ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

INGENIERO ELECTROMECÁNICO

ANALYSIS OF SWITCHING POTENTIAL FROM BACK-UP GENERATORS TO DISTRIBUTED GENERATION

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Madrid

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1. INTRODUCTION

1.1. MAIN ISSUES APPROACH

Distributed generation (DG) refers to power generation at the point of consumption. Generating power on-site, rather than centrally, eliminates the cost, complexity, interdependencies, and inefficiencies associated with transmission and distribution.

In general, DG systems produce power for the buildings which the systems are connected to (e.g. solar panels on a home or business). However, when a DG system produces more power than the customer's load, excess power is sent back to the utility company's electric grid [1].

As long as consumption is equal to output, the frequency and the interchanges remain constant, and the system is stable.

However, the balance between the generation and the load is constantly perturbed by load fluctuations, by imprecise control of the outputs of generating plants, and by the sudden failures of some generating plants or of an interconnection

To maintain the reliability of the system, there must be some stand-by generating capacity – called operating reserves – that is ready to maintain the balance of output and load at each instant.

Nowadays, diesel-powered generators provide the most reliable form of emergency backup power. Many international building codes and standards effectively require diesel generators for code compliance because of the need for rapid response time, load carrying capacity, fuel supply and availability, and reliability. One of the most important and unique features of diesel-powered generators compared to other technologies is quick response time, able to start and absorb a full electrical load within ten seconds of grid power failure.

Emergency diesel generators are available in a range of sizes all based on electricity demands. Units can be permanently installed at fixed locations such as hospitals or can be brought in on a mobile trailer to disaster sites or outage areas. The actual system consists of the diesel engine unit and generating system, fuel storage/supply, and electrical switchgear.

Traditionally utilities have leveraged peaking power plants to increase power generation to meet demand. Demand response (DR) works from the other side of the equation – instead of adding more generation to the system, it pays energy users to reduce consumption. Utilities pay for demand response capacity because it is typically cheaper and easier to procure than traditional generation.

DR allows energy users of all kinds to act as "virtual power plants," adding stability to the grid by voluntarily lowering their demand for electricity. Participants in DR programs get paid for providing demand response capacity.

In some regions, facilities may participate in DR by switching to backup generation (working as DG), thereby reducing demand on the grid. Depending on the type of program, participants may be dispatched just once or twice a year for a few hours, or up to 100 hours per year (limited by standards and regulations). The more frequently dispatched programs typically offer higher payouts.

The only company to carry out these programs is EnerNOC (USA). This is largely due to standards and regulations in force in USA, which allow emergency engines to operate for demand response up to 100 hours per year.

So, main obstacles for the introduction of this capacity market model into other countries are the operating limitations of backup generators.

1.2. MOTIVATION

This project aims to consider backup generators as an additional generator of the electric power system, operating as on-grid DG units. Stand-by generators can contribute to the power system stability in two different ways.

Firstly reducing power system's total load by lowering local energy consumption. The decrease of local consumption is reached starting the backup generator and switching the load from the utility power grid to the backup generator.

Secondly, increasing quick response time generators, able to start and feed power into the grid, in a few seconds (10 seconds approximately).

1.3. METHODOLOGY

The project will be carried out in five different parts:

- Technical description of emergency generators.
- Installed capacity of on-grid DG operation BU's estimation.
- Technical requirements analysis based in regulations and standards in force in Spain and main upgrades needed for on-grid DG operation of BU's.
- Costs analysis for on-grid operation of BU's.
- Benefits analysis for on-grid DG operation of BU's.

2. TECHNICAL DESCRIPTION OF BACK UP GENERATORS

2.1. INTRODUCTION

A back-up generator refers to an emergency power system that supplies back-up electrical power in the event of primary power system failure. These generators work by converting mechanical energy, from a combustion engine, into electrical energy. This chapter will analyze emergency generator from a technical point view [2][3], determining the main elements and types of gensets. Finally, a basic review of diesel gensets and main manufacturers will be carried out

Throughout the project we will also refer to Back-up Generators as Back-up Units (BU), Emergency Generators, Back-up Gensets, Emergency Gensets, Standby Generators, Standby Gensets and Gensets.

2.2. PRIME MOVERS

The engine of a Back-up Unit (BU) may be powered by different types of fuel such as natural gas, gasoline or diesel. As pointed out below, each type of engine has different advantages and disadvantages determining the main operation area of each technology.

2.2.1. Natural Gas/ Propane Engines

Natural gas is a gaseous mixture of hydrocarbons, produced either from gas wells or in conjunction with crude oil production. Other gaseous fuels like propane are also included in this section. There are several Natural Gas powered engines such as gas turbines, micro turbines or spark-ignited internal combustion engines. In order to compare the different internal combustion engines, we will only analyze spark-ignited engines which may be powered by both Natural gas and propane.

Advantages:

- Clean burning, being thus more emission compliant than diesel or gasoline engines.
- Quieter engine noise level
- Good Output Power vs. Fuel cost relation.
- Less expensive air-cooled units compared to similar diesel units.

Disadvantages:

- Highly flammable fuel source.
- May be unavailable during natural disasters and no storage possibility (Natural Gas).
- Fuel system plumbing results in higher installation cost.
- Higher fuel consumption at operation by as much as 3-times the fuel consumption of diesel gensets.
- Shorter life expectancy, compared to diesel powered gensets

Due to the Natural Gas engine features, nowadays these units are mainly used for cogeneration and primer power generation issues rather than standby power generation.

2.2.2. Gasoline engines

Gasoline is a mixture of volatile and flammable liquid hydrocarbons derived from petroleum. Gasoline generators are mainly powered by spark-ignition (two/four-stroke) engines.

Advantages:

- Common fuel source which can be easily obtained (gas stations).
- On site fuel delivery available and storage possibility.
- Increases portability of smaller generators.

Disadvantages:

- Highly flammable fuel source.
- Short shelf life of fuel (approximately 12 months).
- Storing large quantities of fuel is hazardous.
- Low Output Power vs. Fuel cost relation.
- Less efficient compared with diesel engines.

Gasoline Standby gensets are very often small size and portable generators while big size units are not cost-effective compared to the diesel ones.

2.2.3. *Diesel engines*

Diesel fuel is a liquid hydrocarbon used as fuel for diesel engines, ordinarily obtained from fractions of crude oil that are less volatile than the fractions used in gasoline. Diesel powered gensets are always compression-ignited engines that can be both two and four-stroke [4][5][6].

Advantages:

- Least flammable fuel source, on site fuel delivery available and storage possibility.
- Engine life can approach 20,000 hours if properly serviced depending on the application and environment.
- Designed for off-road applications and can operate on B diesel fuel (Gasóleo B in Spain) which is sold without the road tax and thus is considerably cheaper to purchase.
- Engines designed to work under a load for long periods of time and perform better when worked hard rather than operated under light loads.
- Equipment is competitively priced for a comparative sized water-cooled gaseous model with the same features.
- In high use situations overall long term cost of operation is much lower than gaseous gensets.

Disadvantages:

- 18-24 month fuel shelf life, without additives.
- Installing large storage tanks raises cost of system.
- Engine noise is higher on a diesel compared to a gaseous engine.
- In sensitive emission areas in some states, diesel engines are prohibited from operating over a prescribed number of hours per year to help reduce pollution levels.
- Requires clean moisture free fuel and a bit more maintenance than a comparable gaseous unit.

Summary of prime mover technologies for Standby Generation			
Factor	Natural Gas	Gasoline	Diesel
Engine Cost	Variable (lower cost for small size units)	Low	Variable (lower cost for big size units)
Fuel System Installation and Storage Cost	Medium	Medium	Medium
Fire and Personnel Safety	Medium	Low	High
Environmentally Friendly	High	Low	Low
Fuel Availability	Medium	Medium	Medium
Cold Starting and Operation	High	Low	Medium
Engine Life	Medium	Low	High
Output Power vs. Fuel Cost	High	Low	Medium

Table 1. Prime movers comparative

2.3. Portable vs. Stationary Classification

2.3.1. *Portable BU*

As the name implies, portable units are not designed for permanent installation. Instead, they work with stand-alone applications and are meant to temporarily energize a few critical applications via external cords.

These are usually functional for a run time of less than 12 hours, and provide a power output of 500W to 20kW.

Most portable units are gasoline fuelled, air-cooled and hence ought to be operated in the open for availing maximum air ventilation. Arrangements should also be made to protect them from rain, snow and such other elements.

Figure 1. Small portable genset (Honda) vs. portable genset for standalone applications

Often, portable units do not have a provision for sound insulation and can be extremely noisy in operation. Furthermore, there is the added effort that one needs to make in hauling the unit out of its storage, plugging it in and refueling the tank, every time there is a power outage.

Portable units are typically used when backup power requirements are low or only temporary. These serve as handy accessories in residential applications, where they can provide energy for lighting, sump pumps, specific essential appliances like refrigerators and air conditioners, and vital medical equipment.

They also find use at construction sites, farms, motor homes and during camping trips. These units are generally used in trailers where the small power output generated is adequate. Also, being compact and lightweight, these sets can be conveniently stored in the trailer compartment or in the back of a tow vehicle.

2.3.2. Stationary BU

Despite the many advantages associated with portable units, they are not suitable for addressing very high power requirements, such as those of an enterprise or a hospital for very long periods of time. In that case, the permanent standby generator addresses the exacting and urgent power requirements of businesses. This unit provides power by being hard-wired into the main distribution panel and can be started manually or even automatically in the event of a power outage.

Figure 2. CAT stationary diesel genset

During a power failure, an automatic transfer switch isolates the electrical wiring from the utility grid and signals the generator to start functioning. The generator begins to feed power to the lines. When power is restored, a reverse action takes place, wherein incoming feed is once again procured from utility lines and the generator ceases to function and goes into a standby mode.

The transfer time is usually about 10 to 30 seconds. Hence, it is essential to make provisions for uninterrupted power supply (UPS) in the interim so that computer systems and applications are not abruptly shut down during transfer time. Also, it makes practical sense to ensure UPS availability during times when the generator is shut down once in every 50 to 100 hours for the purpose of changing motor oil.

Stationary generators are capable of supporting very high power levels in the range of 10kW to 2MW, for extended periods of time.

2.4. CONTROL PANEL

Any complex piece of machinery requires a user interface to enable the user to monitor its operations, check for efficient functioning, and intervene when required. Visually, a control panel is a set of displays that indicate the measurement of various parameters like voltage, current and frequency, through gauges and meters.

The panel may be set up on the body of the generator itself, which is usually the case with small generators. Control panels for a larger industrial generator can be completely separate from the generator and are typically large enough to stand upon their own. These units may also be shelf-mounted or wall-mounted next to the generator, which is common inside an enclosure or internal applications like a data center.

Control panels can be combined with an Automatic Transfer Switch (ATS) to maintain the continuity of electrical power. The ATS detects an outage of power when the mains fails, then signals the control panel to start the generator.

2.5. TRANSFER SWITCH

The load is coupled to normal power supply and the emergency generator trough a transfer switch. Under normal conditions, the transfer switch connects the load with the utility power source. If there is loss of utility power, the generator will be started and the transfer switch will connect the load to the generator.

2.5.1. Manual Transfer Switch

Manual transfer switches are operated by onsite personnel and are used in situations where the load is not of an emergency nature requiring immediate restoration of the power supply.

2.5.2. *Automatic Transfer Switch*

With an automatic transfer switch, power failures are detected immediately and the transition from utility power to generator power is seamless. The control panel system of a transfer switch is what makes the unit automatic in nature

2.6. DIESEL BACK-UP GENSETS

Since Diesel engines are very often used some specific information about Diesel generator sets will be given.

Nowadays, diesel-powered generators provide the most reliable form of emergency backup power. Many international building codes and standards effectively require diesel generators for code compliance because of the need for rapid response time, load carrying capacity, fuel supply and availability, and reliability. One of the most important and unique features of diesel-powered generators compared to other technologies is quick response time, able to start and absorb a full electrical load within ten seconds of grid power failure .

Emergency diesel generators are available in a range of sizes all based on electricity demands. Units can be permanently installed at fixed locations such as hospitals or can be brought in on a mobile trailer to disaster sites or outage areas. The actual system consists of the diesel engine unit and generating system, fuel storage/supply, and electrical switchgear.

2.6.1. *Power Ratings*

The ISO 3046-1 standard for Diesel engines defines three different types of power rating [7]:

- **Continuous power rating**: the engine can supply 100% rated power for an unlimited time. This rating is normally used for production sets.
- **Prime power rating**: the engine can supply a base load for an unlimited time, and 100% rated power for a limited time. The base load and acceptable time for 100% rated power are different for each manufacturer. Typical values are a base load of 70% of the rated power, and 100% rated power during 500 hours per year.

- **Standby power rating**: this is the maximum power that the engine can deliver and is limited in time, typically less than 500 hours per year. This rating should only be applied to generator sets which are used exclusively for emergency power. Since the engine is incapable of supplying more power, a security factor of at least 10% should be used when defining the standby power rating.

2.6.2. *Main Worldwide Manufacturers*

AKSA

Aksa Generators is a Turkish company that manufactures gasoline, diesel and natural gas powered gensets, among others. AKSA is one of the biggest generating sets manufacturers of the world whose key markets are Middle East and Asia. The company offers a product range of diesel gensets from 10KVA to 2500KVA.

Atlas Copco

Atlas Copco is a multinational group that provides portable and stationary generators throughout the world. The company has worked with contractors in the UAE (United Arabian Emirates) and Oman but, due to its size, Saudi Arabia has been Atlas Copco's most prominent market. Atlas Copco offers gensets in a range from 2KVA to 2200KVA.

Caterpillar

Caterpillar is the world’s leading manufacturer of construction and mining equipment, diesel and natural gas engines, industrial turbines and diesel-electric locomotives. Caterpillar provides gas-powered generator sets from 11KVA to 750KVA and diesel-powered generator sets from 8.75KVA to 20MVA.

Cummins

Cummins is an American international company that designs and manufacturers power generation equipment. The company offers gensets between 15KVA and 3000KVA. The 250KVA to 500KVA range is used during construction for powering offices, cranes and other miscellaneous construction requirements. Generators ranging from 500KVA to 3000KVA are used for permanent installations as back-up power to local utilities companies in most building

FG Wilson

FG Wilson has over 45 years of experience in the supply of diesel and gas generator sets. The company offers a product range from 6.8KVA to 2500KVA, including open and enclosed generator sets providing prime and standby power.

HIMOINSA

Founded in 1982, HIMOINSA is a Spanish manufacturer of power generators based in Murcia, Spain, and has suppliers across the world, including the Middle East, which distributes its products and supplies spare parts. The company offers a product range from 3KVA to 2600KVA generators.

Kirloskar

Incorporated in 1946, KOEL is the flagship company of the Kirloskar group. KOEL specializes in the manufacture of both air-cooled and liquid-cooled diesel engines and generating sets across a wide range of power output from 5kVA to 3000kVA.

MTU

MTU Onsite Energy is a German multinational company, which is one of the leading providers worldwide of onsite energy systems, based on diesel engine (30KVA-3.4MVA), gas engine and gas turbine technology.

SDMO

SDMO is a French company based in several countries around the world. SDMO is specialized in manufacturing gensets, distribution, technical support and power solutions. The company offers a product range from 1.25KVA to 3300KVA generators

2.6.3. Common Manufacturers in Spain

Electra Molins

Electra Molins is a Spanish company specialized in manufacturing gensets, maintenance and automatic controls. The company offers a product range from 28KVA to 3300KVA generators

Gesan

Gesan is a Spanish creation company which has been recently added to the Atlas Copco group. Although Gesan is no longer a company itself, Atlas Copco has kept Gesan brand in line with its brand portfolio strategy. Gesan offers gensets in a range from 2KVA to 2200KVA.

Genesal

Genesal is a Spanish company based in A Coruña, Spain, specialized in manufacturing back-up gensets. The company offers a product range from 28KVA to 3300KVA generators

Inmesol

Inmesol is a Spanish gensets manufacturer based in Murcia, Spain, which offers gensets from a range of 9KVA to 2290KVA, control panels and technical support among others.

Pramac

Pramac is an Italian manufacturer of diesel/gasoline gensets and control systems. The company offers a product range from 3.3KVA to 3600KVA generators

2.7. CONCLUSIONS

As seen along this chapter, back-up generators work as a conventional generator, converting mechanical energy into electricity. Indeed, this mechanical energy may be provided by different prime movers such as gasoline, diesel or gas engines. After a simple comparative of the different prime movers technologies, diesel seems to be the most reliable prime mover in terms of people safety, robustness and fuel storage possibility.

In addition, back-up gensets can also be classified by their portability. Stationary backup units are suitable for addressing very high power requirements, such as those of an enterprise or a hospital for very long periods of time. Portable emergency generators work with stand-alone applications and are meant to temporarily energize a few critical applications via external cords.

After that, the two main elements of a back-up unit, which are the control panel and the transfer switch, have been analyzed. The control panel, as his name implies, is a panel that recovers all the critical parameters of the BU's allowing acting over the genset and controlling the unit operation. If there is loss of utility power, the generator will be started and the transfer switch will connect the load to the generator. Moreover, transfer switches can be automatic (ATS) when operated with a control panel or manual (MTS) if the switch needs an operator on place to switch from the mains to the genset.

Many international building codes and standards effectively require diesel generators for code compliance because of the need for rapid response time, load carrying capacity, fuel supply and availability, and reliability. Moreover, diesel gensets have different power ratios such as continuous power, prime power or standby power depending on the load level and the operation time.

Finally, main worldwide manufacturers have been described in terms of their nationality and the range of BU's size they produce. In order to facilitate the task of the next chapter which is an estimation of the installed capacity of BU's in Spain, common manufacturers in Spain have also been analyzed.

3. ESTIMATION OF INSTALLED CAPACITY OF BU GENSETS IN SPAIN

3.1. INTRODUCTION

The main goal of this section is to determine the available potential of BU in Spain. To facilitate the task, the study area has been reduced to the Madrid municipality. First of all it will be necessary to determine possible locations of BU's.
After that, two estimations will be carried out due to the impossibility to determine exactly all the installed BU's. First there will be a conservative estimation (Estimation 1) based on all the available information. Then, an optimistic estimation (Estimation 2) to consider all the uncertainty of the data collection process will be done.

In some cases the optimistic estimation will be applied to individual data but in many others it makes no sense to do it that way. Otherwise the optimistic estimation (Estimation 2) will be based on the total of the conservative estimation (Estimation 1)

Final results will be used to estimate the potential of BU's in Spain. Then, both Spain and Madrid potentials will be analyzed and compared in terms of other generation power plants and the current generation portfolio of Spain.

3.2. BU LOCATION

First of all, it seems necessary to determine where are located all these back-up generators. In Spain, the REBT's ITC-BT-28 establishes the requirement of emergency and reserve supply in places of public concurrence (Annex A). However, this emergency/reserve supply may be a generator or an additional interconnection point to the grid.

After having consulted several gensets installation companies, gensets manufacturers, gensets maintainers and electrical installations companies, the next infrastructures list arise:

Infrastructures
Airports and Stations
Central Business Districts and Buildings (IFEMA, AZCA,)
Commercial Establishments and Chilled and Frozen Goods (Mall Centers, Supermarkets, ...)
Data Processing Centers
Hospitals, Clinics, Sanatoriums and Health centers
Hotels
Military
Museums, Cinemas, Theatres, Auditoriums and Exposition halls
Public Administration Buildings
Schools, High Schools and Universities
Stadiums and Sports halls
Tunnels
Underground Parking

Table 2. Infrastructures were emergency gensets are usually installed

3.3. BU ESTIMATION IN MADRID MUNICIPALITY

3.3.1. *Airports and Stations*

Airports, train stations and bus stations are locations where BU's are frequently installed due to the standards and regulations in force in Spain. One of the main reasons for the mandatory additional energy supply is the high number of users and the national strategic importance of these infrastructures [8] [9]. The typical size of BU installed in these facilities is in a range between 300kVA and 3MVA

Airports

Airport	Estimation 1 [kVA]	Estimation 2 [kVA]
Adolfo Suarez – Madrid Barajas	10000	20000
Cuatro Vientos	600	1000
TOTAL	10600	21000

Table 3. Airports estimation

Transport exchangers

Transport exchanger	Estimation 1 [kVA]
Avenida de América	2000
Conde de Casal	1600
Legazpi	2400
Moncloa	2000
Plaza de Castilla	4800
Plaza Elíptica	2000
Príncipe Pío	1200
TOTAL	16000

Table 4. Transport exchangers estimation

Train stations

Station	Estimation 1 [kVA]
Cercanías Stations	0
Madrid Chamartín	2400
Madrid Puerta de Atocha	2400
Metro Stations	0
TOTAL	4800

Table 5. Train stations estimation

Summary

Airports and stations	Estimation 1 [MVA]	Estimation 2 [MVA]
TOTAL	31	37

Table 6. Airports, transport exchangers and train stations estimated results

3.3.2. Central Business Districts and Office Buildings

A **central business district** (**CBD**) is the commercial and business centre of a city. In Madrid, AZCA is the main CBD but as seen below there are many other buildings and business complexes that have been taken into account. Most of estimations are based on the gross available surface. The typical size of BU installed in these facilities is in a range between 100kVA and 2MVA

CBT´s and Buildings	Estimation 1 [kVA]
Alfonso XI	400
Alvento	1100
Arturo Soria 343	200
Avenida Europa 1	900
AZCA	82000
Callao	400
Campo de la Naciones	4000
Campus Repsol	4000
Cristalia	3000
Cuatro Torres	9000
Edificio BMW	550
Edificio Ejesur	900
Edificio Elipse	250
Edificio Ferrovial	400
Edificio Mapfre	250
Edificio Torre Europa	6000
Edificio Torre Picasso	3000
Edificios Hnos. Revilla	1800
Foresta	2500
IFEMA	5000
José María Churruca	600
La Gavia	1000
Las Tablas	900
M-30 Zona financiera (Parque norte)	15000
Sanchinarro	600
Sede Grupo Arnaiz	700
Sede PEUGEOT	600
Torre Repsol-YPF	5000
Torres Puerta de Europa	3200
Vía Norte	1200

Table 7. CBT's and buildings estimation

Summary

CBT's and Buildings	Estimation 1 [MVA]	Estimation 2 [MVA]
TOTAL	157	268

Table 8. CBT's and buildings estimated results

3.3.3. Commercial Establishments and Chilled and Frozen Goods

Commercial establishments like supermarkets or mall centers need a backup electricity supply to ensure the cooling systems (chilled and frozen goods), the people safety in case of an emergency and the continuity of supply for the business activity (no electricity supply, no sales) among others. Due to the high amount of different commercial establishments estimations will distinguish between mall centers, supermarkets, hypermarkets and department stores (such as El Corte Inglés).

The typical size of BU installed in these facilities is in the range of 10kVA to 1.6MVA.

What's more, to be able to quantify each type of establishment we will estimate the power of BU's depending on the gross available surface of each one.
The next table shows the recovered information about each type of facility:

Commercial Establishment	Estimation 1 [kVA/m^2]	Estimation 2 [kVA/m^2]
Mall Centers	0.12	0.2
Supermarkets	0.04	0.06
Hypermarkets	0.2	0.32
Department Stores	0.11	0.12

Table 9. Commercial establishments estimation

Summary

Taking into account all the information in [7]-[16], the estimated potential of BU for this section is:

Commercial Establishment	Estimation 1 [MVA]	Estimation 2 [MVA]
TOTAL	169	252

Table 10. Commercial establishments estimated results

3.3.4. Data Processing Centers

A data processing center (DPC) is a facility used to house computer systems and associated components, such as telecommunications and storage systems. It generally includes redundant or backup power supplies, redundant data communications connections, environmental controls (e.g., air conditioning, fire suppression) and various security devices. Large data centers are industrial scale operations using as much electricity as a small town.

Because of their strategic importance it is very critical to reveal their location and security of supply potential. Even the estimations carried out in this project are all based on real data, sources and specific information cannot be published on this paper.

In order to summarize all the collected information, DPC's have been classified in three different levels: big, average and small.

The typical size of BU installed in these facilities goes from 300kVA to 1MVA.

Size of DPC	Number of DPC [pu]	Estimation 1 [kVA]	Estimation 2 [kVA]
Big	15	135180	268000
Average	55	135180	135613
Small	1782	29700	59400
Total	**1852**	**300493**	**463013**

Table 11. DPC's estimation

Summary

DPC	Estimation 1 [MVA]	Estimation 2 [MVA]
TOTAL	300	463

Table 12. DPS's estimated results

3.3.5. Hospitals, Clinics, Sanatoriums and Health centers

It is obvious that medical utilities cannot afford an interruption of electricity supply because human health and safety may be affected. To be able to quantify the installed capacity of BU in hospitals, clinics and other health centers the number of beds has been chosen as the reference for the estimations in hospitals, while in health centers the estimation is based in an average power per center [17].
The typical size of BU installed in these facilities is in a range between 300kVA and 3.1MVA

Hospitals, clinics and sanatoriums

For this section, hospitals, clinics and sanatoriums will be all considered as hospitals.
The table below shows the collected information (real data) of many hospitals in Madrid municipality:

Name of the hospital	Power of the BU [kVA]	Number of beds [pu]
Cemtro	800	90
Fundación Jiménez Díaz	2200	591
Gómez Ulla	2800	1311
Hospital 12 Octubre	4875	1389
Hospital Quirón San José	550	96
Hospital Ramón y Cajal	3000	1196
La Paz	4250	1380
Ruber Internacional	800	123
San Francisco de Asís	500	500
Universitario La princesa	1000	554

Table 13. Surveyed hospitals

In order to obtain a linear expression for the relation between the number of beds and the installed potential of BU's in these hospitals, the following estimation (least squares method) has been done:

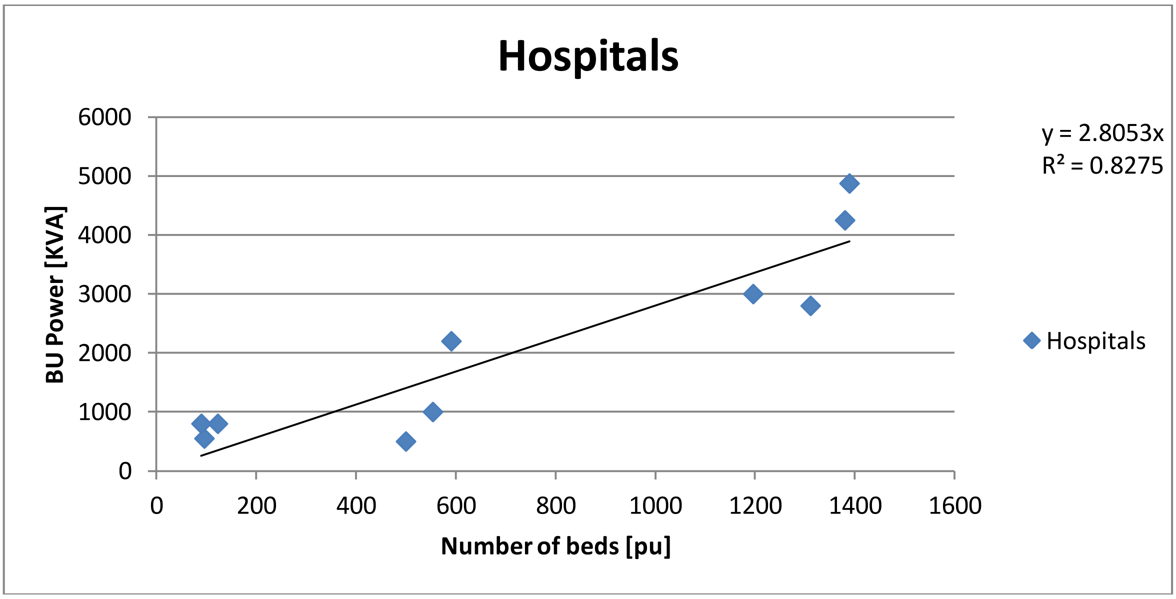

Figure 3. Linear approach for hospitals estimation

Hospitals	Estimation 1 [kVA/bed]	Estimation 2 [kVA/bed]
TOTAL	2.8	4

Table 14. Hospitals estimation

Health Centers

As mentioned before, health centers potential will be quantified by establishing an average BU power per center. After several consults it seems reasonable to establish the following power ratios:

Health centers	Estimation 1 [kVA/center]	Estimation 2 [kVA/center]
TOTAL	100	200

Table 15. Health centers estimation

Summary

Taking into account all the information in Annex C, the estimated potential of BU for this section is:

Hospitals and health centers	Estimation 1 [MVA]	Estimation 2 [MVA]
TOTAL	50	94

Table 16. Hospitals and health centers estimated results

3.3.6. *Hotels*

Since Madrid is one the most visited cities in Europe (up to 10 million tourists in 2012) it seems necessary to evaluate the BU potential installed in these facilities. As done before (hospitals section) the estimation requires a parameter to quantify all the available potential. In this case, the number of rooms of each hotel is a reasonable reference for the calculus. The table below shows the collected information (real data) of many hotels in Madrid municipality:

Name of the hotel	Power of the BU [kVA]	Number of rooms [pu]
H10	140	74
Holiday Piramides	200	250
Hotel de las letras	20	109
Hotel Ibis	44	90
Hotel Plaza Celenque	110	38
Hotel Suecia	250	127
Meliá Av. América	300	322
Meliá Capitán Haya	750	800
Princesa Husa	750	423
Silken Puerta América	550	300
Westin Palace	700	466

Table 17. Surveyed hotels

In order to obtain a linear expression for the relation between the number of rooms and the installed potential of BU's in these hotels, the following estimation (least squares method) has been done:

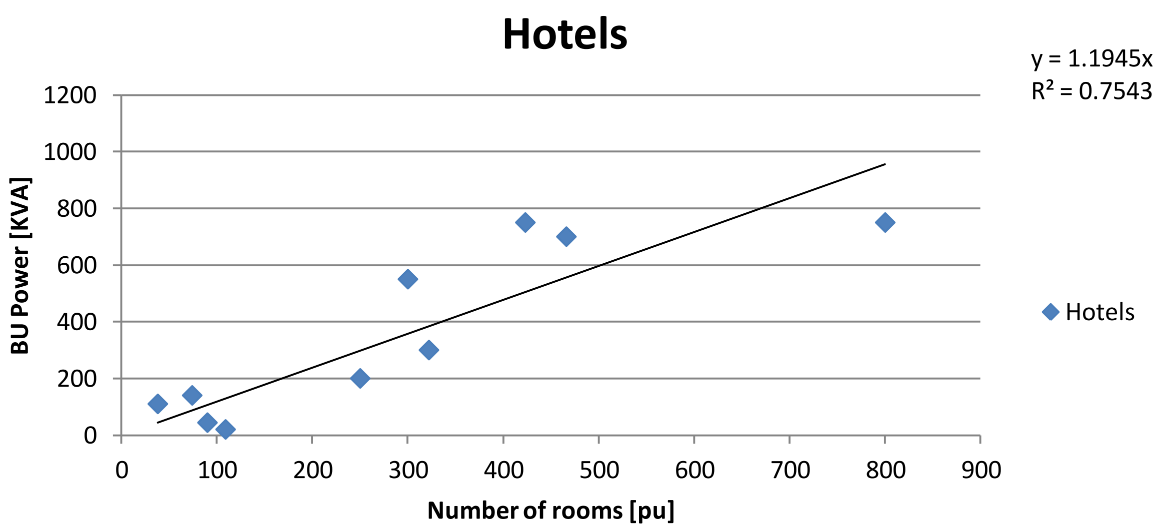

Figure 4. Linear approach for hotels estimation

Hotels	Estimation 1 [kVA/room]	Estimation 2 [kVA/room]
TOTAL	1.2	1.5

Table 18. Hotels estimation

The typical size of BU installed in these facilities is in a range between 50kVA and 700kVA

Summary

Taking into account all the information in Annex D, the estimated potential of BU for this section is:

Hotels	Estimation 1 [MVA]	Estimation 2 [MVA]
TOTAL	41	51

Table 19. Hotels estimated results

3.3.7. Military facilities

As mentioned on the DPC's section, all the information used to estimate the BU's potential in military installations cannot be published on this paper. However, both estimation 1 and estimation 2 are based on real information.

Military facilities considered for this section are facilities such as military bases, logistic facilities, military residences and many other buildings related to the military activity.

The typical size of BU installed in these facilities goes from 300kVA to 1MVA.

Military facilities	Estimation 1 [MVA]	Estimation 2 [MVA]
TOTAL	30	50

Table 20. Military facilities estimated results

3.3.8. Museums, Cinemas and Theatres

Museums, cinemas and theatres require a backup electricity supply for security and people safety issues in case of an emergency. To quantify the available potential, some information from the municipality of Madrid (number of facilities) with the aid of private companies (typical size of BU) has been used for the estimations.

The typical size of BU installed in these facilities goes from 10kVA to 700kVA.

Cinemas

Cinemas	Number of cinemas [pu]	Power 1 of the BU [kVA]	Power 2 of the BU [kVA]	Estimation 1 [kVA]	Estimation 2 [kVA]
Cinemas	43	50	100	2150	4300

Table 21. Cinemas estimation

Theatres

This section includes theatres and auditoriums located in Madrid Municipality.

Theatres capacity	Number of theatres [pu]	Power 1 of the BU [kVA]	Power 2 of the BU [kVA]	Estimation 1 [kVA]	Estimation 2 [kVA]
Less than 50 people	4	0	0	0	0
From 50 to 100 people	41	0	10	0	410
From 101 to 200 people	57	10	30	570	1710
From 201 to 500 people	82	30	100	2460	8200
From 501 to 1.000 people	33	200	300	6600	9900
Above 1.000 people	15	500	800	7500	12000
No data	8	0	20	0	160

Table 22. Theatres estimation

Museums

Museum name	Estimation 1 [kVA]	Estimation 2 [kVA]
Biblioteca Nacional	1000	1500
Museo Africano	100	150
Museo Arqueológico	100	150
Museo Casa de la Moneda	200	300
Museo Cerralbo	100	150
Museo de América	100	150
Museo de Antropología	100	150
Museo de Bellas Artes de Madrid	100	150
Museo de Cera	100	150
Museo de Ciencia y Tecnología	100	150
Museo de Ciencias Naturales	200	300
Museo de Historia	100	150
Museo de los Bomberos	100	150
Museo del Ferrocarril	100	150
Museo del Prado	1000	1500
Museo del Romanticismo	50	75
Museo del Traje	200	300
Museo Geominero	100	150
Museo Nacional de Artes Decorativas	100	150
Museo Naval de Madrid	100	150
Museo Reina Sofía	1000	1500
Museo Sorolla	50	75
Museo Thyssen	1000	1500
Planetario de Madrid	1000	1500
Real Armería de Madrid	100	150
Real Fábrica de Tapices	100	150

Table 23. Museums estimation

Summary

Taking into account all the previous information, estimated potential of BU's for this section is:

Museums, cinemas and theatres	Estimation 1 [MVA]	Estimation 2 [MVA]
TOTAL	27	48

Table 24. Museum, cinemas and theatres estimated results

3.3.9. *Public Administration Buildings*

Public administration buildings refer to buildings owned by the government or public companies. Due to the high amount of buildings with these characteristics it seems very difficult to determine quantitatively the total potential of BU's related to the public activity [18]. However, some facilities have been analyzed for estimation 1, including in estimation 2 all the possible buildings that haven't been taken into account.

The typical size of BU installed in these facilities is in a range between 100kVA and 2MVA

Public Administration Buildings	Estimation 1 [kVA]
Banco de España	3000
Canal de Isabel II	1600
Community of Madrid Buildings	2200
Congreso de los Diputados	20
Consejo General del Poder Judicial	3900
IDAE	2000
Instituto Cervantes	2000
Instituto de Estudios Fiscales	750
Madrid Municipality Buildings	2000
Ministerio de Economía y Hacienda	650
Ministries	9200
OAMI	800
Police Stations	1500
Senado de España	8000
Sistemas Técnicos de Loterías	6000
Sociedad De Bolsas	5000
Tesorería de la Seguridad Social	1500
TOTAL	**50120**

Table 25. Public administration buildings estimation

Summary

Public Administration	Estimation 1 [MVA]	Estimation 2 [MVA]
TOTAL	46	59

Table 26. Public administration building estimated results

3.3.10. *Schools, High Schools and Universities*

This section is one of the most complicated to show due to the high amount of locations that have been analyzed. In order to understand the complexity of the analysis, the following figure shows the location of high schools in the municipality of Madrid.

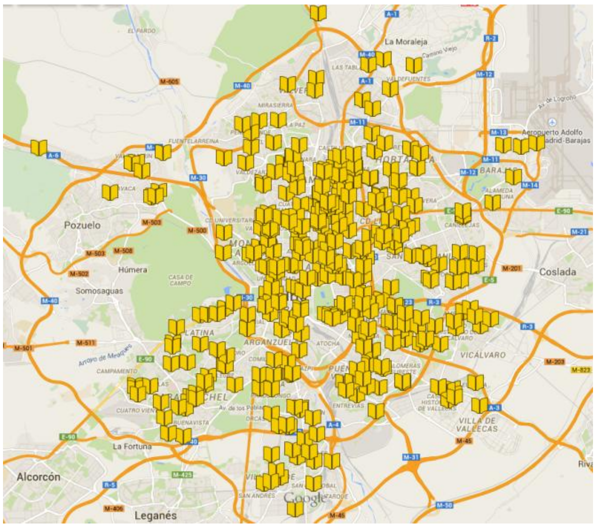

Figure 5. Location of High Schools, Madrid Municipality

In short, up to 1101 different educational entities have been taken into account, determining the presence of BU´s in up to 200 entities.

The typical size of BU installed in these facilities is in a range between 50kVA and 200kVA

Schools, high schools and universities	Estimation 1 [MVA]	Estimation 2 [MVA]
TOTAL	56	78

Table 27. Schools, high schools and universities estimated results

3.3.11. Stadiums and Sports halls

Stadiums and sports halls are facilities with similar requirements in terms of backup electricity supply. The main reason for the mandatory reserve supply is the people safety in case of emergency, so the parameter that will be used to estimate the BU's power of each facility is the maximum seating capacity.

The table below shows estimation 1 which has been done taking into account collected information from gensets manufacturers and maintainers and [10]:

Stadiums and sports halls	**Estimation 1 [kVA]**
Santiago Bernabeu	4000
Estadio Olímpico	5000
Vicente Calderón	1000
Palacio de los deportes	2200
Caja Mágica estadio 1	3000
Caja Mágica estadio 2	500
Caja Mágica estadio 3	300
Vistalegre	1400
Madrid Arena	3000
TOTAL	**20400**

Table 28. Stadiums and sports halls estimation

The typical size of BU installed in these facilities is in a range between 100kVA and 1.7MVA

Summary

Tunnels	**Estimation 1 [MVA]**	**Estimation 2 [MVA]**
TOTAL	20	30

Table 29. Stadiums and sports halls estimated results

3.3.12. Tunnels

Emergency supply in tunnels is mainly used to ensure both lightning and ventilation systems in case of emergency. There are lots of tunnels in Madrid but it is difficult to determine if a tunnel has or not a BU. The estimation will only consider M-30 tunnels and AVE train tunnels.

The typical size of BU installed in these facilities is in a range between 100kVA and 1.5MVA

Tunnels	**Estimation 1 [MVA]**	**Estimation 2 [MVA]**
TOTAL	9	13

Table 30. Tunnels estimated results

3.3.13. Underground Parking

As mentioned in the previous section, the backup supply for these utilities is mainly used to ensure ventilation and lightning systems. In this case the estimation is easier because it can be associated to the number of parking places of each facility (Annex E). Estimation 1 will be carried out only considering public owned underground parking places. Estimation 2 will also consider private owned underground parking places.

The typical size of BU installed in these facilities is in a range between 50kVA and 1MVA

Underground parking	**Estimation 1 [MVA]**	**Estimation 2 [MVA]**
TOTAL	9	19

Table 31. Underground parking estimated results

3.4. ESTIMATION RESULTS IN MADRID MUNICIPALITY

Infrastructure	Conservative Potential [MVA]	Optimistic Potential [MVA]	Minimum size of BU [kVA]	Maximum size of BU [kVA]	Minimum number of BU [pu]	Maximum number of BU [pu]	Availability
Airports and stations	31	37	300	3000	10	123	High
Central Business Districts and Buildings (IFEMA, AZCA,...)	157	268	100	2000	78	2681	High
Commercial Stablishments and Chilled and Frozen Goods (Mall Centers, Supermarkets, ...)	169	252	10	1600	106	25237	Medium
Data Processing Centers	300	463	100	3000	100	4630	Low
Hospitals, clinics, sanatories and health centers	50	94	300	3100	16	313	Medium
Hotels	41	51	50	750	54	1017	Medium
Military	30	50	300	1000	30	167	Low
Museums, Cinemas, Theatres, Auditories and Exposition halls	27	48	10	700	38	4763	High
Public Administration Buildings	46	59	100	2000	23	595	Medium
Schools, High Schools, Universities and student accommodation	56	78	50	200	280	1566	High
Stadiums and sports halls	20	30	100	1700	12	300	High
Tunnels	9	13	100	1500	6	130	High
Underground Parking	9	19	50	1000	9	370	High
TOTAL/AVERAGE	**945**	**1462**	**112**	**1539**	**763**	**41891**	

Table 32. Estimated potential per facility in Madrid municipality

3.5. BU ESTIMATION IN SPAIN

The population ratio is a good parameter to extrapolate the previous results to the entire Spanish country. However final results will only have sense if the energy needs of the considered municipalities are similar to Madrid ones. For that, municipalities with a population ratio below 100000 people will not be considered for the extrapolation.

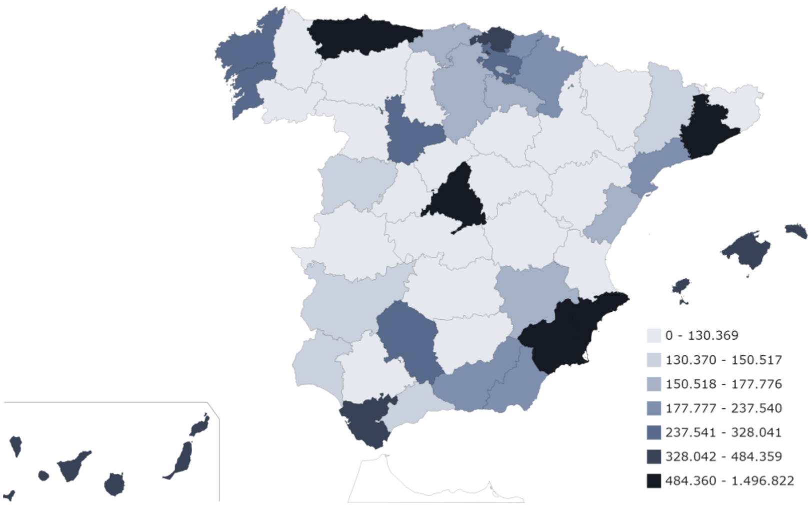

Figure 6. Population density per municipalities (INE)

The next table shows the BU potential extrapolation in terms of municipalities' population ratio bigger than 100000 people:

Area	Population [pu]	Conservative Potential [MVA]	Optimistic Potential [MVA]
Madrid municipality	3165235	945	1462
Spain Municipalities >100.000 people	18499125	5524	8545

Table 33. Extrapolation parameters and resulting potential for Spain

After that, the BU potential to be considered for the rest of the paper is the optimistic potential. This decision has been taken after consulting several BU related companies. The main reason to justify the previous choice is the impossibility to quantify all the infrastructures with a BU.

3.6. BU POTENTIAL ANALYSIS

The main goal of this section is to analyze the previous results in order to determine if this arising generation could be used for economical issues rather than only for emergencies.

3.6.1. Comparative in terms of existing generation plants in Spain

This comparative will be carried out comparing existing generation plants of different technologies and the resulting BU potential of the previous section (Madrid and Spain). To be able to compare the backup gensets potential a cosϕ=0.8 (established by all the manufacturers) will be considered for the active power generation (MW).

Comparative of the total potential of BU's installed in Madrid Municipality in terms of other generation plants				
Plant	Technology	Power [MW]	Conservative	Optimistic
Central Nuclear de Trillo	Nuclear	1066	0.7	1.1
Central de Cedillo	Hydro	500	1.5	2.3
Escombreras	CCGT	831	0.9	1.4
Lada	Coal	515	1.5	2.3
Central de Ceuta	Diesel	45.9	16.5	25.5
Ibersol Puertollano	Solar CSP	50	15.1	23.4

Table 34. Comparative of the estimated installed potential of BU's in Madrid

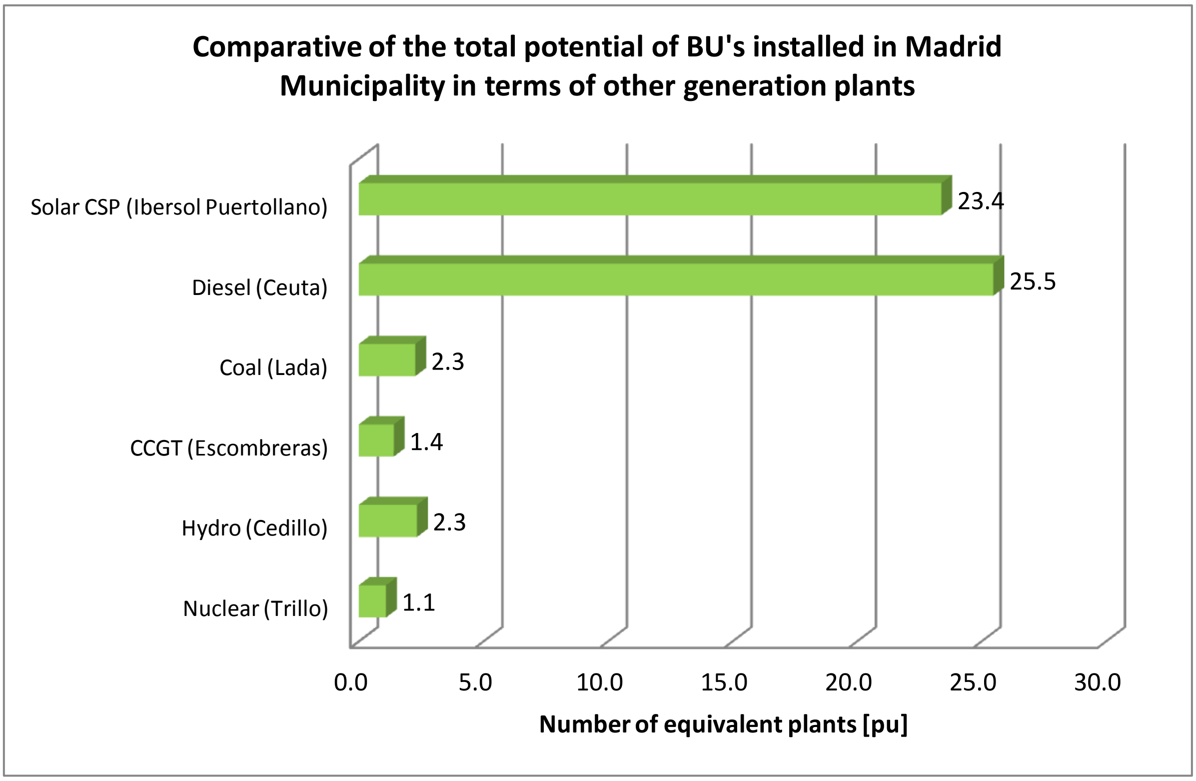

Figure 7. Comparative of Madrid BU's potential in terms of other generation plants

Comparative of the total potential of BU's installed in Spain [1] in terms of other generation plants				
Plant	Technology	Power [MW]	Conservative	Optimistic
Central Nuclear de Trillo	Nuclear	1066	4.1	6.4
Central de Cedillo	Hydro	500	8.8	13.7
Escombreras	CCGT	831	5.3	8.2
Lada	Coal	515	8.6	13.3
Central de Ceuta	Diesel	45.9	96.3	148.9
Ibersol Puertollano	Solar CSP	50	88.4	136.7

Table 35. Comparative of the estimated installed potential of BU's in Spain

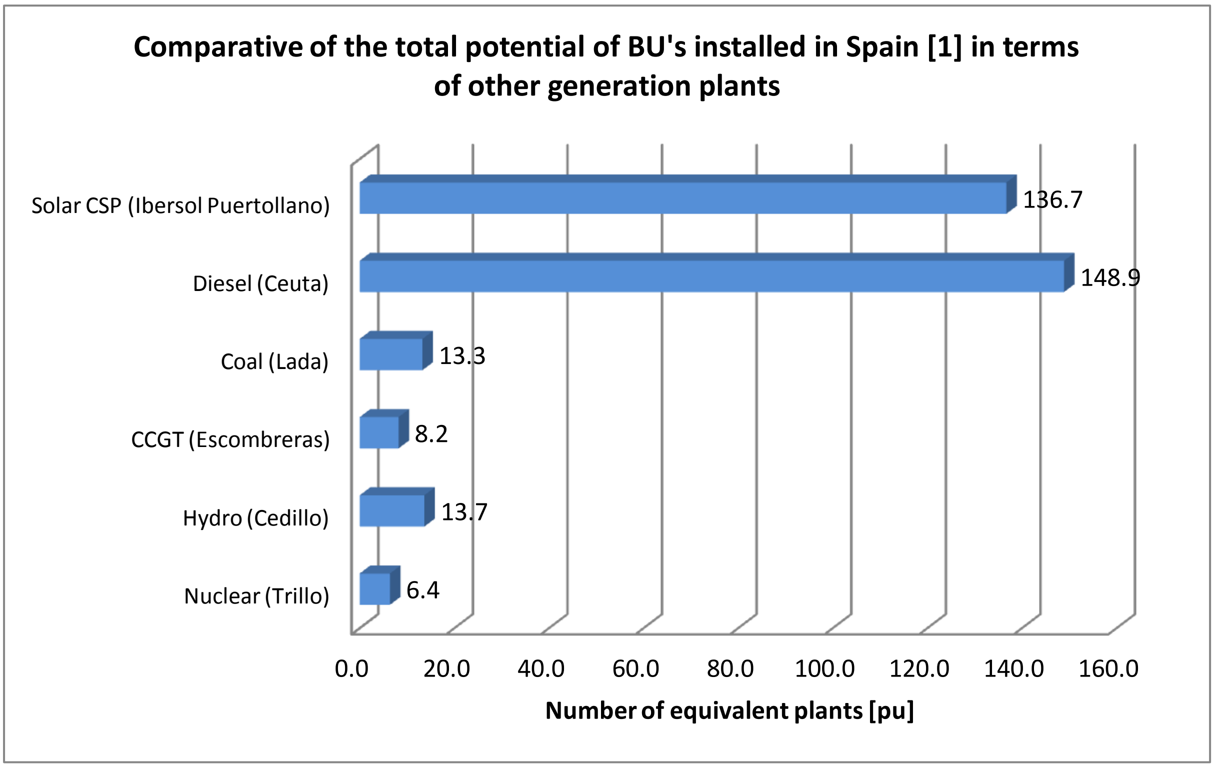

Figure 8. Comparative of Spain BU's potential in terms of other generation plants

As pointed out above, the additional potential provided by BU's is very interesting for DG applications. In the case of Madrid, this potential is bigger than a nuclear power plant like Trillo (1066MW) while in the entire country this potential goes up to 6 nuclear power plants like Trillo.

In terms of a CCGT like Escombreras, the exploitation of this potential is similar to build a new power plant in Madrid and up to 8 new power plants in Spain.

3.6.2. Generation portfolio sensitivity

To analyze the generation portfolio sensitivity current generation portfolio [19] will be compared to the resulting one after considering BU's potential.
The first figure shows the current installed power capacity (Peninsular System) while the second one considers BU's as a new DG technology.

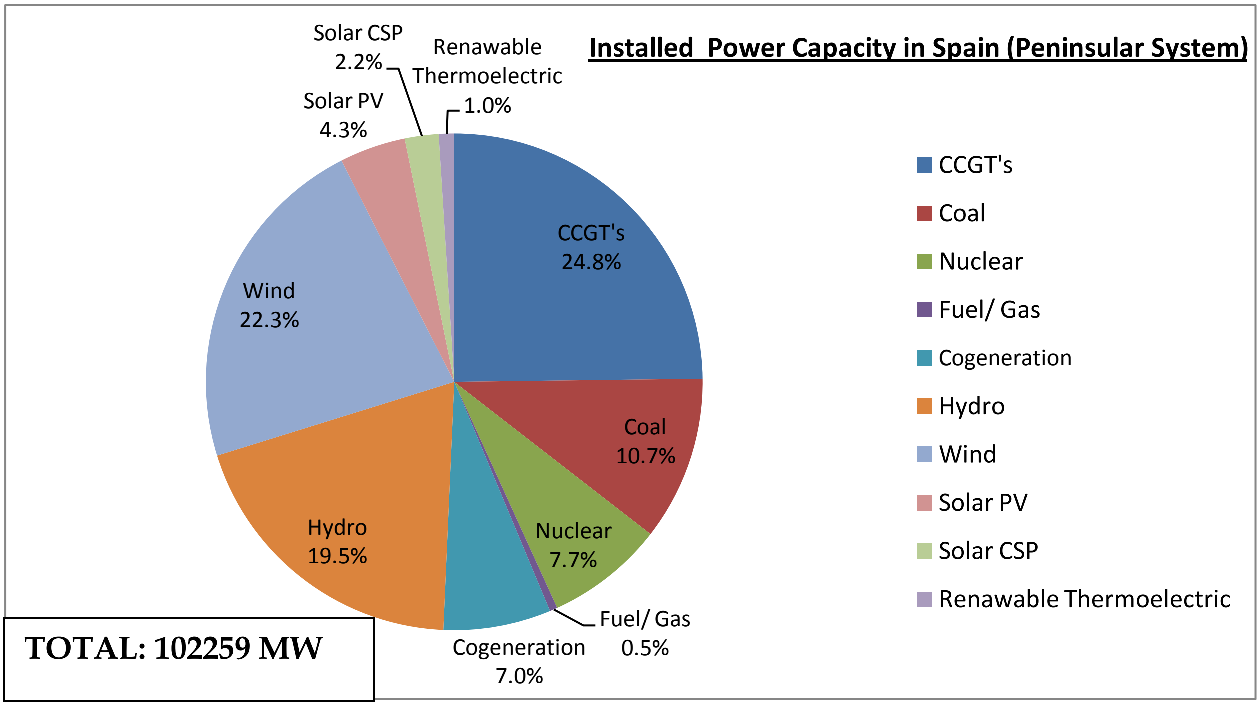

Figure 9. REE, Spanish Peninsular System Installed Capacity, January 2015

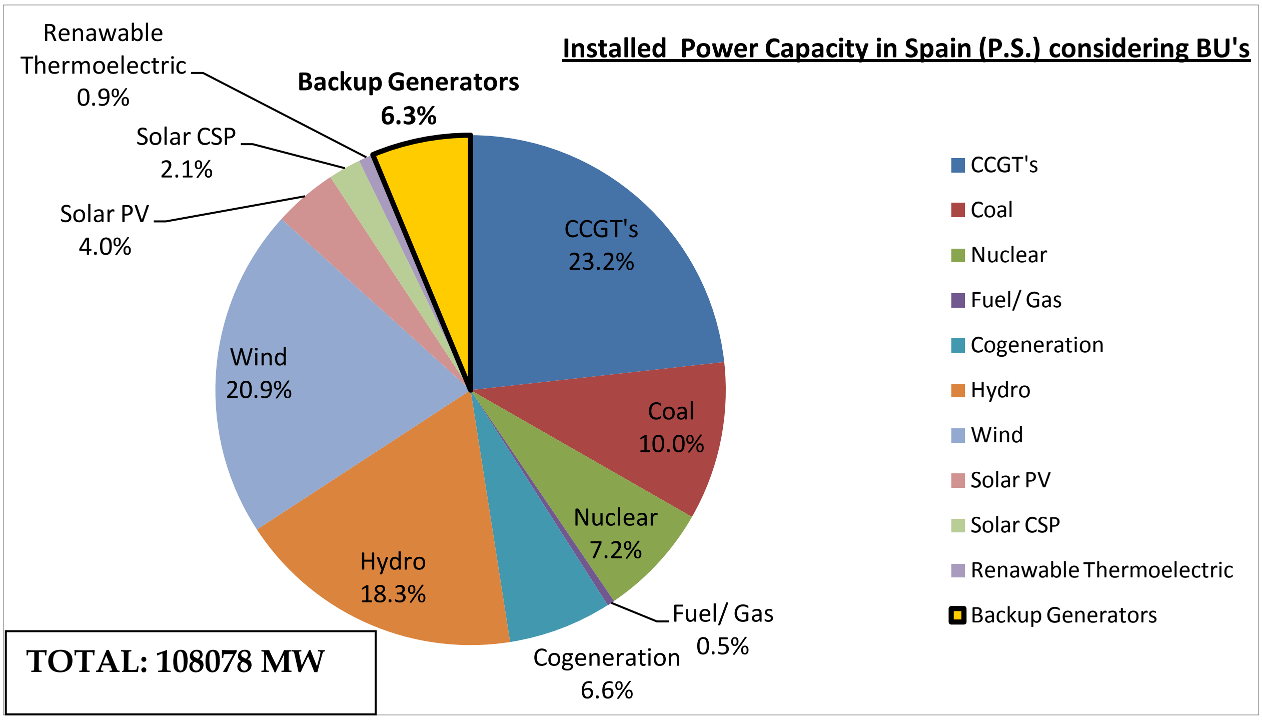

Figure 10. Own creation, Spanish PS Installed Capacity considering BU's as DG.

As it can be appreciated the additional potential provided by the BU's is similar to the current nuclear potential and bigger than all the solar generation capacity (CSP +PV).
Estimated installed capacity of BU for on-grid DG operation (near 5819 MW) is similar to the Installed Capacity in Ceuta, Melilla, Islas Baleares and Islas Canarias [19].

3.7. CONCLUSIONS

After reducing the study area to Madrid municipality and consulting main gensets manufacturers, maintainers and installation companies (up to 44 different companies have been consulted) for possible locations of BU's, next infrastructures list arise: Airports and Stations, Central Business Districts and Buildings, Commercial Establishments and Chilled and Frozen Goods, Data Processing Centers, Hospitals, Clinics, Sanatoriums, Health centers, Hotels, Military Museums, Cinemas, Theatres, Auditoriums, Exposition halls, Public Administration Buildings, Schools, High Schools, Universities, Stadiums, Sports halls, Tunnels and Underground Parking.

Two estimations have been carried out to determine the installed capacity of BU's for on-grid DG operation of each infrastructure. The first one which is Estimation 1 (conservative) is based on all the collected information while estimation 2 (optimistic) aims to consider all the uncertainty of the data collection process.

Resulting estimated capacity of BU's for on-grid DG operation in Madrid is up to 1170 MW for estimation 2. In order to extrapolate Madrid potential to Spain, municipalities with a population ratio above 100000 people have been taken into account. Therefore, resulting estimated capacity of BU's for on-grid DG operation in Spain is up to 6836 MW for estimation 2.

Previous results have been compared with existing generation plants of different technologies such as Ibersol Puertollano (solar CSP), Ceuta (Diesel), Cedillo (Hydro), Trillo (Nuclear) or Escombreras (CCGT). Madrid's installed capacity of BU's estimated before seems to be similar to the nuclear power plant of Trillo (1066 MW) and up to 25 times the Diesel power plant of Ceuta.

Spain's installed capacity of BU's estimated before is up to 6, 4 nuclear power plant like Trillo (1066 MW) and up to 148,9 times the Diesel power plant of Ceuta.

Current generation portfolio grows approximately 5819MW, a potential similar to the installed capacity in Ceuta, Melilla, Islas Baleares and Islas Canarias (5884 MW). In terms of generation technologies, estimated potential for BU's is similar to the nuclear installed capacity and bigger than the solar installed capacity (CSP+PV).

Although estimated BU installed capacity for on-grid DG operation in Spain is similar to other technologies like solar or nuclear, emergency gensets normal operation is to feed critical loads. Therefore, when on-grid DG operation of BU's is required some technical and regulatory challenges need to be solved.

4. TECHNICAL REQUIREMENTS TO PARTICIPATE FOR ON-GRID DG OPERATION

4.1. INTRODUCTION

This section aims to show both technical and regulatory challenges, upgrades and constraints that arise when on-grid DG operation of BU is required.

A systematic analysis of current limitations in BU operation will be carried out in order to determine main obstacles for DG. For this point, the main regulation taken into account will be the REBT (Low Voltage Facilities Regulation).

In addition, some feasible solutions will be considered from the technical and economical point of view.

4.2. THEORETICAL ANALYSIS

Since the main goal of the analysis has been defined, REBT's ITC-BT-40 (Annex B) is going to be the main regulation to be considered.

4.2.1. Facilities classification

First of all, REBT establishes three different types of facilities depending on their operation with the Distribution Network:

A. ***Isolated installations***: those facilities without an interconnection point to the Distribution Network.

B. ***Assisted installations***: those facilities interconnected to the distribution Network; Parallel operation isn't possible.

C. ***Interconnected installations***: those facilities ready to operate in parallel to the Distribution Network.

Emergency gensets (BU) are usually type B facilities. They are operated in case of emergency and parallel operation isn't considered. Parallel operation is

required for the DG operation, so all the type B facilities should change into type C (interconnected facilities)
Moreover, the REBT also distinguish between two different types of C facilities, C1 and C2, depending on the voltage level of the interconnection:

C1. ***Low Voltage interconnected installations:*** those generation facilities where the interconnection to the Distribution Network is on Low Voltage.

C2. ***High Voltage interconnected installations:*** those generation facilities where the interconnection to the Distribution Network is on High Voltage.

Generation facilities up to 100KVA could be interconnected to the Low Voltage Distribution Network.

In those facilities up to 100kVA, High Voltage supply and own transformer center, the interconnection will be on the Low Voltage side of the transformer.

For bigger generators (S>100kVA) the interconnection should be to the High Voltage Distribution Network, through the corresponding step-up transformer.

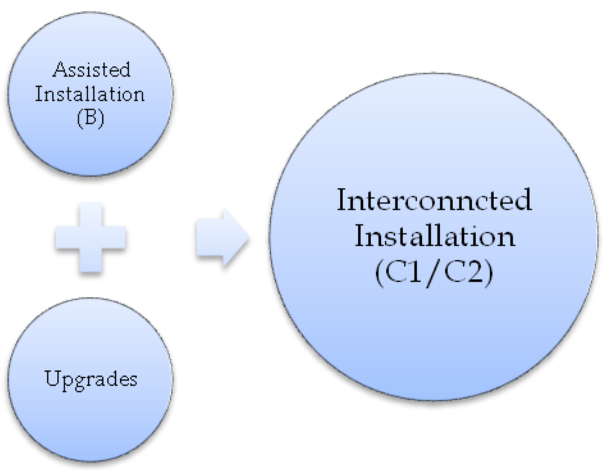

Figure 11. Summary of the current situation

4.2.2. *Connection Requirements*

Synchronization requirements

REBT's power limitation (100kVA) for Low Voltage interconnection refers to the total power the facility. This power will be the power of a generator in case of a single generator facility or the sum of the entire generation capacity, in case of a multiple generators facility (parallel operation).This limitation is one of the most controversial for the implementation of gensets as a new DG source.

Moreover, interconnected power to the Distribution Network cannot exceed the 50% of the output power of the nearest Transformer Center.

When the interconnection between the generator and the main is required, it is necessary to synchronize the back-up unit to the grid.
Since the utility supply is much stronger it will determine the system frequency and the system voltage.

REBT also establishes some requirements for the Distribution Network coupling of a generation facility. First of all it is mandatory to have synchronization device (automatic or manual) in order to be able to adjust all the parameters to the required levels. Then, synchronization parameters such as frequency phase and voltage and the capacity factor required for the synchronization are shown below:

Synchronization Constraints	
S_{max}=100kVA (3x400/230 V)	
S_{max} <50% of S_{CT}	
Δ_{max}Voltage	± 8%
Δ_{max}Frequency	± 0.1 Hz
Δ_{max}Phase	± 10°
Automatic/Manual Synchronizer	
Capacity factor: 0.8-1	

Table 36. REBT's requirements for synchronization

As far as the quality of supply is one the main issues in Distribution Networks, REBT establishes some limitations on the quality of the generated voltage wave:

Voltage Wave Quality	
Even order Harmonics	4/n
Order 3 Harmonics	5
Odd order Harmonics (>5)	25/n
Being n the rms value of the order n harmonic	

Table 37. REBT's requirements for the voltage wave quality

Finally, interconnection cables will be designed following the next table specifications (most restrictive criterion):

Interconnection Cable Design	
Maximum Current	125% I_NGenerator
Maximum Voltage Drop	1.5% U_NGenerator

Table 38. REBT's criteria for cables design

Measurement and protection requirements

As a source of DG, gensets will feed energy into the grid. Measurement and control devices will be needed to control and quantify the energy flow between the grid and the utility, even more in case of demand response programs such as dynamic energy pricing.

Protections will act over an automatic circuit breaker which should be located at the beginning of the indoor installation, in an accessible and single point. Protections must also ensure the impossibility of interconnection while there is an internal fault in the generation facility, avoiding a possible fault in the Distribution Network.

The interconnection minimum protections will be:

- **Overcurrent,** through magneto-thermal relays or similar.
- **Minimum Voltage**, connected between a phase and the neutral. Actuation time less than 0.5 s when the voltage reaches 85% of the Un.

- **Overvoltage**, connected between a phase and the neutral. Actuation time less than 0.5 s when the voltage reaches 110% of the Un.

- **Maximum and minimum Frequency**, connected between different phases. Actuates when the frequency isn't in the range between 49Hz to 51 Hz during more than 5 periods.

- In addition, it is also necessary to install a reverse power protection to prevent future damages on the generator when parallel operation is required [7].

Grounding system

REBT distinguish different types of grounding system depending o the facility. However, assisted facilities (B) and interconnected facilities (C) have the same grounding system configuration: TT [20][21].

The neutral current will be permanently measured in order to be able to disconnect the facility when 50% of I_NGenerator is reached.

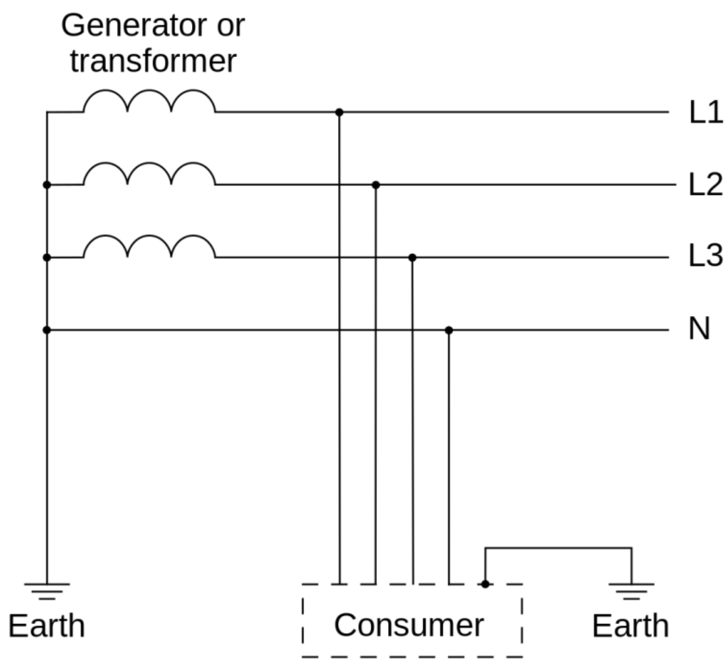

Figure 12. TT earth configuration

Connection Diagram

As mentioned before, the main issue faced in this section is the conversion of B facilities (assisted) into C ones (interconnected). The following schemes will try to show the current configurations and the upgrades or modifications needed for the implementation of BU's as a real DG source.

Following diagrams will only consider a single generator although depending on the facility characteristics it might be several gensets working in parallel.

In order to help the diagrams comprehension, the next legend recovers all the elements that could be represented:

Leyenda para instalaciones receptoras	*Leyenda para instalaciones generadoras*
1 Red de distribución *2 Acometida* *3 Caja general de protección (CGP)* *4 Línea general de alimentación (LGA)* *5 Interruptor general de maniobra (IGM)* *6 Caja de derivación* *7 Centralización de contadores (CC)* *8 Derivación individual (DI)* *9 Fusible de seguridad* *10 Contador* *11 Caja para interruptor de control de potencia (ICP)* *12 Dispositivos generales de mando y protección (DGMP).* *13 Instalación interior* *14 Conjunto de protección y medida (CMP)*	*1 Red de distribución* *2 Acometida* *3 Caja General de Protección (CGP)* *4 Línea General de conexión (LGC)* *5 Interruptor general de maniobra (IGM)* *6 Caja de derivación* *7 Centralización de contadores (CC)* *8 Línea Individual del generador (LIG)* *9 Fusible de seguridad* *10 Contador* *11 Caja para interruptor de control de potencia (ICP)* *12 Dispositivos de mando y protección Interiores (DPI)* *13 Equipo generador-inversor (GEN)* *14 Conjunto de protección y medida (CMP)* *15 Conmutador de conexión red/generador con sistema de sincronismo* *16 Tramo de la conexión privada (TCP)*

Table 39. Connection diagrams legend

The following diagram corresponds to the current configuration of Backup Gensets:

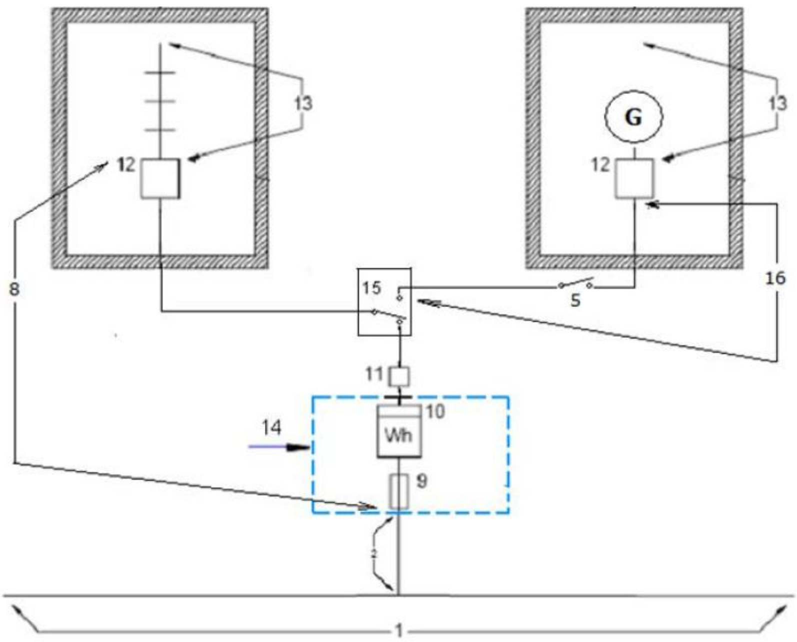

Figure 13. Current connection diagram of BU's

As seen on the previous figure, the genset is connected to the critical loads trough a transfer switch (15)

Low Voltage interconnection (C1 installations)

The following diagram shows a possible configuration for Low Voltage interconnected facilities:

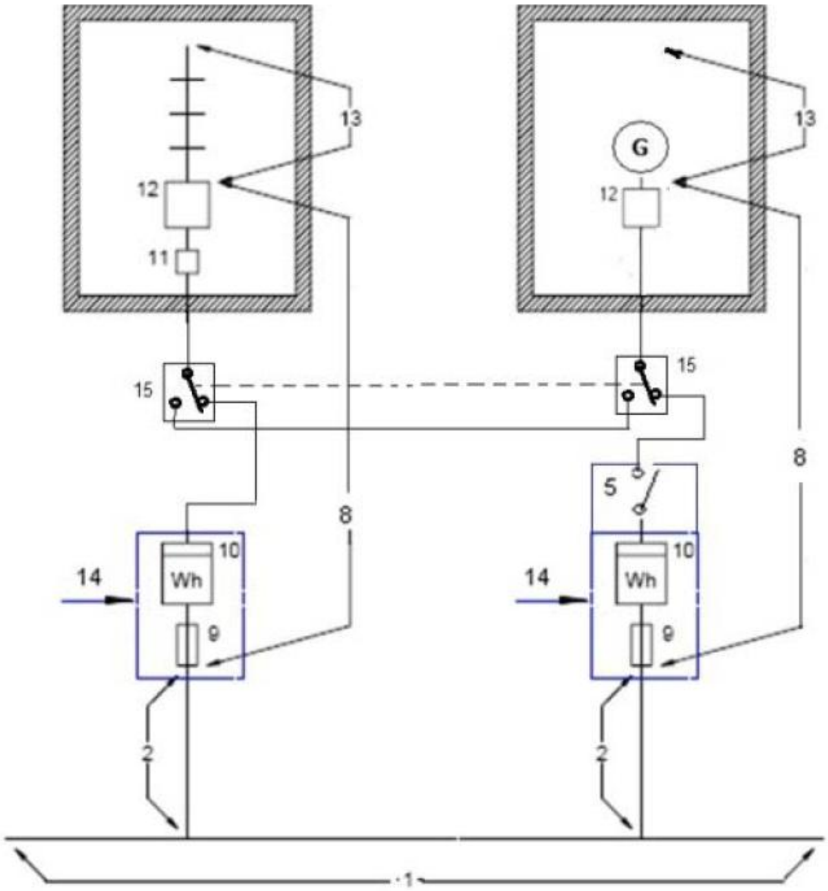

Figure 14. C1 facilities connection diagram

This new diagram adds an additional switch (15) for synchronization and protection issues as well as protection and measurement devices (14) and the interconnection line (2).

The configuration shown above makes possible to supply critical loads from the Low Voltage Distribution Network and the emergency genset but also providing the facility with a synchronization device and all the elements needed for the LV DG operation.

High Voltage interconnection (C2 installations)

Finally, aquellas instalaciones que posean generadores de gran tamaño (S>100 kVA), utilizaría la misma configuración que para el caso anterior, pero modificando la interconexión del generador a la Red por la siguiente:

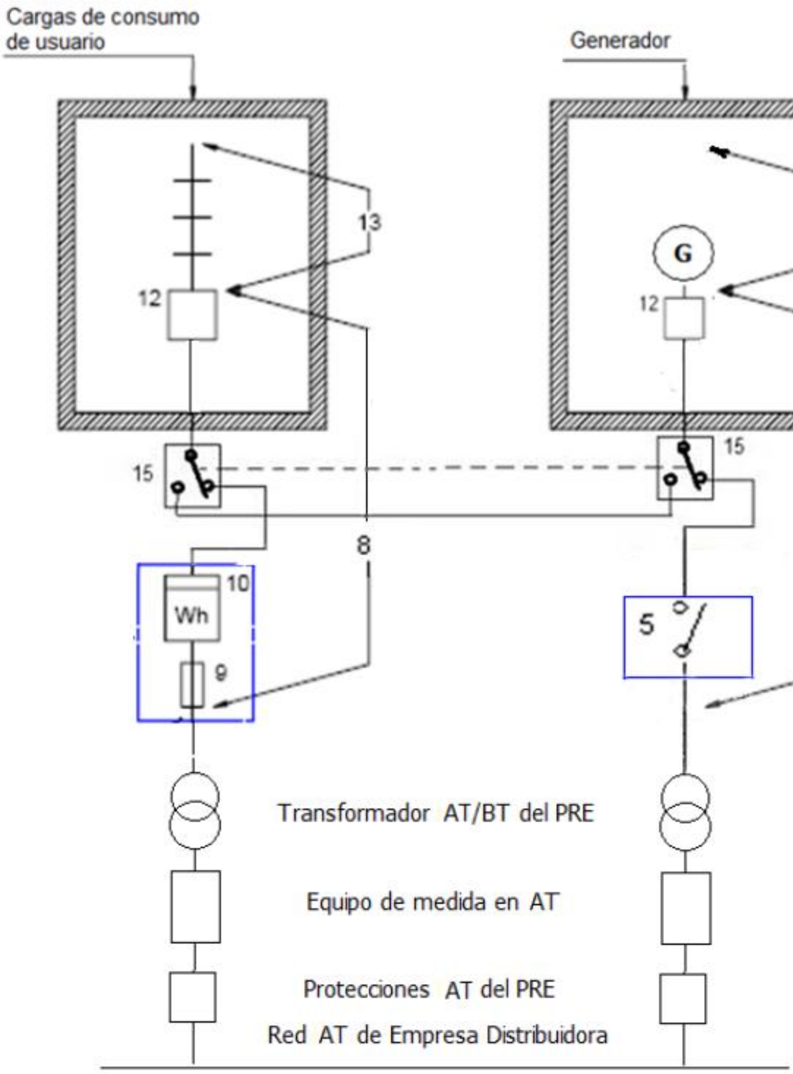

Figure 15. C2 facilities connection diagram

This alternative diagram adds an additional switch (15) for synchronization and protection issues as well as High Voltage protection and measurement devices, a step-up transformer and the interconnection line.

The configuration shown above makes possible to supply critical loads from the High Voltage Distribution Network and the emergency genset but also providing the facility with a synchronization device and all the elements needed for the HV DG operation.

4.3. SOLUTIONS

After having analyzed the main technical requirements for the DG operation of BU's, this section aims to find and propose different solutions for the issues that arise on the previous section.

The different solutions will be analyzed from the technical and economical point of view.

In order to obtain a good estimation for the total investment costs, solutions will be considered for 4 different BU power: 50kVA (C1), 100kVA (C1), 500kVA (C2) and 1000kVA (C2).

4.3.1. *Synchronizer*

AKSA DSE7510 control panel [22] will be used as synchronizer device, acting over an air circuit breaker (Figure 16).The configuration will consist of a control panel per genset; in case of gensets with a parallel control panel already installed (multiple gensets facilities) one single control panel will be used to coordinate all the gensets. Moreover the synchronization function, the DSE7510 control panel will also provide a reverse power protection for the generator.

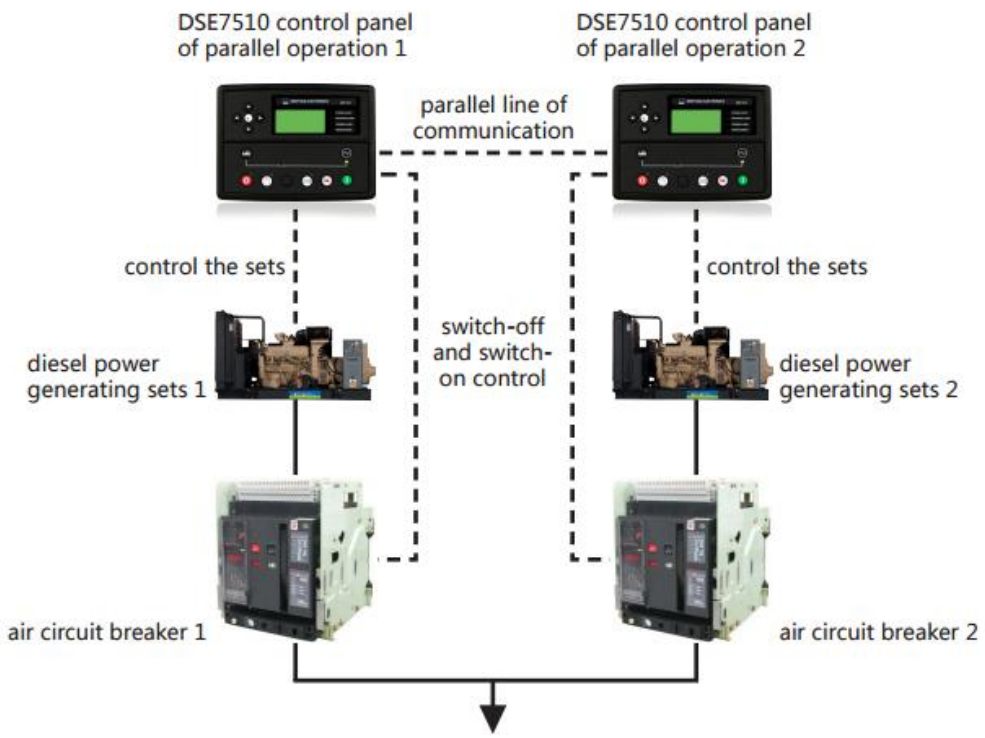

Figure 16. AKSA configuration for parallel operation and synchronization

4.3.2. *Additional switchgear*

All the facilities will use a four poles air circuit breaker that will be controlled by the previous control panel (synchronization). The circuit breaker will be in all cases at the Low Voltage side of the facility (400V).

- For 50kVA facilities, Schneider NG160E-TMD-80A-4P air circuit-breaker [23] with a maximum current of 80A is the best solution to be considered.

- For 100kVA facilities, Schneider NG160E-TMD-160A-4P air circuit-breaker [23] with a maximum current of 160A is the chosen solution.

Figure 17. NG160E-TMD Schneider air circuit breaker

- For 500kVA facilities, General Electric's GE-MN4R1F08-A air circuit-breaker [24] with a maximum current of 800A is the best solution.

- For 1000kVA facilities, General Electric's GE-MS4R1F16-A air circuit-breaker [24] with a maximum current of 1600A is the chosen solution.

Figure 18. GE-MN4R1F08-A General Electric's air circuit breaker

4.3.3. *Electricity Metering and Protection*

As it is said on the analysis, interconnected facilities require electricity metering and protection devices. In Low Voltage facilities both protection and metering functions are provided by the same device. However, for C2 facilities these two functions are separated in two different elements.

C1 installations

As mentioned above, measurement and protection functions will be provided by a single element: the CPM. CPM refers to the measurement and protection box. The CPM is composed by an electricity meter and fuses for protection.

The UR-CPMT300E-T (Iberdrola) CPM is selected to satisfy the measurement and protection requirements for C1 facilities. This CPM has a modem ready to use for demand side programs, indirect measure, fuses and electricity meter.

Figure 19. UR-CPMT300E-T (Iberdrola) CPM

C2 installations

For High Voltage facilities, measure and protection functions will be provided by Ormazabal High Voltage cells. CGMCOSMOS-M will be used for metering while CGMCOSMOS-P will be the protection device.

Figure 20. CGMCOSMOS Ormazábal HV cells

4.3.4. *Connection Cable*

Conductors will be copper for C1 facilities and aluminum for C2 installations as a general design criterion. The total length of cable will be 30m for all the facilities. Section will be calculated using electrotechnical basic fundamentals and the REBT's requirements:

BU Power [KVA]	Interconnection Voltage [kV]	In [A]	Iadm [A]	Length [m]	Conductor	Section $_{Max\ I}$ [mm^2]	Section $_{Max\ \Delta U}$ [mm^2]	Section [mm^2]
50	0,4	72	90	30	Cu	25	15	25
100	0,4	144	180	30	Cu	70	30	70
500	20	14	18	30	Al	25	48	50
1000	20	29	36	30	Al	50	95	95

Table 40. Cables section calculus depending on the BU power

As shown below, resulting cables are chosen from the General Cable catalogue [26][27]:

BU Power [KVA]	Section [mm2]	Cable	Unitary Price[€/m]	Length [m]	Total cost €
50	25	EXZHELLENT XXI 750 V	13,73	30	1648
100	70	EXZHELLENT XXI 750 V	43,02	30	5162
500	50	VULPREN HEPRZ1 12/20 kV	15,62	30	1874
1000	95	VULPREN HEPRZ1 12/20 kV	17,24	30	2068

Table 41. Cables election depending of the BU power

Figure 21. General Cable selected cables

4.3.5. *Step-up transformer*

High Voltage interconnected utilities (C2) need a step-up transformer for the DG operation. In order to be able to feed into the grid the maximum energy, the transformer size will be associated to the BU power.

The chosen transformer will be an Orzamabal conventional oil transformer, similar to the next one:

Figure 22. Ormazabal conventional oil transfomer

4.4. CONCLUSIONS

REBT's ITC-BT-40 distinguishes between isolated installations (without an interconnection point to the Distribution Network), assisted installations (interconnected but off-grid operation) and interconnected installations (on-grid operation)

Emergency gensets (BU) are usually assisted facilities, so the main challenge is to convert assisted facilities into interconnected installations.
Moreover, the REBT also distinguish between two different types of interconnected facilities, C1 (LV interconnection) and C2 (HV interconnection), depending on the voltage level of the interconnection.

For bigger generators (S>100kVA) the interconnection should be to the High Voltage Distribution Network, while generation facilities up to 100KVA could be interconnected to the Low Voltage Distribution Network.

Main issues faced in the theoretical analysis were synchronization requirements, measurement and protection requirements, earth system and connection diagrams.

Synchronization requirements refers to synchronization constraints like voltage or phase lead/lag limits to the generator coupling, voltage wave quality standards and design criteria for interconnection cables.

As a source of DG, gensets will feed energy into the grid. Measure and protection devices will be needed to control and quantify the energy flow between the grid and the utility.

Grounding system required for on-grid DG operation of BU's is TT, which is the same configuration employed currently.

Connection diagrams of C1 and C2 facilities will be similar (C2 facilities will need an additional transformer), adding in both cases measure and protection devices and switchgear for coupling.

Once theoretical analysis has been done, some possible practical solutions have been described, for 4 different cases: 50kVA (C1), 100kVA (C1), 500kVA (C2) and 1000kVA (C2).

In short, main solutions to be adopted are: additional control panel as synchronization device, additional switchgear, measure and protection devices (CPM for C1 facilities and HV cells for C2 installations), interconnection cables (copper for C1 facilities and aluminium for C2 installations) and conventional oil transformer for C2 facilities.

All the previous solutions have an associated cost that will be quantified as CAPEX of the future investment on BU facilities upgrades for on-grid DG operation. As pointed out below, investment OPEX will be determined by operation and maintenance costs

5. COST ANALYSIS FOR ON-GRID DG OPERATION

5.1. INTRODUCTION

This chapter's target is to quantify all the associated costs to the on-grid DG operation of BU facilities. Cost analysis will be carried out in two different parts. Firstly, technically required upgrades proposed on the previous chapter will be quantified (CAPEX). Then, maintenance and operation costs (OPEX) will be determined.

5.2. CAPEX INVESTMENT COSTS

This section's aim is to determine the total cost of the technical upgrades, depending on the utility's BU size.

The next table shows all the information from previous sections, including the economical analysis [25][27]:

Interconnection	Power of BU [KVA]	Item	Model	Unitary Cost [€ /pu]	Total Cost [€]
C1 (LV)	50	Synchronizer	AKSA-DSE7510 + Labor Cost	2500	9148,08
		Air Circuit Breaker	Schneider NG160E - TMD - 80 A - 4P + Labor Cost	2000	
		CPM	CMT-300E-MF + Labor Cost	3000	
		Interconnection Cable	EXZHELLENT XXI 750 V	1648	
C1 (LV)	100	Synchronizer	AKSA-DSE7510 + Labor Cost	2500	12962,16
		Air Circuit Breaker	Schneider NG160E - TMD - 160 A - 4P + Labor Cost	2300	
		CPM	CMT-300E-MF + Labor Cost	3000	
		Interconnection Cable	EXZHELLENT XXI 750 V	5162	
C2 (HV)	500	Synchronizer	AKSA-DSE7510 + Labor Cost	2500	28994,4
		Air Circuit Breaker	GE-MN4R1F08-A	3270	
		MV Protection Cell	CGMCOSMOS-P+ Labor Cost	5200	
		MV Measurement Cell	CGMCOSMOS-M	6150	
		Step-up Transformer	Ormazabal 500kVA, 25kV, oil	10000	
		Interconnection Cable	VULPREN HEPRZ1 12/20 kV	1874	
C2 (HV)	1000	Synchronizer	AKSA-DSE7510 + Labor Cost	2500	37318,32
		Air Circuit Breaker	GE-MS4R1F16-A	4000	
		MV Protection Cell	CGMCOSMOS-P+ Labor Cost	5200	
		MV Measurement Cell	CGMCOSMOS-M+ Labor Cost	6150	
		Step-up Transformer	Ormazabal 1000kVA, 25kV, oil	17400	
		Interconnection Cable	VULPREN HEPRZ1 12/20 kV	2068	

Table 42. Technical requirements for DG operation of BU's, unitary cost and total costs

The previous information will be used to find a relation between the power of the BU (KVA) and the required investment for the DG operation. It seems necessary to distinguish between C1 and C2 facilities because as seen before, required devices are different.

The following figure has been done with the results showed on table 42. In addition it will be useful to determine a linear approach for each interconnection level.

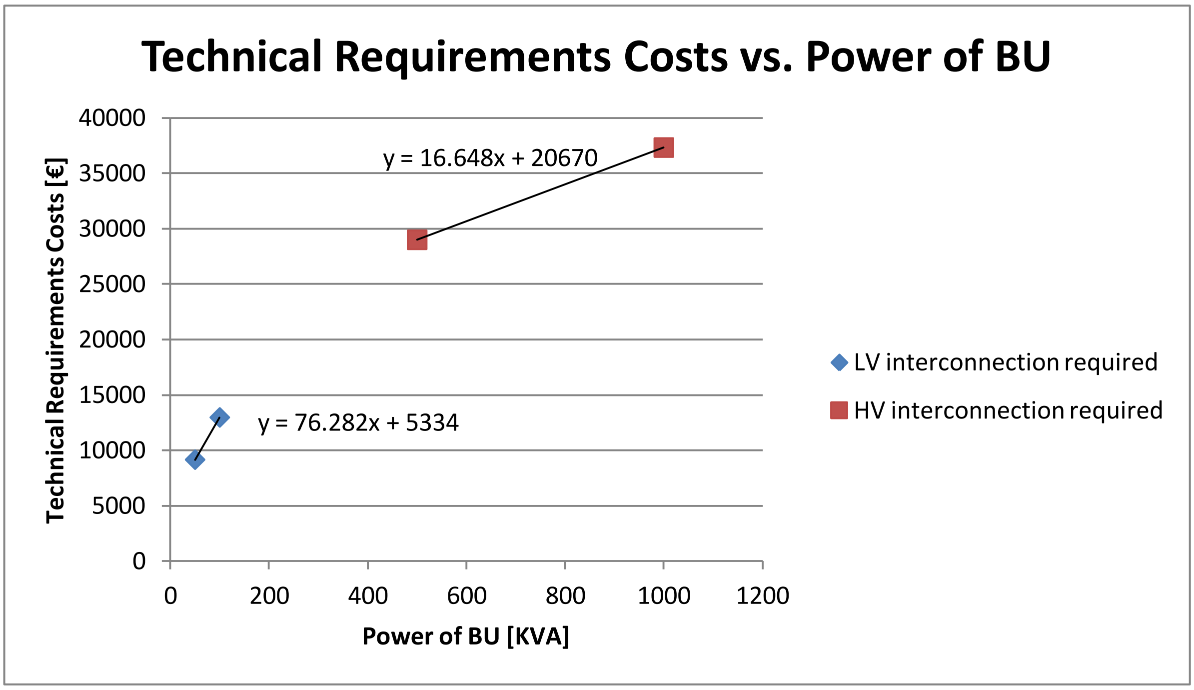

Figure 23. Technical requirements costs representation

After considering the linear approach, it will be very easy to estimate the CAPEX investment costs for different BU's size:

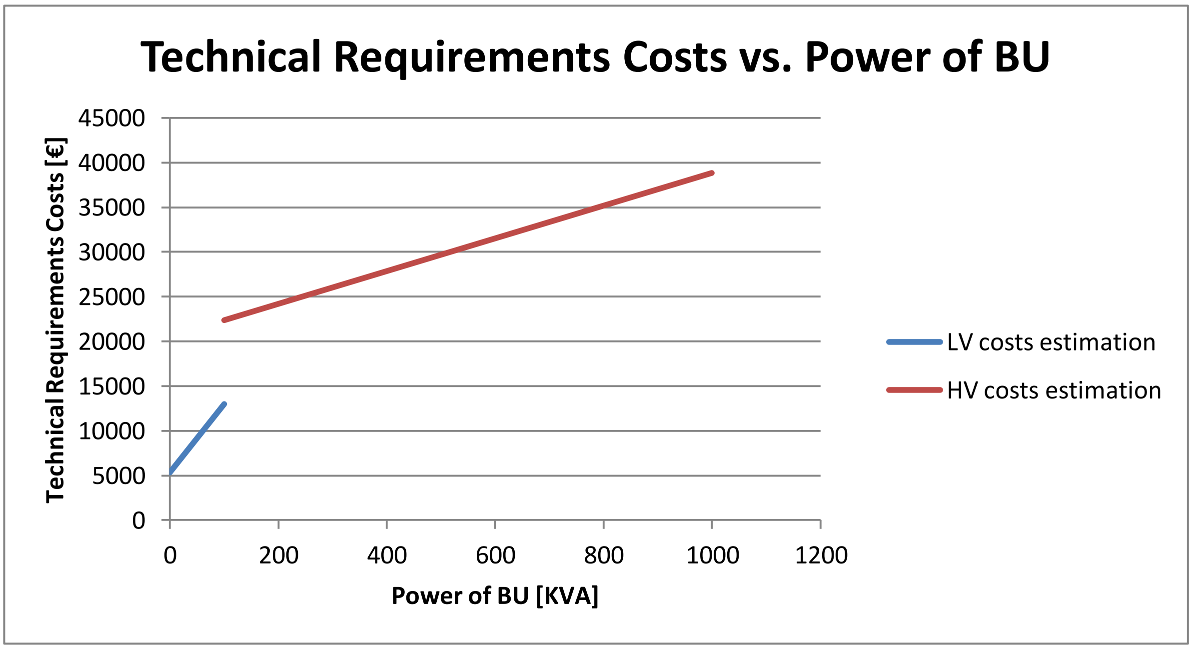

Figure 24. Technical requirements costs, linear approach

As it can be seen on figure 24, there is a costs jump for backup gensets bigger than 100kVA due to the step-up transformer installation. However, although CAPEX investment costs will be higher for units bigger than 100kVA (HV), costs variation as a function of BU's size is lower (smaller slope) than at C1 facilities (LV).

5.3. OPEX OPERATIONAL COSTS

5.3.1. Maintenance Costs

Because of the durability of diesel engines, most maintenance is preventive in nature. Preventive diesel engine maintenance consists of the following operations [28]:

- General inspection
- Lubrication service
- Cooling system service
- Fuel system service
- Servicing and testing starting batteries
- Regular engine exercise

It is generally a good idea to establish and adhere to a schedule of maintenance and service based on the specific power application and the severity of the environment. For example, if the generator set will be used frequently or subjected to extreme operating conditions, the recommended service intervals should be reduced accordingly. Some of the factors that can affect the maintenance schedule include:

- Using the diesel generator set for continuous duty (prime power)
- Extreme ambient temperatures
- Exposure to weather
- Exposure to salt water
- Exposure to dust, sand or other airborne contaminates

If the generator set will be subjected to some or all of these extreme operating conditions, it is best to consult with the engine manufacturer to develop an appropriate maintenance schedule. The best way to keep track of maintenance intervals is to use the running time meter on the generator set to keep an accurate log of all service performed. This log will also be important for warranty support. Figure 25 shows a typical diesel engine maintenance schedule for generator sets

Maintenance Items	Service time				
	Daily	Weekly	Monthly	6 Months	Yearly
Inspection	X				
Check coolant heater	X				
Check coolant level	X				
Check oil level	X				
Check fuel level	X				
Check charge-air piping	X				
Check/clean air cleaner		X			
Check battery charger		X			
Drain fuel filter		X			
Drain water from fuel tank		X			
Check coolant concentration			X		
Check drive belt tension			X		
Drain exhaust condensate			X		
Check starting batteries			X		
Change oil and filter				X	
Change coolant filter				X	
Clean crankcase breather				X	
Change air cleaner element				X	
Check radiator hoses				X	
Change fuel filters				X	
Clean cooling system					X

Figure 25. Typical diesel engine maintenance tasks (Cummins)

Maintenance costs for BU's operated as DG facilities will be considered fixed costs because will be incurred over fixed time intervals without consideration of the annual operating hours. This only applies to distributed generation units that operate less than about 300 hours per year, which is the case.

Maintenance costs are comprised of annual maintenance, unscheduled repairs, taxes, insurance, and in some cases environmental permits. Annual fixed maintenance costs will be considered in the range of 2000-4000 € per generating unit [29] , depending on the scope of tasks performed and the number of BU's per facility. Next table shows a simple estimation of maintenance costs:

BU Size [kVA]	Number of BU [pu]	Maintenance costs [€/BU/year]
100	1	3000
100	3	2000
1000	1	3500
1000	3	2500

Table 43. Maintenance costs estimation for different BU's configuration facilities

Finally, it is necessary to comment that maintenance tend to be a critical issue in "real life" for BU's owner. As long as emergency generators aren't usually needed, gensets owners carry out inadequate maintenances to save some money. This decision is directly translated to future malfunctions and reliability loss on back-up resources.

5.3.2. *Operation Costs*

Operating costs are driven by the fuel costs, efficiency of the machines and number of hours of operation. Fuel consumption is directly proportional to genset's output and there is a range of fuel consumption depending on the size and model of the generation unit.

The following table contains consumption data of 14 different BU's, depending on the load (%Pn):

Generator Size [kW]	1/4 Load [L/h]	1/2 Load [L/h]	3/4 Load [L/h]	Full Load [L/h]
30	4.9	6.8	9.1	11.0
40	6.1	8.7	12.1	15.1
60	7.6	11.0	14.4	18.2
75	9.1	12.9	17.4	23.1
100	9.8	15.5	22.0	28.0
125	11.7	18.9	26.9	34.4
135	12.5	20.4	28.8	37.1
150	13.6	22.3	31.8	41.3
175	15.5	25.7	36.7	48.1
200	17.8	29.1	41.6	54.5
230	20.1	33.3	47.3	62.8
250	21.6	36.0	51.5	68.1
300	25.7	42.8	60.9	81.4
350	29.9	49.6	70.8	94.6
400	33.7	56.4	80.6	108.3
500	41.6	70.0	99.9	135.1
600	50.0	83.3	119.2	162.0
750	61.7	103.7	148.8	202.1
1000	81.8	137.8	197.2	269.1
1250	101.8	171.5	246.0	336.1
1500	121.9	205.5	294.5	403.1
1750	141.9	239.2	343.3	470.1
2000	162.0	273.3	391.7	537.1
2250	182.1	307.0	440.6	604.1

Table 44. Diesel Service and Supply Web. Fuel consumption of different size gensets, depending on the load

Previous information has been used to calculate the expected generation costs (energy generation) and the gensets efficiency. For that, some additional information like fuel prices and heat ratio are needed. Heat ratio of diesel will be considered as **10.28 kWh/L** while diesel (gasóleo B) price will assumed as **0.8€/L**.

The first figure shows, as mentioned before, expected costs of fuel consumption for energy generation. As it can be appreciated on figure 26, generation costs decrease for bigger generation units (better efficiency). It is also interesting to comment costs variation due to the load level. For some generators the lower costs will be for the 75% load while in others, minimum cost will be at full load.

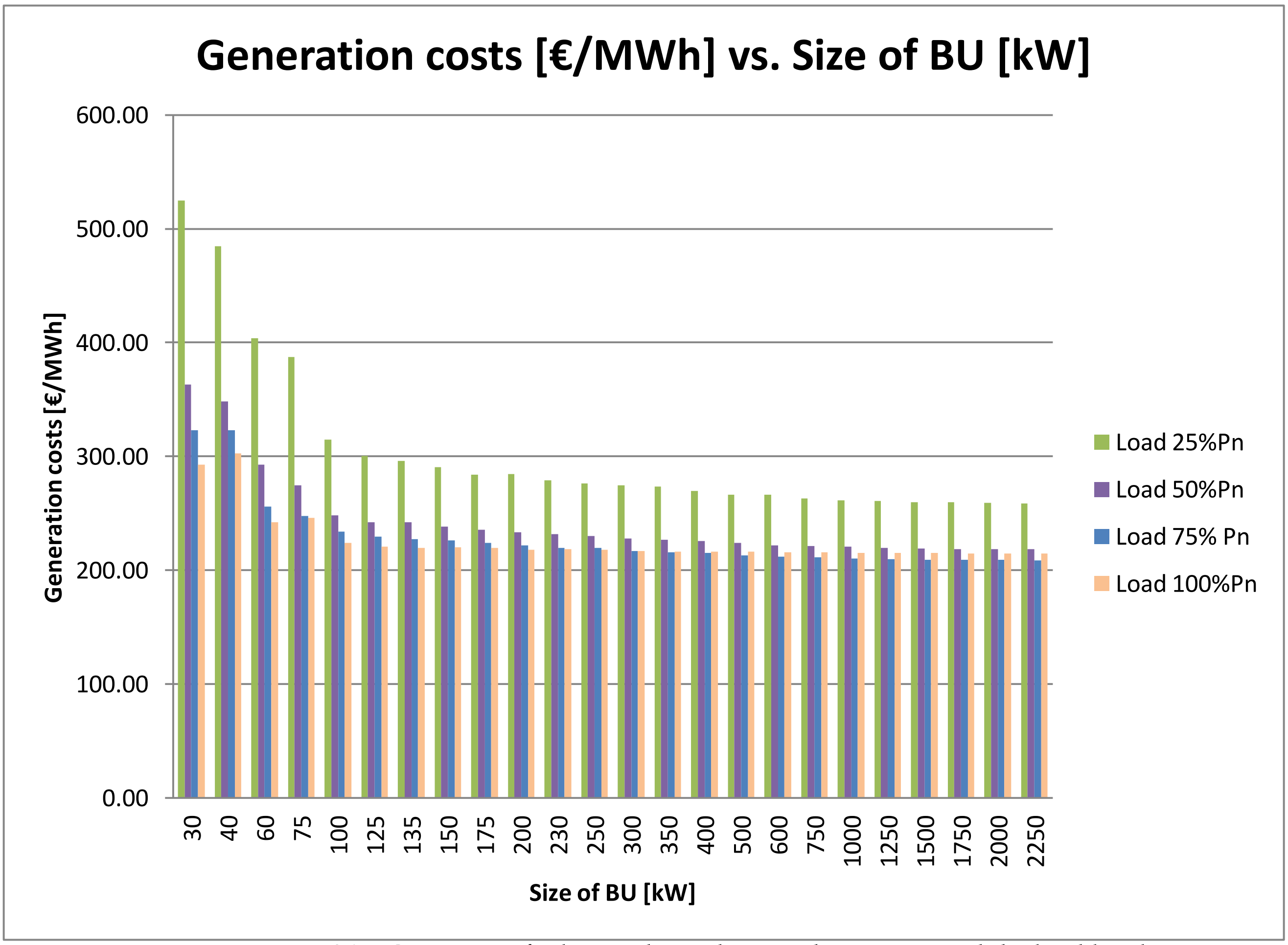

Figure 26. Generation fuel costs depending on the BU size and the load level

In order to establish a typical generation costs value and considering figure 26 information, **230 €/MWh** seems to be a reasonable approach.

Then, following figures purpose is to show how the efficiency of BU's is affected by the load level:

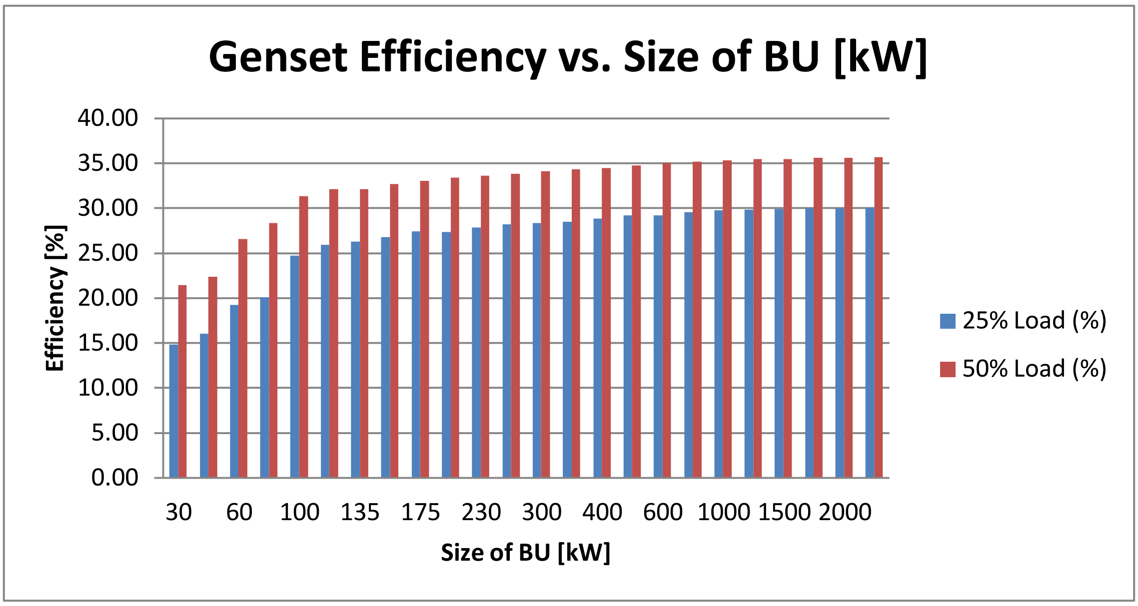

Figure 27. Emergency gensets efficiency vs. size of generators (I)

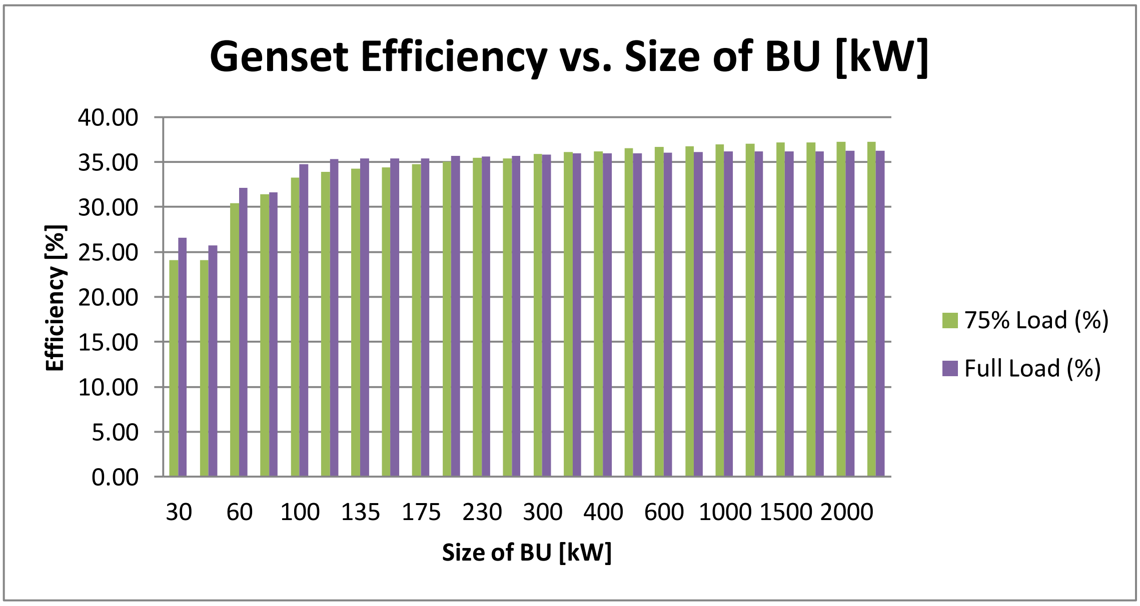

Figure 28. Emergency gensets efficiency vs. size of generators (II)

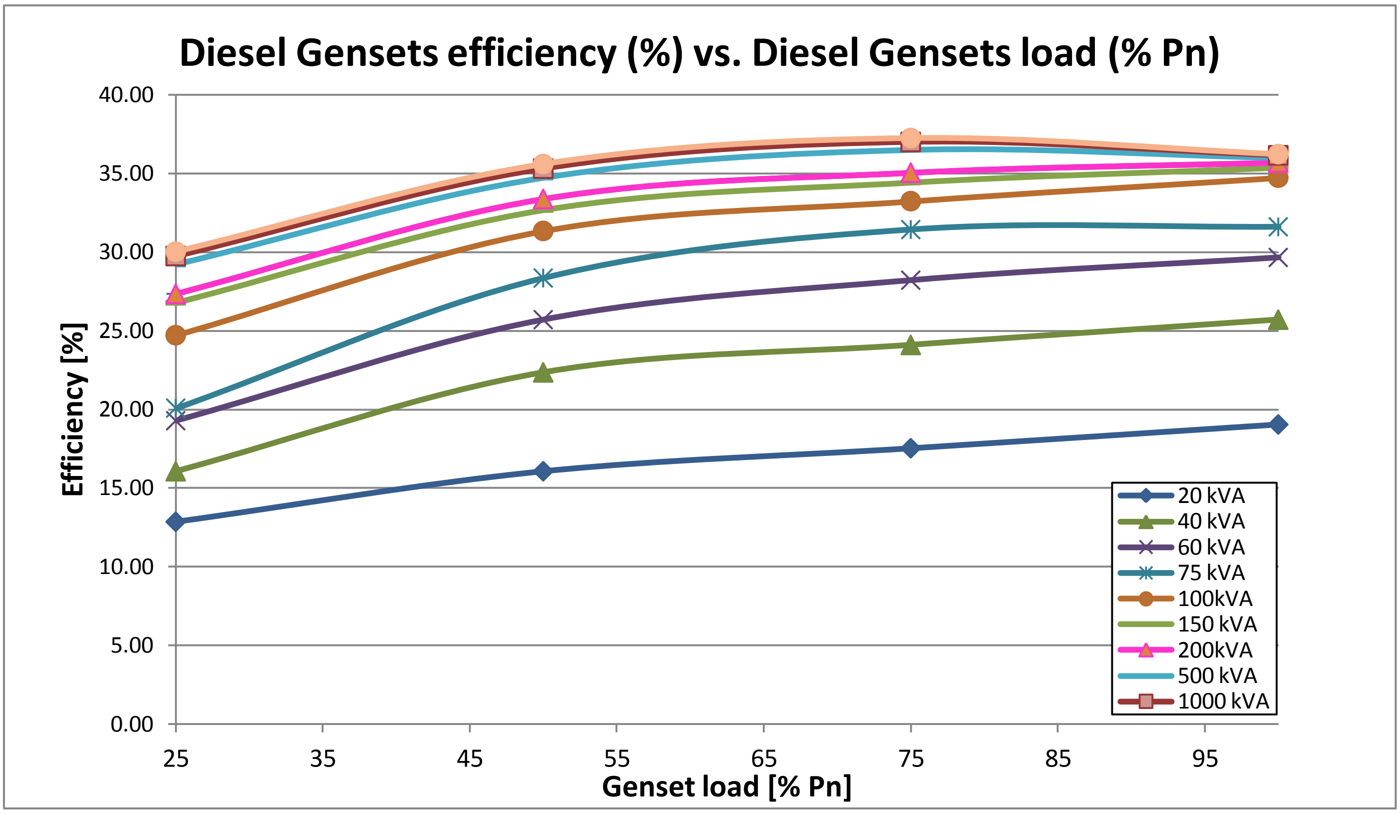

Figure 29. Efficiency variation of BU's depending on the load level

As expected, higher efficiency levels are reached for 75% and 100% of Pn load. To be precise, small units (P<300kW) are more efficient at full load while P>300kW units efficiency is maximum at the 75%Pn load. In short, the optimal load operation point will be in the range between 75%Pn and 100%Pn.

5.4. CONCLUSIONS

Cost analysis for on-grid DG operation of BU's has been carried out in two different parts. The first one aim is to determine CAPEX (investment costs) while OPEX (operation costs) has been quantified on the second part.

CAPEX (investment costs) refers to the total cost of the technical upgrades needed for on-grid DG operation of BU's. These costs have been analyzed in four different cases: 50kVA (C1 facility), 100kVA (C1 facility), 500kVA (C2 facility) and 1000kVA (C2 facility). After that, resulting data has been represented and analyzed in order to determine a linear approach (CAPEX vs. BU size). The linear approach shows a costs jump for backup gensets bigger than 100kVA due to the step-up transformer installation. However, although CAPEX investment costs will be higher for units bigger than 100kVA (HV), costs variation as a function of BU's size is lower (smaller slope) than at C1 facilities (LV).

OPEX (operation costs) are mainly composed by maintenance costs and operations costs. Maintenance costs for BU's operated as DG facilities have been considered fixed costs (2000-4000 €) because will be incurred over fixed time intervals without consideration of the annual operating hours. Unless maintenance is a critical issue in diesel gensets operation, BU owners typically carry out inadequate maintenances to save some money. This decision is directly translated to future malfunctions and reliability loss on back-up sources

Operation costs have been determined taking into account the fuel consumption of 14 different sizes BU's, for different load levels. Generation costs have thus been estimated as 230 €/MWh. In addition, diesel gensets efficiency has been analyzed determining the optimal load level in a range between 75% and 100% Pn.

Since on-grid DG operation associated costs have been quantified, a benefit analysis need arises to be able to determine the viability of BU's as DG units.

6. BENEFIT ANALYSIS FOR ON-GRID DG OPERATION

6.1. INTRODUCTION

The main objective of this section is to identify then analyze the different services that backup generators could provide to earn revenues from their on-grid DG operation. In addition to the available services in Spain, some other services based on the operational advantages of BU will be explored [30].

The benefit study will be carried out in two different parts. The first one will introduce the possible services provided by BU's, analyzing two possible scenarios per asset (I and II), and finally determining operational benefits (without considering CAPEX and Maintenance costs) in terms of the size of the BU (€/ BU kVA). Prices considered for energy/availability remuneration will be mainly 2014 REE's historic.

Then, the second part of the study will only consider operating profitable services from the previous analysis (€/ BU kVA > 0). After that, CAPEX and maintenance costs will be considered in order to determine if CAPEX will be recovered in a reasonable period of time (simplified financial analysis).

6.2. POSSIBLE SERVICES

6.2.1. *Balancing service*

Secondary Reserve

The Secondary Reserve is an optional ancillary service that is aimed to keep generation and demand balance controlled by means of correcting frequency deviations and imbalances in forecasted power scheduled in the Spain-France interconnection. This service is paid for two concepts using market procedures: Band availability (MW) and utilization (MWh).

Generators sent secondary reserve bids for each Energy Scheduling Unit that has been authorized to take part in the market. These bids are allocated using minimum cost procedures until all system requirements are cover and finally, a marginal secondary reserve price is obtained.

Secondary Reserve							
Product	Buyer	Utilization [hours/year]	Expected fuel consumption [€/ BU kVA]	Expected price	Expected incomes per year [€/ BU kVA]	Expected benefits per year [€/ BU kVA]	Expected Competitors
Availability (I)	REE	1000	-	24 €/MW	24.0	-43.7	Nuclear, Hydro, CCGT, Coal
Energy (I)	REE	300	86.25	62.64 €/MWh	18.6		Nuclear, Hydro, CCGT, Coal
Availability (II)	REE	500	-	24 €/MW	12.0	-10.6	Nuclear, Hydro, CCGT, Coal
Energy (II)	REE	100	28.75	62.64 €/MWh	6.2		Nuclear, Hydro, CCGT, Coal

Table 45. Secondary reserve service analysis

Tertiary Reserve

The Tertiary Reserve is an optional Ancillary Service that is managed and repaid according to market procedures. It is aimed to restore the secondary reserve band that has been used, using all the bids sent by Energy Scheduling Units that have been authorized to take part in the Tertiary Reserve market. This service is only paid for utilization (MWh). Modifications scheduled as a result of this market will be valued according to the marginal price of all Tertiary Reserve bids that have been allocated.

Tertiary Reserve							
Product	Buyer	Utilization [hours/year]	Expected fuel consumption [€/ BU kVA]	Expected price [€/MWh]	Expected incomes per year [€/ BU kVA]	Expected benefits per year [€/ BU kVA]	Expected Competitors
Energy (I)	REE	100	23	74.44	7.4	-15.6	Nuclear, Hydro, CCGT, Coal
Energy (II)	REE	300	69	74.44	22.3	-46.7	Nuclear, Hydro, CCGT, Coal

Table 46. Tertiary reserve service analysis

6.2.2. *Black-Start Capability service*

Black-Start Capability reefers to the capability of a generation unit to start-up and operate after a wide-system loss of the electric power system, without relying on the external electric network.

This procedure requires thus generation units with a quick response time, island start-up capability and both voltage and frequency regulation devices integrated in the generator.

Expected price for energy will be considered as 0 profits price (generation costs) while availability prices have been estimated for a typical Black-start service.

Black-Start Capabilty Service							
Product	Buyer	Utilization [hours/year]	Expected fuel consumption [€/ BU kVA]	Expected price	Expected incomes per year [€/ BU kVA]	Expected benefits per year [€/ BU kVA]	Expected Competitors
Avaibality (I)	Retailers/REE	-	-	3000€/MW/year	3	3	CCGT, OCGT
Energy (I)	Retailers/REE	100	28.75	287.5 €/MWh	28.75		
Avaibality (II)	Retailers/REE	-	-	1000€/MW/year	1	1	CCGT, OCGT
Energy (II)	Retailers/REE	50	14.38	287.5 €/MWh	14.38		

Table 47. Black-start capability service analysis

6.2.3. *Capacity service*

Nowadays there is no Capacity Market in Spain, however there are Capacity Payments. These Capacity payments can be long term and short term, depending on the assets considered for the payment.

In Short Term Capacity Payments, generation agents get paid each hour, according to the probability of a system load loss.

In Long Term Capacity Payments, generation agents get paid once per year, according to the electricity production, installed capacity and production during demand peaks.

In short, remuneration in Long Term Payments is based in the firm installed capacity (MW), which is the available capacity at a particular time, while in Short Term Payments production (MWh) is the driver for revenues.

However, capacity payments service is mainly focused for big generation units (50-90 MW blocks) while BU's tend to be smaller than 20MW.

6.2.4. *Energy service (Daily Market)*

The purpose of the daily market, as an integral part of electricity power production market, is to handle electricity transactions for the following day through the presentation of electricity sale and purchase bids by market participants. The daily market is regulated by the OMIE (Operador del Mercado Ibérico de la Electricidad) which is the company responsible for the operation of both Spanish and Portuguese Electricity Markets.

Daily Market							
Product	Buyer	Utilization [hours/year]	Expected fuel consumption [€/ BU kVA]	Expected price [€/MWh]	Expected incomes per year [€/ BU kVA]	Expected benefits per year [€/ BU kVA]	Expected Competitors
Energy (I)	OMIE	100	28.75	55	5.5	-23.25	Nuclear, Wind, Hydro, Solar, CCGT, Coal
Energy (II)	OMIE	100	28.75	180	18	-10.75	Nuclear, Wind, Hydro, Solar, CCGT, Coal

Table 48. Daily market energy service analysis

6.2.5. *Interruptibility service*

The interruptibility service is a demand side management mechanism to provide a rapid and efficient response to electric system needs according to technical criteria (system security) and economic criteria (reducing system costs). This service is activated in response to a power reduction order issued by Red Eléctrica, as System Operator, to consumers subscribed to this service. This service is assigned by auction and paid for availability (MW), once per year.

Interruptibility							
Product	Buyer	Utilization [hours/year]	Expected fuel consumption [€/ BU kVA]	Expected price [€/MWh]	Expected incomes per year [€/BU kvar]	Expected benefits per year [€/ BU kVA]	Expected Competitors
Energy (I)	REE	100	23	92.95	9.3	-13.7	CCGT, OCGT
Energy (II)	REE	300	69	92.95	27.9	-41.1	CCGT, OCGT

Table 49. Interruptibility service analysis

6.2.6. *Islanding operation service*

Islanding operation service is very similar to the black-start capability service. Indeed, the main difference between black-start and islanding operation is the utilization. While in islanding operation BU's will be used as prime generators, black-start capability operation is only required in case of a wide-system loss of the electricity power system.

Expected price for energy will be considered as 0 profits price (generation costs).

Islanding Operation							
Product	Buyer	Utilization [hours/year]	Expected fuel consumption [€/ BU kVA]	Expected price [€/MWh]	Expected incomes per year [€/ BU kVA]	Expected benefits per year [€/ BU kVA]	Expected Competitors
Energy (I)	Retailers/	100	23	230	23	0	CCGT, OCGT
Energy (II)	Retailers/	300	69	230	69	0	CCGT, OCGT

Table 50. Islanding operation service analysis

6.2.7. *Voltage Control service*

The main concept of this service is the regulation of the reactive power (VAR) flow into both transmission and distribution network nodes. This is regulated by two market mechanisms: the network constraint management and the voltage control ancillary service. Constraint management is conducted by the SO, who asks generators to modify their outputs to solve power system voltage problems. This service is mandatory and has no remuneration.

On the other hand, the voltage control ancillary service consists of an annual auction where reactive regulation capacity VAR resources are agreed, as well as the scheduling and real-time operation of these VAR resources. This service is paid for availability (Mvar) and utilization (Mvarh). Expected prices for energy and availability are from [31].

Voltage Control Service							
Product	Buyer	Utilization [hours/year]	Expected fuel consumption [€/ BU kvar]	Expected price	Expected incomes per year [€/BU kvar]	Expected benefits per year [€/ BU kVA]	Expected Competitors
Availability (I)	REE/DSO´s	-	-	1000€/Mvar/year	1	-18.2	CCGT, OCGT
Energy (I)	REE/DSO's	50	19.17	0.5€/Mvarh	0.01		
Availability (II)	REE/DSO´s	-	-	1000€/Mvar/year	1	-6.7	CCGT, OCGT
Energy (II)	REE/DSO's	20	7.67	0.5€/Mvarh	0.01		

Table 51. Voltage service analysis

6.2.8. *Real Time Security service*

REE has already a real time security market service. However, real time security market managed by the TSO is a market with a high volatility because of the penetration or RES (Renewable Energy Sources) and technical constraints nature. As it can be seen on the next figure, price for energy generated to solve real time technical constraints (RTTCS) can be extremely volatile.

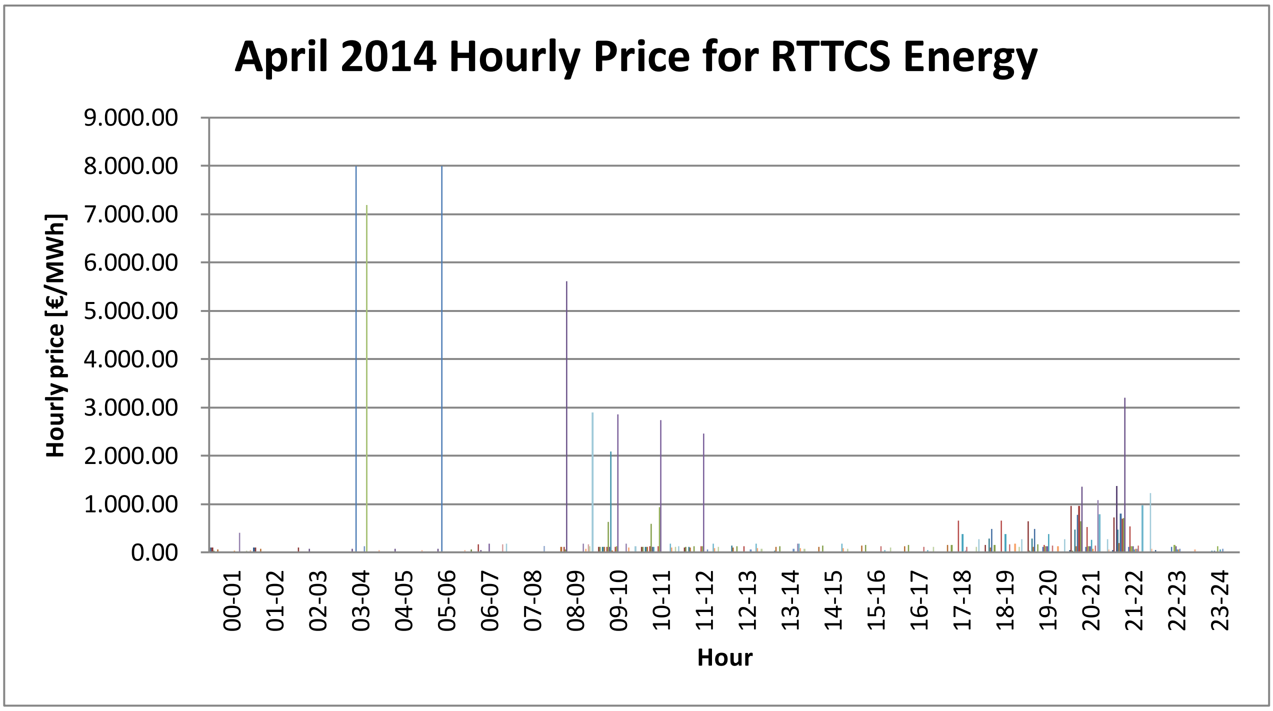

Figure 30. Real time security market hourly price, April 2014. Source: REE

In order to be able to carry out the economic analysis, two different prices will be determined. The first one (Energy I) will be the REE's weighted price for April 2014 (April is typically where RTTCS reaches higher prices). The second one will be the 2014 REE's annual weighted price for RTTCS.

Real Time Security Market							
Product	Buyer	Utilization [hours/year]	Expected fuel consumption [€/ BU kVA]	Expected price [€/MWh]	Expected incomes per year [€/BU kVA]	Expected benefits per year [€/ BU kVA]	Expected Competitors
Energy (I)	REE	40	11.5	422.44	16.9	5.4	CCGT,OCGT, Hydro.
Energy (II)	REE	100	28.75	150	15.0	-13.8	CCGT,OCGT, Hydro.

Table 52. Real time security service analysis

6.3. RESULTING BENEFITS

Profitable services from the previous section are Black-Start capability (BSC), Islanding Operation and Real time security. This section aim is to quantify real benefits (CAPEX+OPEX), giving examples of particular facilities configuration and determining the optimal BU size to provide each service.

In order to obtain economical benefits from BU-s energy production, expected price for energy will be considered 290 €/MWh for Black-start capability service and 240 €/MWh for real time security service.

After that, resulting benefits per year are shown in the next three tables:

Service	BU Size [kVA]	Number of BU [pu]	Maintenance costs [€/year]	Incomes [€/year]	Benefits [€/year]
Black-Start (I)	100	1	3000	325	-2675
	100	3	6000	975	-5025
	1000	1	3500	3250	-250
	1000	3	7500	9750	2250

Table 53. Black-start capability service benefits

Service	BU Size [kVA]	Number of BU [pu]	Maintenance costs [€/year]	Incomes [€/year]	Benefits [€/year]
Islanding Operation (II)	100	1	3000	300	-2700
	100	3	6000	900	-5100
	1000	1	3500	3000	-500
	1000	3	7500	9000	1500

Table 54. Islanding operation service benefits

Service	BU Size [kVA]	Number of BU [pu]	Maintenance costs [€/year]	Incomes [€/year]	Benefits [€/year]
Real Time Security (I)	100	1	3000	540	-2460
	100	3	6000	1620	-4380
	1000	1	3500	5400	1900
	1000	3	7500	16200	8700

Table 55. Real time security service benefits

As it can be seen, generation facilities become more profitable when the size and number of BU's increases. Facilities under 100kVA aren't economically profitable when maintenance costs are considered. However, 1000kVA facilities become profitable when the number of BU's increases (smaller maintenance costs per unit). Moreover, Black-start capability and Islanding operation services will only be profitable when several genset are installed (at least 3 units). On the other hand, real time security service will always be economically profitable when 1000kVA BU's are on-grid operated (single unit or several units) due to the high prices considered for this analysis.

Finally, it only remains to estimate how long it will take to recover CAPEX investment costs. For that, a simplified financial analysis will be carried out:

Service	BU Size [kVA]	Number of BU [pu]	Benefits [€/year]	CAPEX [€]	CAPEX recovery time [years]
Black-Start (I)	1000	3	2250	70614	31
Islanding Operation (II)	1000	1	1500	37318	25
Real Time Security (I)	1000	1	1900	37318	20
	1000	3	8700	70614	8

Table 56. CAPEX recovery time estimation

As seen above, CAPEX recovery time will be around 20 years, which is a higher number for generation facilities. Since, current operation of BU's implies fixed annual costs when maintenance is required. These costs will be maintenance costs and fuel consumption costs of the emergency genset during 6 hours per year (1 operation hour every two months for maintenance issues).

The next table's target is to determine the time period when current BU's operation costs will be equal to the on-grid DG operation CAPEX investment costs. Maintenance costs will be considered lower than in on-grid DG operation because current BU's don´t participate in energy/ availability services.

As long as maintenance operations are typically low load operations, BU's efficiency will be very poor (Less than 20%). In order to quantify this issue, a cosϕ=1 will be considered for the fuel consumption costs.

Service	BU Size [kVA]	Number of BU [pu]	Maintenance costs [€/year]	Fuel Consumption* [€/ year]	Benefits [€/year]
Current BU operation	1000	1	3000	1380	-4880
	1000	3	6000	4140	-10140

Table 57. Current BU's yearly costs

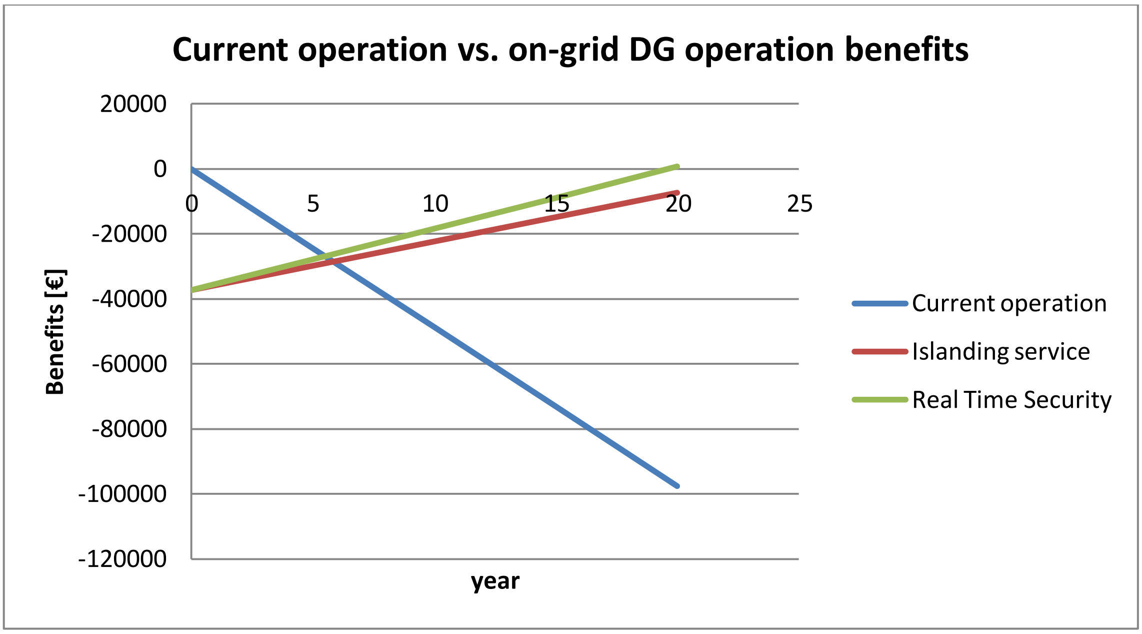

Figure 31. 1000kVA (single BU) comparative. Current vs. On-grid DG operation

As shown above, CAPEX investment costs for on-grid DG BU's operation are similar to current operation BU's costs for a time period of 6 year (approximately).

6.4. CONCLUSIONS

After having analyzed possible services to be provided by BU's, as DG, next list arises: Balancing service, Black-start capability service, Capacity service, Energy service (daily market), Interruptibility service, Islanding operation service, Voltage control service and Real time security service.

The benefit study has been carried out analyzing two possible scenarios per service (I and II), and finally determining operational benefits (without considering CAPEX and Maintenance costs) in terms of the size of the BU (€/ BU kVA).

Profitable services from the previous list (including maintenance costs) are Black-Start capability (BSC), Islanding Operation and Real time security. In addition, generation facilities become more profitable when the size and number of BU's increases.

CAPEX recovery time will be in a range between 8 and 31 years, being 20 years the average time period to make profitable the total investment. Moreover, when current operation benefits of BU's are compared to on-grid operation costs in a 20 years scope, on-grid BU's recover their CAPEX investment costs, while current operation BU's have only negative benefits.

Moreover the different studied services that BU's can provide, it is also necessary to comment that maintenance starts are mandatory but usually carried out at low electricity demand periods of time. So, it will be interesting to coordinate maintenance starts to the whole electricity power system in order to switch potential from BU's to the electricity power system when demand is higher (when peaking plants are required).

7. CONCLUSIONS

7.1. SUMMARY

Back-up generators work as a conventional generator, converting mechanical energy into electricity. Indeed, this mechanical energy may be provided by different prime movers such as gasoline, diesel or gas engines.

After a simple comparative of the different prime movers technologies, diesel seems to be the most reliable prime mover in terms of people safety, robustness and fuel storage possibility. In addition, back-up gensets can also be classified by their portability, being stationary backup units suitable for high power requirements and portable emergency generators for stand-alone applications.

BU's main elements are the control panel and the transfer switch. If there is loss of utility power, the control panel will start the generator and the transfer switch will connect critical loads to the emergency generator.

In addition, in order to facilitate the estimation task, main both worldwide and Spain manufacturers have been described in terms of their nationality and the range of BU's size they produce.

As long as the estimation task is complex in nature, study area has been reduced to Madrid municipality and typical locations of BU's have been determined by consulting main gensets manufacturers, maintainers and installation companies (up to 44 different companies have been consulted).

Two estimations have been carried out to determine the installed capacity of BU's for on-grid DG operation of each infrastructure. The first one which is Estimation 1 (conservative), based on all the collected information while estimation 2 (optimistic) aims to consider all the uncertainty of the data collection process.

Resulting estimated capacity of BU's for on-grid DG operation in Madrid is up to 1170 MW. When extrapolated to Spain, previous potential is up to 6836 MW. Resulting capacity has been compared with existing generation plants of different technologies and the current generation portfolio of Spain. For instance, Spain's installed capacity of BU's is up to 6, 4 nuclear power plants like Trillo (1066 MW) and up to 148,9 times the Diesel power plant of Ceuta.

On the other hand, if BU's potential is considered as a DG source of the Spanish electricity power system, current generation portfolio will grow approximately

5819MW, a potential similar to the installed capacity in Ceuta, Melilla, Islas Baleares and Islas Canarias (5884 MW).

Although estimated BU installed capacity for on-grid DG operation in Spain is similar to other technologies like solar or nuclear, emergency gensets normal operation is to feed critical loads. Therefore, on-grid operation will require some upgrades and reviews on these facilities.

REBT's ITC-BT-40 distinguishes between different generation facilities, depending on the way they are operated respect to the grid. Emergency gensets are usually assisted facilities, so the main challenge is to convert assisted facilities into interconnected installations. Main issues faced in the theoretical analysis were synchronization requirements, measure and protection requirements, grounding and connection diagrams.

Once theoretical analysis has been done, some possible practical solutions have been described. In short, main solutions to be adopted are: additional control panel as synchronization device, additional switchgear, measure and protection devices, interconnection cables and conventional oil transformers when required.

All the previous solutions have an associated cost that will be quantified as CAPEX of the future investment on BU facilities upgrades for on-grid DG operation. Cost analysis has been carried out in two different parts. The first one aim is to determine CAPEX (investment costs) while OPEX (operational costs) has been quantified on the second part.

CAPEX refers to the total cost of the technical upgrades needed for on-grid DG operation of BU's. These costs have been analyzed for different cases then represented and analyzed in order to determine a linear approach (CAPEX vs. BU size). The linear approach shows a costs jump for backup gensets bigger than 100kVA due to the step-up transformer requirement. However, although CAPEX investment costs will be higher for units bigger than 100kVA (HV), costs variation as a function of BU's size is lower (smaller slope) than at C1 facilities (LV).

OPEX are mainly composed by maintenance costs and operations costs. Maintenance costs for BU's operated as DG facilities have been considered fixed costs (2000-4000 €) because will be incurred over fixed time intervals.

Operation costs have been determined taking into account the fuel consumption of 14 different sizes BU's, for different load levels. Generation costs have thus been estimated as 230 €/MWh when operated at optimal load level, which is in a range between 75% and 100% Pn.

Since on-grid DG operation associated costs have been quantified, a benefit analysis is needed to be able to determine the viability of BU's as DG units.
After having analyzed possible services to be provided by BU's, next list arises: Balancing service, Black-start capability service, Capacity service, Energy service (daily market), Interruptibility service, Islanding operation service, Voltage control service and Real time security service.

The benefit study has been carried out analyzing two possible scenarios per service (I and II), and finally determining operational benefits (without considering CAPEX and Maintenance costs) in terms of the size of the BU (€/ BU kVA). Profitable services from the previous list (including maintenance costs) are Black-Start capability (BSC), Islanding Operation and Real time security.

In general, generation facilities become more profitable when the size and number of BU's increases (higher power BU's operated in parallel). CAPEX recovery time will be in a range between 8 and 31 years, being 20 years the average time period to make profitable the total investment. As long as life expectancy of diesel engines is around 20 years, total investment seems to be unprofitable.

However, BU's current operation entails yearly fixed (maintenance costs+ fuel consumption) without any type of remuneration. When current operation of BU's yearly costs are compared to previously analyzed services costs they are both similar for a time scope of 5 years. When 20 years of time scope is considered, DG operation of BU's becomes nearly profitable while current operation of emergency gensets entails higher costs since, approximately, the 6th year of the analysis.

Moreover the different studied services that BU's can provide, it is also necessary to comment that maintenance starts are mandatory but usually carried out at low electricity demand periods of time. So, it will be interesting to coordinate maintenance starts to the whole electricity power system in order to switch potential from BU's to the electricity power system when demand is higher (when peaking plants are required).

7.2. CONTRIBUTIONS

Main contributions of this project could be summarized in three points.

The first one is a first approach on the electricity back-up potential installed in Spain, which is an analysis that has never been carried out before. This analysis has considered main infrastructures where BU's are typically installed in Madrid municipality, and then resulting potential has been extrapolated to Spain.

The second one is an exhaustive analysis of technical requirements and upgrades needed for the DG operation of BU and all the associated costs (OPEX+CAPEX) of these upgrades as a function of the BU size.

Finally an unprecedented costs analysis has been carried out in order to determine possible remunerated services for on-grid DG operation of BU's.

7.3. FUTURE DEVELOPMENT

Future development to be considered could be batteries replacement of stand-by generators, fuel change from diesel to gas or an exhaustive electricity market and financial analysis for on-grid DG operation of BU's.

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9. ANEXES

9.1. ANNEX A. ITC-BT-28

9.2. ANNEX B. ITC-BT-40

9.3. ANNEX C

1. Centros hospitalarios por Dependencia Funcional según Finalidad Asistencial

Finalidad Asistencial	TOTAL	Entidades Públicas: Comunidad Autónoma - SERMAS y MATEP	Entidades no públicas: Total	Entidades no públicas: Privados No Benéficos y Mutuas Patronales	Entidades no públicas: Privados Benéficos (Iglesia y Otros)
2011	**50**	**15**	**35**	**25**	**10**
Hospitales generales	**25**	10	15	10	5
Hospitales especializados infantiles	**1**	1	0	0	0
Hospitales de salud mental y tratamiento de toxicomanías	**6**	1	5	3	2
Hospitales especializados oncológicos	**1**	0	1	1	0
Hospitales de media y larga estancia	**2**	0	2	1	1
Otros hospitales especializados	**15**	3	12	10	2

*SERMAS: Servicio Madrileño de Salud; MATEP: Mutuas de Accidentes de trabajo y Enfermedades Profesionales.

2. Camas en funcionamiento por Dependencia Funcional según Especialidad

Especialidad	TOTAL	Entidades Públicas: Comunidad Autónoma - SERMAS y MATEP	Entidades no públicas: Total	Entidades no públicas: Privados No Benéficos y Mutuas Patronales	Entidades no públicas: Privados Benéficos (Iglesia y Otros)
2011	**11.856**	**7.266**	**4.590**	**3.177**	**1.413**
Especialidades Médicas	**3.935**	**2.811**	**1.124**	**881**	**243**
Especialidades Quirúrgicas	**2.575**	**1.590**	**985**	**806**	**179**
Traumatología y Ortopedia	**1.051**	**605**	**446**	**334**	**112**
Obstetricia y Ginecología	**867**	**431**	**436**	**319**	**117**
Pediatría	**989**	**784**	**205**	**141**	**64**
- Medicina y Cirugía Pediátricas	687	582	105	68	37
- Neonatología	203	141	62	49	13
- Intensivos Neonatales	99	61	38	24	14
Rehabilitación	**280**	**18**	**262**	**106**	**156**
Medicina Intensiva	**597**	**373**	**224**	**187**	**37**
- U.C.I	485	296	189	152	37
- Unidad Coronarios	102	67	35	35	0
- Unidad Quemados	10	10	0	0	0
Larga Estancia	**217**	**0**	**217**	**100**	**117**
Psiquiatría	**853**	**470**	**383**	**272**	**111**
- Unidad de Agudos	383	276	107	62	45
- Unidad Larga Estancia	470	194	276	210	66
Otras	**492**	**184**	**308**	**31**	**277**

*SERMAS: Servicio Madrileño de Salud; MATEP: Mutuas de Accidentes de trabajo y Enfermedades Profesionales

FUENTE: E.C.S.A.E. 2011. Área de Gestión y Análisis de la Información. Consejería de Sanidad. Comunidad de Madrid.

3. Infraestructura extrahospitalaria según Tipo de Centro por Distrito

Distrito	TOTAL	TIPO			
		Centro de Especialidades	Centro de Salud	Consultorio Urbano	Centros Salud Mental (1)
2013	**169**	**18**	**127**	**1**	**23**
01. Centro	**6**	..	5	..	1
02. Arganzuela	**10**	1	8	..	1
03. Retiro	**4**	..	3	..	1
04. Salamanca	**7**	1	5	..	1
05. Chamartín	**9**	..	7	..	2
06. Tetuán	**8**	1	6	..	1
07. Chamberí	**8**	1	6	..	1
08. Fuencarral-El Pardo	**12**	2	7	1	2
09. Moncloa-Aravaca	**9**	1	7	..	1
10. Latina	**15**	1	12	..	2
11. Carabanchel	**9**	1	7	..	1
12. Usera	**8**	1	6	..	1
13. Pte. Vallecas	**16**	3	12	..	1
14. Moratalaz	**5**	1	3	..	1
15. Ciudad Lineal	**10**	..	9	..	1
16. Hortaleza	**8**	1	6	..	1
17. Villaverde	**8**	1	6	..	1
18. Villa Vallecas	**5**	1	3	..	1
19. Vicálvaro	**3**	..	3	..	..
20. San Blas - Canillejas	**6**	1	4	..	1
21. Barajas	**3**	..	2	..	1

(1) Existen otros Centros de Salud Mental ubicados en Centros de Especialidades o de Salud y no se contabilizan

FUENTE: Comunidad de Madrid. Consejería de Sanidad y Consumo. Subdirección General de Planificación Sanitaria

9.4. ANNEX D

1. Oferta Hotelera por Tipo, Categoría del establecimiento y Distrito en la Ciudad de Madrid. 2014

Distrito	Total		5 Estrellas		4 Estrellas		3 Estrellas		2 Estrellas		1 Estrella	
	Habita-ciones	Plazas	Habita-ciones	Plazas	Habita-ciones	Plazas	Habita-ciones	Plazas	Habita-ciones	Plazas	Habita-ciones	Plazas
Total establecimientos	**40.374**	**77.653**	**4.194**	**8.043**	**21.744**	**42.898**	**7.074**	**13.478**	**4.564**	**8.283**	**2.798**	**4.951**
01. Centro	**14.880**	**27.062**	755	1.175	5.525	10.494	3.179	5.881	3.565	6.371	1.856	3.141
02. Arganzuela	**1.445**	**2.764**	0	0	739	1.479	543	1.003	18	28	145	254
03. Retiro	**1.093**	**2.169**	180	432	784	1.516	129	221	0	0	0	0
04. Salamanca	**4.280**	**8.599**	714	1.516	2.951	5.972	486	881	28	59	101	171
05. Chamartín	**2.171**	**4.383**	303	630	1.631	3.227	226	446	0	0	11	80
06. Tetuán	**2.675**	**5.183**	0	0	2.124	4.297	232	415	185	270	134	201
07. Chamberí	**2.098**	**4.321**	625	1.602	526	946	790	1.515	79	128	78	130
08. Fuencarral-El Pardo	**1.573**	**2.758**	1.073	1.786	486	951	0	0	0	0	14	21
09. Moncloa-Aravaca	**1.539**	**2.928**	269	548	675	1.321	512	932	32	55	51	72
10. Latina	**18**	**21**	0	0	0	0	0	0	18	21	0	0
11. Carabanchel	**537**	**1.049**	0	0	412	813	76	157	34	58	15	21
12. Usera	**39**	**77**	0	0	0	0	0	0	39	77	0	0
13. Puente de Vallecas	**0**	**0**	0	0	0	0	0	0	0	0	0	0
14. Moratalaz	**0**	**0**	0	0	0	0	0	0	0	0	0	0
15. Ciudad Lineal	**1.218**	**2.536**	0	0	960	1.917	154	326	104	293	0	0
16. Hortaleza	**914**	**1.543**	0	0	874	1.465	25	50	15	28	0	0
17. Villaverde	**0**	**0**	0	0	0	0	0	0	0	0	0	0
18. Villa de Vallecas	**447**	**963**	0	0	226	439	0	0	0	0	221	524
19. Vicálvaro	**88**	**176**	0	0	0	0	88	176	0	0	0	0
20. San Blas-Canillejas	**2.888**	**6.304**	0	0	2.346	4.984	367	981	47	83	128	256
21. Barajas	**2.471**	**4.817**	275	354	1.485	3.077	267	494	400	812	44	80
Hoteles	**33.985**	**66.294**	**4.194**	**8.043**	**21.744**	**42.898**	**6.022**	**11.504**	**1.660**	**3.097**	**365**	**752**
01. Centro	**9.651**	**17.821**	755	1.175	5525	10.494	2.405	4.425	908	1.623	58	104
02. Arganzuela	**1.282**	**2.482**	0	0	739	1.479	543	1.003	0	0	0	0
03. Retiro	**1.093**	**2.169**	180	432	784	1.516	129	221	0	0	0	0
04. Salamanca	**4.115**	**8.303**	714	1.516	2.951	5.972	433	781	14	28	3	6
05. Chamartín	**2.171**	**4.383**	303	630	1.631	3.227	226	446	0	0	11	80
06. Tetuán	**2.497**	**4.893**	0	0	2.124	4.297	151	265	185	270	37	61
07. Chamberí	**1.904**	**3.990**	625	1.602	526	946	753	1.442	0	0	0	0
08. Fuencarral-El Pardo	**1.559**	**2.737**	1.073	1.786	486	951	0	0	0	0	0	0
09. Moncloa-Aravaca	**1.454**	**2.810**	269	548	675	1.321	488	898	22	43	0	0
10. Latina	**0**	**0**	0	0	0	0	0	0	0	0	0	0
11. Carabanchel	**473**	**942**	0	0	412	813	61	129	0	0	0	0
12. Usera	**39**	**77**	0	0	0	0	0	0	39	77	0	0
13. Puente de Vallecas	**0**	**0**	0	0	0	0	0	0	0	0	0	0
14. Moratalaz	**0**	**0**	0	0	0	0	0	0	0	0	0	0
15. Ciudad Lineal	**1.218**	**2.536**	0	0	960	1.917	154	326	104	293	0	0
16. Hortaleza	**899**	**1.515**	0	0	874	1.465	25	50	0	0	0	0
17. Villaverde	**0**	**0**	0	0	0	0	0	0	0	0	0	0
18. Villa de Vallecas	**324**	**635**	0	0	226	439	0	0	0	0	98	196
19. Vicálvaro	**88**	**176**	0	0	0	0	88	176	0	0	0	0
20. San Blas-Canillejas	**2.862**	**6.252**	0	0	2.346	4.984	341	929	47	83	128	256
21. Barajas	**2.356**	**4.573**	275	354	1.485	3.077	225	413	341	680	30	49
Hostales y Pensiones	**6.389**	**11.359**	**0**	**0**	**0**	**0**	**1.052**	**1.974**	**2.904**	**5.186**	**2.433**	**4.199**
01. Centro	**5.229**	**9.241**	0	0	0	0	774	1.456	2.657	4.748	1.798	3.037
02. Arganzuela	**163**	**282**	0	0	0	0	0	0	18	28	145	254
03. Retiro	**0**	**0**	0	0	0	0	0	0	0	0	0	0
04. Salamanca	**165**	**296**	0	0	0	0	53	100	14	31	98	165
05. Chamartín	**0**	**0**	0	0	0	0	0	0	0	0	0	0
06. Tetuán	**178**	**290**	0	0	0	0	81	150	0	0	97	140
07. Chamberí	**194**	**331**	0	0	0	0	37	73	79	128	78	130
08. Fuencarral-El Pardo	**14**	**21**	0	0	0	0	0	0	0	0	14	21
09. Moncloa-Aravaca	**85**	**118**	0	0	0	0	24	34	10	12	51	72
10. Latina	**18**	**21**	0	0	0	0	0	0	18	21	0	0
11. Carabanchel	**64**	**107**	0	0	0	0	15	28	34	58	15	21
12. Usera	**0**	**0**	0	0	0	0	0	0	0	0	0	0
13. Puente de Vallecas	**0**	**0**	0	0	0	0	0	0	0	0	0	0
14. Moratalaz	**0**	**0**	0	0	0	0	0	0	0	0	0	0
15. Ciudad Lineal	**0**	**0**	0	0	0	0	0	0	0	0	0	0
16. Hortaleza	**15**	**28**	0	0	0	0	0	0	15	28	0	0
17. Villaverde	**0**	**0**	0	0	0	0	0	0	0	0	0	0
18. Villa de Vallecas	**123**	**328**	0	0	0	0	0	0	0	0	123	328
19. Vicálvaro	**0**	**0**	0	0	0	0	0	0	0	0	0	0
20. San Blas-Canillejas	**26**	**52**	0	0	0	0	26	52	0	0	0	0
21. Barajas	**115**	**244**	0	0	0	0	42	81	59	132	14	31

NOTA: La información es proporcionada por la base de datos w w w .spain.info. Los establecimientos pueden decidir si figuran o no en la misma, de ahí las posibles variaciones de un año a otro

FUENTE: Turespaña

9.5. ANNEX E

1. Utilización de los aparcamientos de uso público por meses

Años (media mensual) / meses	Aparcamientos de concesión municipal				
	Capacidad (nº de plazas)	Nº de usuarios	Permanencia media (horas)	Rotación media	Utilización media
2011	**18.501**	**882.646**	**2.61**	**1.67**	**4.35**
Enero	17.049	905.972	2.99	1.77	5.30
Febrero	17.049	826.675	2.78	1.62	4.49
Marzo	17.049	928.555	2.65	1.82	4.81
Abril	17.049	896.427	2.73	1.75	4.78
Mayo	17.049	941.683	2.75	1.84	5.06
Junio	17.049	891.235	2.65	1.74	4.62
Julio	17.049	604.774	2.90	1.18	3.43
Agosto	17.049	494.166	2.44	0.97	2.36
Septiembre	18.501	923.427	2.29	1.66	3.81
Octubre	18.501	1.042.409	2.35	1.88	4.41
Noviembre	18.501	1.020.423	2.34	1.84	4.30
Diciembre	18.501	1.116.002	2.42	2.01	4.87

FUENTE: Área de Gobierno de Medio Ambiente, Seguridad y Movilidad. Dirección General de Control Ambiental. Subdirección General de Transportes y Aparcamientos. Resumen de la Memoria de Estacionamientos Públicos y Mixtos