhibiting much more lower levels each brand whole product range average trend is what should be taken into account for this study purposes.

3.2.1.1.3 CUSTOMER PERCEPTIONS

According to the Spanish customer willingness data that is shown in previous Figures 6 and 8 the following analysis can be done,

- Following the willingness of buying an EV 50% is the average to be considered to predict future EV sales. If it's so then every year 50% of the total amount of purchased cars should be EV's. The truth is that, in year 2013, the EV sales hardly reached the 685 units on the whole Spanish country over a total of 772,703 new cars registrations on the same period. Which is far away from the 336,350 units of EV and PHEV predicted by the panel. Such a very big difference could relay on the lack of charging facilities, the poor EV product range, the high prices and the maybe two much high acceptance of the EV when fulfilling the
patterns that suddenly declines when it comes to go to the car shop and pay for it.

-Following the customer perception and according to Figure 8 a 32% of EV penetration is to be expected by year 2022. This data should be taken carefully as the panelists could not have enough information when answering this question and it must be better considered as a simple guess more than an educated opinion.

To end this analysis next Table 2 shows in numbers what are the results of the survey translated into number of cars. The difference between the market share evaluation, and the averaged penetration stimation, is almost of 100% so there's not a great coherence on the panel regarding the customer perceptions.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cars in Spain</th>
<th>Mkt share</th>
<th>Total EV 1</th>
<th>Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>22,247,528</td>
<td>1,112,376</td>
<td>1,112,376</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>22,456,558</td>
<td>1,122,828</td>
<td>2,235,204</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>22,665,587</td>
<td>1,133,279</td>
<td>3,368,484</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>22,874,617</td>
<td>1,143,731</td>
<td>4,512,215</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>23,083,647</td>
<td>1,154,182</td>
<td>5,666,397</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>23,292,676</td>
<td>1,164,634</td>
<td>6,831,031</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>23,501,706</td>
<td>1,175,085</td>
<td>8,006,116</td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>23,710,736</td>
<td>1,185,537</td>
<td>9,191,653</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>23,919,766</td>
<td>1,195,988</td>
<td>10,387,641</td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>24,128,795</td>
<td>1,206,440</td>
<td>11,594,081</td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td>24,337,825</td>
<td>1,216,891</td>
<td>12,810,972</td>
<td>7,788,104</td>
</tr>
</tbody>
</table>

Where,

-Mkt share accounts for a 50% market share of EV over the yearly total sales considered constant over the 10 years period under study.

-Total EV 1 accounts for the addition of the present and every previous market share over the period until year 2022.

-Penetration shows the total amount of running EV in Spain in 2022 according to averaged 32% penetration level found on Figure 8.

As a conclusion of customer perceptions evaluation the most relevant item is to notice that maybe there's a too optimistic thought but that this could be revealing something that one can call electro-friendship with the newcomer EV.
3.2.1.1.4 RESULTS

Using the previous data coming from the demography and the emission regulations some calculations could be made in order to forecast the future amount of EV in Spain. The customer perceptions will be used as a filter in case of abnormal results.

At the point 2.5 a technical dilemma between the EU regulation and the thermal engines efficiency arises. The solutions to cope with this could be resumed into three main options,

1-Running cars on biofuel.

For this study purposes no significant biofuel usage will be considered on passenger cars as biofuel availability is compromised with crop usage of the available land and due to the difficulty for the car makers to asses in front of the authorities whether a given car will run on biofuel or fossil fuel when justifying their CO2 level.

2-Use of hydrogen driven fuel-cells or engines.

No significant deployment of H2 cars is taking place comparing with the latest developments and actual commercial proposals seen in fully electrical and hybrid automotive powertrains. The H2 supply and storage stills being a dangerous and unsolved item today.

3-The EV/PHEV.

Finally, as the only remaining way to pass the coming regulation, EV and PHEV are to be deployed as a significant part of every manufacturer product range in order to dilute the average CO2 emissions. To calculate their share first we do need to know how many cars will be sold on 2020. To do so there's from one side the average age of the Spanish passenger car fleet that is, and will be for this job purposes,10 years [29], and from the other side the total amount of cars on 2020 forecast, that is of 23.919.765 units based on the evolution of the C/I ratio as pointed on 3.2.1.1.1 and population data [32]. Taking into account this data a total 2.391.977 car sales can be expected on 2020 that will split into thermal and electrical driven ones.

From the previous data the Expression 2 is proposed to determine wich part of
the passenger car sales on 2020 will be thermally driven and which one will be electrically driven.

\[2391977 \cdot 120 \cdot (1 - X) + 2391977 \cdot 0 \cdot X = 2391977 \cdot 0.95\]

Exp. 2

Where \(X\) is the amount of EV, accounting for 0 g CO2 /km, that should be part of the total passenger car sales in order to full fill the regulation. Once calculated we do have \(X=0.21\), that means, 21% of total sales of EV should be electrical ones and this is 497,531 EV sold in Spain in 2020.

Next is to move from 2020 to 2030 considering that previous sales are negligible. To do so it will be assumed that, even if a improvement on CO2 emission level could be expected over a period of 10 years, it will not be considered. The reason for such a statical approach is that any further efficiency improvements on engine emissions will came together with new legal limits in that manner that both effects are auto-cancelling each other. Indeed it can be considered that future efforts on automotive R&D programs will concentrate on EV and all the surrounding items that must be improved from today’s state of the art as high energy density batteries, ultra efficient air conditioning equipment, energy recovery systems and many others that are on the stack.

As a result of the previous considerations, and assuming a constant 21% participation of EV on yearly car sales, a table can be constructed as the following.

<table>
<thead>
<tr>
<th>Year</th>
<th>C/I ratio</th>
<th>Total Passenger Cars</th>
<th>Annual EVs sold</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>0.5064</td>
<td>23,919,766</td>
<td>497,531</td>
</tr>
<tr>
<td>2021</td>
<td>0.5097</td>
<td>24,352,208</td>
<td>506,526</td>
</tr>
<tr>
<td>2022</td>
<td>0.513</td>
<td>24,788,231</td>
<td>515,595</td>
</tr>
<tr>
<td>2023</td>
<td>0.5163</td>
<td>25,227,836</td>
<td>524,739</td>
</tr>
<tr>
<td>2024</td>
<td>0.5196</td>
<td>25,671,022</td>
<td>533,957</td>
</tr>
<tr>
<td>2025</td>
<td>0.5229</td>
<td>26,117,789</td>
<td>543,250</td>
</tr>
<tr>
<td>2026</td>
<td>0.5262</td>
<td>26,568,138</td>
<td>552,617</td>
</tr>
<tr>
<td>2027</td>
<td>0.5295</td>
<td>27,022,067</td>
<td>562,059</td>
</tr>
<tr>
<td>2028</td>
<td>0.5328</td>
<td>27,479,578</td>
<td>571,575</td>
</tr>
<tr>
<td>2029</td>
<td>0.5361</td>
<td>27,940,670</td>
<td>581,166</td>
</tr>
<tr>
<td>2030</td>
<td>0.54</td>
<td>28,436,940</td>
<td>591,488</td>
</tr>
</tbody>
</table>

**TOTAL EV on 2030** | **5,980,504**

Tab. 3 EV penetration evolution
Where the result of 5.980.504 EV's in 2030 is lower than the pessimistic forecast of the previous customer predictions and thus probably more realistic.

### 3.2.1.2 EU REPORTED EV PENETRATION FORECAST FOR YEAR 2030

Some investigations already exist forecasting the future EV penetration [27]. According to an EU commissioned study [33] based mainly on the Total Cost of Ownership (TCO) influence there are three scenarios describing the EV presence in Europe in year 2030. The mentioned scenarios, already translated to the Spanish case, can be found on the following Table 4.

<table>
<thead>
<tr>
<th>Scenarios year 2030</th>
<th>Total amount of EV in Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimistic</td>
<td>7739830</td>
</tr>
<tr>
<td>Realistic</td>
<td>4281690</td>
</tr>
<tr>
<td>Pessimistic</td>
<td>1665101</td>
</tr>
</tbody>
</table>

*Tab. 4 Future EV penetration in Spain*

Where the previously calculated result of 5.980.504 EV in 2030 is right between the Optimistic and the Realistic scenarios. Furthermore this study comes from April 2011, three years before, and some key points that at the time where uncertainties today are more clearly defined, especially those related to batteries life and capacity.

### 3.2.1.3 CONCLUSIONS

As already mentioned there's a quite big coincidence between the two ways of predicting the total amount of EV than will be running on the Spanish roads on year 2030.

According to the shown data the biggest value is to be used in the following areas of this study because it's within the acceptance level for the customers panel and also because the EU study was performed, as already said, under some uncertainties that no longer exist allowing then to be a little more optimistic.

As a conclusion a total amount of 5.980.504 EV on 2030, 21% of the total passenger cars in Spain, will be one of the calculation basis to be used from now on in this study.
3.2.2 EV ENERGY DEMAND

Since the total amount of EV is already estimated next comes the energy and power demands that such a fleet will require. To proceed on the way to unveil this information some steps are to be done, in detail,

- Single EV, averaged, energy demand according to today's available data regarding user patterns, thermal engines efficiency, thermal engines fuel consumption and related electric and electronic equipment efficiency.

- Local scaling from a single vehicle to a community, apartments building case, aggregate.

- Regional scaling from single vehicle to a given geographical area.

- National scaling from single vehicle to the whole Spanish continental area, V2G potential.

The main target of this chapter is to find a value of energy that an averaged EV will need to cope with his owner mobility needs. To achieve it will be interesting to move from actual thermal engine passenger cars wide available information to the future EV since the already stated analysis criteria in point 4.1 is that people mobility performance must not change.

As soon as the thermal car value of kWh/km will be available the next step will be to calculate how much energy does it means when trying to do the same job by electric means. In both cases the correlation point will be the engine driving shaft, the crankshaft for the thermal case or the electric motor axis for the EV. In both cases the gearbox looses needed to adapt the vehicle speed to the engine speed will be assumed as the same.

3.2.2.1 THERMAL CAR EFFICIENCY DATA SOURCE

The starting data, coming from the ANFAC [34], shows an average fuel consumption of 5.33 l/100km on the cars sold in Spain on 2012. Together with this data but in a different document [35] the market segmentation on 2012 by fuel type can be found as showed in next Table 5.
Then every 100 km run is, in average, made of,

\[-5,33 \times 0,313 = 1,667 \text{ litters of gasoline}\]
\[-5,33 \times 0,672 = 3,582 \text{ litters of diesel}\]

Next step up into the calculation three is to consider that the given consumption data is a result of calculations made with makers consumption data taken in laboratory tests. However in real conditions, where the driver often faces many situations like traffic jumps or simply doesn't master very well the so-called efficient-conduction technique, the consumption is quite higher.

As a very popular topic, several specialized motor revues offer in a regular basis data regarding the consumption level differences between makers data and actual data. One of them is the well known “Autopista” [36], part of a very important German motor press group, that offers, extracted from a study done over 800 passenger car models, the following results,

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>17,00%</td>
</tr>
<tr>
<td>Diesel</td>
<td>22,00%</td>
</tr>
</tbody>
</table>

Then, applying the above differences to the makers official consumption on every 100 km,

- Gasoline → $1,667 \times 1,17 = 1,95$ litters
- Diesel → $3,582 \times 1,22 = 4,37$ litters

Which means that the public, ideal, laboratory made, average of 5,33 litters every hundred kilometres moves to a higher 6,32 litters in the real world.

Following the process, and considering that the kWh/km value is the target, now is time to move from litters of gasoline/diesel to energy. In this sense the lower heating values (LHV) of each fuel are to be considered as no condensation is
allowed on the exhaust mufflers to prevent their corrosion and damage. As a official data \[^{[37]}\] for the above mentioned LHV the following Table 7 will be accepted,

<table>
<thead>
<tr>
<th>Fuel</th>
<th>LHV (kWh/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>8,45</td>
</tr>
<tr>
<td>Diesel</td>
<td>8,32</td>
</tr>
</tbody>
</table>

Tab. 7 LHV by fuel \[^{[37]}\]

So, in terms of total energy available from the fuel at the engine incoming pump every 100 km the value will be,

\[
Te = 8,45 \cdot 1,95 + 8,32 \cdot 4,37 = 52,84 \text{ kWh/100km}
\]

Exp. 3

Unfortunately internal combustion engines still have a quite poor efficiency and only a small part of the incoming energy could be expected at the engine crankshaft in order to be used. Focused on it there’s a paper of the Japan Society of Mechanical Engineers \[^{[38]}\] showing the following average engines efficiency depending on the fuel type,

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Thermal efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>0,36</td>
</tr>
<tr>
<td>Diesel</td>
<td>0,45</td>
</tr>
</tbody>
</table>

Tab. 8 Engines thermal efficiency \[^{[38]}\]

Applying the above data to the Exp. 3 the available energy can be calculated.

\[
Te = 8,45 \cdot 1,95 \cdot 0,36 + 8,32 \cdot 4,37 \cdot 0,45 = 22,29 \text{ kWh/100km}
\]

Exp. 4

Which gives the target value of 0,223 kWh energy used to run an averaged conventional thermal engine passenger car over 1 km distance. As an average of 58 km daily run, that will be recalculated on point 3.3.1.2.2.1, is showed by the JRC data \[23\], a daily amount of 12,93 kWh should be expected on the driving shaft, and the same for the EV.

### 3.2.2.2 EV EFFICIENCY

This title aims to evaluate the EV total efficiency from the AC power supply on the
charging spot to the final energy available at the electric engine axis when running. To do so the EV main components as batteries, chargers, engines and electronic drivers have to be screened by using reliable data. Additionally, even if this case is not about dealing with present technology as we do with thermal cars but future, no further improvements from today state of the art will be estimated except those coming from future regulations.

According to the previous target, following investigations will deal with an energy flow as shown below in Fig. 9.

**Fig.9 EV energy flow and losses**

On a bottom to top analysis it must start from the Gearbox incoming shaft by using the value of 0.223 kWh/Km calculated at the previous point, and end at the AC main supply. Step by step calculations could be made as follows.

- **Engine & drive.**

  It is intended to account for the losses generated by the electrical engine and those of his electronic drive. It’s a quite complex matter to study as both elements are coupled and working together in very complex fashion. Moreover the amount of available data about electrical engines and electronic drivers alone is very small and difficult to use as a calculation basis.

  To reach the target in this case a combined engine and driver efficiency maps are the best data source. In this sense the following Fig.10 shows graph with testing data of a given pair of automotive engine and driver by UQM [39].
Fig. 10 Efficiency map of a given engine+driver set [39]

Where many different efficiency areas are showed, depending on the engine+driver operating conditions, ranging from 90% to 60%. From this data a further calculation can be performed to get the average efficiency by considering a minimum level of 60% and a maximum speed of 1200rpm. Next Fig.11 is a schema of Fig.10 where every efficiency area surface is calculated.

Fig. 11 Efficiency map, surfaces vs efficiencies calculation
Finally, and by doing some calculations over the Fig.11 data, the average efficiency of an automotive set of electrical engine and drive could be calculated as shown in Tab. 9.

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Surface 1</th>
<th>Surface 2</th>
<th>Sub Total</th>
<th>Efficiency contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>0.49</td>
<td></td>
<td>0.49</td>
<td>2.26</td>
</tr>
<tr>
<td>65</td>
<td>0.63</td>
<td></td>
<td>0.63</td>
<td>3.15</td>
</tr>
<tr>
<td>70</td>
<td>0.75</td>
<td></td>
<td>0.75</td>
<td>4.03</td>
</tr>
<tr>
<td>75</td>
<td>1.2</td>
<td></td>
<td>1.2</td>
<td>6.91</td>
</tr>
<tr>
<td>80</td>
<td>0.89</td>
<td>0.05</td>
<td>0.94</td>
<td>5.78</td>
</tr>
<tr>
<td>82.5</td>
<td>1.19</td>
<td>0.17</td>
<td>1.36</td>
<td>8.62</td>
</tr>
<tr>
<td>85</td>
<td>2.08</td>
<td>0.57</td>
<td>2.65</td>
<td>17.30</td>
</tr>
<tr>
<td>87.5</td>
<td>1.04</td>
<td>2.39</td>
<td>3.43</td>
<td>23.05</td>
</tr>
<tr>
<td>90</td>
<td>0.41</td>
<td>1.16</td>
<td>1.57</td>
<td>10.85</td>
</tr>
</tbody>
</table>

**Total surface** 13.02

**Av. Efficiency** 81.95%

Tab. 9 Engine and drive efficiency

Where, as a conclusion, an 81.95% efficiency value could be expected from the engine and drive components. According to this the original 0.223 kWh/km increases till 0.274 kWh/km that must be feed by the battery to the engine and his driver.

- Battery.

The batteries play an essential role on the EV and are also responsible of some of they drawbacks. Regarding the efficiency of the batteries, as their capability of giving back the absorbed energy from the battery charger, it's useful to talk about "usable energy" as some manufacturers do. More in detail the company A123 systems, Inc. [40] shows the following graph in one of his public papers.
Regarding this figure it's easy to realize that only 500 Wh of the total 700 Wh are usable and, thus, 200 Wh can be considered as losses. In the real world it's mandatory for the batteries life that the user tries to never reach the full discharge of the battery so, only 100 Wh of the unused 200 Wh could be considered as real losses, it is an 85% of the total energy.

Furthermore the above battery efficiency calculation matches with another source [41] where also an 85% could be found as a result of some tests and calculations.

By considering this 85% the previous 0.274 kWh/km now scale up to a higher 0.32 kWh/km at the output of the battery charger.

- Battery charger.

It's the last element on the losses chain and today's battery chargers efficiency roughly moves between 80 and 85%. Moreover, regarding this devices there's a new regulation that entered into force in year 2014 [42] asking the makers/vendors, in the US California, to offer at least a minimum 89% efficiency on their products. This will be the minimum efficiency that is going to be considered for this study and now, after applying it, the 0.32 kWh flowing from the battery charger grow to a new 0.36 kWh drawn from the AC main supply for every Kilometre of run.
3.2.2.3 CONCLUSION

As shown after adding every expected energy loss a total of 0.36 kWh/km should came from the main supply in order to charge the EV or PHEV batteries. Next Fig. 13 illustrates now the previously showed losses diagram with the respective values.

Furthermore, as the final energy on the engine shaft must be 0.223 kWh/km an overall efficiency of 62% could be expected from the full automotive electric system, which in turn is better than what's available on thermal engine cars if we don't consider electric generation and transport losses.

Finally it's mandatory to point that there's no regenerating power system applied to the above calculations but also there's no air conditioning or other comfort systems taken into account. As today these two items are on their way of being fully developed and improved this study considers that they are cancelling each other.

3.3 IMPACT OF THE EV ON THE EXISTING ELECTRICAL INFRASTRUCTURES

Since the energy needs in terms of kWh/km is already know this study moves toward to the next step by evaluating the impact of the EV in the existing electrical transport and distribution systems at a different scales starting from the apartment building case to the Spanish continental scenario through a regional analysis of the Barcelona's metropolitan area (BMA). Suburb single family LV case will be out of the scope of this study as the owner could probably efficiently
manage himself his own house energy demand.

3.3.1 LOCAL SCALING, APARTMENTS BUILDING CASE

As a starting point for this case it must be stated that Spain is the European country where more people do actually live in flats, 65.4% of the Spanish population are doing so according to Eurostat data for 2011 [43].

When dealing with the addition of a new load to a pre-existing electrical energy supply system there are a few questions that must answered,

-Which load is the system designed for.
-How big is the new load.
-Is the result acceptable or a system upgrade is needed.

The concerned infrastructures that should be taken into account when trying to give answers to the previous questions are the MV/LV transformers, their ancillary MV/LV systems, the LV feeders and the metering devices. Regarding the MV lines we'll apply to them the same conclusions as the LV systems because its a item that could not be generally studied or modeled as every MV line is a singular case and could have free room or not depending on how many consumptions are connected to it.

The final target will be to avoid as much as possible that the EV introduction could result in changing all of the above mentioned devices due to the huge monetary cost and the environmental impact that it would mean.

Following points are to deploy and study the above three items and to state some conclusions that should be able to be applied to any apartment building in Spain and thus will look mainly not only to averaged values but to those that statistically could be expected. To perform this calculations a 50 flats apartment building is going to be considered as a pilot.

3.3.1.1 LV DESIGN LOAD AND TOLERANCE

Next calculations will show which will be the design load for an standard 50 flats building and will check if there's some allowance to introduce the EV on the existing LV infrastructures without replacing transformers and so on.
3.3.1.1.1 LV DESIGN LOAD

In Spain the electrical regulation to define the design load for an apartments building [44] sets which are the coefficients of use (CU) depending on how many flats are to be connected. In the case of more than 21 flats the following expression to calculate it,

\[ CU = 15.3 + (n - 21) \cdot 0.5 \]

Where,

\( n \) = number of flats

Giving a CU= 29.8, less than the existing 50 flats, that 5.75 times, brings a total simultaneous power related to the apartments of 171.5 kW. Additional power is to be considered as the one for the elevators, if there are any, the common areas lighting and parking ventilation and lighting. A total of 10 kW for the elevator, 9kW for a 900m2, one level, parking for 50 cars with no ventilation and 5kW for common areas lighting, added to the previous 171.5 kW, results on a 195.5 kW design load for the 50 flat building.

Finally, as the transformers are kVA rated, considering a power factor of 0.8, 244.4 kVA are the target.

3.3.1.1.2 DESIGN TOLERANCE

Every facility or system uses to be designed to fulfil a given demand and that's what engineers take into account when dealing with it so any increase of demand without increasing capacity couldn't be accepted without violating some design safety margins. Such a rule works also for the electric connection systems between the MV lines and the final consumer LV lines but some uncertainties can arise when talking about transformers capacity mainly because the way that their power rates are chosen.

According to the Spanish electrical infrastructures regulation the main LV supply companies, the Spanish Distribution System Operators (DSO), deserve some rights to establish technical rules as long as they are country's law compliant. In this case they could establish the available transformer power for the MV to LV stations, more in detail and focusing on the three main operators next Table 10
shows the available power sizes,

<table>
<thead>
<tr>
<th>Company/Power</th>
<th>160 kVA</th>
<th>250 kVA</th>
<th>400 kVA</th>
<th>630 kVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endesa</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>U.Fenosa</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Iberdrola</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Tab. 10 Spanish DSO available transformer power rates

In the case of the 50 flat apartments building, considering Endesa as the transformation centre owner, a 250 kVA unit, bigger than the design 244.4 kVA, will be the choice.

At first sight such a way of doing seems to be giving some allowance for future loads to be connected without any change on the MV to LV transformer or on the ancillary equipment related depending on how bigger is the transformer size related to the building demand. Unfortunately, as the DSO usually owns the transformer utility, another customers could be connected to it filling any remaining capacity. Do to this and for this job purpose it will be considered that no any remaining capacity is available at the transformation centres and so for the related ancillary equipment.

3.3.1.2 EV RELATED LOAD

It's time now to define which load could mean the EV introduction on a given apartments building by taking into account the previous data and calculations.

3.3.1.2.1 NUMBER OF EV ON THE BUILDING PARKING

As said before this study will concentrate on a 50 flat building connected to the LV network. First of all the total amount of EV should be estimated by using the penetration forecast of 21% of EV over the total amount of passenger cars on 2030 as concluded on point 3.2.1.3.

Another input data will be the number of cars on the referred building parking area that would be at least equal to the number of flats, 50 cars. Additionally, and assuming that the fleet of cars parked on the building will show the same penetration that can be seen in the whole country a total of 11 EVs should be there on 2030.
3.3.1.2.2 POWER DEMAND AND PROFILE

As the total amount of cars is already stated this data is going to be translated on how much energy demand it means and when this energy, and the related power, will be needed.

As a input for this calculations the study data on which the JRC report “Projections for Electric Vehicle Load Profiles in Europe Based on Travel Survey Data” [24] is based and the energy calculations done on point 3.2.2 will be the main sources.

3.3.1.2.2.1 CAR USAGE PATTERNS

Three main parameters are to be unveiled by thriving on the above mentioned study [24], how many cars over the total of 50 are moving repeatedly from one day to another, how long are they journeys and when they are parked to reload their batteries assuming that charging out of the residential parking will be avoided as much as possible in order to save money.

- Total amount of EV to be charged every day.

According to the available data [24] a total of 55% of the total amount of vehicles in Spain get out to the streets and roads on a typical week day and from these a 93% are the same vehicles from one day to another. In our case this data means that a total of 28 cars do leave their parking place and return to it every week day and, according to the EV penetration, it means that 6 of them over a total of 11 are to be charged every day.

-Daily distance covered by the moving EV.

Based on the same study [24] data source the first easy result to calculate is the average of all the distances reported by the panelists. Doing so the result over 5529 runs shows an average of 29 km per run, which means 58 km taking into account the way back home.

As a result of this calculations the total amount of energy on a given day to charge the EV batteries could be easily obtained by multiplying the run distance, 58 km, by the number of cars running, 6, and the calculated 0.36 kWh/km. The result is a total of 125.3 kWh to be drawn from the LV system every day or 20.9
kWh for every moving EV.

-Parking times.

The third requested information to calculate the expectable power demand is to know at which time the cars will be parked on the building in order to proceed to charge their batteries. To know it the source data of the JRC report [24] will be the basis.

Thriving on the mentioned data the following graph could be extracted where the relative amount of cars running on a given hour could be checked.

![Average 7 days](image)

**Fig.14  Hourly graph of cars running over the total amount of cars**

Assuming that,

-At the end of the day, every car that leaved the parking at the morning will return home within the same day.

-A 2.5 hours period, starting as soon as every car reaches his parking place, will be the average charging time in order to get a 90% of VAC. This could be called “on demand charging time” as the battery reload starts automatically with no additional control as soon as the car is connected to the charging system.

Next is to divide by 2 the total amount of cars that are moving on a given day. The result of such a operation points the 14 hours as the time at what the total amount of running cars halves the total of the day and thus the hour from which the cars that leaved during the morning start their way back home. Even if such a
consideration tends to be a little simple reflects what is the cars common use, from home to the destination, that could be the job, the university or a shopping area or mall, and back home again. A further more detailed driving patterns study should be done to accurately depict the user behaviour.

![Average 7 days](image)

**Fig.15 Hourly distribution of cars leaving and returning to the parking**

Then, and assuming that no one car will expend more than one hour on his 29 km journey back home, the previous figure could be analized as follows,

14h → 0'13x50 cars running back home → 1 EV parked at 15h starting battery charge

15h → 0'12x50 cars running back home → 1 EV parked at 16h starting battery charge

16h → 0'09x50 cars running back home → 1 EV parked at 17h starting battery charge

17h → 0'08x50 cars running back home → 1 EV parked at 18h starting battery charge

18h → 0'09x50 cars running back home → 1 EV parked at 19h starting battery charge
charge

19h → 0.065x50 cars running back home → 1 EV parked at 20h starting battery charge

At 20h we do have 0.05x50 cars running back home, that means 2.5 cars and it, by the 0.21 EV penetration, gives 0.52 EV which is at the limit between 1 (bigger than 0.5) or 0 (smaller than 0.5) cars. It will be assumed as 0 because the total amount of EV running on a given day was calculated previously as 6. Anyway the calculations made are showing a quite good convergence giving confidence on the results even tough that the data source has not been taken in order to do this study.

3.3.1.2.2.2 EV POWER DEMAND WITH ON DEMAND CHARGING

As the available charging times are already available and assuming that the charging happens immediately after each car arrival to his parking place next is to calculate much power is needed to do so.

As assumed on chapter 3.3.1.2.2 a 90% of VAC will be the target. To achieve it a 2.5 hours long continuous charge is to take place which in turn will draw a continuous 8.4 kW from the LV system.

Next Figure 16 shows how the charging periods will be arranged as the EV arrive to the building parking.
Where written on every rectangle is,

\[ A \times B \times C \rightarrow \]

\( A \) stands for the simultaneous amount of EV to be charged, \( B \) stands for the power drawn by each of the EV to charge and \( C \) stands for the charging time.

Next Table 11 comes to help adding individual power demands,

<table>
<thead>
<tr>
<th>Charging table, 21% EV penetration, 90% of VAC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hours</strong></td>
</tr>
<tr>
<td><strong>Minutes</strong></td>
</tr>
<tr>
<td>EV_1</td>
</tr>
<tr>
<td>EV_2</td>
</tr>
<tr>
<td>EV_3</td>
</tr>
<tr>
<td>EV_4</td>
</tr>
<tr>
<td>EV_5</td>
</tr>
<tr>
<td>EV_6</td>
</tr>
<tr>
<td><strong>Total power</strong></td>
</tr>
<tr>
<td><strong>Hour peak</strong></td>
</tr>
</tbody>
</table>

**Tab. 11 Batteries charge power demand by hour**

At first sight the main conclusion is that, from 17h to 21 h the total power needed to charge the EV is 25.2 kW, 13% more than the design capacity of the facilities. To be more clear the following Figure 17 shows the power demand profile calculated by using the
previous data through the Table 12 data.

<table>
<thead>
<tr>
<th>Time</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-16</td>
<td>8.4</td>
</tr>
<tr>
<td>16-17</td>
<td>16.8</td>
</tr>
<tr>
<td>17-18</td>
<td>25.2</td>
</tr>
<tr>
<td>18-19</td>
<td>25.2</td>
</tr>
<tr>
<td>19-20</td>
<td>25.2</td>
</tr>
<tr>
<td>20-21</td>
<td>25.2</td>
</tr>
<tr>
<td>21-22</td>
<td>16.8</td>
</tr>
<tr>
<td>22-23</td>
<td>8.4</td>
</tr>
</tbody>
</table>

**Tab. 12 Batteries charge power simplified**

Where the maximum power drawn from the main supply of 25.2 kW from 17h to 21h could be easily verified. The above data is displayed on the following Figure 17 together with the residential maximum of 195.5 kW previously calculated on chapter 3.3.1.1.1 for a 50 flat apartments building.

![Figure 17 Charging power demand](image)

Where the green one represents the EV batteries hourly power demand.

**3.3.1.2.2.3 RESIDENTIAL CONSUMPTION PROFILE**

Once the power demand and the facility design capacity are already known the third factor, the residential demand, is to be unveiled.

In Spain the main source of electric demand data comes from REE and the following graph [45] shows the residential electrical consumption profile on a given winter day. Even if the summer day profile is a less acute than the winter one, the
worst case criteria again should drive this study concerns and thus only the winter one will be considered.

Fig. 18 Residential (“Residencial”) hourly power demand [45]

Comparing with Figure 17 the maximum demand periods seems to be coincident.

3.3.1.3 CONCLUSION

As the whole information is already available next Figure 19, a further development of Figure 17 based on REE data [45], is intended to be in help of making a conclusion about the impact of the EV on the residential LV systems,

Fig. 19 EV charging load impact on the LV system, 21% EV

54
Where the blue plot shows the Spanish winter residential demand coming from REE data [45], the green one represents the EV batteries hourly power demand and the red one traces the addition of the previous both demands. The total power demand clearly exceeds the building design load as calculated before. As a conclusion of the previous data it can be said that the impact of the EV on the LV infrastructure could not be ignored. The residential consumption profile peak matches in time with the battery charging demand and gives an overload of the system of 13% forcing to consider a countermeasure plan to avoid incidences, outages and expensive, environmentally harmful, equipment demand. Moreover almost all the rest of the calculation parameters could be worst than the ones considered. Following some possibilities that could drive the situation to an even more dangerous scenario,

1)- The EV penetration increases over the predicted 21%.

2)- Presence of cases where the owner has some special need that is not compatible with waiting 2,5h to have the car battery fully resulting on a bigger power demand.

3)- Batteries ageing. As the car batteries cumulate hours of service the maintenance current will increase giving an extra continuous load that is not considered for this study.

To cover this uncertainties an 1,2 safety margin should be considered moving from the calculated 25,2 kW to a new 30,2 kW which in turn means an 15,5% increase of power demand over the standard calculation for a 50 flat apartment building.

A countermeasure to this overload problem will be proposed later after evaluating the regional and full Spanish country impacts as any solution should be fully compatible with the whole electrical system.

### 3.3.2 REGIONAL CASE, BARCELONA’S METROPOLITAN AREA

Next step into the study of the impact of the EV on the electrical transport and distribution infrastructure is the study of a geographical area where detailed data
is available. The chosen one is the Barcelona's Metropolitan Area (BMA) due to two main reasons,

- High economical relevance. The BMA represents more than the 10% of the total Spanish GDP and has a special authority that cares of his activity and keeps updated their statistical parameters.

- REE official information includes a map showing the HV and LV lines crossing the BMA borders and the available Power Generation facilities on it.

To perform the analysis of this area the following points need to be cleared,

- Today’s electric power transport capability and demand profile.

- Total amount of EV on 2030 at the BMA and related related load profile.

- Relation between the needs and the available infrastructure, conclusion.

But prior to this a geographical relation between the BMA map and the REE map is to be established. To do so the following Figure 20 could be in help.

![Fig.20 BMA and REE maps matching](image-url)
Where the yellow lines are signalling the limits of the BMA \(^{[49]}\), excluding some important cities like Terrassa, Sabadell and others. To correct this and therefore use the REE map of lines their population and a proportional part of GDP will be manually added to the BMA data.

### 3.3.2.1 ELECTRIC POWER TRANSPORT CAPABILITY

In order to give a better understanding the following graph enumerates, in Spanish, the transport lines feeding the BMA.

![Lines identification](image)

**Fig. 21 Lines identification**

In terms of electrical power capacity next Table 13 does the addition of these lines capacity.
3.3.2.2 GENERATION CAPACITY

There are, inside the BMA, some power stations accounting for a total of 2540 MVA according to REE [47].

3.3.2.3 POWER DEMAND

The residential consumption together with the services and industrial ones are to be calculated in order to have the picture of today's electrical demand inside the area of the REE map [47] that could be the basis to forecast the future 2030 condition where the EV will be deployed as previously calculated. To do so the BMA statistical sources will be used by adding some relevant cities out of the BMA but feed by the same transport lines.

3.3.2.3.1 RESIDENTIAL DEMAND

The target population is calculated by the following Table 14 where the BMA population in 2012 [49] is added to the following main cities, Sabadell [50], Terrassa [51], Vilafranca del Penedés [52], Granollers [53], Vilanova i la Geltrú [54], and

### Tab. 13 BMA lines capacity

<table>
<thead>
<tr>
<th>Drawing label</th>
<th>Written name</th>
<th>Tension kV</th>
<th>Simple/Double</th>
<th>Thermal transport capacity (MVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tarragona</td>
<td>132/110</td>
<td>Simple</td>
<td>217</td>
</tr>
<tr>
<td>2</td>
<td>Vandellós</td>
<td>400</td>
<td>Simple</td>
<td>1251</td>
</tr>
<tr>
<td>3</td>
<td>Foix</td>
<td>220</td>
<td>Double</td>
<td>944</td>
</tr>
<tr>
<td>4</td>
<td>Bellisens</td>
<td>220</td>
<td>Simple</td>
<td>590</td>
</tr>
<tr>
<td>5</td>
<td>Castellet</td>
<td>220</td>
<td>Double</td>
<td>229</td>
</tr>
<tr>
<td>6</td>
<td>Puigpelat</td>
<td>220</td>
<td>Simple</td>
<td>336</td>
</tr>
<tr>
<td>7</td>
<td>Mequinenza</td>
<td>400</td>
<td>Simple</td>
<td>220</td>
</tr>
<tr>
<td>8</td>
<td>Ascó-La Esplugà</td>
<td>400</td>
<td>Double</td>
<td>2370</td>
</tr>
<tr>
<td>9</td>
<td>Santa Margarita</td>
<td>132/110</td>
<td>Double</td>
<td>90</td>
</tr>
<tr>
<td>10</td>
<td>Vandellós</td>
<td>400</td>
<td>Double</td>
<td>2304</td>
</tr>
<tr>
<td>11</td>
<td>Rubió</td>
<td>220</td>
<td>Simple</td>
<td>94</td>
</tr>
<tr>
<td>12</td>
<td>Pont de Suer-Pobla</td>
<td>220</td>
<td>Double</td>
<td>229</td>
</tr>
<tr>
<td>13</td>
<td>La Pobla de Segur</td>
<td>132/110</td>
<td>Simple</td>
<td>170</td>
</tr>
<tr>
<td>14</td>
<td>Cardona</td>
<td>132/110</td>
<td>Double</td>
<td>95</td>
</tr>
<tr>
<td>15</td>
<td>Solsona</td>
<td>132/110</td>
<td>Double</td>
<td>out of the BMA</td>
</tr>
<tr>
<td>16</td>
<td>Maresa</td>
<td>132/110</td>
<td>Double</td>
<td>170</td>
</tr>
<tr>
<td>17</td>
<td>Ascó</td>
<td>400</td>
<td>Double</td>
<td>2370</td>
</tr>
<tr>
<td>18</td>
<td>Sallent-Calders</td>
<td>400</td>
<td>Double</td>
<td>1185</td>
</tr>
<tr>
<td>19</td>
<td>Sant Celoni</td>
<td>220</td>
<td>Simple</td>
<td>305</td>
</tr>
<tr>
<td>20</td>
<td>Bescanò</td>
<td>400</td>
<td>Simple</td>
<td>1251</td>
</tr>
<tr>
<td>21</td>
<td>Vic</td>
<td>400</td>
<td>Simple</td>
<td>1251</td>
</tr>
<tr>
<td>22</td>
<td>Sant Celoni</td>
<td>220</td>
<td>Double</td>
<td>305</td>
</tr>
<tr>
<td>23</td>
<td>Vic</td>
<td>220</td>
<td>Double</td>
<td>320</td>
</tr>
</tbody>
</table>

**TOTAL MVA**: 16296
Mataró \[^{[59]}\], out of the BMA but inside or closer to the REE map. A total of guessed 2% correction is applied to take into account the rest of inhabitants of the REE area.

<table>
<thead>
<tr>
<th>Entity</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMA</td>
<td>3,239,337</td>
</tr>
<tr>
<td>Sabadell</td>
<td>207,938</td>
</tr>
<tr>
<td>Terrassa</td>
<td>215,678</td>
</tr>
<tr>
<td>Mataró</td>
<td>124,084</td>
</tr>
<tr>
<td>Vilanova I la Geltrú</td>
<td>66,591</td>
</tr>
<tr>
<td>Granollers</td>
<td>59,753</td>
</tr>
<tr>
<td>Vilafranca del Pendés</td>
<td>39,035</td>
</tr>
<tr>
<td><strong>SUBTOTAL</strong></td>
<td><strong>3,952,416</strong></td>
</tr>
<tr>
<td><strong>2% correction</strong></td>
<td><strong>79,048</strong></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>4,031,464</strong></td>
</tr>
</tbody>
</table>

### Tab. 14 Population within the REE defined area

Where a total of 4,031,464 persons are calculated living on the area inside the REE map, the 8,63% of the total 46,704,314.

To calculate the power need of such amount of population the Figure 18 is to be used again considering that in the rush hour the population parameter is giving both residential and services consumption. Such a values could be extracted as shows the next Figure 19, a review of the above mentioned Figure 18.

![Population related electrical power demand](image)

Then the previously calculated 8,63% of the population, over the total 21,500 MW, gives a power need for today’s residential and services consumption that is
1.855 MW. This value, multiplied by population ratio in Spain between 2030 and today, gives a total of 2.091 MW. Accepting 0.8 as an average power factor in can be converted to a total of 2.614 MVA in terms of population apparent electrical power needs.

3.3.2.3.2 INDUSTRIAL DEMAND

By using the same Figure 21 [45] and considering that the BMA itself generates 10% [46] of the total Spanish GDP the industrial demand could be considered, after adding the additional cities GDP's as being 12.4% of 13.500 MW, that is, 1.674 MW in 2012.

Next is to move from 2012 to 2030 and to do so the PIB growth average from 1998 to 2012 shows a 2.03% in year to year increase which, in turn, moves the above industrial power demand from 1.674 MW in 2012 to 1.707 MW in 2030.

Finally, again by using 0.8 as a power factor, the industrial demand will account for 2135 MVA in 2030.

3.3.2.3.3 EV DEMAND

Next is to estimate which power demand will be introduced by the forecast EV penetration on year 2030. To do so a first question on how many cars will be on the REE map area [47] on year 2030 can get his answer by looking back to the point 3.2.1.1.1 where the cars/inhabitant ratio of 0.54 is stated and the total Spanish population of 52.661.000 individuals in 2030 is presented. By using this data and considering that, in year 2030, the REE map area stills represent the 8.63% of the total Spanish population, a total of 2.454.108 cars can be expected inside the referred area.

Now, by applying the 21% penetration level saw in point 3.2.1.1.4, the total amount of EV will be of 515.363 units that, multiplied by 0.55 as described in point 3.3.1.2.2.1, gives a total of 283.450 EV moving every day thus to be daily charged. At the end, and assuming a constant 8hrs 4.86 kW to charge every EV as calculated on point 3.3.1.2.2, the required power for the EV is 1.378 MW or 1.722 MVA inside the REE map area [47].
3.3.2.4 CONCLUSION

As the whole data is already calculated and available regarding the regional analysis the following Table 15 shows the balance results for the area delimited by the REE map [47] surrounding Barcelona city and its BMA.

<table>
<thead>
<tr>
<th>Power capability (MVA)</th>
<th>Power demand (MVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation (today)</td>
<td>16296</td>
</tr>
<tr>
<td>Residential (2030)</td>
<td>2614</td>
</tr>
<tr>
<td>Generation (today)</td>
<td>2540</td>
</tr>
<tr>
<td>Industrial (2030)</td>
<td>2135</td>
</tr>
<tr>
<td>EV (2030)</td>
<td>1722</td>
</tr>
<tr>
<td>TOTAL</td>
<td>18836</td>
</tr>
<tr>
<td>TOTAL</td>
<td>6471</td>
</tr>
</tbody>
</table>

**Tab. 15 Power balance on Barcelona’s area**

A few conclusions could be extracted from this results,

- On the area included inside the REE map [47] the electrical energy transportation and generation capabilities are 200% higher than the expected demand including the EV. This means than, even if a full blackout happens to the Tarragona's nuclear and combined cycles power plants together with an international connection failure, this area can still be electrically feed by the remaining Pyrenean hydropower plants and BMA's combined cycles with a total of 6.892 MVA.

- Disregarding the above described meshing safety strategies, it will be no problem for the local area power capability when it comes to deal with the EV even considering that there's no any improvement on the facilities from today till year 2030. Moreover the safety margin is factor 3 and, even considering a 100% EV penetration on year 2030, one third of the power capabilities will remain unused.

Last on this chapter is to remember that this local analysis was done over a specific area and may not apply to another Spanish regions that could exhibit lower or higher facilities presence and/or capability. Due to the scope of this investigation and in regard of the the available information it's not possible to go further this way.

3.3.3 SPANISH CONTINENTAL SCALE

On the way of increasing the size of the analysis area the final step of this study
will be the whole Spanish continental area. To evaluate it REE data is available showing from one side the total electric generation capability and from the other the total power demand profile on a given day at a given hour. Such data will be combined with the EV penetration forecast, for the whole country but the islands this time, and its related power demand.

3.3.3.1 CONTINENTAL TRANSPORT CAPABILITY

Regarding the REE continental available data [56] only the generation capability is on their site so an assumption is to be done considering that the transport infrastructure will be at least capable of driving the whole production power to the different consumption areas and customers.

According to REE a total of simultaneous 127.851 MVA could be generated by the Spanish continental electric system. No international connection contributions will be considered for this study purposes but, as a huge continental community, the European Union could have interesting synergies between their countries in the electric power distribution.

3.3.3.2 CONTINENTAL POWER DEMAND

On year 2013 the peak of demand was reached from 20 to 21hrs on February 27th with 49.953 MVA [56]. Assuming that such a peak is fully population dependant then, considering that the population ratio between the year 2030 forecast and the 2012 available data is 1’13, the expectable power peak on year 2030 should be of 56.324 MVA.

3.3.3.3 EV POWER DEMAND

To calculate it a first continental population estimation on 2030 should be stated. In Spain the continental population accounts for the 93% of the country's total population [57]. According to this a total of 48,974,730 Spaniards will be in the Spanish continental area on year 2030. Using the already calculated on point 3.2.2.1.4 C/I ratio of 0,54 and the 21% of EV penetration from point 3.2.1.1.4 a total of 5,553,734 EVs could be expected in the Spanish continental area on year 2030.
Applying the 3.3.1.2.2.1 calculation result that shows 55% of the cars moving every day there will be 3,054,554 EVs to be charged on a given day and, as long as the 4.86 kW calculated on point 3.3.1.2.2 are to be used to charge everyone of them, a total of 18,556 MVA will be needed if they all charge at the same time.

3.3.3.4 CONCLUSION

Next Table 16 comes to summarize the results from the above calculations.

<table>
<thead>
<tr>
<th>Spanish continental area</th>
<th>Power capability (MVA)</th>
<th>Power demand (MVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation (today)</td>
<td>127851</td>
<td>56324</td>
</tr>
<tr>
<td>EV (2030)</td>
<td></td>
<td>18556</td>
</tr>
<tr>
<td>TOTAL</td>
<td>127851</td>
<td>TOTAL 74880</td>
</tr>
</tbody>
</table>

Tab. 16 Spanish continental area power balance

From Table 16 the following conclusions could be stated,

- Considering the calculated penetration of the EV the Spanish continental electrical system will be able, even without any improvement from today’s condition and disregarding meshing criteria that could not be established through this investigation, to hold the new load that their introduction could represent.

- Even in the case of a massive introduction of the EV into the Spanish market, and disregarding again any system improvements from today to 2030 and also meshing requirements, the Spanish electrical power system can almost cope with the deal. In such a case, with 100% of EV penetration, only a 17% of power generation growth will be enough to cope with the demand.

3.4 ENERGY BALANCE CONCLUSIONS

After the evaluation done over the three chosen sizes of the transport and distribution infrastructures, local, regional and continental, this study unveils that the challenge arises on the low voltage, local size, systems, that will be the ones most likely demanding countermeasures to allow the EV deployment.

On the other hand the regional and continental Spanish infrastructures studied proved to be, generally speaking and by using the available data, oversized enough to cope with the estimated EV penetration and even more without any kind of improvement from today to year 2030.
Next and last in this investigation will be a countermeasure proposal and study to make possible the EV introduction as a desirable improvement to the Spanish low carbon mobility mix and taking into account that whatever this countermeasure will be must came in help of the main issue, the EV introduction, but also must be synchronized with the rest of the Spanish electrical power system. In this sense it will be desirable that such a countermeasure contributes to solve some of the main issues today as the flattening of the demand curve and the effective injection of the renewable sources to the grid when generated.

### 3.5 VEHICLE AVAILABILITY CONCLUSIONS

As a conclusion for the vehicle availability criteria till now the only strategy applied was to sep-up a charging time of 8 hours starting as soon as the cars are parled on their places. With such a strategy the vehicle availability is only of 66% and seems difficult to be improved with no additional countermeasures as the LV systems are already overloaded and will not allow any faster charge but instead of this appear to be asking for a longer times.

### 4 COUNTERMEASURE REQUIREMENTS

Prior to propose any countermeasure a deeper analysis of what was written at the previous 3.4 and 3.5 conclusions points is to be done. The target will be to get a reliable picture of what is the real problem and what are the immediate solutions for it by using the up-to-date available strategies and technologies.

Together with the above study a very important stakeholder implication is to be considered, the regulator. It's on the administration hands to force or at least to easy the massive EV deployment and the proposal must take into account the way that they should or could act.

Finally another constraints should be taken into account or at least numbered. Following a few of them,

- Cost. Very expensive solutions should not be considered.

- Physical space. As in some cases the countermeasure should be applied to already existing buildings with almost no free room for big facilities special care should be taken with this parameter.
-Safety. Whatever the proposed countermeasure will be it must be 100% safe for the building inhabitants following all the existing regulations in this sense.

-Technology maturity. The countermeasure should rather use existing technology than a new one that could take many years to develop, not so much time is available.

-Technology upgrade. It must be easy for the technological elements included on the countermeasure to be upgraded. Single device integrated solutions should be avoided in order to be able to upgrade the system element by element as new and convenient improvements reach the market.

Next points will deploy the previous items more in detail and one by one. After deeply considering all the previous points, countermeasure proposal and analysis could eventually take place showing which advantages does it will have over the standard solutions.

4.1 ITEMS TO FIX

This point will summarize and describe in detail the different issues to cope with and the standard, today available, solutions that can help solving it evaluating their suitability in each case. A review of the criteria exposed on point 3.1 could be in help understanding what follows this lines.

4.1.1 LV SYSTEM CONGESTION

A countermeasure to fix the LV system congestion due to the EV is a must item as today's infrastructure could not handle the power demand growth that its batteries charging process would request. To do so today's available standard solutions could be summarized at the following two,

a- Change all the LV systems upgrading transformers, cells, feeders and many of the related ancillary equipment. This will work for sure but will also have an enormous economical and ecological impact related to the dismantling, installing, recycling and disposal processes of many equipment and toxic materials as oils, resins, etc. No any proposal in this sense can be seen on the available papers and technical documents related to the EV introduction as probably everyone agrees that his big and painful impacts are not allowable.
b- Change the charging times to a valley hours in order to avoid the LV systems overloads. This is a very popular solution suggested by many authors and seems to be the only one available and technically possible today.

Unfortunately this countermeasure means also a VAC worsening. Forcing to charge all the EV in valley hours means forcing to avoid vehicle usage for a long period of time for these users that reach home after hour 16\textsuperscript{th} as they will not be able to have their cars fully charged till half past midnight. Next Figure 23 comes to illustrate this effect.

\textbf{Fig. 23 Valley charging strategy [45]}

Where the left-upper dashed area stands for the forbidden power area as it's over the design load of 195.5 kW and the right-lower one is where the first one has to me moved in order to have room to charge the EV batteries. The equivalences are calculated in therms of energy, kWh, and the result could be readed in therms of total charging time which in this case is 7.5 hours for those cars left after the 16\textsuperscript{th} hour as already pointed.

The VAC now will be as low as,

\[ VAC = \frac{(24 - 7.5)}{24} = 0.69 \]

\textbf{Exp. 6}

Which could be hardly accepted by the vehicle owners.

\subsection{4.1.2 VEHICLE AVAILABILITY COEFFICIENT}

This issue was already described enough on points 3.3.1.2.2 and 3.5. To fix it the only standard solution available is the one stated on point “a” of chapter
4.1.1. Unless another dedicated countermeasure takes place no other way than increasing the LV system power capability could effectively deal with it and improve the VAC by shortening the batteries charging times.

4.1.3 POWER GRID RENEWABLES INTEGRATION

It's well known that the main technical concern on the renewable energy injection to the power grid is that the power generation, specially from wind turbines, and the power demand could not happen at the same time.

To fix this the Spanish DSO are deploying Pumping Storage Hydropower stations in order to be able to store the unwanted energy in peak production hours or days and to draw it back to the power grid on peak demand periods. Such a technology could cope with the deal and store the unwanted energy on a given time but not without some drawbacks,

- Regulation. The regulation of the pump/trubine groups stills today a main item for the equipment manufacturers to adjust in order to make the power station response as fast as possible to effectively interact with the power grid needs.

- Environmental impact due to the quite huge infrastructure elements as the water vessel, the pipes, the inlet and inlet water ports, the power lines to connect the station to the power grid, etc.

- Operating cost due to the high complexity of the facilities and maintenance requirements.

- Distance between the generation, the pumping storage and the consumption spots. The vessels should no be far from water resources and elevations or mountains and could be far from windy areas, specially future offshore farms, and consumption centres.

Another approaches to absorb and inject energy to the power grid when needed are inertia flywheels, compressed air, hydrogen production and, finally, batteries storage at big facilities. All of them are today in their beginnings as a massive scale solution and can't compete with the previously presented Pumping Storage facilities.
4.2 ADMINISTRATION CONCERNS

Till now the calculations done where based on the EV penetration forecast among another important informations. Based on this the total amount of EVs moving on a given day was calculated and so was the energy and power needs.

From the administration point of view the usual way to go in this cases is to issue a national code that, for the EV charging systems, will force the present and future building owners to ad it to the existing facilities allowing a safe and reliable EV deployment. Keeping in mind that the cost must be reasonable the administration, when issuing the code, could not stablish a forecast on EV market penetration and should consider a 100% market share of EV, otherwise the risk of forcing the owners to build-up underestimated overflowed facilities will be quite big.

Something similar was done in Spain 8 years ago when the CTE Edification Technical Code (CTE) [58] was issued forcing all the new apartment buildings to have thermal solar energy on their roofs and also the existing ones if they plan to undergo some important refurbishment. In this case, to make possible the EV deployment, not only the new buildings but also the existing ones, e.g. as some percent of their inhabitants ask for it, should be forced to prepare to charge the EV.

5 COUNTERMEASURE PROPOSAL

After the previous chapter 4 evaluation its time to make a countermeasure proposal.

First to tell that the author of this study finds clear similarities between the EV batteries charging problem and the one already existing on the centralized sanitary water supply in an apartments building. The big thermal power demand i on peak periods in order to produce enough hot water uses to be solved in two ways,

1st - By providing enough thermal power by using huge boilers that will also provide a huge gas consumption.

2nd – By producing the sanitary water at a much slower rate by using smaller, more efficient, boilers than the previous ones and storing it on an inertia
tank that could provide the required flow at the required temperature in rush hours.

Stated the above similarity also a similar countermeasure will be proposed. The main idea will be to add an inertia battery (IB) in the path between the utility LV bus bars and the cars batteries (CB). The following Figure comes to show this proposal,

Where,

- The bloc “FC” stands for the energy flow control that will manage the energy flow sense allowing several combinations.

- The bloc “BC” stands for standard battery chargers fitted at every parking place and working on AC.

Next chapters will define more in detail the control strategy, the FC block general structure, the inertia batteries estimated dimension and how the proposal satisfies the chapter 4 requirements and constraints.

5.1 CONTROL STRATEGY

The control strategy will try to make possible that the countermeasure could solve the chapter 4 requirements by switching from one to another state the FC system. To do so a simplified and discretized regulation Table 17 is described bellow. The actual condition will involve several states between every two possibilities, now only binary options like charged/discharged or high/low are considered, but such a huge evaluation is beyond the purpose of this job and at this point following lines will be a rough presentation of how it would look like the
regulation of the FC system.

<table>
<thead>
<tr>
<th>Inertia battery</th>
<th>Car batteries</th>
<th>LV system</th>
<th>Renewals production</th>
<th>National consumption</th>
<th>FC system state</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHARGED</td>
<td>SATURATED</td>
<td>HIGH</td>
<td>HIGH</td>
<td>State 4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>FREE ROOM</td>
<td>HIGH</td>
<td>LOW</td>
<td>State 5</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SATURATED</td>
<td>LOW</td>
<td>HIGH</td>
<td>State 4</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FREE ROOM</td>
<td>HIGH</td>
<td>LOW</td>
<td>State 4</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SATURATED</td>
<td>LOW</td>
<td>HIGH</td>
<td>State 5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
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**Tab. 17 Simplified control table for the FC system**

Where the different possible states are,

- **State 1.** Energy flows from the LV bus bars to the IB and the CB.

![State 1 Diagram](image1)

- **State 2.** Energy flows from the LV bus bars to the CB.

![State 2 Diagram](image2)

- **State 3.** Energy flows from the LV bus bars and the IB to the CB. Probably the most common state almost don't appear at the regulation table as it is strongly discretized. This state will take place when there's some room on the
LV system and some charge on the IB but none of them alone could assume the CB charging load.

- **State 4.** Energy flows from the IB to the LV bus bars.

- **State 5.** The LV bus bars are disconnected from the IB and the CB.

- **State 6.** The LV bus bars are disconnected from the IB and the CB are being charged by the IB.

- **State 7.** The energy flows from the IB to the CB and the LV bus bars. It could happen at a different rates depending mainly on how energy remains on the IB that is available to use to energize the LV bus bars.
- **State 8.** The energy flows from the LV bus bars to the IB.

- **State 9.** The CB are charged at a low speed while the IB is disconnected. This option needs that some information could reach the CB chargers in order to instruct them to do it at a lower speed, a PLC system or another should be in use for it.

More on Table 17,

- **LV system** stands for the MV/LV TC, LV feeders an ancillary systems. On the Table two conditions are considered,

  - **LV system saturated** stands for such a condition where the LV system is closer to his design maximum load and couldn't be more charged.

  - **LV system free room** stands for such a condition where the LV system is under his design load and could accept moree charge.

  - **Discharged** stands in both cases, IB and CB, for a state of charge (SOC) around 25% of te inertia and car batteries.

  - **National consumption** stands for the whole country electric energy consumption and is discretized in two states,

    - **High**, that occurs when the total energy consumption is closer to the maximum statistical level but also when some of the following infrastructures goes closer to his thermal limit,

      - **MV line feeding the TC where the FC is connected.**

      - **HV line feeding the MV line that feeds the TC where the TC is connected.**
- ES receiving and issuing respectively HV and MV lines that sequentially feed the TC where the FC is connected from the power station.

- Low, that occurs when there's a small national demand and none of the electrical infrastructures defined above is closer to their thermal limit.

Furthermore an additional condition must be considered, not included into the Table 17 on a specific column for simplicity, that stands for the cases of overload of any line, MV or HV, above the MV/LV transformers that could be relieved by energizing the grid from the IB. It tries to cover emergency situations as unexpected overloads or partial failures that will mean energy deviations from one line to another to avoid outages.

According to the regulation table next chapters will develop in detail every case and will show how it can help to solve the main items to fix in order to make possible the EV charging and to fulfil as mush as possible the chapter 4 requirements.

5.1.1 CASES DEFINITION

Next a case by case description of the 32 different situations included on Table 17 will be presented. Nevertheless its important to say again that this part of the study deals with a simplified model where the infinite combinations between two binary states are not taken into account.

Some priorities must be defined before starting with the case by case analysis and decision making. The general priorities and their prevalence will be,

1st - Keep the houses electrical service quality and continuity by energizing the grid when there's a possible outage due to an overload. This information should be provided to the FC by the TSO or by the DSO.

2nd - Keep the CB SOC as big as possible to make the VAC as high as possible.

3rd - Keep the IB SOC as big as possible and, at the same time, help the grid to store renewals production when their production is high and the national consumption is low when possible. Some additional information from the TSO or the DSO should be provided to the FC in order to make it possible.
4th - Try to reduce the power grid load in their LV/MV/HV stages to improve overall transport and distribution energy efficiency by energizing the grid from the IBs.

5th - Try to minimize the charge/discharge cycles on the IB to improve his life span.

Next Figure 24 comes to help understanding the following descriptions.

**Fig. 25 Elements and energy flow identification**

Where,

-CB1...CBn stand for the cars batteries, identified before as CB.

-BC1...BCn stand for the battery chargers, feed on AC power, and with an additional control to slow down the charging speed when needed.

-FC stands for the Flow Control system than should make possible what’s defined on Table 17.

-IB stands for the already described inertia battery intended to couple the CB energy demand with the LV system load profile without generating overloads and to help the LV/MV/HV power grid in cases of high thermal loads or
emergency.

-BFEF stands for the building feeder energy flow that, in Table 17, is included on the LV System column and discretized into two single states, saturated or free room.

-TC stands for a LV TC feeding energy to many buildings and consumptions through a local LV grid.

-TCEF stands for the TC energy flow that, in Table 17, is included into the “LV System” column and discretized into two single states, saturated or free room.

-MVEF stands for a MV line energy flow that, in Table 17, is included into the “National consumption” column and discretized into two states, high or low. A third state not included on Table 17 will be the emergency state where the line is closer to his thermal limit.

-ES stands for an electric substation that feeds MV lines from HV.

-ESEF stands for an electric substation energy flow that, in Table 17, is included on the “National consumption” column and discretized into two states, high or low. A third flow level not included on Table 17 will be the emergency one where the line is closer to his thermal limit, this should be considered in some cases that will be described further on this chapter.

-HVEF stands for a HV line energy flow that, in Table 17, is included into the “National consumption” column and discretized into two states, high or low. A third state not included on Table 17 will be the emergency state where the line is closer to his thermal limit.

Since the previous informations are already presented now is time to go with a deep analysis of the 32 cases of the Table 17.

-Case 1. The situation can be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.
- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF
or the ESEF or the HVEF that are feeding the MV/LV TC.

- The IB is full and there's no need of energy to charge the CB that are exhibiting also a 100% SOC.

- The renewals energy production is high.

After evaluating the priorities list in this case the first one that be satisfied will be the 4th and thus some energy stored on the IB should be returned to the power grid, is the State 4 that appears on Table 17.

**Case 2.** The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.

- The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.

- The IB is full and there's no need of energy to charge the CB that are exhibiting also a 100% SOC.

- The renewals energy production is high.

After evaluating the priorities list in this case the first one to be satisfied will be the 3rd as the renewals production is high and the National consumption is low but due to the LV system saturation and the IB and CB SOC no more energy could be assumed by the system. As a result the next to be satisfied will be the 4th and thus some energy stored on the IB should be returned to the power grid, is the State 4 that appears on Table 17.

**Case 3.** The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.

- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.
The IB is full and there's no need of energy to charge the CB that are exhibiting also a 100% SOC.

The renewals energy production is low.

After evaluating the priorities list in this case the first one to be satisfied will be the 4th and thus some energy stored on the IB should be returned to the power grid, is the State 4 that appears on Table 17.

**Case 4.** The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal capacities.
- The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.
- The IB is full and there's no need of energy to charge the CB that are exhibiting also a 100% SOC.
- The renewals energy production is low.

After evaluating the priorities list in this case the first one to be satisfied will be the 4th and thus some energy stored on the IB should be returned to the power grid, is the State 4 that appears on Table 17.

**Case 5.** The situation could be summarized as follows,

- The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.
- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.
- The IB is full and there's no need of energy to charge the CB that are exhibiting also a 100% SOC.
- The renewals energy production is high.

After evaluating the priorities list in this case the first one to be satisfied
will be the 4th and thus some energy stored on the IB should be returned to the power grid, is the State 4 that appears on Table 17.

**Case 6.** The situation could be summarized as follows,

- The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.
- The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.
- The IB is full and there's no need of energy to charge the CB that are exhibiting also a 100% SOC.
- The renewals energy production is high.

After evaluating the priorities list in this case no one could be satisfied by the FC and thus the EV charging system has to be disconnected from the grid, is the State 5 that appears on Table 17.

**Case 7.** The situation could be summarized as follows,

- The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.
- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.
- The IB is full and there's no need of energy to charge the CB that are exhibiting also a 100% SOC.
- The renewals energy production is low.

After evaluating the priorities list in this case the first one to be satisfied will be the 4th and thus the EV charging system has to be disconnected from the grid, is the State 4 that appears on Table 17.
- **Case 8.** The situation could be summarized as follows,

- The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.

- The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.

- The IB is full and there’s no need of energy to charge the CB that are exhibiting also a 100% SOC.

- The renewals energy production is low.

After evaluating the priorities list in this case no one could be satisfied by the FC and thus the EV charging system has to be disconnected from the grid, is the State 5 that appears on Table 17

- **Case 9.** The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.

- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.

- The IB is full but the CB need to be charged.

- The renewals energy production is high.

After evaluating the priorities list in this case the first one that could be satisfied will be the 2nd and thus the EV charging system must charge the CB by using the IB stored energy, is the State 6 that appears on Table 17. Moreover in this case the shift from the State 6 to the State 7, where the priority for the IB is to energize the power grid while charging the CB as a secondary target, should be performed if the TSO or the DSO send an emergency signal to do so.
-Case 10. The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.

- The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.

- The IB is full but the CB need to be charged.

- The renewals energy production is high.

After evaluating the priorities list in this case the first one that could be satisfied will be the 2nd and thus the EV charging system must charge the CB by using the IB stored energy, is the State 6 that appears on Table 17.

-Case 11. The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.

- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.

- The IB is full but the CB need to be charged.

- The renewals energy production is low.

After evaluating the priorities list in this case the first one that could be satisfied will be the 2nd and thus the EV charging system must charge the CB by using the IB stored energy, is the State 6 that appears on Table 17. Moreover in this case the shift from the State 6 to the State 7, where the priority for the IB is to energize the power grid while charging the CB as a secondary target, should be performed if the TSO or the DSO send an emergency signal to do so.

-Case 12. The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the
TCEF or both are closer to their maximum thermal limits.

- The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.
- The IB is full but the CB need to be charged.
- The renewals energy production is low.

After evaluating the priorities list in this case the first one that could be satisfied will be the 2nd and thus the EV charging system must charge the CB by using the IB stored energy, is the State 6 that appears on Table 17.

**Case 13.** The situation could be summarized as follows,

- The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.
- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.
- The IB is full but the CB need to be charged.
- The renewals energy production is high.

After evaluating the priorities list in this case the first one that could be satisfied will be the 2nd and thus the EV charging system must charge the CB by using the IB stored energy and the LV system, is the State 3 that appears on Table 17. Moreover in this case the shift from the State 3 to the State 7, where the priority for the IB is to energize the power grid while charging the CB as a secondary target, should be performed if the TSO or the DSO send an emergency signal to do so.

**Case 14.** The situation could be summarized as follows,

- The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.
– The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC

– The IB is full but the CB need to be charged.

– The renewals energy production is high.

After evaluating the priorities list in this case the first one that could be satisfied will be the 2nd and thus the EV charging system must charge the CB by using the IB stored energy and the LV system, is the State 3 that appears on Table 17.

**Case 15.** The situation could be summarized as follows,

– The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.

– The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.

– The IB is full but the CB need to be charged.

– The renewals energy production is low.

After evaluating the priorities list in this case the first one that could be satisfied will be the 2nd and thus the EV charging system must charge the CB by using the IB stored energy and the LV system, is the State 3 that appears on Table 17. Moreover in this case the shift from the State 3 to the State 7, where the priority for the IB is to energize the power grid while charging the CB as a secondary target, should be performed if the TSO or the DSO send an emergency signal to do so.

**Case 16.** The situation could be summarized as follows,

– The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.

– The National consumption is low due to the low Spanish
nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC

- The IB is full but the CB need to be charged.
- The renewals energy production is low.

After evaluating the priorities list in this case the first one that could be satisfied will be the 2nd and thus the EV charging system must charge the CB by using the IB stored energy and the LV system, is the State 3 that appears on Table 17.

**Case 17.** The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.
- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.
- The CB are charged but the IB is discharged.
- The renewals energy production is high.

After evaluating the priorities list in this case no one could be satisfied by the FC and thus the EV charging system has to be disconnected from the grid, is the State 5 that appears on Table 17.

**Case 18.** The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.
- The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.
- The CB are charged but the IB is discharged.
- The renewals energy production is high.

After evaluating the priorities list in this case no one could be satisfied by the FC and thus the EV charging system has to be disconnected from the grid. 

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The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.
- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.
- The CB are charged but the IB is discharged.
- The renewals energy production is low.

After evaluating the priorities list in this case no one could be satisfied by the FC and thus the EV charging system has to be disconnected from the grid, is the State 5 that appears on Table 17.

**Case 20.** The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.
- The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.
- The CB are charged but the IB is discharged.
- The renewals energy production is low.

After evaluating the priorities list in this case no one could be satisfied by the FC and thus the EV charging system has to be disconnected from the grid, is the State 5 that appears on Table 17.

**Case 21.** The situation could be summarized as follows,

- The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.
- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF
or the ESEF or the HVEF that are feeding the MV/LV TC.

- The CB are charged but the IB is discharged.
- The renewals energy production is high.

After evaluating the priorities list in this case the first to satisfy is the 3rd one so the FC should switch to the State 8 that appears on Table 17. Moreover, as the National consumption is high, an emergency signal of overload risk from the DSO or the TSO is more likely to arrive changing the FC to the State 5.

-Case 22. The situation could be summarized as follows,

- The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.

- The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.

- The CB are charged but the IB is discharged.

- The renewals energy production is high.

After evaluating the priorities list in this case the first to satisfy is the 3rd one so the FC should switch to the State 8 that appears on Table 17.

-Case 23. The situation could be summarized as follows,

- The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.

- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.

- The CB are charged but the IB is discharged.

- The renewals energy production is low.

After evaluating the priorities list in this case the first to satisfy is the 3rd
one so the FC should switch to the State 8 that appears on Table 17. Moreover, as the National consumption is high, an emergency signal of overload risk from the DSO or the TSO is more likely to arrive changing the FC to the State 5.

-Case 24. The situation could be summarized as follows,
- The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.
- The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.
- The CB are charged but the IB is discharged.
- The renewals energy production is low.

After evaluating the priorities list in this case the first to satisfy is the 3rd one so the FC should switch to the State 8 that appears on Table 17.

-Case 25. The situation could be summarized as follows,
- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.
- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.
- The CB and the IB are both discharged.
- The renewals energy production is high.

After evaluating the priorities list in this case no one could be satisfied by the FC and thus the EV charging system has to be disconnected from the grid, is the State 5 that appears on Table 17.

-Case 26. The situation could be summarized as follows,
- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.
- The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.

- The CB and the IB are both discharged.

- The renewals energy production is high.

After evaluating the priorities list in this case no one could be satisfied by the FC and thus the EV charging system has to be disconnected from the grid, is the State 5 that appears on Table 17.

**Case 27.** The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.

- The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.

- The CB are charged but the IB is discharged.

- The renewals energy production is low.

After evaluating the priorities list in this case no one could be satisfied by the FC and thus the EV charging system has to be disconnected from the grid, is the State 5 that appears on Table 17.

**Case 28.** The situation could be summarized as follows,

- The local LV system is saturated because the BFEF or the TCEF or both are closer to their maximum thermal limits.

- The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.

- The CB and the IB are both discharged.

- The renewals energy production is low.

After evaluating the priorities list in this case no one could be satisfied by the FC and thus the EV charging system has to be disconnected from the grid.
grid, is the State 5 that appears on Table 17.

-Case 29. The situation could be summarized as follows,
   - The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.
   - The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.
   - The CB and the IB are both discharged.
   - The renewals energy production is high.

After evaluating the priorities list in this case the first to satisfy is the 2\textsuperscript{nd} one followed by the 3\textsuperscript{rd} so the FC should switch to the State 1 that appears on Table 17 where the IB and the CB are charged by the LV system. Moreover, as the National consumption is high, an emergency signal of overload risk from the DSO or the TSO is more likely to occur changing the FC to the State 9 where the IB is disconnected and the CB could be charged at a low rate. Finally, in case of a persisting overload, FC must switch to State 5.

-Case 30. The situation could be summarized as follows,
   - The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.
   - The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.
   - The CB and the IB are both discharged.
   - The renewals energy production is high.

After evaluating the priorities list in this case the first to satisfy is the 2\textsuperscript{nd} and after the 3\textsuperscript{rd} one so the FC should switch to the State 1 that appears on Table 17.
-**Case 31.** The situation could be summarized as follows,
  - The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.
  - The National consumption is high due to the high Spanish nationwide consumption or due to the high level of the MVEF or the ESEF or the HVEF that are feeding the MV/LV TC.
  - The CB and the IB are both discharged.
  - The renewals energy production is low.

After evaluating the priorities list in this case the first to satisfy is the 2\textsuperscript{nd} one followed by the 3\textsuperscript{rd} so the FC should switch to the State 1 that appears on Table 17 where the IB and the CB are charged by the LV system. Moreover, as the National consumption is high, an emergency signal of overload risk from the DSO or the TSO is more likely to occur changing the FC to the State 9 where the IB is disconnected and the CB could be charged at a low rate. Finally, in case of a persisting overload, FC must switch to State 5.

-**Case 32.** The situation could be summarized as follows,
  - The local LV system has free room to transport energy because the BFEF and the TCEF are far from their maximum thermal limits.
  - The National consumption is low due to the low Spanish nationwide consumption and due to the low level of the MVEF and the ESEF and the HVEF that are feeding the MV/LV TC.
  - The CB and the IB are both discharged.
  - The renewals energy production is low.

After evaluating the priorities list in this case the first to satisfy is the 2\textsuperscript{nd} and after the 3\textsuperscript{rd} one so the FC should switch to the State 1 that appears on Table 17.
5.1.2 FLOW CONTROL STRUCTURE

To achieve the previous regulation proposal a key component of the system is the FC system that makes the energy flow in a convenient manner to reach the regulation targets defined on Table 17. Next Figure 25 shows a proposal of the main elements that could integrate the FC system as a detail of what was shown on Figure 24.

Fig. 26 Flow Control system structure

Where,

- CB\_i \ stands for the car batteries and their battery chargers.

- cl \ stands for an unidirectional data line or bus intended to send control orders to the existing solid state relays.

- dl \ stands for an unidirectional data line or bus intended to bring
information between the regulator and the linked element. Case by case,

- The LV system tells the FC when it's saturated and thus unavailable to charge the batteries, nor the IB neither the CB.

- The ammeters are intended to provide feedback to the regulator about the real energy flow.

- The TSO or the DSO bring to the regulator information regarding the renewals production, the national consumption, the desired power factor and the risk of overload on any of the MV/HV elements that can be found upstream his FC.

  - \textit{xl} stands for a bidirectional data line or bus dedicated to convey both information and control orders. In this sense,

  - The Battery Charger brings information to the regulator about the SOC of the IB. At the same time the regulator tells the Battery Charger how much power is left to be used charging the IB before getting the LV systems overloaded.

  - The Inverter tells the regulator about how much energy still remains on the IB. The regulator tells the Inverter about how much energy, active and reactive, should be make available to the system on a given time regarding the CB charging state, the LV saturation, the National consumption and power factor.

  - The CB\_i tells to the regulator their SOC. The regulator tells the CB\_i about the maximum charging speed on a given time to avoid LV saturation or to help the MV/HV upstream grids to overcome a coming or actual overload.

Finally, even if the Table 17 regulation could be achieved by bringing to the existing elements the requested orders and setpoints, solid state relays are implemented to achieve a low operating risk trough redundancy.

5.1.3 ENERGY BALANCE

Following all the previous informations an energy balance should be performed in order to check the applicability of the proposed countermeasure and to start sizing the IB. This must be done by keeping some requirements,
- The VAC should be improved by the use of an IB. As already defined on chapter 3.3.1.2.2 a 90% availability will be this study target. Probably it stills being a poor rate comparing with the almost 100% VAC of the thermal engine cars but means 2,5 hrs of charging time and notably improves the maximum 75% availability if the EV batteries charging overload is going to be solved simply by shifting the charging times to valley hours as already seen on chapter 4.1.1.

- The LV overload should be always avoided.

- Even if until now we considered an EV 21% market share on 2030, the EV penetration will be assumed as 100% for this calculations purposes as stated on point 4.2. The though is that this would be the real situation and the administration, when it comes to issue a EV charging facility code, will be more likely to refer to a 100% EV deployment than to a partial, temporal, 21% one.

5.1.3.1 ENERGY AVAILABILITY

The total available energy on a residential building must be calculated in order to determine whether the countermeasure is possible or not. To do so the following Figure 27 shows graphically how much energy could be drawn from the main supply without trespassing the LV system maximum load on the study case of a 50 flat building.

![Fig. 27 Maximum energy in kWh](image)

Where the dashed area represents the total amount of energy, in therms of kWh, that could be obtained from the LV system by using the remaining available power over the blue plot that represents the residential electric consumption according REE [45].
Since the gross amount of energy is already known, and according to the FC description on chapter 5.1.2, some efficiency coefficients must be applied in order to take into account the elements included on it.

Considering what was calculated on chapter 3.2.2.2 we should apply the following efficiencies,

- IB charger. The energy to be stored at the IB should run his way through the charger and thus a 89% of the incoming kWh could be expected arriving to the battery.

- Battery. Not the whole energy stored into the battery will be recovered at the discharge process. A new 85% is to apply to get the useable energy.

- Inverter. The energy that we could recover from the battery has to pay a last tribute on his way to the CB charger. In this case a 96% efficiency, coming from the serious developments done over the photovoltaic energy systems, will tax the flow.

For this study purposes the chosen solid state relays will be considered as ideal switches.

Then, by applying the previous coefficients the original 1721 kWh shrink to a thinner 1249 kWh available at the CB chargers if the whole energy flow has to follow the IB cycle.

5.1.3.2 ENERGY DEMAND

According with what was calculated on chapter 3.3.1.2.2.1 and defined on chapter 3.3.1.3 the following can be stated,

- On a 50 flats apartments building a total of 27,5 cars is moving every day leaving and returning to the parking after a run of 58 km.

- The energy need on every EV charger is 0,36 kWh/km which, applying a 1,2 safety coefficient, moves to a higher 0,432 kWh/km.

Considering that now we are assuming that a 100% of the parked cars are electrically driven, so all of them are EV, the total amount of energy needed on a given day is 689 kWh.
5.1.3.3 CONCLUSIONS

As a pure mathematical conclusion the energy availability is enough to fulfil the need of it and, according to this finding, its possible to feed the EV without improving the LV system power capability just by adding an IB and the FC regulator.

Nevertheless the situation could be improved even more recalling that Table 17 regulation forces to charge only trough the IB at the times where the building consumption is near to his maximum design load using as much as possible the direct charge from the LV system when possible. In this sense 250 kWh can be obtained from the LV system from 15 to 24 hours what in turn means that the rest of the previously calculated 689 kWh, 439 kWh, must be driven to the EV battery chargers by the IB. To do so, after applying the efficiencies chain seen before, 604 kWh will flow from the LV system to the IB on the valley hours to store the desired amount of energy.

Next Figure 28 comes to show it graphically assuming that the valley hours are from 0 to 8 thus giving a constant charging power of 101kW to get the requested 538 kWh on the IB that later will be used to charge the CB.

![Fig.28 EV batteries energy sources.](image)

Where the red plot still have some gap regarding the LV design maximum power and the time window allowing even bigger loads.

5.2 INERTIA BATTERY DEFINITION

Next points will try to define the most critical element of the whole countermeasure proposal, the battery. Its type, size and arrangement will be...
calculated on the basis of the required power flows and thriving among commercially available batteries in order to select which one to use, how many and how to connect them to the load and to the charger.

### 5.2.1 BATTERY TYPE AND ARRANGEMENT

Today's commercially available batteries that could bring a log time, high current, voltage stable discharge could be divided into two main families: lead acid and Lithium-ion. Next Table 18, based on the **WB-LYP1000AHA** lithium battery from Winston Battery ltd. and the **IND17-6V** lead acid battery from Trojan Battery Co. whose both data sheets could be found at this document annex, shows the main differences between these two families,

<table>
<thead>
<tr>
<th></th>
<th>Lead-acid</th>
<th>Lithium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy density (Wh/Kg)</td>
<td>26.17</td>
<td>80.72</td>
</tr>
<tr>
<td>Peukert's number</td>
<td>1.3</td>
<td>1.016</td>
</tr>
<tr>
<td>€/kWh</td>
<td>184.1</td>
<td>313.6</td>
</tr>
<tr>
<td>Life span with 80% DOD (cycles)</td>
<td>1500</td>
<td>5000</td>
</tr>
</tbody>
</table>

Where, even at a higher price, the best choice are the Lithium batteries as the small Peukert's number \[^9\] allows a quite short time discharge with much more smaller looses than the Lead-acid one. It means that, when it's about to deal with a few hours discharge as for this case, the real Ah value is higher for the Lithium batteries than for the Lead-acid ones. Such a advantage, together with the life span, makes the Lithium batteries the right choice for our application.

Since the battery technology is chosen next is to look for a high capacity one and it means to use modules with big active surfaces rather than looking for a high voltage, heavily stacked, configurations. There are two reasons for it,

- The commercially available inverters are designed to work with a maximum voltage around 600-1000V, thus to achieve the desired current parallel batteries arrangement is to be used if voltage prevalence is the selection.

- Parallel batteries arrangement should not be used to avoid self discharge between batteries.
5.2.2 DEMAND PROFILE

Before setting up the size and the arrangements a demand profile will be calculated by using power flow values, voltages and currents.

As a first step the demand profile related to the EV should be estimated. It’s about to do same already done on chapters 3.3.1.2.2.1 and 3.3.1.2.2.2 but this time considering that 100% of the cars are EV ones and that we do charge them on a 2,5 hours period to achieve the desired 90% VAC. Next Figure 28 reproduces the previous Figure 15 for a better understanding and convenience.

![Average 7 days](image)

**Average 7 days**

Then, and assuming that no one car will expend more than one hour on his 29 km journey back home, the previous figure analysis could be as follows,

- 14h → 0'13x50 cars running back home → 6 EV parked at 15h starting battery charge
- 15h → 0'12x50 cars running back home → 6 EV parked at 16h starting battery charge
- 16h → 0'09x50 cars running back home → 4 EV parked at 17h starting battery charge
17h → 0'08x50 cars running back home → 4 EV parked at 18h starting battery charge

18h → 0'09x50 cars running back home → 4 EV parked at 19h starting battery charge

19h → 0,065x50 cars running back home → 3 EV parked at 20h starting battery charge

At 20h we do have 0'05x50 cars running back home, that means 2'5 cars which is too much as only one more car is expected to arrive in order to cumulate the 28 moving cars. Only one car should be then considered arriving to the parking at 20 hrs.

As the charging times are already available and assuming that the charging happens immediately after each car arrival to his parking place the next Figure 30 shows their power demand and duration in order to proceed with a demand curve calculation.

![Fig.30 Charging power hourly distribution](image)

Where written on every rectangle is,

\[ A \times B \times C \rightarrow A \] stands for the simultaneous amount of EV to be charged, \( B \) stands for the power drawn by each of the EV to charge and \( C \) stands for the charging time.
From the above data the following Table 18 could be created where the charging periods for every parked car are displayed within a 30 minutes resolution grid,

<table>
<thead>
<tr>
<th>Minutes</th>
<th>0-30</th>
<th>30-60</th>
<th>0-30</th>
<th>30-60</th>
<th>0-30</th>
<th>30-60</th>
<th>0-30</th>
<th>30-60</th>
<th>0-30</th>
<th>30-60</th>
<th>0-30</th>
<th>30-60</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EV_1</td>
<td>EV_2</td>
<td>EV_3</td>
<td>EV_4</td>
<td>EV_5</td>
<td>EV_6</td>
<td>EV_7</td>
<td>EV_8</td>
<td>EV_9</td>
<td>EV_10</td>
<td>EV_11</td>
<td>EV_12</td>
</tr>
<tr>
<td>EV_12</td>
<td>EV_13</td>
<td>EV_14</td>
<td>EV_15</td>
<td>EV_16</td>
<td>EV_17</td>
<td>EV_18</td>
<td>EV_19</td>
<td>EV_20</td>
<td>EV_21</td>
<td>EV_22</td>
<td>EV_23</td>
<td>EV_24</td>
</tr>
<tr>
<td></td>
<td>EV_25</td>
<td>EV_26</td>
<td>EV_27</td>
<td>EV_28</td>
<td>Total power</td>
<td>Hour peak</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-16</td>
<td>50,4</td>
</tr>
<tr>
<td>16-17</td>
<td>100,8</td>
</tr>
<tr>
<td>17-18</td>
<td>134,4</td>
</tr>
<tr>
<td>18-19</td>
<td>117,6</td>
</tr>
<tr>
<td>19-20</td>
<td>100,8</td>
</tr>
<tr>
<td>20-21</td>
<td>92,4</td>
</tr>
<tr>
<td>21-22</td>
<td>67,2</td>
</tr>
<tr>
<td>22-23</td>
<td>33,6</td>
</tr>
</tbody>
</table>

**Tab. 19 Batteries charge power demand by hour**

Which could be simplified to the following Table 19,

<table>
<thead>
<tr>
<th>Time</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-16</td>
<td>50,4</td>
</tr>
<tr>
<td>16-17</td>
<td>100,8</td>
</tr>
<tr>
<td>17-18</td>
<td>134,4</td>
</tr>
<tr>
<td>18-19</td>
<td>117,6</td>
</tr>
<tr>
<td>19-20</td>
<td>100,8</td>
</tr>
<tr>
<td>20-21</td>
<td>92,4</td>
</tr>
<tr>
<td>21-22</td>
<td>67,2</td>
</tr>
<tr>
<td>22-23</td>
<td>33,6</td>
</tr>
</tbody>
</table>

**Tab. 20 Batteries charge power simplified**

The contents of which, together with the residential consumption profile, will be the basis of the battery size calculations.

On the other hand, and in the period of time ranging from 15 to 24 hours certain
amount energy could be send to the CB directly from the LV system free from the IB charge/discharge cycles and their related losses as seen on previous chapter 5.1.3.3.

Next Figure 31, based on Table 20, shows the power demand of the CB and displays the amount of it that must came from the IB.

**Fig.31  CB charging power split**

Where the red line shows the power required to charge the CB that must be supplied by the IB in cooperation with the available power from the LV system. Mathematically it can described as follows by using each plot color,

\[ \text{red} = \text{green} - (\text{magenta-blue}) \]  

**Exp.7**

Which is the expression that will drive, together with the energy capacity, the IB sizing as it reveals how much power should be drawn from the IB at any time and also how long this power flow must be sustained to achieve the CB charging.

In order to have a more easy to use data following Figure 32 simplifies this red
plot by introducing equivalent, averaged constant lines, 

Where the brown plot approximates the real red one to a more easy, workable, line to size the battery system. According to this 79 kW the maximum current could be now calculated as a function of the voltage which, in turn, depends on how many batteries are going to be used in a serial assembly.

5.2.3 INERTIA BATTERY SIZING

This process starts by selecting the battery module to be assembled in series to create the desired IB. As stated on chapter 5.2.1 Lithium-ion batteries type will be the choice and for this study purposes the compared one, the **WB-LYP1000AHA** lithium battery from Winston Battery ltd. will be selected.

Since the battery module is already selected then the number of them to be connected in series is to be determined. The resulting assembly should meet the following requirements,

a -Total capacity bigger than 538 kWh. As already calculated on chapter 5.1.3.3 a total of 439 kWh will be needed to charge the CB but this amount of energy should be increased in order to consider the battery efficiency, 85%, and the inverter efficiency, 96%.

b -Discharge capacity enough to provide the power, and so the current, shown on Figure 32 to charge the CB.
c - Maximum Depth Of Discharge (DOD) of 80% at the end of the CB charging process to ensure a life span of at least 5000 cycles.

Next Figure 33 will try to illustrate what was described above by showing in detail the energy flow from and to the LV through the different FC elements to the CB,

![Energy flow through the FC elements and the IB](image)

**Fig.33 Energy flow through the FC elements and the IB**

As a first result a combination of points “a” and “c” gives the total amount of energy to be stored by the IB of 672.5 kWh, obtained dividing the minimum 538 kWh by 0.8. Estimating each battery capacity on 3.2 kWh a total of 210 batteries will be needed and thus a total maximum voltage of 682.5V could be expected at the IB terminals when fully loaded as the following Figure 34 indicates for an operating temperature of 25ºC.

![LYB battery's discharge curve under different temperatures](image)

**Fig.34 IB single module voltage/charge vs temperature plots**
Where 3.25V can be seen at battery full state and 3.2V with an 80% DOD. An average could be extracted from these two values that gives a 3.225V during the discharge process between the 0 and the 80% DOD. Applying it to our IB assembly the averaged total voltage along the discharge process will be 677.5V.

Now as the voltage and the required power, Figure 32, are known, the current could be calculated resulting in a maximum of 117A. More in detail and derived from Figure 32 next Figure 35 comes to show the current demand profile,

![Fig.35 IB to CB current flow profile](image)

Where the IB discharge is divided in three periods. Next is to confirm the time duration of each discharge period according to the chosen battery, the calculated current and the Peukert's coefficient.

- Period A. The current ramps up from zero to his maximum value in two hours so an average constant current of 58.5A will be considered. According to this current the Peukert's law gives to us the following,

\[ t = Ah \times I^{-k} = 1000 \times 58.5^{-1.016} = 16 \text{ hours} \]

Here 16 hours are eight times bigger than the required 2 hours what makes the desired discharge of Period A possible.

- Period B. The maximum current of 117A remains stable for a 3.5h hours long period. In this case, in order to go with the Peukert's expression, it must be considered that the battery already flowed out 117 Ah on Period A so Period B will start from 883 Ah. The result this time is,

\[ t = Ah \times I^{-k} = 883 \times 117^{-1.016} = 7 \text{ hours} \]

Here 7 hours are two times bigger than the required 3.5 hours what
makes the desired discharge of Period B possible.

-Period C. The current ramps down from his maximum value to zero in two hours. so an average constant current of 58,5A will be considered. In this case as in the previous one, in order to go with the Peukert's expression, it must be considered that the battery already flowed out 117 Ah on Period A and 409,5 Ah on Period B so, in Period C will start from 473,5 Ah . The result this time is,

\[ t = Ah \times I^{-k} = 473,5 \times 58,5^{-1.016} = 7,6 \text{ hours} \]

Here 7,6 hours are three times bigger than the required 2,5 hours what makes the desired discharge of Period C possible.

As a main result of what was done in this chapter the IB should be composed of a single serial arrangement of 210 units of the **WB-LYP1000AHA** Lithium battery from Winston Battery ltd. As a secondary target the Inverter can now be selected as it must fulfil two main items, maximum power bigger than 79 kW and maximum voltage bigger than 682,5V. With these parameters a suitable inverter could be the SIRIO K80, from AROS-SOLAR, that exhibits a maximum power of 88 kW and a maximum voltage of 800V, his brochure could be found on the annex of this document.

### 5.2.4 INERTIA BATTERY CHARGING SYSTEM

To charge the 210 modules a 48V/150A automatic charger designed for Lithium batteries will be the choice. It's the GWL/Power Charger 48V/150A from GWL/Powergroup Technology Solutions whose data sheet could be found on the annex of this study.

According to the nominal voltage of the charger a total of 14 chargers feeding each one a section of 15 batteries must be installed. The structure of the resulting system will be as shown in next Figure 36.
Fig. 36. Battery chargers arrangement

Where the battery chargers distribution could be verified. On the figure a switch “SW” is placed between each set of 15 batteries in order to avoid short-circuits as all the battery chargers work from the same AC source so, when a IB charge process starts, these switches open and isolate the battery series. This switch is considered as an ideal one with no losses for this study purposes.

To finish describing the battery charger it must be said that its efficiency, 80%, has been artificially increased to the 89% to follow what was written on chapter 3.2.2.2.

5.3 ECONOMIC VALUATION

Essentially the described countermeasure and their components valuation will be the one that usually applies when it is about to deal with an investment on a production item by using the pay-back method. In this sense the main elements to consider will be,

- The countermeasure investment, including installation and
commissioning.

- The economic performance, intended as the difference between the the fuel savings and the electric expenses.

On this economic study no loan interests will be considered as the administration probably would enable a soft-credit line giving a interest rate equal to the inflation ratio in order to make it possible. More on this the administration will benefit from the EV in many other ways as the healthcare system savings on lung and another pollution related diseases.

5.3.1 COUNTERMEASURE INVESTMENT

At this point almost all the countermeasure components are already described within the previous chapters and now its time to give to them their price. Regarding this process the following assumptions should be stated,

- The CB chargers and metering devices are included on the EV's. On the parking site only a 240V connection is existing. Signals from the CB charger to the FC regulator could be drived trough the power line itself.

- The metering device of the FC system should behalf to the DSO and his price is not included on the budget.

- The wiring and civil works are estimated ones to avoid considering a particular parking layout which could not be essential for this study purposes.

- The labour is considered as only 15% of the total cost because this is not a labour intensive project but equipment intensive due to the cost of the different elements.

- The Lithium batteries price is assumed to be reduced in the following 15 years. It's because the scale economy, technology evolution and increased demand that could not be priced today using the traditional net present value (NPV), it's not a mature product. In this sense there's a study [60] from 2009 that shows the following Figure 37 where a Lithium-ion batteries cost trend is presented divided in three main scenarios,
Where the price forecast for 2014 of 263 €/kWh matches very well with what's today's real price, 280 €/kWh. According to this the optimistic forecast will be used in order to predict future Lithium-ion batteries price thus assuming 175 €/kWh or 564 €/module.

Next Table 21 summarizes the whole cost structure of the countermeasure,

<table>
<thead>
<tr>
<th>Pos.</th>
<th>Description</th>
<th>Quantity</th>
<th>Unit Price (€)</th>
<th>Price (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Batteries 3,2V 1000Ah LiFePO4, Winston WB-LYP1000AHA</td>
<td>210</td>
<td>564</td>
<td>118.440</td>
</tr>
<tr>
<td>2</td>
<td>Inverter 88 kW, SIRIO K80 HV</td>
<td>1</td>
<td>17.000</td>
<td>17.000</td>
</tr>
<tr>
<td>3</td>
<td>IB chargers, GWL/Power Charger 48V/150A</td>
<td>14</td>
<td>553</td>
<td>7.742</td>
</tr>
<tr>
<td>4</td>
<td>Control (equivalent to Siemens PLC S400)</td>
<td>1</td>
<td>1.300</td>
<td>1.300</td>
</tr>
<tr>
<td>5</td>
<td>Solid State Relays, Crydom HDC100D160</td>
<td>12</td>
<td>121</td>
<td>1.453</td>
</tr>
<tr>
<td>6</td>
<td>Wires, protections and construction material, estimated</td>
<td>1</td>
<td>4.000</td>
<td>4.000</td>
</tr>
</tbody>
</table>

Total: 172.425 €

Subtotal: 149.935 €

Labour (15%): 22.490 €

VAT: 172.425 €

**Tab. 21, Countermeasure required investment**

Unfortunately, as the residents communities doesn't have commercial activity, the VAT should be considered for the pay-back study. Assuming today's 21% lasting unmodified for the next 15 years a total investment of 208.634,- € VAT included should be expected.
5.3.2 ECONOMIC PERFORMANCE

To calculate the “production” of the countermeasure assets the following should be considered,

-Fuel savings. As the whole cars are EV no fuel consumption is there, so according with what's calculated on chapter 3.2.2.1, the following Table 22 could be created,

<table>
<thead>
<tr>
<th>Liters/100 Km</th>
<th>€/litre*</th>
<th>Subtotal (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>1.95</td>
<td>1.466</td>
</tr>
<tr>
<td>Diesel</td>
<td>4.37</td>
<td>1.36</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tab. 22, €/Km cost of running on thermal engine cars.

Then, as stated on chapter 5.1.3.2, every day 27,5 cars are leaving and returning to the parking after an average run of 58 Km then the daily cost of mobility on thermal engines is 140,4 € VAT included and the yearly cost, accounted for 12 commercial months, is 50.540,- € VAT included.

Finally about fuel savings, even if has not been considered for this study purposes because, a big growth, even much more bigger than the inflation ratio, could be expected on oil price as the world demand starts growing again.

-Electric expenses. According to the findings of chapter 5.1.3.3 next Figure 38, a review of Figure 28, will help understanding the next calculation procedure,

<table>
<thead>
<tr>
<th>kW</th>
<th>valley</th>
<th>flat</th>
<th>peak</th>
<th>flat</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 38, electric energy consumption vs tariff periods, winter

Where the different energy consumptions, according to the access tariff 3.0A (>15 kW) [°], are distributed among their tariff periods in order to calculate
the electric energy expenses on winter days. For summer days the situation is even better as the “peak” period ranges from 12 to 15 hours where there’s no electric consumption related to the EV nor to the IB. Next Table summarizes the electric expenses taking into account both summer and winter conditions,

<table>
<thead>
<tr>
<th>Tariff period</th>
<th>Tariff (€/kWh)</th>
<th>Energy (kWh)</th>
<th>Winter cost (€)</th>
<th>Summer cost (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.14231</td>
<td>52</td>
<td>7.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Flat</td>
<td>0.11698</td>
<td>198</td>
<td>23.2</td>
<td>29.2</td>
</tr>
<tr>
<td>Valley</td>
<td>0.078921</td>
<td>604</td>
<td>47.7</td>
<td>47.7</td>
</tr>
</tbody>
</table>

Daily subtotal (€)  78.2   76.9
VAT (21%)  16.4   16.2
Total 6 months (€)  17038.6  16751.7
Total one year (€)  33790.3

Tab. 23, Electric energy yearly expenses

To be added to the above result for electric energy is the power tax that its related with how much power is used and in which period is used. To calculate it in this case next Table 24 include the whole data and results,

<table>
<thead>
<tr>
<th>Tariff period</th>
<th>Tariff (€/kW*year)</th>
<th>Power</th>
<th>Winter cost (€)</th>
<th>Summer cost (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>40.73</td>
<td>46</td>
<td>936.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Flat</td>
<td>24.4373</td>
<td>64</td>
<td>782.0</td>
<td>1344.1</td>
</tr>
<tr>
<td>Valley</td>
<td>16.2915</td>
<td>101</td>
<td>822.7</td>
<td>822.7</td>
</tr>
</tbody>
</table>

Subtotal 6 months (€)  2541.5  2166.6
VAT (21%)  533.7   455.0
Total 6 months (€)  3075.2  2621.8
Total one year (€)  5697.0

Tab. 24, Electric power tax yearly expenses

So, adding both tables the electric expenses in one year are of 39.487 €,- VAT included.

Finally, in terms of electric expenses, a yearly maintenance cost of 500 €,- VAT included is estimated as the facility does not have serviceable parts and the preventive maintenance will be restricted to what’s legally prescribed for LV systems.

As a result of the previous calculations a yearly savings amount of 10.053,- € VAT included could be expected from use of the EV and the IB energy storage system.

5.3.3 PAY-BACK VALUATION

As stated at the beginning of point 5.3 the Pay-Back evaluation method will be used to examine the countermeasure proposal. From the previous points the total
investement and the yearly savings are already known and the required evaluation could be done as next Table 25 shows,

<table>
<thead>
<tr>
<th>Pay-Back evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility cost (€)</td>
</tr>
<tr>
<td>Yearly savings (€)</td>
</tr>
<tr>
<td>Pay-Back (years)</td>
</tr>
</tbody>
</table>

**Tab. 25, Pay-Back evaluation, original countermeasure**

Where a period of almost 21 years is to be considered as a Pay-Back of the investment. As the battery life span in 5000 cycles and considering one charge-discharge cycle per day a 13.7 years will be the expectable life battery. The result is that the residents should pay together, within the first 13.7 years, a yearly amount of 5175 €,- VAT included, which in turn means adding 103 €/year to the pre-existing averaged fuel consumption.

If the above result is to be improved one attempt could be to increase a little the IB capacity in order to completely avoid any EV related energy or power demand on “peak” hours and to reduce the “flat” ones. To do so the easiest way is to add 30 modules to the existing IB assembly in a new series of 16 batteries, with an extra charger, and to increase the previous series size from 15 units to a 16. No other changes will be needed as the Inverter maximum voltage is 800V, bigger than the new 780V series voltage. In economic terms the total cost will be increased in 24.313,-€ VAT included but the savings will be also increased leaving the following result of Table 26.

<table>
<thead>
<tr>
<th>Pay-Back evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility cost (€)</td>
</tr>
<tr>
<td>Yearly savings (€)</td>
</tr>
<tr>
<td>Pay-Back (years)</td>
</tr>
</tbody>
</table>

**Tab. 26, Pay-Back evaluation, improved countermeasure**

Where now the difference is just of 1.9 years which in turns means that every resident should pay 41 €/year more than the expectable expense on Gasoline or Diesel to get their electric charging facility.

**5.4 FUNCTION VALUATION**

On point 4.1 the items to be fixed by the countermeasure where described and now, with the countermeasure technically defined, is time to check for these functionalities that are,
-LV system congestion. The problem disappears as the IB stores energy when there's free room to do so and charges the CB directly without the LV system when its capacity is already fulfilled.

-Improve the VAC. Here the IB significantly helps to reduce the charging times and thus helps to improve the VAC. As seen on chapter 4.1.1, even with only a 21% penetration of the EV, the VAC is a 69% if no countermeasure is taken but delaying the charge to valley hours. The IB allows for a 90% VAC with a 100% presence of the EV.

-Power grid renewables integration. The IB charging process offers a big opportunity to become a well to store energy in valley hours when there's not enough consumption to directly use it. In this sense it's a bit better option than the traditional hydropower pumping storage because the IB should be closer to the final consumer, not in a far spot in the mountains, and thus could absorb demand variations in a very short time. In terms of efficiency the IB could offer an overall efficiency in the same range, around 75%, than the pumping stations one.

5.5 ENVIRONMENTAL IMPACT

The overall environmental impact of the countermeasure could be divided into two kinds, positive and negative.

-Negative. The IB is made of several Lithium-ion modules that, at the end of his life, should be recycled or disposed. Nevertheless the Lithium, the plastics and the metals, mostly Cobalt and Nickel, that integrate a Lithium-ion battery are almost fully recyclable materials so almost no disposal is there to deal with.

-Positive. The replacement of the thermal engine by EV means that almost a half of the energy used to power the passenger cars will be carbon free as can be seen on the 2013 electric energy mix in Spain[62] on next Figure 39.

Fig. 39 Spanish electricity generation mix.
Assuming thermal generation and transport electric efficiencies similar to those of the cars engines the total CO2 emissions related to the passenger cars could be reduced roughly around a 35%.

Especial mention should be posted when talking about the air quality in cities or nearby high traffic density highways, where the expected improvement will be very high and where only residential heating will remain as a source of combustion pollutants after a 100% introduction of the EV.

More on it this project, on the exploitation phase,

- The related facilities are all of them included inside of existing buildings so they don't have any direct impact in any natural environment.
- There's are no any material flow inside/outside of the system son there's no any natural resources need or pollutant emissions.
- There are no acoustic emissions.
- There are some thermal emissions related to the efficiency of the equipments. These account for a total of 165 kWh/day and are equivalent to those of a single flat air conditioning equipment.

5.6 COUNTERMEASURE PLANNING

If this study countermeasure is to be applied there are some important phases to cover from today to a future where a real system able to deploy the whole required functionalities is existing. As a guide next Figure 40 shows what will be the steps to walk forward.

**Fig. 40 Countermeasure development timeline**

Where the phase durations are estimated from the experience of the author in complex projects development and assuming enough founding with distinct, closely related teams as software engineers, electronic engineers, electric engineers and so on. In any case it
could be defined a bit more in detail with a WBS that is out of this study purposes. Nevertheless what comes clear from it is that the challenge ahead is not small so time and resources should be dedicated to it if some achievement is to be reached.
1 “Toward a smart grid”, S.Massoud Amin, Bruce Wollenberg, IEEE power & energy magazine, September/October 2005.
3 “Design and Simulation of V2G Bidirectional Inverter and DC-DC Converter”, Allan Agatep and Mason Ung, California Polytechnic State University, fall/winter 2011.
8 “Standarisation mandate to CEN, CENELEC and ETSI concerning the charging of electric vehicles”, European Comission, June 2010.
9 “Informe de gobierno corporativo 2012”, Red Eléctrica de España, April 2013.
10 “An expert system for contingency analysis in transmission networks”, © 1990 IEEE
12 “CECOEL, Centro de control eléctrico”, REE, 2013.
16 “El ministro Soria acompaña a S.A.R. el Príncipe en el acto de inauguración del proyecto de movilidad eléctrica "Zem2All!", Ministerio de Industria, Turismo y Comercio, Gobierno de España, April 2013.

23 "Driving and parking patterns of European car drivers, a mobility survey.", EU JRC, 2012.
24 "Projections for Electric Vehicle Load Profiles in Europe Based on Travel Survey Data". EU JRC, 2012.
26 “A temporal assessment of vehicle use patterns and their impact on the provision of vehicle-to-grid services.”, Chioke B Harris and Michael E Webber, University of Texas at Austin, September 2012.
27 “Paving the way to electrified road transport”. EU JRC, 2013.
29 “Parque de vehículos”. ANFAC, July 2013.
33 “Impacts of electric vehicles—Summary report”, EC by ICF, April 2011.
36 http://www.autopista.es/noticias-motor/articulo/consumo-real-coches-49700.htm
41 “Analysis of the key factors affecting the energy efficiency of batteries in electric vehicle ”, Harbin Institute of Technology, 2010.
45 “Guía de consumo inteligente”, REE, November 2010.
50 [http://www.idescat.cat/emex/?id=081878](http://www.idescat.cat/emex/?id=081878)
51 [http://www.idescat.cat/emex/?id=082798](http://www.idescat.cat/emex/?id=082798)
52 [http://www.idescat.cat/emex/?id=083054](http://www.idescat.cat/emex/?id=083054)
53 [http://www.idescat.cat/emex/?id=080961](http://www.idescat.cat/emex/?id=080961)
54 [http://www.idescat.cat/emex/?id=083073](http://www.idescat.cat/emex/?id=083073)
55 [http://www.idescat.cat/emex/?id=081213](http://www.idescat.cat/emex/?id=081213)
57 “Anuario estadístico de España 2012, demografía”, INE.
59 “A comparative study Lithium-ion batteries”; Oswal, Paul & Zhao, University of South California, 2010.
60 “AN EVALUATION OF CURRENT AND FUTURE COSTS FOR LITHIUM-ION BATTERIES FOR USE IN ELECTRIFIED VEHICLE POWERTRAINS”; Anderson, Duke University.
ANNEX
DATASHEETS AND BROCHURES
温斯顿牌稀土锂钇动力电池性能说明

**SPECIFICATION FOR WINSTON RARE EARTH LITHIUM YTTRIUM POWER BATTERY**

### 型号 (MODEL): WB–LYP1000AHC

<table>
<thead>
<tr>
<th>性能指标</th>
<th>数值</th>
</tr>
</thead>
<tbody>
<tr>
<td>標稱容量 (Nominal Capacity)</td>
<td>1000Ah</td>
</tr>
<tr>
<td>工作電壓 (Operation Voltage)</td>
<td>充電 (Charge) 4.0V</td>
</tr>
<tr>
<td>最大充電電流 (Max Charge Current)</td>
<td>( \leq 5\text{CA} )</td>
</tr>
<tr>
<td>最大放電電流 (Max Discharge Current)</td>
<td>恆流 (Constant Current) ( &lt; 3\text{CA} )</td>
</tr>
<tr>
<td>標准充放電電流 (Standard Charge/Discharge Current)</td>
<td>0.5CA</td>
</tr>
<tr>
<td>循環壽命 (Cycle Life)</td>
<td>(80DOD%) ( &gt; 5000\text{Times} )</td>
</tr>
<tr>
<td>殼體耐溫性 (Temperature Durability Of Case)</td>
<td>( \leq 200^\circ\text{C} )</td>
</tr>
<tr>
<td>適應環境 (Operating Temperature)</td>
<td>充電 (Charge) (-45^\circ\text{C} \sim 85^\circ\text{C})</td>
</tr>
<tr>
<td>自放電率 (月) (Self-discharge Rate)</td>
<td>( \leq 3%) (Monthly)</td>
</tr>
<tr>
<td>單體電池重量 (Weight)</td>
<td>35kg ± 500g</td>
</tr>
</tbody>
</table>
WB–LYP1000AHC型電池的充放電特性
WB–LYP1000AHC CHARGE & DISCHARGE CHART

常温下LYP類電池的放電特性曲線
LYP battery’s discharge curve under normal temperature

常温下LYP類電池的循環充放電特性曲線
LYP battery’s circulation charging and discharging curve under normal temperature

不同環境溫度下LYP類電池的放電特性曲線
LYP battery’s discharge curve under different temperatures

在常溫環境下LYP類電池的存儲特性曲線
LYP battery’s storage characteristic curve in normal temperature
**MODEL:** IND17-6V

**DIMENSIONS:** inches (mm)

**BATTERY:** Flooded/wet lead-acid battery

**COLOR:** Maroon (case/cover)

**MATERIAL:** Polypropylene (internal cell container)
Polyethylene (outer container)

---

**SMART CARBON™**

Deep-cycle batteries used in off-grid and unstable grid applications are heavily cycled at partial state of charge (PSOC). Operating at PSOC on a regular basis can quickly diminish the overall life of a battery, which results in frequent and costly battery replacements.

To address the impact of PSOC on deep-cycle batteries in renewable energy (RE), inverter backup and telecom applications, Trojan Battery has now included Smart Carbon™ as a standard feature in its Industrial and Premium flooded battery lines.

**PRODUCT SPECIFICATIONS**

<table>
<thead>
<tr>
<th>BCI GROUP SIZE</th>
<th>TYPE</th>
<th>5-Hr Rate</th>
<th>10-Hr Rate</th>
<th>20-Hr Rate</th>
<th>48-Hr Rate</th>
<th>72-Hr Rate</th>
<th>100-Hr Rate</th>
<th>240-Hr Rate</th>
<th>ENERGY (kWh)</th>
<th>VOLTAGE TERMINAL Type</th>
<th>DIMENSIONS Inches (mm)</th>
<th>WEIGHT Lbs. (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>IND17-6V</td>
<td>727</td>
<td>820</td>
<td>925</td>
<td>1085</td>
<td>1156</td>
<td>1202</td>
<td>1205</td>
<td>7.21</td>
<td>6 VOLT</td>
<td>14</td>
<td>7.21 (691)</td>
</tr>
</tbody>
</table>

**CAPACITY AMP-HOURS (AH)**

<table>
<thead>
<tr>
<th>Cutoff Voltage</th>
<th>5-Hr Rate</th>
<th>10-Hr Rate</th>
<th>20-Hr Rate</th>
<th>48-Hr Rate</th>
<th>72-Hr Rate</th>
<th>100-Hr Rate</th>
<th>240-Hr Rate</th>
<th>100-Hr Rate</th>
<th>240-Hr Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.75 vpc</td>
<td>727</td>
<td>820</td>
<td>925</td>
<td>1085</td>
<td>1156</td>
<td>1202</td>
<td>1205</td>
<td>7.21</td>
<td>6 VOLT</td>
</tr>
<tr>
<td>1.80 vpc</td>
<td>655</td>
<td>771</td>
<td>888</td>
<td>1057</td>
<td>1128</td>
<td>1172</td>
<td>1175</td>
<td>7.21</td>
<td>6 VOLT</td>
</tr>
<tr>
<td>1.85 vpc</td>
<td>594</td>
<td>700</td>
<td>816</td>
<td>945</td>
<td>1029</td>
<td>1104</td>
<td>1106</td>
<td>7.21</td>
<td>6 VOLT</td>
</tr>
<tr>
<td>1.90 vpc</td>
<td>434</td>
<td>561</td>
<td>680</td>
<td>790</td>
<td>874</td>
<td>981</td>
<td>983</td>
<td>7.21</td>
<td>6 VOLT</td>
</tr>
</tbody>
</table>

**CHARGING INSTRUCTIONS**

**CHARGER VOLTAGE SETTINGS (AT 77°F/25°C)**

<table>
<thead>
<tr>
<th>Voltage per cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorption charge</td>
</tr>
<tr>
<td>Float charge</td>
</tr>
<tr>
<td>Equalize charge</td>
</tr>
</tbody>
</table>

Do not install or charge batteries in a sealed or non-ventilated compartment. Constant under or overcharging will damage the battery and shorten its life as with any battery.

**OPERATIONAL DATA**

**Operating Temperature**

-4°F to 113°F (-20°C to +45°C). At temperatures below 32°F (0°C) maintain a state of charge greater than 70%.

**Specific Gravity**

The specific gravity at 100% state-of-charge is 1.260

**CHARGING TEMPERATURE COMPENSATION**

To the Voltage Reading -- Subtract 0.005 volt per cell (VPC) for every 1°C above 25°C or add 0.005 volt per cell for every 1°C below 25°C.

**EXPECTED LIFE VS. TEMPERATURE**

Chemical reactions internal to the battery are driven by voltage and temperature. The higher the battery temperature, the faster chemical reactions will occur. While higher temperatures can provide improved discharge performance the increased rate of chemical reactions will result in a corresponding loss of battery life. As a rule of thumb, for every 10°C increase in temperature the reaction rate doubles. Thus, a month of operation at 35°C is equivalent in battery life to two months at 25°C. Heat is an enemy of all lead acid batteries, FLA, GEL, and AGM alike and even small increases in temperature will have a major influence on battery life.

Made in the USA
TROJAN IND17-6V PERFORMANCE

**BATTERY DIMENSIONS**

**TERMINAL CONFIGURATIONS**

**VENT CAP OPTIONS**

A. The amount of amp-hours (AH) a battery can deliver when discharged at a constant rate at 77°F (25°C) and maintain a voltage above 1.75 V/cell. Capacities are based on peak performance.

B. Dimensions are based on nominal size. Dimensions may vary depending on type of handle or terminal.

C. Dimensions taken from bottom of the battery to the highest point on the battery. Heights may vary depending on type of terminal.

D. Terminal images are representative only.

Trojan's Premium Line is tested to BCI and IEC 61427 standards.

Additional Terminals Available

Trojan batteries are available worldwide.

We offer outstanding technical support, provided by full-time application engineers.

**call 800.423.6569 or + 1.562.236.3000 or visit www.trojanbatteryRE.com**

12380 Clark Street, Santa Fe Springs, CA 90670 • USA or email re@trojanbattery.com
### POW48V150A CHARGER SPECIFICATION
(with BMS option)

#### 1. Input characteristics

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Technical specification</th>
<th>Unit</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>Rated input voltage</td>
<td>230V</td>
<td>Vac</td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>Input voltage range</td>
<td>180V – 264V</td>
<td>Vac</td>
<td></td>
</tr>
<tr>
<td>1-3</td>
<td>AC input voltage frequency</td>
<td>47 - 63 Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-4</td>
<td>Inrush current</td>
<td>&lt; 50 A</td>
<td>A</td>
<td>@ 264Vac start-up in cold condition</td>
</tr>
<tr>
<td>1-5</td>
<td>Max input current</td>
<td>3x 16 A</td>
<td>A</td>
<td>three-phase socket</td>
</tr>
</tbody>
</table>

#### 2. Output characteristics

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Technical specification</th>
<th>Unit</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>Nominal charge voltage</td>
<td>48V</td>
<td>Vdc</td>
<td>16 cells @ 3.00V</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4 batteries @ 12.00V</td>
</tr>
<tr>
<td>2-2</td>
<td>Fast charge voltage</td>
<td>64V</td>
<td>Vdc</td>
<td>16 cells @ 4.00V</td>
</tr>
<tr>
<td></td>
<td>(V-max)</td>
<td></td>
<td></td>
<td>4 batteries @ 16.00V</td>
</tr>
<tr>
<td>2-3</td>
<td>Maintain voltage</td>
<td>64V</td>
<td>Vac</td>
<td>(Float voltage, same as V-MAX)</td>
</tr>
<tr>
<td>2-4</td>
<td>Constant current (I-CC)</td>
<td>150A</td>
<td>A</td>
<td>Maximal current during full charge</td>
</tr>
<tr>
<td>2-5</td>
<td>Deep voltage level (V-deep)</td>
<td>43V</td>
<td>Vac</td>
<td>Deep discharge voltage level, bellow this voltage, the current is limited to I-min</td>
</tr>
<tr>
<td>2-6</td>
<td>Deep discharge current (I-min)</td>
<td>2A</td>
<td>A</td>
<td>The limited current bellow V-Deep</td>
</tr>
<tr>
<td>2-7</td>
<td>BMS limit current (I-BMS)</td>
<td>approx 2A</td>
<td>A</td>
<td>The limited current for cell balancing (controlled by BMS)</td>
</tr>
<tr>
<td>2-8</td>
<td>Power efficiency</td>
<td>&gt;80%</td>
<td></td>
<td>@ 230Vac</td>
</tr>
</tbody>
</table>

#### 3. Protection characteristics

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Technical specification</th>
<th>Unit</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1</td>
<td>Output over voltage protection</td>
<td>140 V</td>
<td>Vdc</td>
<td></td>
</tr>
<tr>
<td>3-2</td>
<td>Software over voltage protection</td>
<td>The charger software limits the maximum output voltage to a level suitable for the connected battery system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-3</td>
<td>Thermal cutback</td>
<td>The internal temperature monitor reduces the charger output power in extreme operational temperature to prevent damage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-4</td>
<td>Output current limiting protection</td>
<td>155 A</td>
<td>A</td>
<td>@ CC Mode</td>
</tr>
<tr>
<td>3-5</td>
<td>Output short circuit protection</td>
<td>Short circuit protection at the output terminals. Automatic recovery after restoring to normal conditions.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-6</td>
<td>Electronic reverse battery protection</td>
<td>The charger is electronically protected against permanent reversed battery connection.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 4. Charge indicator (LED)

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Technical specification</th>
<th>Unit</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-1</td>
<td>Deep charging</td>
<td>LED flashing (slow)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-2</td>
<td>Fast charging</td>
<td>LED flashing (fast)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-3</td>
<td>Complete charge</td>
<td>LED on</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-4</td>
<td>Voltage indicator</td>
<td>LED display</td>
<td>V</td>
<td>Not calibrated measuring,</td>
</tr>
<tr>
<td>4-5</td>
<td>Current indicator</td>
<td>LED display</td>
<td>A</td>
<td>indication only</td>
</tr>
</tbody>
</table>

### 5. Safety & EMC (CE Conformity Requirements)

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Technical specification</th>
<th>Unit</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-1</td>
<td>Electric strength test input – output</td>
<td>1500 V / 10 mA /1 minute Vac</td>
<td></td>
<td>No breakdown</td>
</tr>
<tr>
<td>5-2</td>
<td>Isolation resistance</td>
<td>&gt; 10 MOhm @ 500 Vdc</td>
<td>MOhm</td>
<td>Input – ground (GND)</td>
</tr>
<tr>
<td>5-3</td>
<td>Isolation resistance</td>
<td>&gt; 10 MOhm @ 500 Vdc</td>
<td>MOhm</td>
<td>Output – ground (GND)</td>
</tr>
<tr>
<td>5-4</td>
<td>Leakage current</td>
<td>&lt; 3.5 mA</td>
<td>A</td>
<td>Vin = 264Vac, 50-60 Hz</td>
</tr>
<tr>
<td>5-5</td>
<td>Safety</td>
<td>EU standards for small electrical appliances</td>
<td></td>
<td>CE MARK</td>
</tr>
<tr>
<td>5-6</td>
<td>EMC – RE</td>
<td>Class B</td>
<td></td>
<td>EN55014</td>
</tr>
<tr>
<td>5-7</td>
<td>EMC – CE</td>
<td>Class B</td>
<td></td>
<td>EN55014</td>
</tr>
<tr>
<td>5-8</td>
<td>EMC – air discharge</td>
<td>Level 3</td>
<td></td>
<td>EN61000-4-2 (dis. B)</td>
</tr>
<tr>
<td>5-9</td>
<td>EMC – contact discharge</td>
<td>Level 3</td>
<td></td>
<td>EN61000-4-2 (dis. B)</td>
</tr>
<tr>
<td>5-10</td>
<td>EMC – RS</td>
<td>Level 3</td>
<td></td>
<td>EN61000-4-6 (dis. A)</td>
</tr>
<tr>
<td>5-11</td>
<td>EMC – CS</td>
<td>Level 3</td>
<td></td>
<td>EN61000-4-3 (dis. A)</td>
</tr>
<tr>
<td>5-12</td>
<td>EMC – EFT</td>
<td>Level 3</td>
<td></td>
<td>EN61000-4-4 (dis. B)</td>
</tr>
<tr>
<td>5-13</td>
<td>EMC – Surge</td>
<td>Level 3</td>
<td></td>
<td>EN61000-4-5 (dis. A) 1 kV, 2 kV (dis. B)</td>
</tr>
<tr>
<td>5-14</td>
<td>EMC – EFT</td>
<td>Level 3</td>
<td></td>
<td>EN61000-4-5 (dis. A) 1 kV, 2 kV (dis. B)</td>
</tr>
</tbody>
</table>

### 6. Environmental test requirements

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Technical specification</th>
<th>Unit</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-1</td>
<td>High ambient operating temperature</td>
<td>+40 °C</td>
<td>deg C</td>
<td>continuous operation</td>
</tr>
<tr>
<td>6-2</td>
<td>Low ambient operating temperature</td>
<td>-10 °C</td>
<td>deg C</td>
<td>continuous operation</td>
</tr>
<tr>
<td>6-3</td>
<td>Highest storage temperature</td>
<td>+70 °C</td>
<td>deg C</td>
<td>allow 2 hours to recover to normal temperature</td>
</tr>
<tr>
<td>6-4</td>
<td>Lowest storage temperature</td>
<td>-40 °C</td>
<td>deg C</td>
<td>allow 2 hours to recover to normal temperature</td>
</tr>
<tr>
<td>6-5</td>
<td>Drop shock</td>
<td>40 g peak</td>
<td></td>
<td>EN60068-2-32:1993</td>
</tr>
</tbody>
</table>
7. Charging curve (current A – red, voltage V - blue)
### 8. BMS connector operation (OPTIONAL, only for the model with BMS option)

<table>
<thead>
<tr>
<th>Contacts</th>
<th>Status</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC12V</td>
<td>not connected</td>
<td>the charger works the standard way at MAX power</td>
</tr>
<tr>
<td>ON/OFF</td>
<td>not connected</td>
<td></td>
</tr>
<tr>
<td>HIGH/LOW</td>
<td>not connected</td>
<td></td>
</tr>
<tr>
<td>GND</td>
<td>not connected</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contacts</th>
<th>Status</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC12V</td>
<td>+12V</td>
<td>the charger works the standard way at MAX power</td>
</tr>
<tr>
<td>ON/OFF</td>
<td>GND</td>
<td></td>
</tr>
<tr>
<td>HIGH/LOW</td>
<td>GND</td>
<td></td>
</tr>
<tr>
<td>GND</td>
<td>GND</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contacts</th>
<th>Status</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC12V</td>
<td>+12V</td>
<td>the charger stops working</td>
</tr>
<tr>
<td>ON/OFF</td>
<td>not connected</td>
<td></td>
</tr>
<tr>
<td>HIGH/LOW</td>
<td>any</td>
<td></td>
</tr>
<tr>
<td>GND</td>
<td>GND</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contacts</th>
<th>Status</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC12V</td>
<td>+12V</td>
<td>the charger works the standard way at REDUCED power (10%)</td>
</tr>
<tr>
<td>ON/OFF</td>
<td>GND</td>
<td></td>
</tr>
<tr>
<td>HIGH/LOW</td>
<td>not connected</td>
<td></td>
</tr>
<tr>
<td>GND</td>
<td>GND</td>
<td></td>
</tr>
</tbody>
</table>

![Diagram of a charger with BMS support](image-url)
(The delivered product may differ from the image)
(The delivered product may differ from the image)
Sirio K80 and K80 HV

MODELS

<table>
<thead>
<tr>
<th>Sirio K80</th>
<th>Sirio K80 HV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate power of the photovoltaic field</td>
<td>300 kWp max</td>
</tr>
<tr>
<td>Rated AC power</td>
<td>80 kW</td>
</tr>
<tr>
<td>Maximum AC power</td>
<td>88 kW</td>
</tr>
</tbody>
</table>

INPUT

<table>
<thead>
<tr>
<th></th>
<th>800 Vdc</th>
<th>880 Vdc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum DC voltage in an open circuit</td>
<td>800 Vdc</td>
<td>880 Vdc</td>
</tr>
<tr>
<td>MPPT operating range</td>
<td>300÷700 Vdc</td>
<td>450÷700 Vdc</td>
</tr>
<tr>
<td>Working range</td>
<td>300÷700 Vdc</td>
<td>450÷700 Vdc</td>
</tr>
<tr>
<td>Maximum input current</td>
<td>260 A</td>
<td>196 A</td>
</tr>
<tr>
<td>Initial feeding voltage</td>
<td>390 Vdc</td>
<td>540 Vdc</td>
</tr>
<tr>
<td>Ripple voltage</td>
<td>&lt;1%</td>
<td></td>
</tr>
<tr>
<td>Number of inputs</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>MPPT number</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>D.C. connectors</td>
<td>Bar</td>
<td></td>
</tr>
</tbody>
</table>

OUTPUT

<table>
<thead>
<tr>
<th></th>
<th>400 Vac</th>
<th>400-160 Vac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating voltage</td>
<td>400 Vac</td>
<td>400-160 Vac</td>
</tr>
<tr>
<td>Operating interval</td>
<td>340÷460 Vac</td>
<td></td>
</tr>
<tr>
<td>Maximum power range</td>
<td>340÷460 Vac</td>
<td></td>
</tr>
<tr>
<td>Frequency range</td>
<td>47.5÷51.5 Hz (1)</td>
<td></td>
</tr>
<tr>
<td>Settable frequency range</td>
<td>47÷53 Hz</td>
<td></td>
</tr>
<tr>
<td>Nominal current</td>
<td>115 Aac</td>
<td></td>
</tr>
<tr>
<td>Maximum current</td>
<td>146 Aac</td>
<td></td>
</tr>
<tr>
<td>Fault level contribution</td>
<td>219 Aac</td>
<td></td>
</tr>
<tr>
<td>Current Harmonic Distorsion (THD)</td>
<td>&lt;3%</td>
<td></td>
</tr>
<tr>
<td>Power factor</td>
<td>from 0.9 ind. to 0.9 cap. (1)</td>
<td></td>
</tr>
<tr>
<td>Galvanic separation</td>
<td>LF transformer</td>
<td></td>
</tr>
<tr>
<td>A.C. connectors</td>
<td>Bar</td>
<td></td>
</tr>
</tbody>
</table>

SYSTEM

<table>
<thead>
<tr>
<th></th>
<th>96.1%</th>
<th>96.1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum efficiency</td>
<td>96.1%</td>
<td>96.1%</td>
</tr>
<tr>
<td>European efficiency</td>
<td>95%</td>
<td>95%</td>
</tr>
<tr>
<td>Stand-by consumption</td>
<td>&lt;30W</td>
<td></td>
</tr>
<tr>
<td>Night consumption</td>
<td>&lt;30W</td>
<td></td>
</tr>
<tr>
<td>Internal protections</td>
<td>MOCB AC side, Switch DC side</td>
<td></td>
</tr>
<tr>
<td>Off-Grid protection</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Detecting earth leakage</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Heat dissipation</td>
<td>Controlled fans</td>
<td></td>
</tr>
<tr>
<td>Operating temperature</td>
<td>0°C÷45°C (without derating)</td>
<td></td>
</tr>
<tr>
<td>Storage temperature</td>
<td>-20°C÷70°C</td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>0÷95% non-condensing</td>
<td></td>
</tr>
</tbody>
</table>

FEATURES

Colour: RAL 7035
Dimensions (WxDxH): 800x800x1900 mm
Weight: 650 Kg
Protection level: IP20
Acoustic noise: <68dBA

COMMUNICATION

Display: Color LCD touch screen
Communication interface: Ethernet, USB, 2xRS232 as standard, RS485 optional (slot version)
Protocols: ModBUS and ModBUS/TOP

STANDARDS

EMC: EN61000-6-3, EN61000-6-2, EN61000-3-11, EN61000-3-12
Security: EN62109-1, EN62109-2
Grid connection criteria: CEI 0-21, CEI 0-16, A70, VDE AR-N-4105, VDE 0126-1-1, G59/2, Real Decreto 1663-2000, PO12.3

OPTION ON REQUEST

- Pole/earth connection kit (positive or negative)
- Overvoltage protection (SPD)

(1) These values can vary according to the local regulations