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EPI GIJÓN

ESCUELA POLITÉCNICA DE INGENIERÍA DE GIJÓN.

GRADO EN INGENIERÍA DE TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

SISTEMA DE ALMACENAMIENTO DE ENERGÍA PARA MEJORAR EL RENDIMIENTO DE UN PARQUE EÓLICO

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1. Introducción.

La estabilidad del Sistema Eléctrico de un país requiere asegurar en cada momento un equilibrio entre la energía eléctrica que se genera y que se consume. La demanda eléctrica, aunque sigue una cierta curva previsible, no es gestionable y el Operador del Sistema debe ajustar la Generación al Consumo en cada momento.

Tradicionalmente la Generación eléctrica estuvo basada en “Power Plants” gestionables, Hidráulica, Térmica con combustibles fósiles (carbón, fuel, gas) o Térmica nuclear, que pueden seguir las consignas del Operador del Sistema de aumento o descenso de potencia generada que permitan ajustar la Curva de Generación a la Curva de Demanda.

Las Energías Renovables presentan indiscutibles ventajas en lo referente a la sostenibilidad y la independencia eléctrica de un país, si bien dependen intrínsecamente de elementos naturales (viento o sol) no gestionables. Con la introducción creciente de Energías Renovables, la Generación también tiene un porcentaje no gestionable que hace más difícil al Operador del Sistema Eléctrico mantener el equilibrio Generación-Demanda que asegure la estabilidad del sistema.

Para facilitar la integración de la generación renovable a la red eléctrica, en diferentes países de la UE (Rumanía, España, etc…) el Regulador, exige un “forecast” diario (hora a hora) de la producción que una determinada planta (eólica o solar) va a verter a la red al día siguiente. En este marco regulador, el precio de venta de la energía viene premiado o penalizado por el porcentaje de desvíos entre el “forecast” realizado y la curva real de energía entregada cada día.

En los diferentes países esta regulación aplicable a las energías renovables es diferente, pero desde el punto de vista técnico, una generación que se ajuste a un programa preestablecido es siempre beneficioso para la gestión del Sistema Eléctrico.

Los sistemas de almacenamiento de electricidad en grandes bloques de baterías, si bien hasta la fecha presentan altos costes económicos, son una de las herramientas claves para asegurar el equilibrio Generación/Demanda en un escenario penetración creciente de las energías Renovables.

Los actuales sistemas de predicción meteorológica permiten un forecast del viento que hora a hora se va a registrar al día siguiente en un determinado emplazamiento. Desafortunadamente, la precisión que se obtiene en estas precisiones es baja, y cuando se transforman esas previsiones de viento en previsiones de producción eléctrica de un parque eólico, los desvíos están en rangos medios anuales de más del 30 %

Se trata de diseñar un bloque de baterías que se conecten en paralelo a un parque eólico, de modo que con un sistema de control adecuado, se minimice el desvío entre la curva de producción diaria de un parque eólico y su curva diaria programada. El alcance de este Trabajo Fin de Grado incluye:

- Estudio comparativo de los diferentes modelos de baterías, seleccionando el idóneo desde un punto de vista técnico/económico.
- Diseño básico de una planta de baterías de 1 MW de potencia nominal, incluyendo banco de baterías, convertidor AC/DC, transformador LV/HV, e interruptor de conexión a la red de HV del parque eólico
- Modelo básico de algoritmo de control de los ciclos de carga/descarga de las baterías dependiendo si la producción que se va obteniendo es por exceso o por defecto de la programada.

2. Estudio de las Baterías.

Una batería es un dispositivo que produce energía eléctrica a partir de reacciones químicas. En general, una batería consta de dos electrodos, uno negativo llamado ánodo y uno positivo llamado cátodo, un electrolito que es un líquido o un sólido que transporta las cargas del ánodo al cátodo. Cuando se conecta a un aparato, los electrodos negativos suministran una corriente de electrones que fluyen a través de la aplicación y son aceptados por el electrodo positivo. Las baterías suelen estar compuestas por un número de células electroquímicas. Cada celda utiliza reacciones químicas para almacenar energía y convertir esta energía en electricidad.

Tipos:

A continuación se expondrá los tipos de baterías estudiados con un breve resumen de cada una de ellas.

- **Lead acid**

Las baterías de plomo ácido están hechas de dos rejillas de electrodos de aleación de plomo y ácido sulfúrico como electrolito. La aleación normalmente está hecha de una mezcla de antimonio, calcio, estaño o selenio y mejora la resistencia mecánica de los cátodos.

La tecnología de plomo ácido se compone de dos categorías principales; ventilado (inundado) y regulado por válvula (sellado). Mientras que los electrodos de las baterías de plomo ácido ventilados están sumergidos en líquido, las baterías de plomo ácido reguladas por válvula utilizan gel o un separador absorbente para inmovilizar el electrolito. Las baterías ácidas de plomo con ventilación se utilizan para una ráfaga de energía corta, como se usa en aplicaciones de calidad de energía con una vida útil corta de aproximadamente 3 a 7 años o hasta 1000 ciclos con 10% de descarga, dependiendo del uso. Con la investigación más reciente, se han desarrollado las llamadas baterías avanzadas de plomo-ácido, que reducen el mantenimiento y aumentan las expectativas de vida.

- ## Baterías de electrodo de níquel.

Las baterías de electrodo de níquel se conocen como celdas secas, donde cada celda contiene un par de electrodos. Uno es un electrodo positivo de níquel y el otro es un electrodo negativo hecho de cadmio, zinc, hierro, hidrógeno o haluro metálico. Los electrodos porosos están separados por una partición y el electrólito líquido circula en ellos. Solo se han desarrollado químicos que utilizan electrodos de cadmio y hierro y se han instalado para demostraciones de almacenamiento hasta el momento, donde el más popular es el níquel cadmio. Sin embargo, debido a la toxicidad del cadmio, estas baterías se utilizan actualmente solo para aplicaciones estacionarias en Europa. Desde 2006 están prohibidos para uso del consumidor.

- ## Baterías de iones de litio

Una batería de iones de litio está hecha de electrodos de grafito negativos y óxido de metal positivo separados por un polímero microporoso y un éter como electrolito orgánico con iones de litio disueltos. Durante la carga, los iones de litio fluyen desde el óxido de metal positivo al electrodo de grafito negativo. Cuando la batería se descarga, el flujo de iones se invierte. El óxido utilizado para el electrodo positivo generalmente está hecho de cobalto, manganeso o hierro y fosfato. El material del electrodo determina las características técnicas de la batería de iones de litio, pero se pueden identificar algunas cualidades generales. En general, tienen una energía y una densidad de energía muy altas, lo que les otorga un voltaje de celda mucho más alto que otras tecnologías de batería, lo que a su vez requiere menos células para la misma potencia de salida.

- ## Baterías de NaS

Una batería de NaS consta de azufre líquido (fundido) en el electrodo positivo y líquido (fundido) de sodio en el electrodo negativo como materiales activos separados por un electrolito cerámico sólido de alúmina beta. El electrolito permite que solo los iones de sodio positivos lo atraviesen y se combinen con el azufre para formar polisulfuros de sodio. Durante la descarga, los iones positivos de Na + fluyen a través del electrolito y los electrones fluyen en el circuito externo de la batería produciendo aproximadamente 2 voltios. Este proceso es reversible ya que la carga hace que los polisulfuros de sodio liberen los iones de sodio positivos a través del electrólito para que se recombinen como sodio elemental.

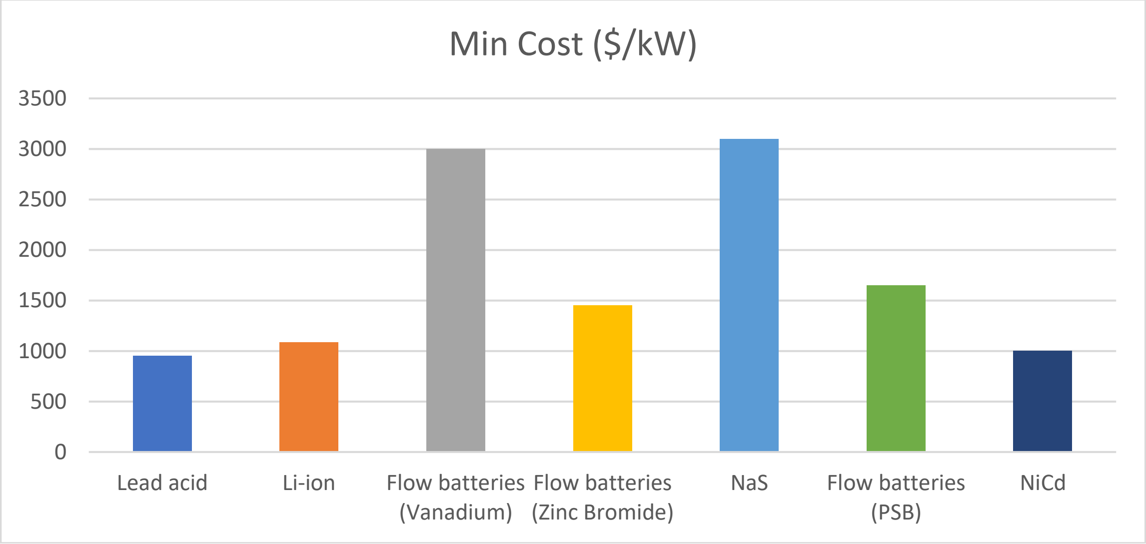
- **Baterías de Flujo**

El principio de funcionamiento de las baterías de flujo se basa en reacciones electroquímicas reversibles que ocurren en un conjunto de celdas conectadas en serie, en paralelo o en ambos, para lograr el nivel de voltaje deseado. A diferencia de las baterías convencionales, dos soluciones electrolíticas acuosas diferentes están contenidas en tanques separados. Durante el funcionamiento normal de la batería, estas soluciones acuosas se bombean a través de la celda electroquímica donde ocurren las reacciones. La capacidad de energía de estas baterías es fácilmente escalable, ya que depende del volumen del electrolito almacenado, también estas baterías pueden descargarse completamente sin daños y tienen una descarga automática muy baja, ya que los electrolitos se almacenan en tanques sellados separados.

Comparativa:

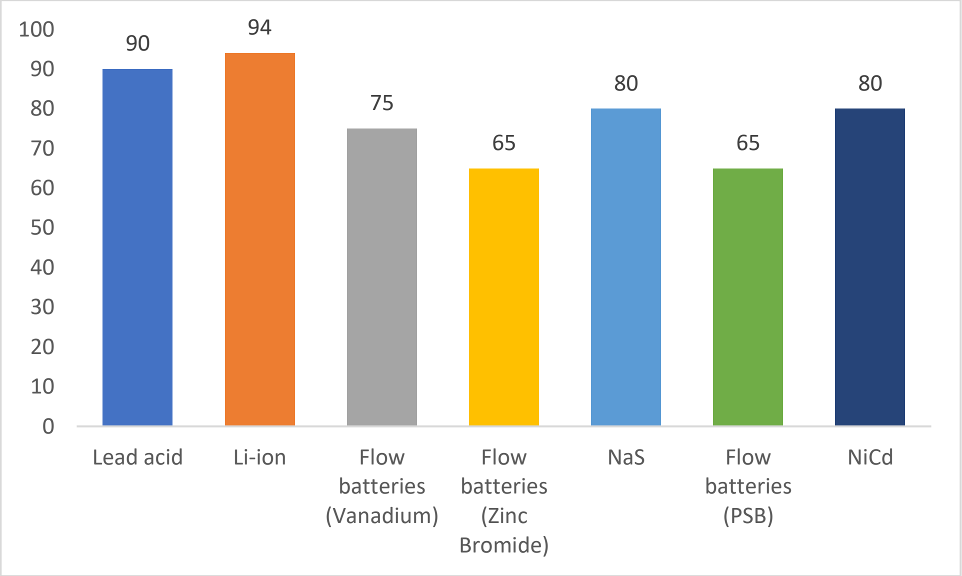
La comparativa que llevaremos a cabo en esta sección estará basada en los datos obtenidos en cuatro diferentes aspectos:

1. Coste de cada tipo de batería.



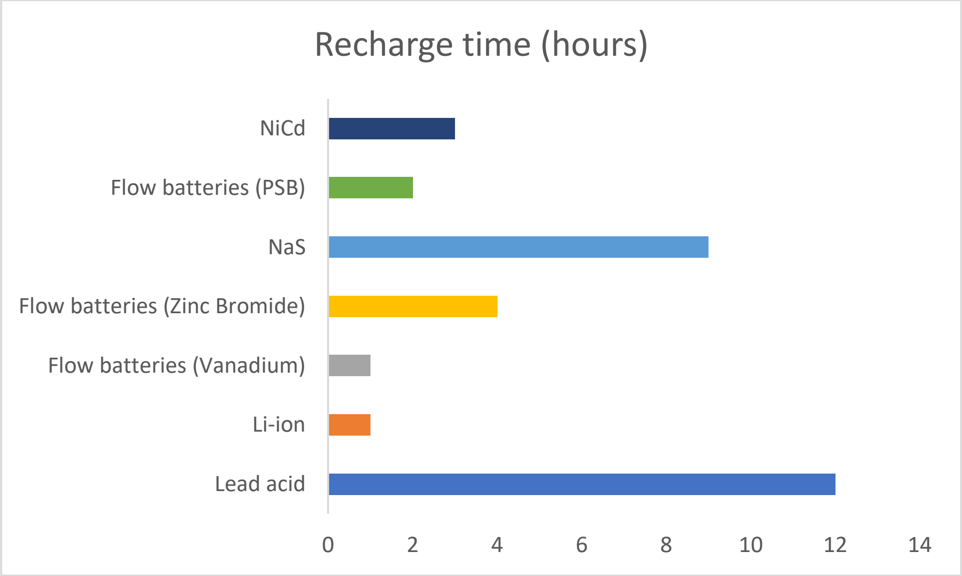
Gráfica comparativa según costes.

2. Eficiencia.



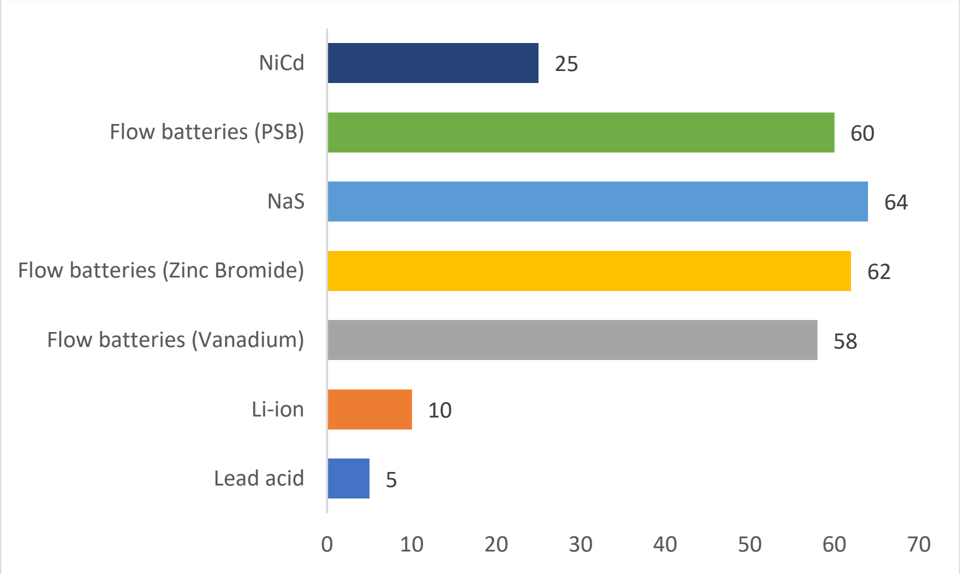
Eficiencia de cada batería en porcentaje (%)

3. Tiempo de Recarga



Tiempo de recarga en horas (h)

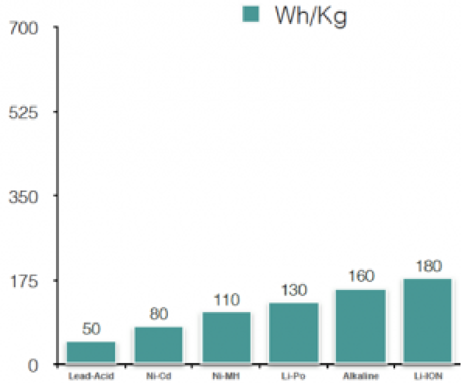
4. Pérdidas de energía



Porcentaje de energía perdida con el paso del tiempo.

Una vez que hayamos compilado las diferentes variantes de comparaciones, podemos proceder a la selección de la batería. Para que esta batería cumpla con los requisitos del proyecto, debe ser económica, tener buena eficiencia y ser competente en los ciclos de carga (bajas pérdidas y coeficiente de autodescarga). Para ello, elegiremos baterías de Li-ion, que se destacan por cumplir con estos requisitos y por su desarrollo en los últimos años, junto con una mejora en el precio de estas.

Si revisamos la tendencia de instalación en este campo también podemos ayudarnos a fortalecer nuestra elección. Debido a sus excelentes características y buen rendimiento, las baterías de iones de litio se han convertido en las más comunes en el mercado.



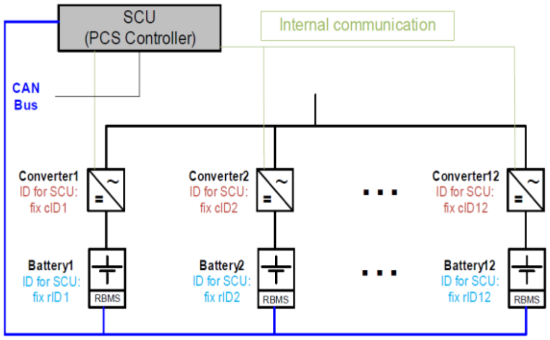
Tendencia de instalación de baterías.

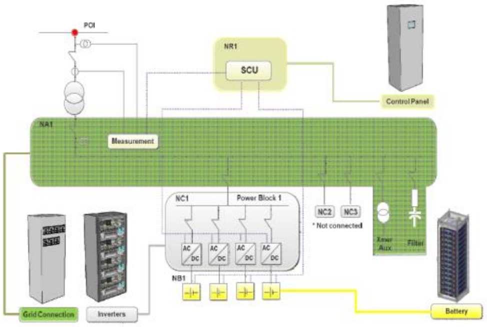
3. DISEÑO DE SISTEMA DE ALMACENAMIENTO.

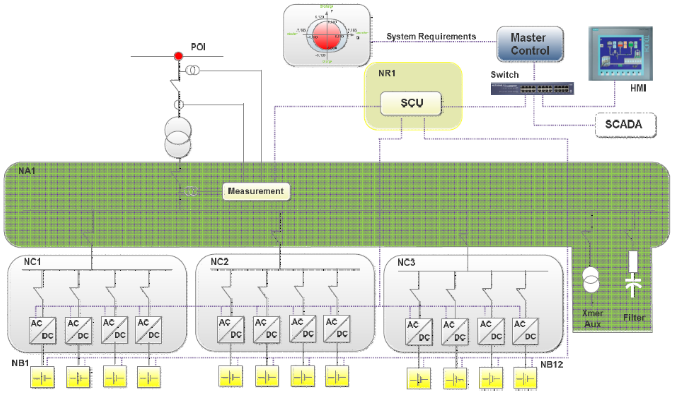
Una vez que se determina el tipo de batería que se va a utilizar, Li-ion, diseñamos el Sistema de Estator de Energía de la Batería (BESS), basado en modelos comerciales disponibles en el mercado.
Analizamos los catálogos y la información técnica disponible. Elegimos baterías LG Chem integradas en el sistema Siestorage de Siemens, como una solución de almacenamiento de energía modular que combina electrónica de potencia de vanguardia y baterías de iones de litio de alto rendimiento para aplicaciones de red.

Con la explicación de cada componente y esquemas de instalación se propone una posible solución para la instalación de un sistema de almacenamiento capaz de albergar 1 MWh.

A continuación se presentan parte de los esquemas de instalación:







4. ALGORTIMO DE MONITORIZACIÓN.

Una vez finalizada la instalación, necesitaremos un algoritmo que nos permita monitorear el funcionamiento de la batería en los momentos de exceso o falta de energía generada.

Para esto comenzaremos con tres variables o "imputs":

- La potencia real generada en cualquier momento por los aerogeneradores, que dependerá directamente de la velocidad del viento en un momento dado. Esta tabla de entrada está siendo actualizada por el sistema de control de la planta cada 10 minutos.
- Pronóstico o pronóstico de generación diaria que el sistema de control de la planta usará como referencia para ajustar la producción neta de energía al máximo posible, y de esta manera, ajustar la curva de suministro de energía al pronóstico establecido y minimizar las penalizaciones para desviaciones
- El estado de carga de la batería, ya que la batería no se puede utilizar para dar energía una vez agotada ni para acumular esa energía en caso de estar completamente cargada.

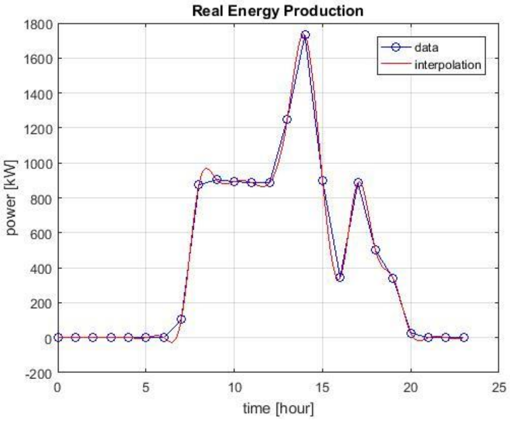
Para construir el algoritmo, usaremos funciones lógicas en el programa Matlab para que una vez que el algoritmo haya finalizado, pueda decirnos el estado de funcionamiento de la batería en cada momento, además de la energía que proporciona o acumula. En este caso, hemos utilizado para la explicación tanto la producción como el pronóstico de un día supuesto. De la misma manera, podemos ajustar el monitoreo semanal, mensual, etc., y el algoritmo podría generar resultados en otros períodos de tiempo.

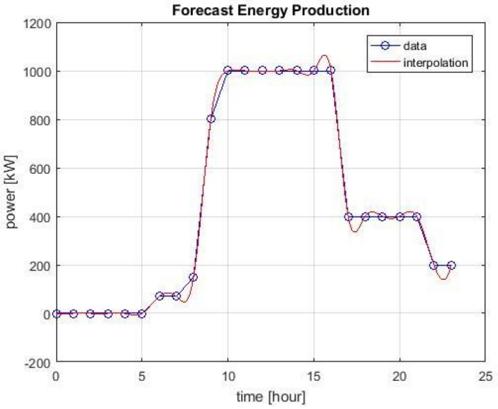
Para comenzar este algoritmo es necesario leer inicialmente las variantes de entrada de la producción de energía real y el pronóstico. Una vez leído, generará un gráfico comparativo que nos dará una idea estimada de los momentos de máxima necesidad de la batería, es decir, los momentos en que la generación real de energía de los aerogeneradores tenga una mayor desviación del pronóstico.
Una vez que se genera este gráfico, el algoritmo realizará una interpolación de datos tanto de la energía real producida como de la energía asumida en el pronóstico para lograr una función que describa continuamente la curva de las energías. Esta interpolación es necesaria ya que además de ayudarnos a tratar los datos, nos permite obtener de una serie de medidas (cada 10 min aprox) una función continua que nos permite conocer la energía en cualquier momento.

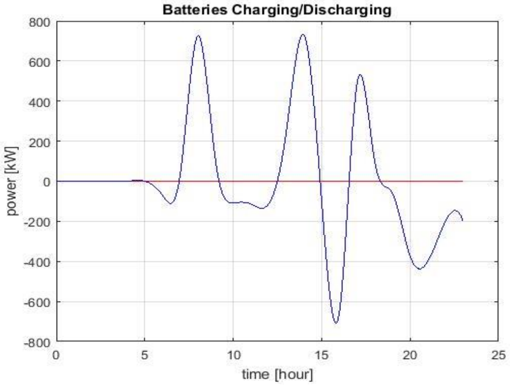
Una vez que el algoritmo finaliza la interpolación y muestra que las gráficas de las funciones descritas anteriormente comenzarán a generar gráficas que mostrarán el estado de la batería en cada momento, ya que por medio de funciones lógicas se comparará la energía real producida con la estimación de la previsión, de modo que si la energía producida es inferior a lo que se estimó en la previsión, el sistema dependerá de las baterías para compensar la diferencia, así como cuando la energía producida es mayor que la estimada, el sistema superará el excedente en las baterías para recargarlos. También hay condiciones límite (temperatura de la batería, pérdidas de energía, condiciones climáticas ...) tanto de las baterías como del sistema en general que garantizarían que el sistema se detuviera en caso de fallo, pero estas condiciones ya estarían programadas en los sistemas de control de ambos. Las baterías y el parque para que no sea necesario incluir medidas de seguridad en este algoritmo.

Finalmente, el algoritmo nos mostrará un diagrama gráfico del uso de las baterías, donde destacarán los momentos en que las baterías son más necesarias, pudiendo así conocer los momentos más críticos de producción del parque eólico.

A continuación se adjuntas distintas gráficas a modo de ejemplo de las generadas por el algoritmo en el proceso de control:







5. CONCLUSIONES.

Una vez concluido el montaje podemos apreciar como la instalación de baterías pese a su actual desarrollo es una forma de incrementar el rendimiento de un parque eólico, cuando hablamos de la mejora de rendimiento nos referimos tanto a la mejora económicamente ya que al ajustar la curva de producción al forecast se ahorrarían penalizaciones, como al incremento de aprovechamiento del viento ya que de esta manera se aprovecharían los casos de excedente de viento y se reduciría la pérdida en caso de una producción insuficiente.

Por otro lado el algoritmo de monitorización nos permitiría hacer un control en paralelo del sistema ya que además del control pertinente que nos entregan los sistemas de control internos, tendríamos un estudio paralelo con la monitorización y los resultados entregados por dicho algoritmo.

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ENERGY STORAGE SYSTEM FOR IMPROVING THE PERFORMANCE OF A WIND FARM

FINAL PROYECT

TUTOR: Henryk Olszewski

Elbląg 2017

CONTENTS

Acronyms:

AC:	Alternating Current
BBMS:	Bank Battery Management System
BMS:	Battery Management System
CB:	Circuit Breaker
DC:	Direct Current
DOD:	Depth of Discharge
DSO:	Distribution System Operator
EOL:	End of Life
ESS:	Energy Storage System
FOC:	Fibre-Optic Cable
HF:	High Frequency
HMI:	Human Machine Interface
MBMS:	Module Battery Management System
POI:	Point of Interconnection
PS:	Power Stack
PU:	Pre-charge Unit
RBMS:	Rack Battery Management System
SCU:	SIESTORAGE Control Unit
SMS:	Storage Management System
SPS:	Stand-by Power Supply
SW:	Software
UPS:	Uninterruptible Power Supply

1.INTRODUCTION

The electrical system of each country needs to be able to ensure the balance between the electric energy consumed and the energy generated at all times. The energy consumed, although not manageable, follows a generally foreseeable demand curve, which allows to adjust to the System Operator the produced energy needed to satisfy said demand.

Traditionally, power generation was based on manageable Power Plants, Hydraulics, Fossil Fuel Thermal (coal, fuel, gas) or Nuclear Thermal, which can follow the Operator's instructions of power increase or decrease easily generated in a way that allows adjustment The Generation Curve at the Demand Curve.

During the last years, the development of technologies in the field of renewable energies has managed to introduce as a new factor to take into account, the production of renewable energy. This energy presents management problems by using unmanaged resources such as wind or sunlight. The Generation has a non-manageable percentage that makes it more difficult for the Electrical System Operator to maintain the Generation / Demand balance that ensures the stability of the system.

These energies have indisputable advantages in terms of the sustainability and the electrical independence of a country. As the percentage of production of renewables is increasing with the passage of time, more and more means are needed to guarantee the manageability of this energy.

In order to facilitate the integration of renewable generation into the electricity grid, the Regulator of several countries of EU requires a daily (hourly) forecast of production that a given wind power plant (or solar) will pour into the grid the next day. In this regulatory framework, the sale price of energy is rewarded or penalized by the percentage of deviations between the forecast realized and the actual energy curve delivered each day. In different countries, this regulation applies to renewable energies, but from a technical point of view, a generation that fits a pre-established program is always beneficial for the management of the Electricity System.

An alternative designed to adjust the deviation of the energy Generation / Demand curve in particular in wind farms where wind uncertainty is never zero, are the systems of storage of electricity in large blocks of batteries where to be able to accumulate this energy in the moments In overproduction and where to resort at times when production is not enough.

1.1. OBJECTIVES OF THE PROJECT

The current meteorological forecasting systems allow a wind forecast to be recorded the next day at a given location on an hourly basis. Unfortunately, the precision obtained in these forecasts is low, and when these wind forecasts are transformed into forecasts of wind power production, deviations are in average annual ranges of more than 30%.

It is a matter of designing a battery pack that is connected in parallel to a wind farm, so that with a suitable control system, the deviation between the daily production curve of a wind farm and its daily scheduled curve is minimized.

The scope of this Final Project includes:

- Comparative study of the different models of batteries, selecting the ideal from a technical / economic point of view.

- Basic design of a block of “1 MW” rated Energy storage plant, including battery bank, AC / DC converter, LV / HV transformer, and HV grid connection switch of the wind farm

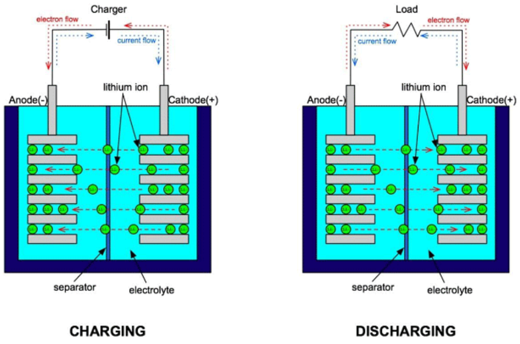
- Basic model of algorithm to control the charge / discharge cycles of the batteries depending on whether the production that is being produced is by excess or by default of the programmed.

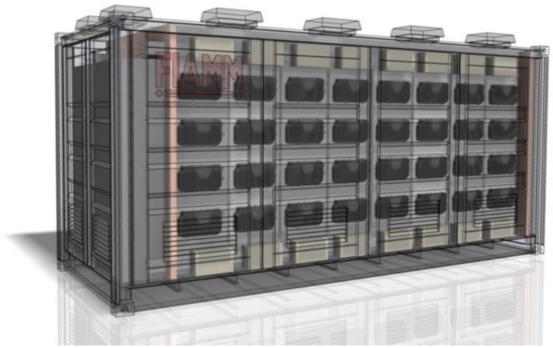
2.STUDY OF THE BATTERIES

To counteract the problem of the deviation of the Generation / Demand curve and thus adjusting the possible forecast, we are interested in using a device that allows us to control the energy output of the station more efficiently than the wind gives us. One possible solution is the use of batteries, which would give us the necessary tool to control the deviations of the curve thanks to the energy reserve that we can use to deliver to the network when needed and also storage when the production exceeds expectations.

2.1.CONCEPT OF BATTERY.

A battery is a device that produces electrical energy from chemical reactions. In general a battery consists of two electrodes, one negative called the anode and one positive called cathode, an electrolyte which is either a liquid or solid that transports the charges from anode to cathode. When connected to an appliance the negative electrode supplies a current of electrons that flow through the appliance and are accepted by the positive electrode. Batteries are usually made up of a number of electrochemical cells. Each cell uses chemical reactions to store energy, and convert this energy into electricity.





a.Chemical reaction. b.Industrial battery.

2.2.DIFFERENT TECHNOLOGIES OF BATTERIES.

Within this chapter we will find a series of options to consider when choosing the best option considering the performance of the battery from a technical / economic point of view to finish in the next chapter with the comparison of the same and its justified choice. Following this approach we will consider only the best loading / unloading cycles required for this type of project.

- ***Lead acid***

Lead acid batteries are made of two lead alloy electrode grids and sulfuric acid as electrolyte. The alloy is typically made of a blend of antimony, calcium, tin or selenium and lead to improve the mechanical strength of the cathodes.

Lead acid technology is made out of two main categories; vented (flooded) and valve-regulated (sealed). While vented lead acid batteries' electrodes are immersed in liquid, valve-regulated lead acid batteries uses gel or an absorbent separator to immobilize the electrolyte. Vented lead acid batteries are used for short power burst as used in power quality applications with short life time expectancies around 3-7 years or up to 1000 cycles with 10% discharging depending on use. A subcategory of vented lead acid batteries used for stationary applications such as standby emergency power and telecommunications system have longer life expectancy ranging up to 30 years. They are thus a common choice for energy storage projects. The valve-regulated types, can be mounted in any orientation, and do not require constant maintenance. They are used for uninterruptible power supply (UPS) and possess a low life expectancy ranging from 5 to 10 years due to their sensitivity to temperature and corrosion etc. Their optimal operation temperature is around 25°C with deviations leading to possible explosion (below -40°C) and overheating causing faster degradation. Common disadvantages include also; self- discharge, sulfatation which reduces cell power and degradation (general deprivation of structures and components) leading to battery failure. With more recent research so called advanced lead acid batteries have been developed, reducing maintenance and increasing life expectancies.

Advantages	Inexpensive and simple to manufacture; low cost per watt-hour Low self-discharge; lowest among rechargeable batteries High specific power, capable of high discharge currents Good low and high temperature performance
Limitations	Low specific energy; poor weight-to-energy ratio Slow charge; fully saturated charge takes 14-16 hours Must be stored in charged condition to prevent sulfation Limited cycle life; repeated deep-cycling reduces battery life Flooded version requires watering Transportation restrictions on the flooded type Not environmentally friendly

a. Advantages/Limitations og Lead acid battery

Worldwide around 35 MW of installed power capacity for energy storage are based on lead-acid technology. Starting as early as in the 1870's lead acid batteries have been used for load leveling and peaking in central electric plants of that time. Despite low energy and power density, short cycle life, toxicity and high maintenance requirements they remain a popular choice for energy storage application thanks to their low cost and technical maturity.

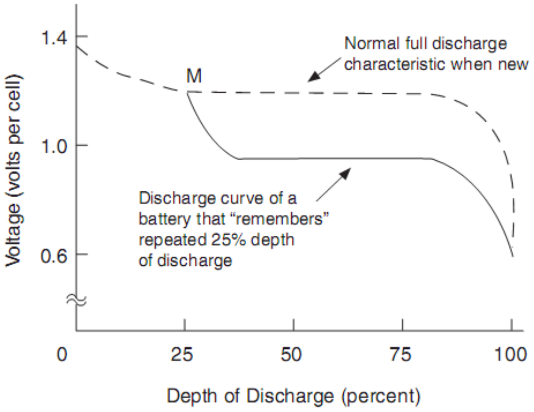
Battery	**Wh/kg**	**Typical lifetime (years)**	**Recharge time (hours)**	**Round trip efficiency**	**Nominal cell voltaje**	**Operating temperature (ºC)**	**Toxicity**
Lead Acid	30-50	3-15	8-16	70-80%	2 V	-20 to 50	Very high

b. Typical characteristic of Lead acid battery

In this table we can observe a low weight-energy ratio compared to other possibilities, a high recharge time and also the problem of high toxicity.

- ***Nickel electrode batteries***

Nickel electrode batteries are known as dry cells where each cell contains a pair of electrodes. One is a positive nickel electrode and the other a negative electrode made of cadmium, zinc, iron, hydrogen or metal halide. The porous electrodes are separated by a partition and liquid electrolyte is circulated into them. Only chemistries using cadmium and iron electrodes have been developed and been installed for storage demonstrations so far where the most popular is nickel cadmium. However, because of the toxicity of cadmium, these batteries are presently used only for stationary applications in Europe. Since 2006 they have been prohibited for consumer use.



a.Discharging curve of battery Ni-cd.

The round trip efficiency ranges from 65-85% for nickel electrode batteries in general and 60-70% for nickel cadmium batteries. Nickel cadmium batteries are prone to irreversible degradation and efficiency losses due to temperature sensitivity and depth and frequency of discharge. Life expectancies vary between different constructions ranging from around 100 cycles to 3 500 cycles with 80% depth of discharge. This translates roughly into 15-20 years for lightly cycled applications. The exception is nickel iron batteries with long service lives up to 25 years.

NiMH batteries were developed initially to replace NiCd batteries. Indeed, NiMH batteries have all the positive properties of NiCd batteries, with the exception of the maximal nominal capacity which is still ten times less when compared to NiCd and lead acid.

Battery	**Wh/kg**	**Typical lifetime (years)**	**Recharge time**	**Round trip efficiency**	**Nominal cell voltaje**	**Operating temperature (ºC)**	**Toxicity**

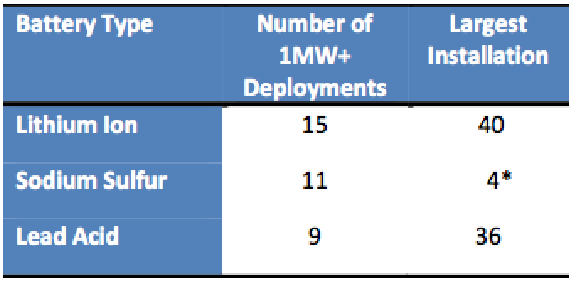
NiCd	45-80	15-20	< 1	70-80%	1,2 V	-20 to 65	Very high
NiHm	60-120		2-4				Medium

c. Typical Nickel electrode batterias characteristics.

There is a great contrast between both versions despite sharing some characteristics, improving the energy ratio and solving the problem of toxicity, NiHm batteries have greater ease of use, despite worsening with respect to NiCd versions in the need for Time for loading.

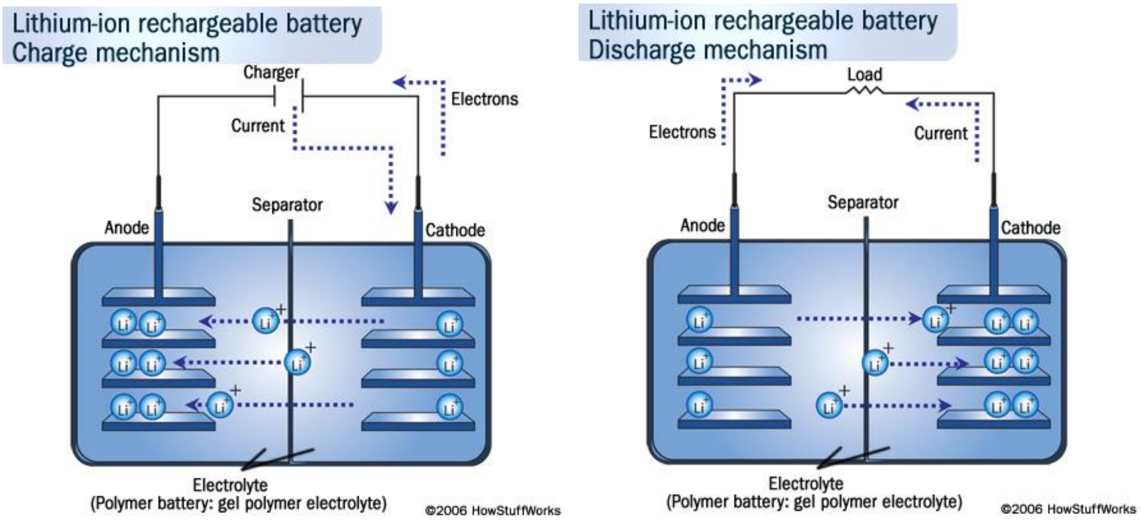
- ***Lithium-ion batteries***

A lithium ion battery is made out of negative graphite electrodes and positive metal-oxide separated by a micro-porous polymer and an ether as organic electrolyte with dissolved lithium ions. During charging the lithium ions flow from the positive metal oxide to the negative graphite electrode. When the battery is discharge the ion flow is reversed. The oxide used for the positive electrode is typically made of cobalt, manganese or iron and phosphate. The electrode material determines the technical characteristics of the lithium ion battery but some general qualities can be identified. In general they have a very high energy and power density giving them a much higher cell voltage than other battery technologies which in turn requires less cells for the same power output.



Battery Type	Number of 1MW+ Deployments	Largest Installation
Lithium Ion	15	40
Sodium Sulfur	11	4*
Lead Acid	9	36

a. Table of installations of batteries (2014)



Source: http://electronics.howstuffworks.com/everyday- tech/lithium-ion-battery1.htm

With their superior characteristics the biggest hurdle for the breakthrough of lithium ion batteries is the high capital cost relative to other technologies like lead acid and NiCd. The driving force for the price reduction of Li-ion battery technology is believed to be the automobile industry where this type of battery has become the most commonly used. Several companies are working to reduce the manufacturing cost of Li-ion batteries to capture large energy markets.

Battery	Wh/kg	Typical lifetime (years)	Recharge time	**Round trip efficiency**	Nominal cell voltaje	Operating temperature (ºC)	Toxicity
LiMn	100-135	8-15	< 1	85-92%	3,8 V	-20 to 60	Medium
LiCo	150-190		2-4		3,6 V		
LiPO	90-120		< 1		3,3 V		

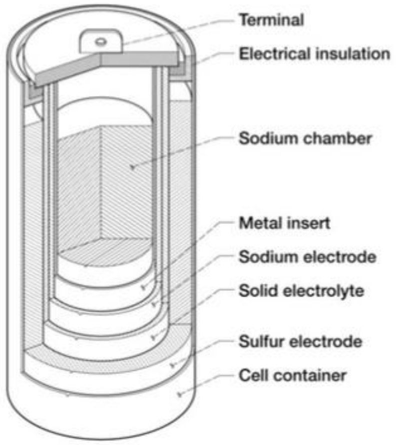
a.Typical lithium characteristics

It is remarkable the great increase in weight-energy ratio that these batteries present along with their need for a sufficiently small recharge time. In addition the cells of the battery have a higher rated voltage which will save us putting a greater number of blocks for the desired power.

- ***NaS batteries***

A NaS battery consists of liquid (molten) sulfur at the positive electrode and liquid (molten) sodium at the negative electrode as active materials separated by a solid beta alumina ceramic electrolyte. The electrolyte allows only the positive sodium ions to go through it and combine with the sulfur to form sodium polysulfides. During discharge, as positive Na+ ions flow through the electrolyte and electrons flow in the external circuit of the battery producing about 2 volts. This process is reversible as charging causes sodium polysulfides to release the positive sodium ions back through the electrolyte to recombine as elemental sodium.

NaS battery cells are usually designed in a tubular manner where the sodium is normally contained in an interior cavity formed by the electrolyte.



a.Typical NaS battery.

An important feature of this type of battery is its high temperature operation, around 350˚C. There are many concerns regarding the high temperature operation of the battery. As the cell reactions are exothermic, the energy input required to maintain a proper operating temperature is low and therefore, the efficiency of the battery is not substantially reduced . Tthe lower the electrolytic resistance of the battery, the better the performance due to the minimization of the energy lost in form of heat in the electrolyte.

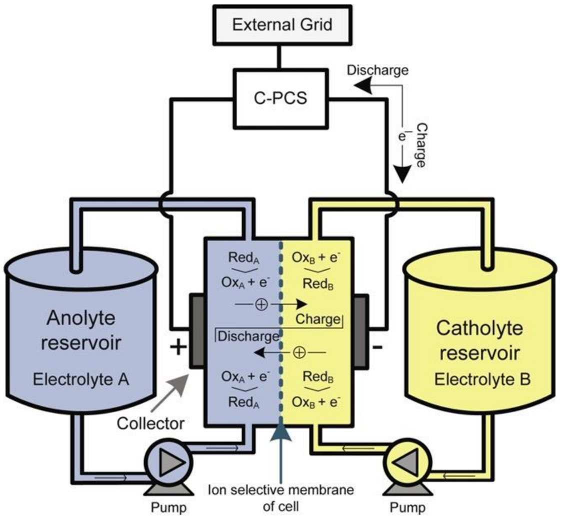
Battery	**Wh/kg**	**Typical lifetime (years)**	**Recharge time (hours)**	**Round trip efficiency**	**Nominal cell voltaje**	**Operating temperature (ºC)**	**Toxicity**
NaS	80-140	12-20	9	70-90%	2 V	300-360	High

a. Typical NaS characteristics

These batteries have a good life, in addition to good performance. Its main limitations are toxicity and high operating temperatures, these batteries need to be handled correctly because with water it can cause explosions.

- ***Flow batteries***

Flow batteries operating principle is based on reversible electrochemical reactions that occur in a set of cells connected in series, parallel or both, in order to achieve the desired voltage level. Unlike conventional batteries, two different aqueous electrolytic solutions are contained in separate tanks. During the normal operation of the battery, these aqueous solutions are pumped through the electrochemical cell where the reactions occur. The energy capacity of these batteries is easily scalable, since it depends on the volume of the stored electrolyte, also these batteries can become fully discharged without any damage and they have very low self-discharge, since the electrolytes are stored in separate sealed tanks.



a. Typical Flow battery.

These types of batteries are also called redox flow batteries because their operation is based on reduction and oxidation reactions of the electrolyte solutions.

There are three important kinds of this batteries:

- **Vanadium Redox Battery (VRB)**. When an electrochemical reaction occurs, carbon electrodes enable the electron flow through the load, while the electrical balance is achieved by means of the migration of a hydrogen ion through the membrane which separates the two electrolytes. Since the products of chemical reactions remain dissolved in the electrolytes, the reverse process leads solutions to their initial state. VRB was pioneered in the Australian University of New South Wales (UNSW) in early 1980's.

- **Zinc Bromine Battery (ZnBr)** based on Zn and Br and stored in separate tanks, flow through electrolytic cells where the reversible electrochemical reactions are produced.

- **Polysulphide Bromide Battery (PSB)** are based on the electrochemical reactions between two salt-based electrolytes: sodium bromide (NaBr) and sodium pölysulphide ($Na_2 S_x$). The electrolytes are separated by a polymer membrane which only allows the interchange of positive sodium ions

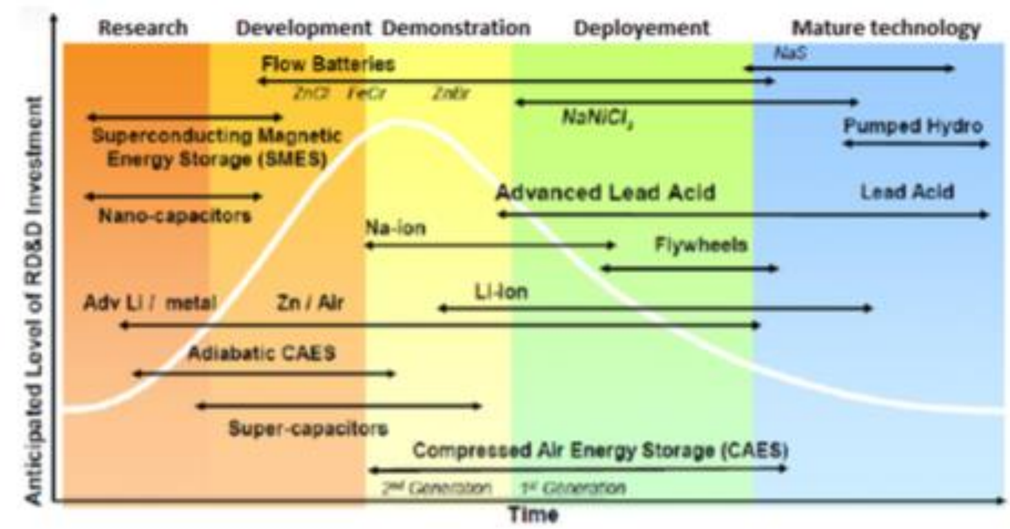
Battery	Wh/kg	Typical lifetime (years)	Recharge time	**Round trip efficiency**	Nominal cell voltaje	Operating temperature (ºC)	Toxicity
VRB	20-30	10-20	< 1	60-65%	1,4 V	-5 to 55	High
ZnBr	30-45	5-10	4		1,8 V		
PSB	20-30	5-10	6		0,8V		

a. Typical flow batteries characteristics.

We can see how the energy density is small (returning to values similar to Lead Acid batteries) in addition to a low voltage per cell of energy and the need for a large space for installation. On the other hand the energy capacity of these batteries is easily scalable what has aroused the interest in many companies. (VRB storages have been installed in Japan by SEI, ZnBr battery was developed by Exxon, Regenesys Technologies and Tennessee Valley Authority (TVA) are testing PSB).

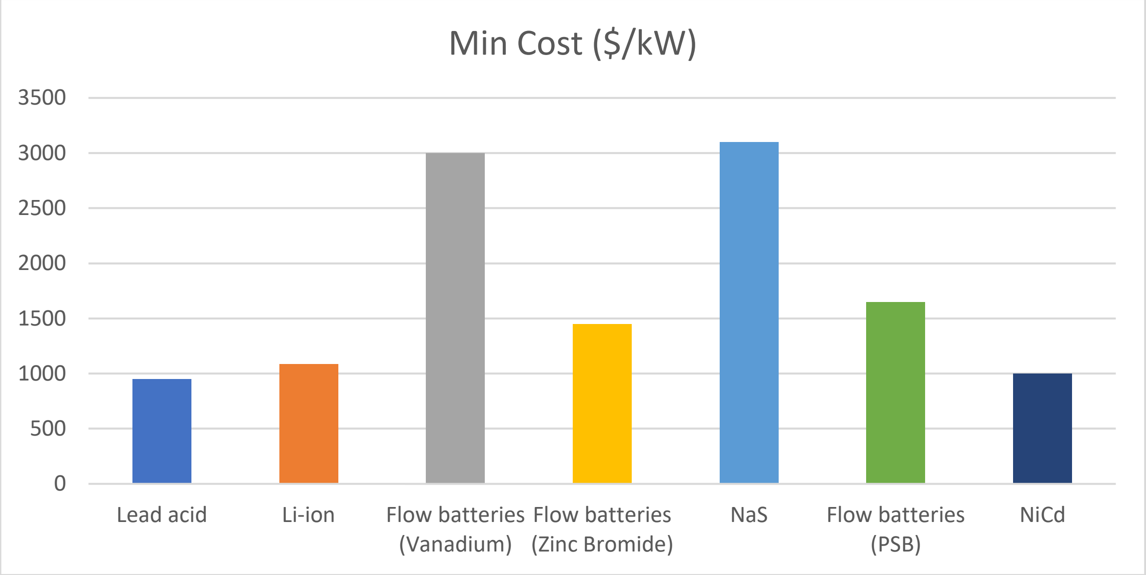
2.3. COMPARATIVE OF BATTERIES AND ELECTION.

To compare the different types of batteries we will start with an overview of how the current state of development of each technology is. We will be able to observe in which phase of development this technology is and that it is expected of each one in the future.



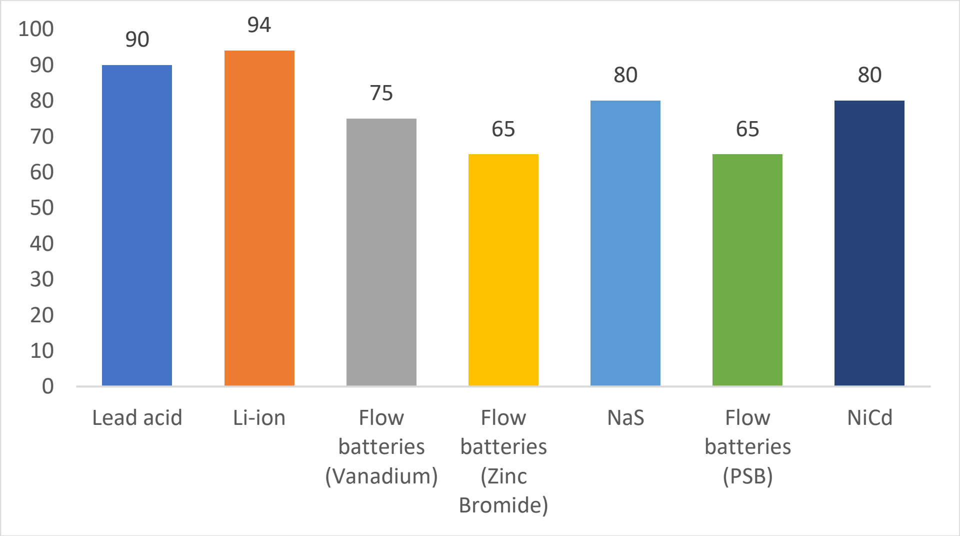
As we can see both Flow batteries and Li-ion have an expectation of improvement over the years despite being in use phase. On the other hand we observed how the Lead Acid despite having reached its maximum progression are still used. The rest of the studied cases (NaS and NiCd) have also reached their maximum progression and have opted for possible variations such as can be in the case of NiCd, which have been replaced by NiHm.

Once put in situation of how is the development of each technology we must take into account the price of the same. The following graph presents a minimum cost ($/kW) of each type.



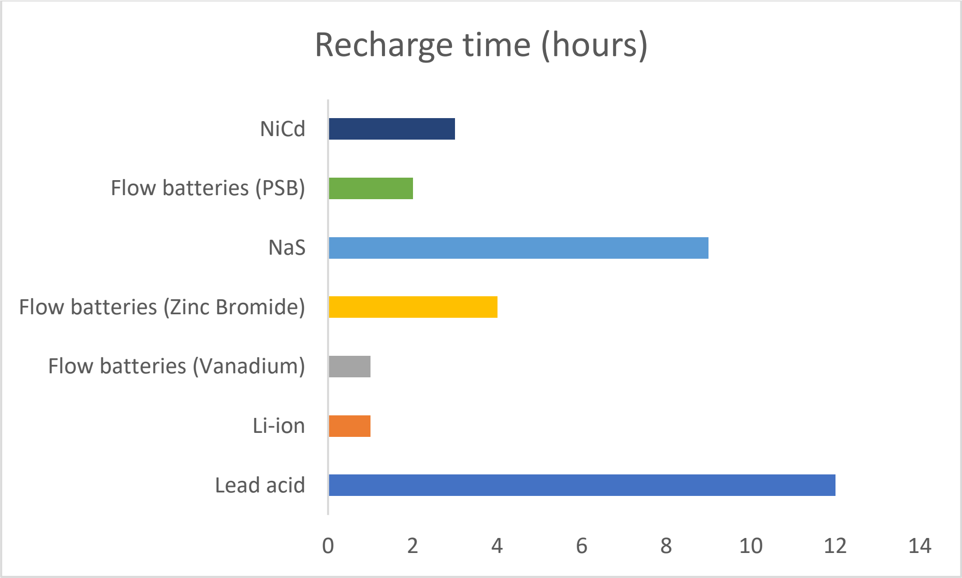
We can highlight the high costs of the Flow batteries and the NaS compared to the other alternatives, one of the most important qualities that should have our choice is the profitability so it seems logical to take this data very closely.

Now that we have a framework in wich to locate us, we will study other important variants such as the efficiency of each battery as well as its charging times.



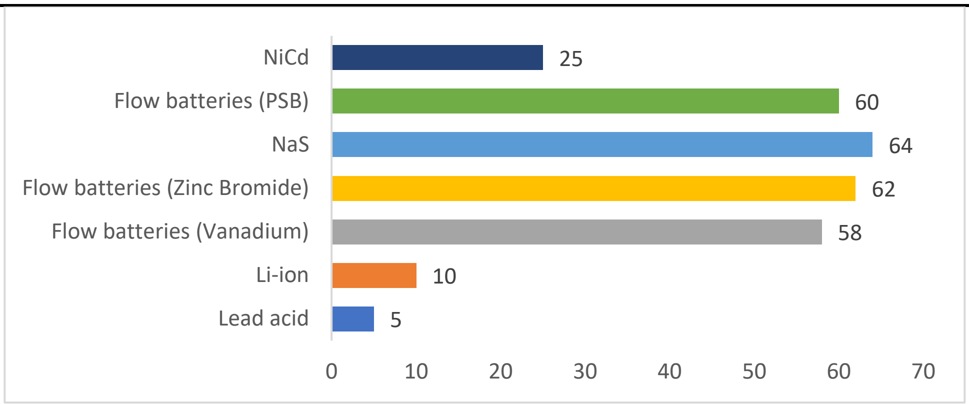
Efficiency of batteries (%).

In terms of efficiency we can see how the batteries of Lead acid and Li-ion are the best performers remaining behind the Flow batteries.



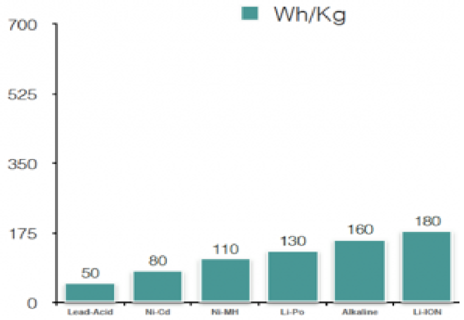
The need for fast charge cycles for this type of project is very important so choosing a battery type like NaS or Lead Acid, would not make sense. In contrast we can see how with such short times as the Li-ion or Flow batteries of Vanadium could meet the required requirements.

Finally we have to take into account the energy losses presented by each battery. We can appreciate how the batteries that need a high working temperature have greater losses thanks to the energy that dissipates with the thermal difference with the environment.



a. Energy lost of the batteries.

Once we have compiled the different variants of comparisons we can proceed to the selection of the battery. For this battery to meet the requirements of the project it needs to be economical, to have good efficiency and to be competent in load cycles (low losses and self-discharge coefficient). For this we will choose Li-ion batteries, which stand out for meeting these requirements and for its development in recent years along with an improvement in the price of them.



a. Comparative of principal existing battery technology.

If we check the trend of installation in this field can also help us to strengthen our choice. Due to its great characteristics and good performance Li-ion batteries have become the most common in the market.

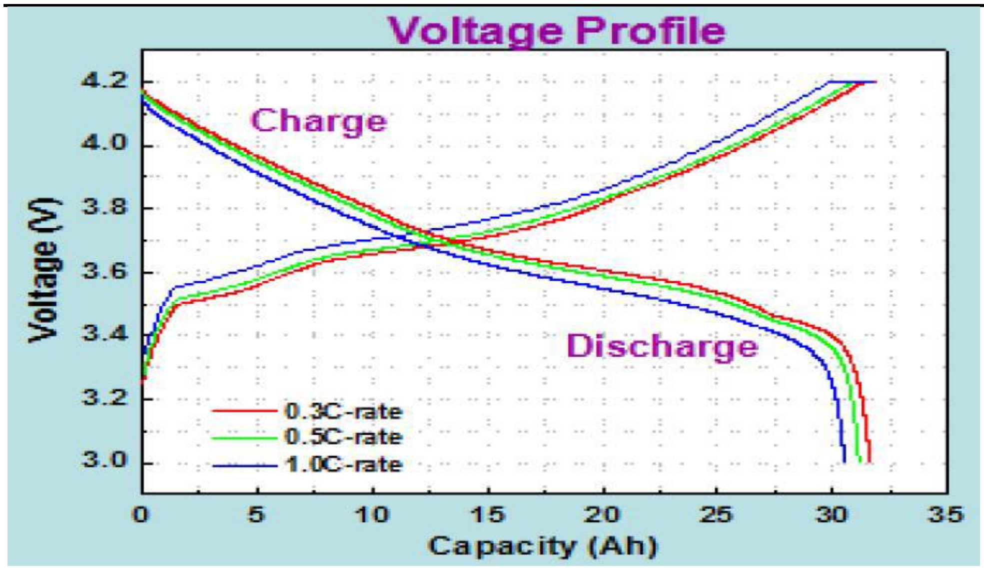
3. DESIGN OF BATERY ENERGY STORAGE SYSTEM

3.1. STORAGE SYSTEM

Once the type of battery to be used, Li-ion, is determined, we design the Battery Energy Stator System (BESS), based on commercial models available in the market.
Analyzed the catalogs and available technical information we chose LG Chem batteries integrated in Siestorage system of Siemens, as a modular energy storage solution which combines cutting-edge power electronics and high-performance Li-ion batteries for grid applications.
Battery manufacturers distinguish between installed and usable energy storage capacity. The installed energy storage capacity is the maximum amount of energy that could be extracted from the battery (typically at low discharge rates, and disregarding battery lifetime aspects. As an example, consider the LG JH2 cell, the restrictions to the usable capacity is approx. 85% of the installed capacity for a charge/discharge at a C-rate of 1.

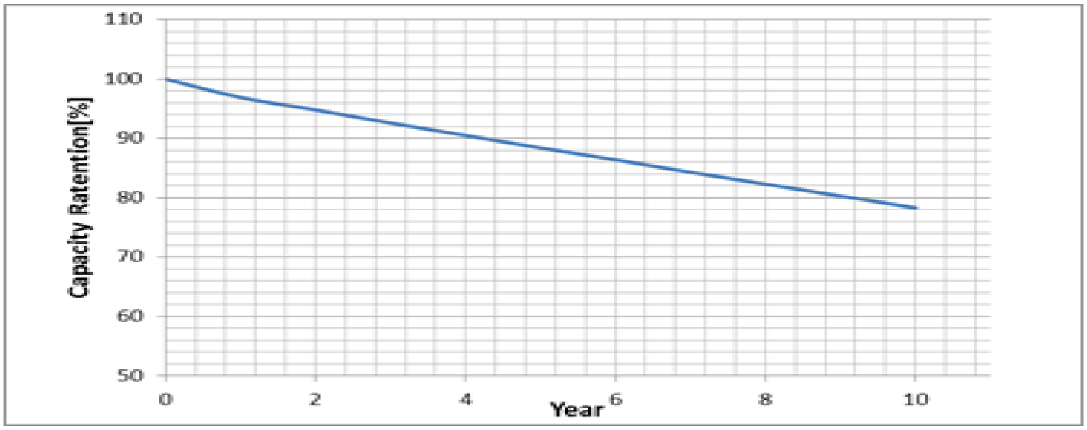
The C-rate describes the ratio of charging or discharging current (in A) divided by the installed capacity (in Ah), e.g.

- Capacity = 62 Ah, Current = 31 A => C-rate = 0.5 (0.5 C)
- Capacity = 62 Ah, Current = 62 A => C-rate = 1 (1 C)
- Capacity = 62 Ah, Current = 124 A => C-rate = 2 (2 C)



Battery cell voltage (V) vs. energy content (Ah) for a single LG JH2 battery cell

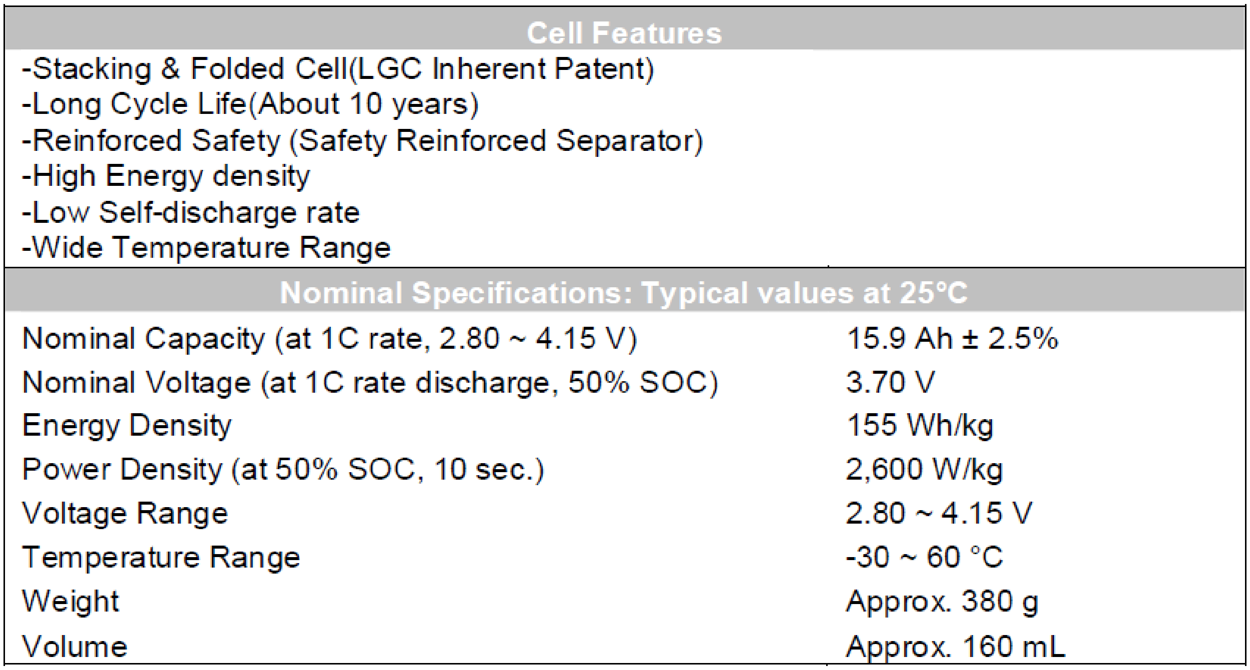
To obtain an Energy Storage block with a capacity of 1 MWh load / discharge we must consider the Capacity Ratention of the batteries over time.



For a 10-year life of our BESS plant, we set the design capacity of 1MWh at the end of the useful life, this implies that initially the capacity must be equal to or greater than 1 / 0.78 = 1,282 MWh. With this minimum capacity we design the battery packs from the models available in the market.

- **LG Battery Cell**

Starting from de battery cels, the technical caracteristics are:



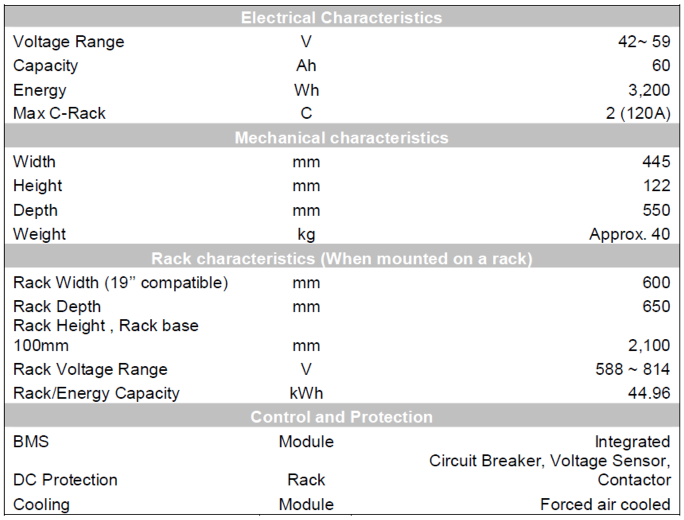
Cell Features

-Stacking & Folded Cell(LGC Inherent Patent)
-Long Cycle Life(About 10 years)
-Reinforced Safety (Safety Reinforced Separator)
-High Energy density
-Low Self-discharge rate
-Wide Temperature Range

Nominal Specifications: Typical values at 25°C	
Nominal Capacity (at 1C rate, 2.80 ~ 4.15 V)	15.9 Ah ± 2.5%
Nominal Voltage (at 1C rate discharge, 50% SOC)	3.70 V
Energy Density	155 Wh/kg
Power Density (at 50% SOC, 10 sec.)	2,600 W/kg
Voltage Range	2.80 ~ 4.15 V
Temperature Range	-30 ~ 60 °C
Weight	Approx. 380 g
Volume	Approx. 160 mL

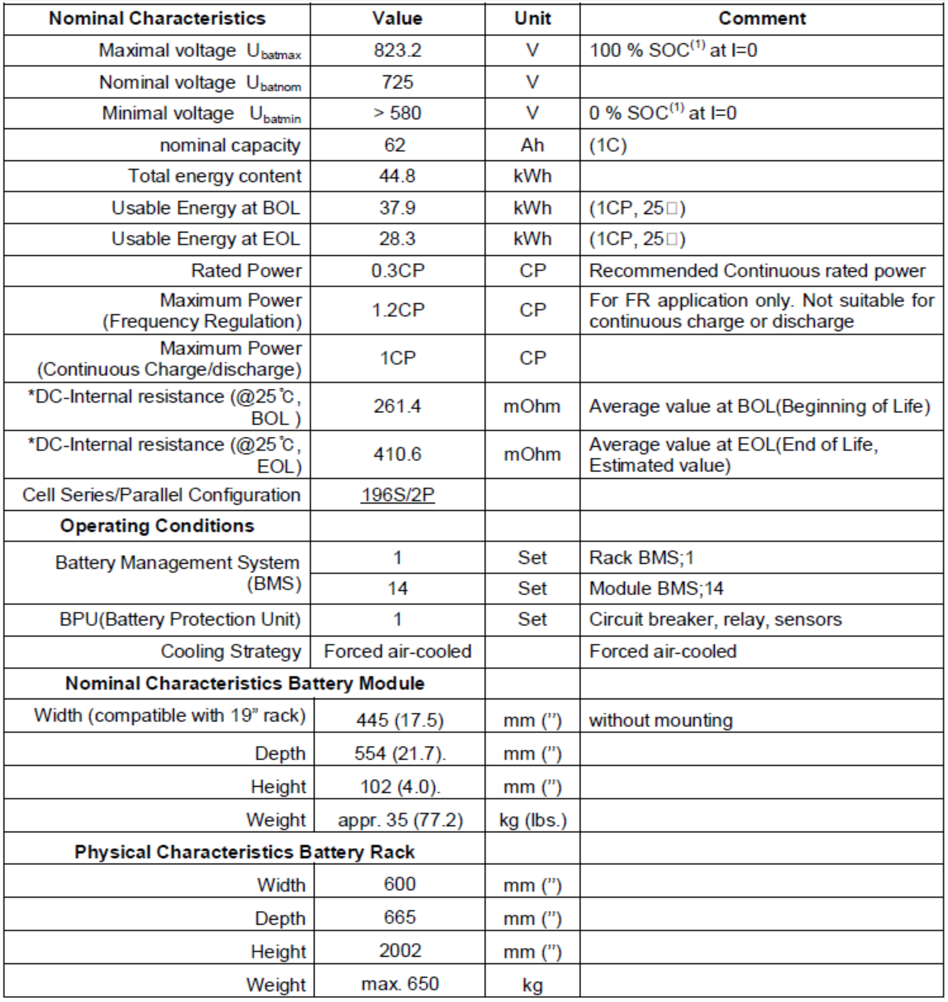
LG provide this battery cels integrates in a module with the the follows caracteristics:

LG ESS Module M4860



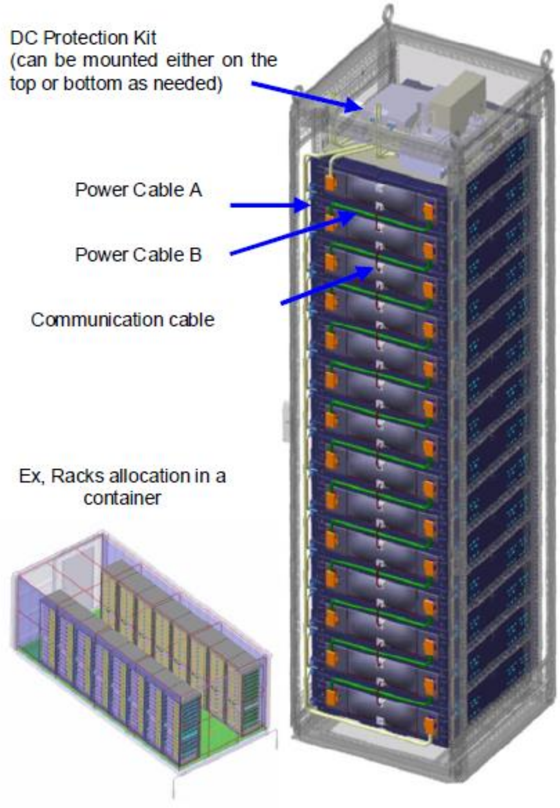
Electrical Characteristics		
Voltage Range	V	42~ 59
Capacity	Ah	60
Energy	Wh	3,200
Max C-Rack	C	2 (120A)
Mechanical characteristics		
Width	mm	445
Height	mm	122
Depth	mm	550
Weight	kg	Approx. 40
Rack characteristics (When mounted on a rack)		
Rack Width (19” compatible)	mm	600
Rack Depth	mm	650
Rack Height , Rack base 100mm	mm	2,100
Rack Voltage Range	V	588 ~ 814
Rack/Energy Capacity	kWh	44.96
Control and Protection		
BMS	Module	Integrated
DC Protection	Rack	Circuit Breaker, Voltage Sensor, Contactor
Cooling	Module	Forced air cooled

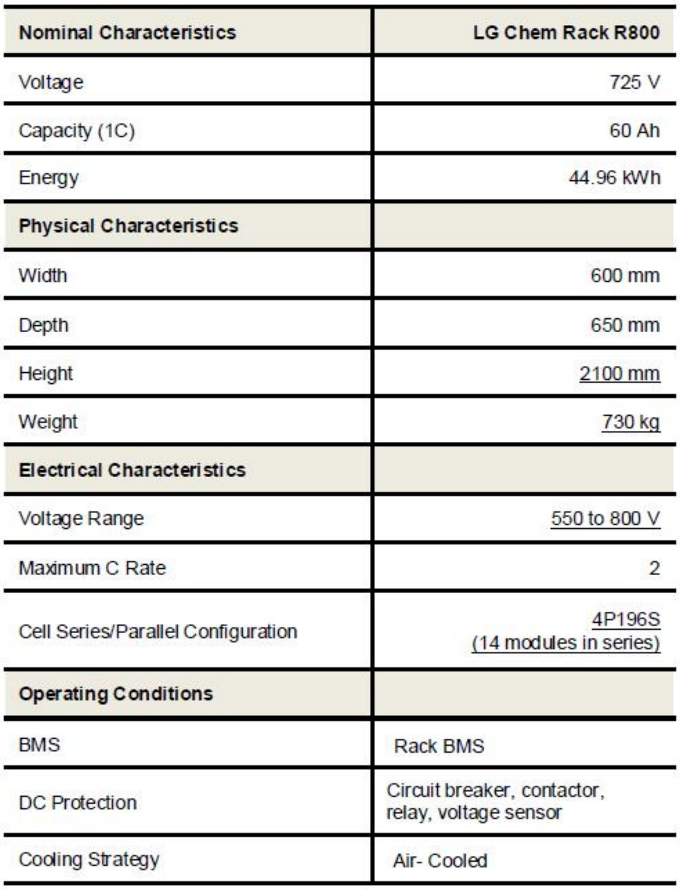
LG Chem. provides fully assembled battery racks containing up to 14 battery modules. The battery modules have a maximum voltage of 60 V DC, and they can be pulled out, inserted and moved individually. The dimensions (W x D x H) of a battery rack are 600mm x 600mm x 2200mm



Nominal Characteristics	Value	Unit	Comment
Maximal voltage U_{batmax}	823.2	V	100 % SOC$^{(1)}$ at I=0
Nominal voltage U_{batnom}	725	V	
Minimal voltage U_{batmin}	> 580	V	0 % SOC$^{(1)}$ at I=0
nominal capacity	62	Ah	(1C)
Total energy content	44.8	kWh	
Usable Energy at BOL	37.9	kWh	(1CP, 25□)
Usable Energy at EOL	28.3	kWh	(1CP, 25□)
Rated Power	0.3CP	CP	Recommended Continuous rated power
Maximum Power (Frequency Regulation)	1.2CP	CP	For FR application only. Not suitable for continuous charge or discharge
Maximum Power (Continuous Charge/discharge)	1CP	CP	
*DC-Internal resistance (@25℃, BOL)	261.4	mOhm	Average value at BOL(Beginning of Life)
*DC-Internal resistance (@25℃, EOL)	410.6	mOhm	Average value at EOL(End of Life, Estimated value)
Cell Series/Parallel Configuration	196S/2P		
Operating Conditions			
Battery Management System (BMS)	1	Set	Rack BMS;1
	14	Set	Module BMS;14
BPU(Battery Protection Unit)	1	Set	Circuit breaker, relay, sensors
Cooling Strategy	Forced air-cooled		Forced air-cooled
Nominal Characteristics Battery Module			
Width (compatible with 19" rack)	445 (17.5)	mm ('')	without mounting
Depth	554 (21.7).	mm ('')	
Height	102 (4.0).	mm ('')	
Weight	appr. 35 (77.2)	kg (lbs.)	
Physical Characteristics Battery Rack			
Width	600	mm ('')	
Depth	665	mm ('')	
Height	2002	mm ('')	
Weight	max. 650	kg	

Technical Data of the LG Battery Rack JH2





Nominal Characteristics	LG Chem Rack R800
Voltage	725 V
Capacity (1C)	60 Ah
Energy	44.96 kWh
Physical Characteristics	
Width	600 mm
Depth	650 mm
Height	2100 mm
Weight	730 kg
Electrical Characteristics	
Voltage Range	550 to 800 V
Maximum C Rate	2
Cell Series/Parallel Configuration	4P196S (14 modules in series)
Operating Conditions	
BMS	Rack BMS
DC Protection	Circuit breaker, contactor, relay, voltage sensor
Cooling Strategy	Air- Cooled

According to the established design capability, we will have 30 racks of the LG Battery model JH2

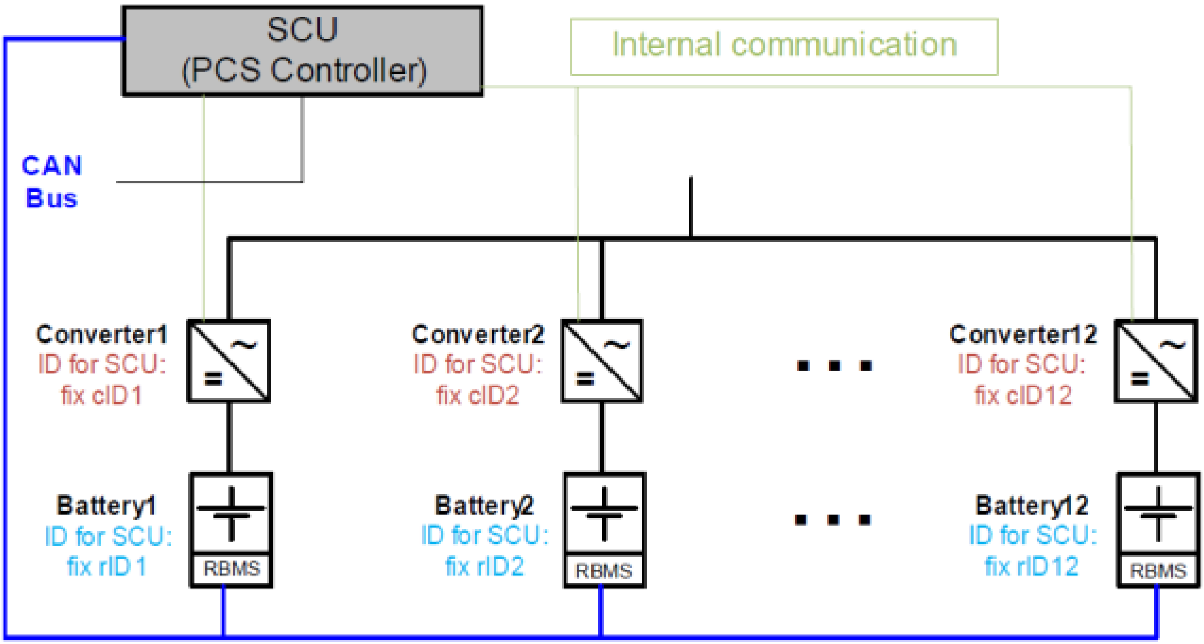
- **LG Battery Management System**

Together with the battery modules and battery racks, LG Chem. provides a hierarchical Battery Management System (BMS). Each battery module is controlled by a Module BMS; each battery rack is controlled by a Rack BMS. The Rack BMS is part of the Battery Rack and installed at the bottom level.

If several racks are to be connected in parallel, then an additional Bank BMS is needed. A Bank BMS can control up to 14 battery racks. For our 30 battery racks, we need 3 bank of BMS

The Battery Management System (BMS) has the following tasks:

- Measurement of relevant battery data (voltages, currents, temperatures)
- Realization of security concept, e.g.
    - cell voltage monitoring
    - temperature monitoring
    - current monitoring
    - fault switch-off
- Monitoring of operational data, e.g.
    - State of Charge (SOC)
    - State of Health (SOH).
- Charge and Discharge Management
- Charge algorithm
- Charge / Discharge control
- Thermal management
- Cell voltage balancing



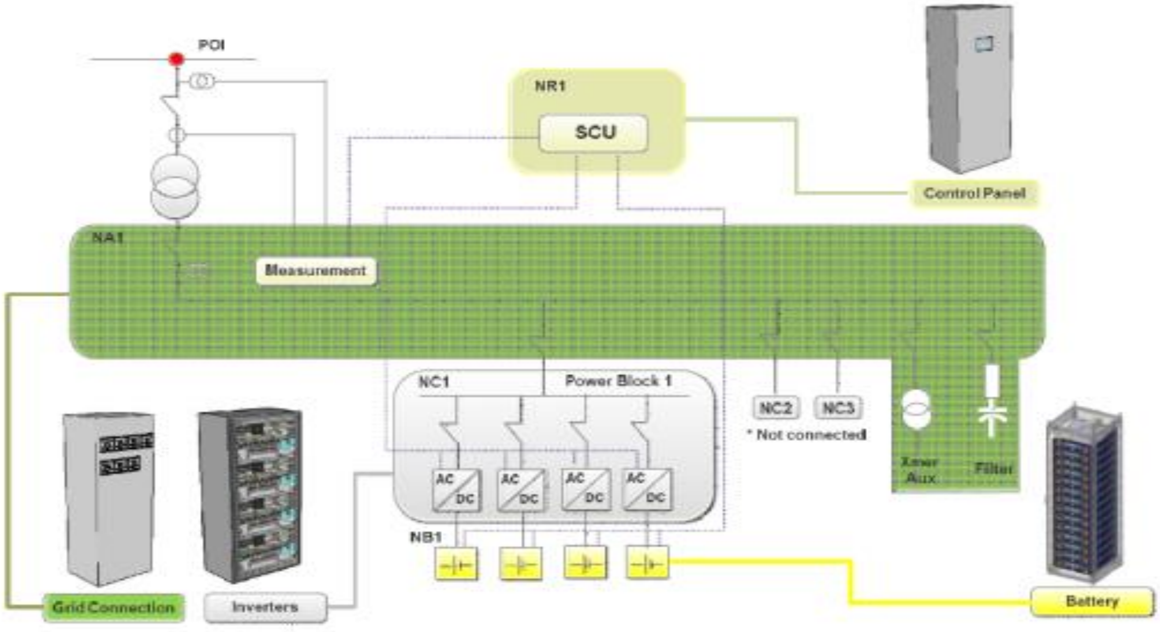
Setup with Rack BMS (RBMS)

3.2. BASIC SYSTEM CONFIGURATION

One standard block (named 4PS) of SIESTORAGE system design whit 4 Converter Units (118 kVAs each), is based in four main modules:

- Control Cabinet (NR1)
- Power Distribution and Network Connection Cabinet (NA1)
- Inverter Panel (NC1)
- 4 Battery Racks (NB1…4)

The diagram below shows the electrical connection and mechanical layout of a typical 4PS block



In order to facilitate the maintenance and safe operation, the battery modules have a maximum voltage of 60 V DC, and can be pulled out, inserted and moved individually. Each battery cabinet is individually connected to a single inverter; then all the four inverters are interconnected on the AC side.

The converter used is the SIPLINK converter. Each SIPLINK bidirectional inverter charges and discharges only its respective battery rack. Operating commands and sequence of operation of the power inverters are dictated by the SCU (SIPLINK CONTROL UNIT).

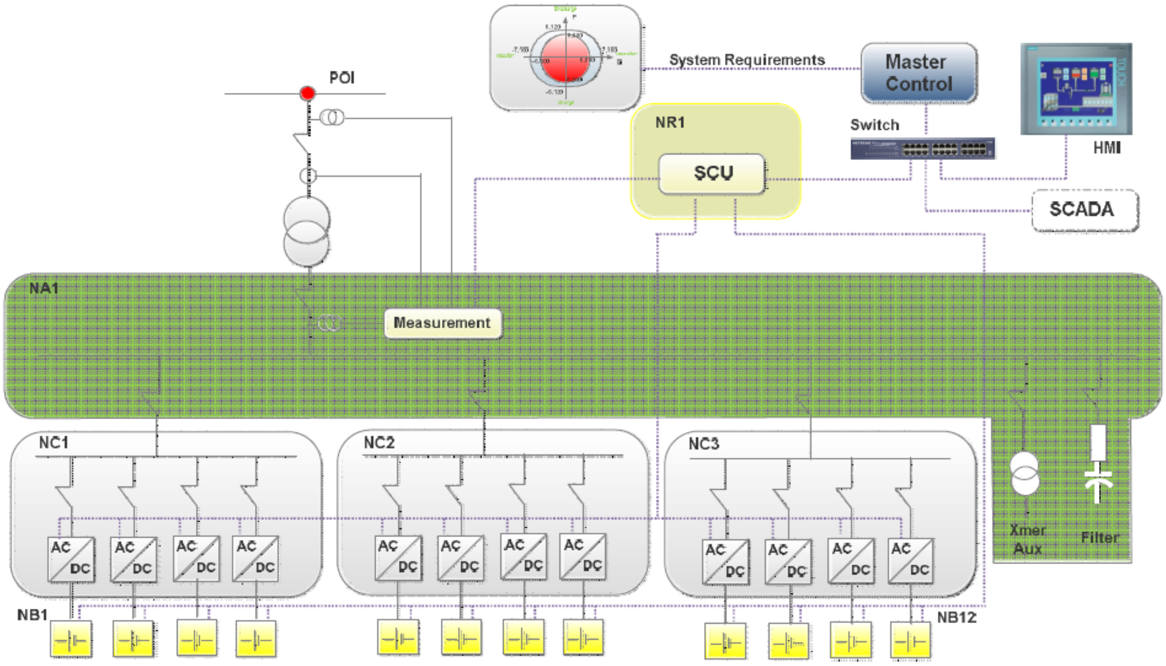
Every battery rack is equipped with one Battery Management System (BMS). The intelligent BMS monitors, for instance, parameters such as the state of charge, voltage and temperature of the individual battery modules. The BMS exchanges data with the SCU located in the Communication panel of its respective block.

Based on this standard block, we configured our BESS plant, sized for the 30 battery racks defined above.

- **System Configuration Proposed**

In order to operate the energy storage system we additionally need a Switch to manage the communications between the SCU and the different devices:

- The human machine interface (HMI),
- The Master Control. The one receiving the data and / or network requirements
- The SCADA system of the Wind Farm owner



The connection to the electrical network, is performed through a transformer and its auxiliary equipment to ensure the safe operation, protection, control and energy measurement. Thesse functionalities are provides by the Power Distribution and Network Connection Cabinet (Substation side).

The power transformer is considered between this cabinet and the grid to adapt the output from the system with the voltage level required by the grid.

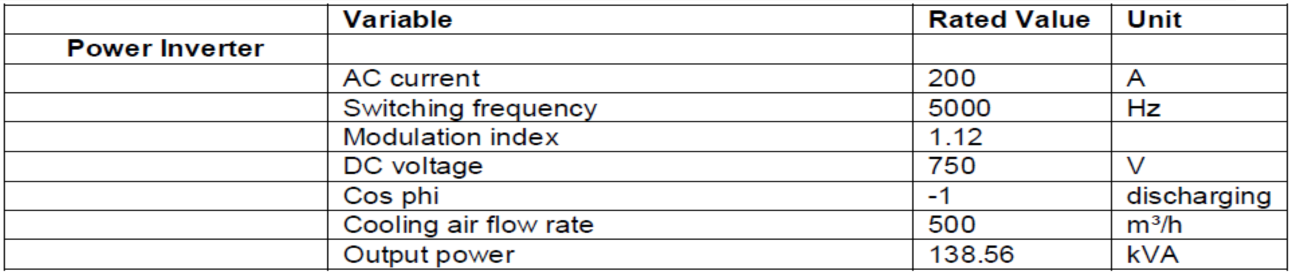
The Power Distribution and Network Connection Cabinet is equipped with filters for mitigation of

harmonics and measurement units. An auxiliary transformer is included in the cabinet to provide auxiliary power supply, for instance, to heating and HVAC systems.

3.2.2 Overview of Components

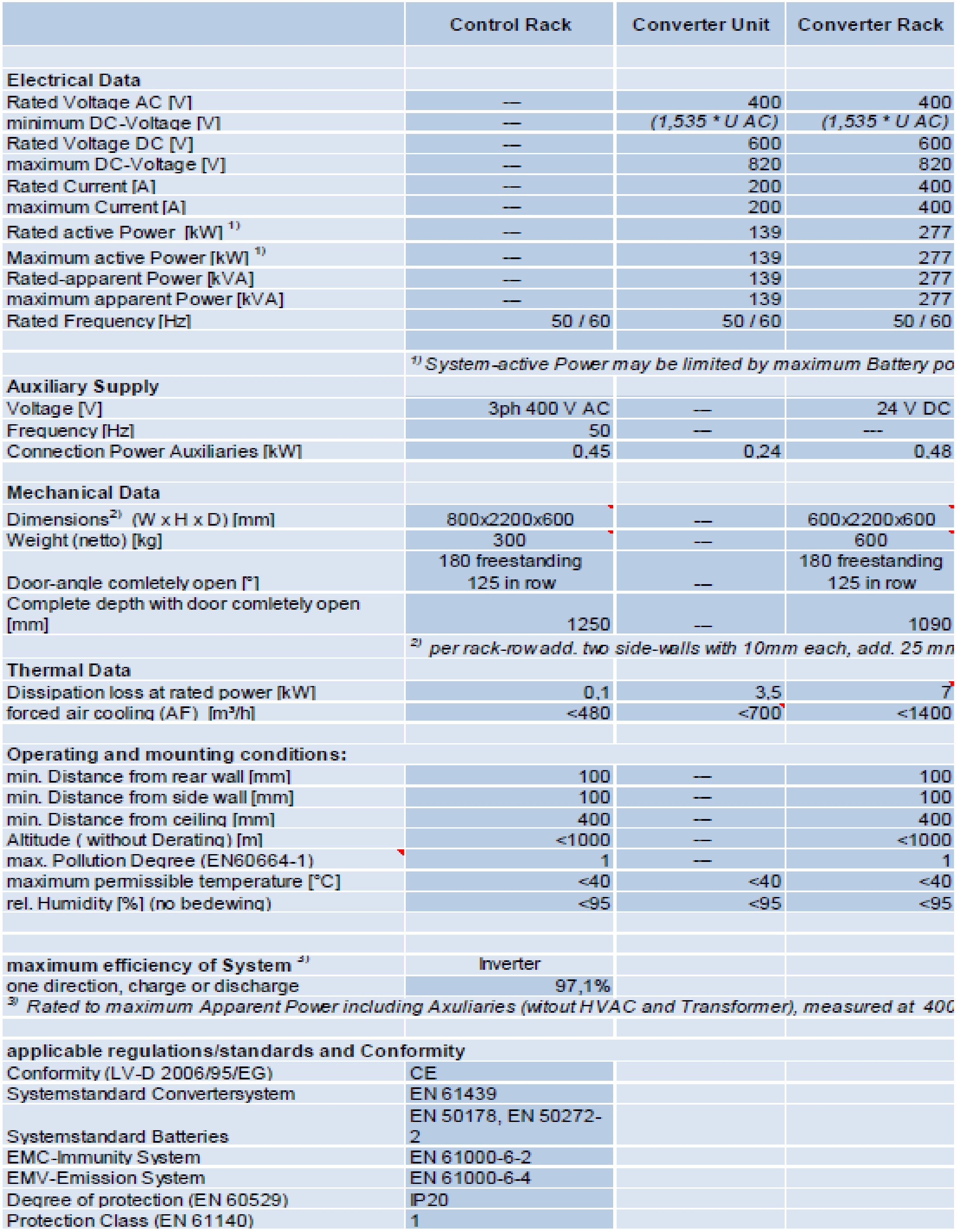
- **Converter Panel**

The converter rack in an electrical cabinet is also referred to as converter cabinet. Since the losses of a power converter depend on the operating conditions, the typical operating conditions (“rated values”) for the rated power need to be defined. The rated values listed below are based on the datasheet used in each SIESTORAGE power converter.



	Variable	Rated Value	Unit
Power Inverter			
	AC current	200	A
	Switching frequency	5000	Hz
	Modulation index	1.12	
	DC voltage	750	V
	Cos phi	-1	discharging
	Cooling air flow rate	500	m^3/h
	Output power	138.56	kVA

Rated values for the rated power

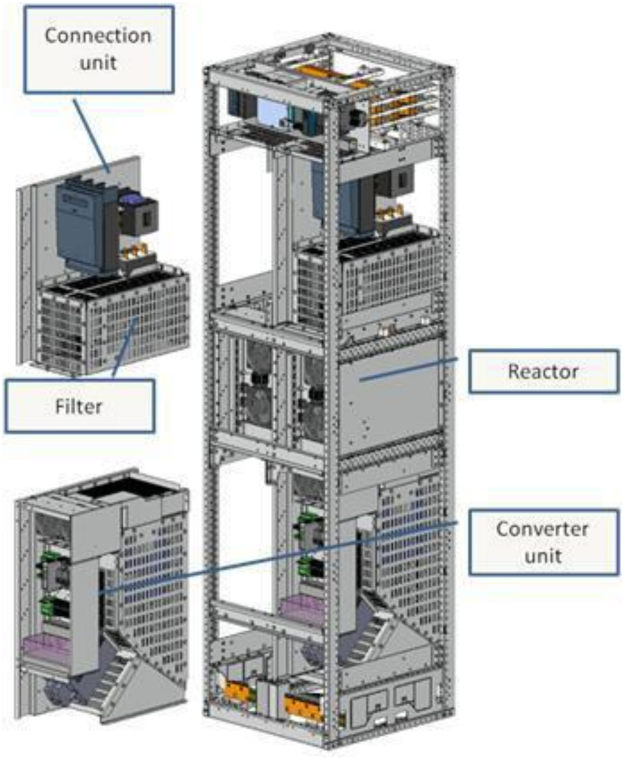


	Control Rack	Converter Unit	Converter Rack
Electrical Data			
Rated Voltage AC [V]	---	400	400
minimum DC-Voltage [V]	---	*(1,535 * U AC)*	*(1,535 * U AC)*
Rated Voltage DC [V]	---	600	600
maximum DC-Voltage [V]	---	820	820
Rated Current [A]	---	200	400
maximum Current [A]	---	200	400
Rated active Power [kW] 1)	---	139	277
Maximum active Power [kW] 1)	---	139	277
Rated-apparent Power [kVA]	---	139	277
maximum apparent Power [kVA]	---	139	277
Rated Frequency [Hz]	50 / 60	50 / 60	50 / 60
	1) System-active Power may be limited by maximum Battery po		
Auxiliary Supply			
Voltage [V]	3ph 400 V AC	---	24 V DC
Frequency [Hz]	50	---	---
Connection Power Auxiliaries [kW]	0,45	0,24	0,48
Mechanical Data			
Dimensions 2) (W x H x D) [mm]	800x2200x600	---	600x2200x600
Weight (netto) [kg]	300	---	600
Door-angle comletely open [°]	180 freestanding 125 in row	---	180 freestanding 125 in row
Complete depth with door comletely open [mm]	1250	---	1090
	2) per rack-row add. two side-walls with 10mm each, add. 25 m		
Thermal Data			
Dissipation loss at rated power [kW]	0,1	3,5	7
forced air cooling (AF) [m^3/h]	<480	<700	<1400
Operating and mounting conditions:			
min. Distance from rear wall [mm]	100	---	100
min. Distance from side wall [mm]	100	---	100
min. Distance from ceiling [mm]	400	---	400
Altitude (without Derating) [m]	<1000	---	<1000
max. Pollution Degree (EN60664-1)	1	---	1
maximum permissible temperature [°C]	<40	<40	<40
rel. Humidity [%] (no bedewing)	<95	<95	<95
maximum efficiency of System 3)	Inverter		
one direction, charge or discharge	97,1%		
3) Rated to maximum Apparent Power including Axuliaries (witout HVAC and Transformer), measured at 40			
applicable regulations/standards and Conformity			
Conformity (LV-D 2006/95/EG)	CE		
Systemstandard Convertersystem	EN 61439		
Systemstandard Batteries	EN 50178, EN 50272-2		
EMC-Immunity System	EN 61000-6-2		
EMV-Emission System	EN 61000-6-4		
Degree of protection (EN 60529)	IP20		
Protection Class (EN 61140)	1		

Technical data of the SIESTORAGE product

- **Overall Layout Converter Rack**

Front View Converter Rack



Details of the Converter Module Assembly

The connection module (contactor, fuse disconnector, RC-Filter) and the converter module (Power Stack, DC-contactor, pre-charge, Control-box) are extractable for easy replacement or service. The converter unit has to be connected to the Control Rack and also with the AC-connection rack.

- **Control Panel**

The SCU and Measurement Cards are mounted on the Control Panel of their respective Power Block. The Master Control Unit and HMI are assembled in one of the Control Panels.

The interface to any upper level control system (i.e. Substation Controller, etc) is carried out from an internet switch. A range of different protocols is available as shown in the miscellaneous section

- **Overall Layout Control Panel**l

The control cabinet contains the following components:

(1) SCU control rack

(2) Internal voltage measurement

(3) SITOP 24 V power supply

(4) AC Distribution MCB‘s

(5) DC Distribution MCB‘s

(6) SIMATIC S7, ET200 and touch panel

(7) Terminals

(8) Terminal-Relays

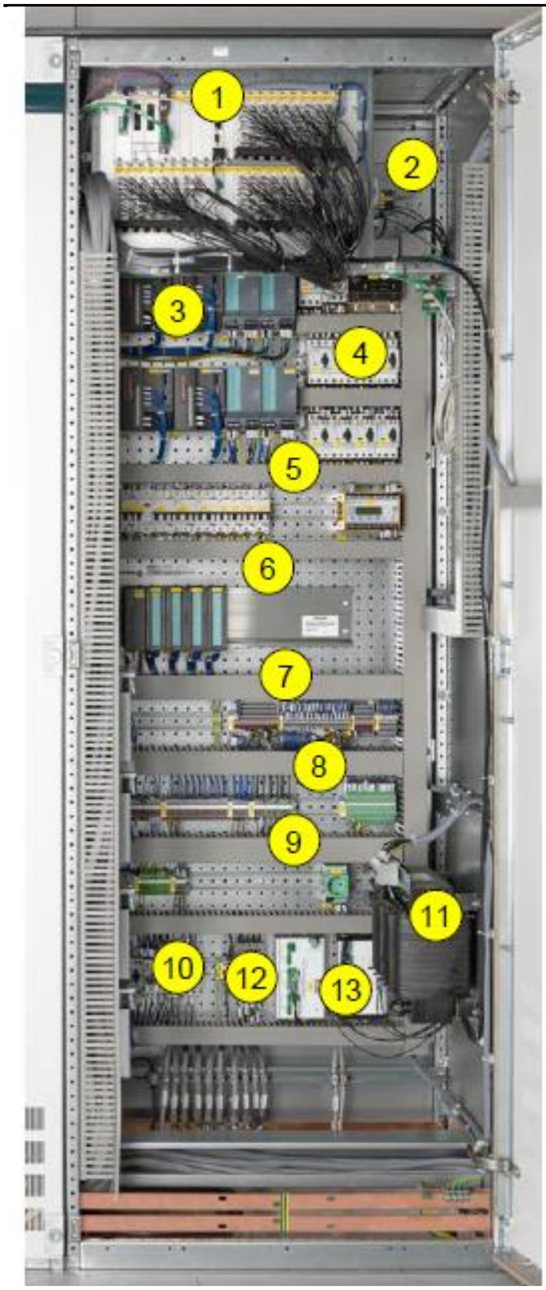
(9) 230 V socket

(10) AC auxiliary supply input MCB and switch over

(11) AC auxiliary supply transformer

(12) Current measurement terminals

(13) External current and voltage measurement,



Front View Control Rack Figure Look inside the control rack

The SCU in the control cabinet communicates with the driver boards of the power converters via fibre-optic cables (FOCs).

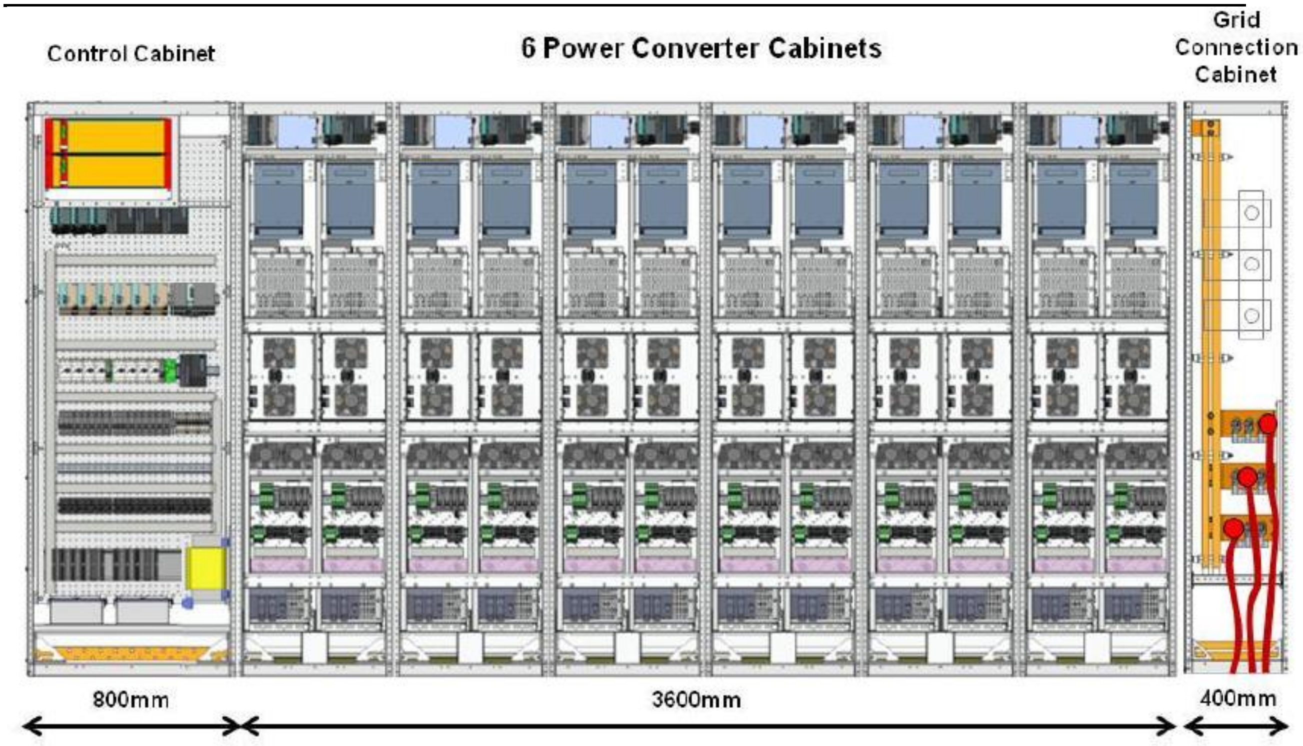
The Simatic S7 communicates with the touch panel via the integrated MPI interface. The standard S7 protocol is used for this communication. The integrated Ethernet port on the touch panel can be used for a separate connection to a different network (for example an office network). On this Ethernet connection the touch panel can be remotely controlled by a web client. The touch panel is working as a web server and the access to this server is password protected The Simatic S7 is the master controller of the SIESTORAGE system. System operation and control mode, as well as corresponding nominal values for control algorithms are set via the S7 interfaces or the panel.

The master controller consists of following two major parts:

- The S7 system for data handling, control and communication (SCU, overall system and panel).

- The touch panel as interface to the operator and logging unit.

The following figure shows an example of configuration including a control cabinet, 6 converter cabins and an auxiliary cab connecting the Low Voltage



Example of PS SIESTORAGE System Configuration

- **LV Panelboards**

As low voltage power distribution, we select SIVACON® S8. It permits a power distribution board system up to 7,000 A for the simple and consistent distribution of power guarantees maximum personal and system safety.

The low-voltage power distribution board is a design-tested power switchgear and controlgear assembly with a design verification based on testing.

- **MV/LV Transformer**
-

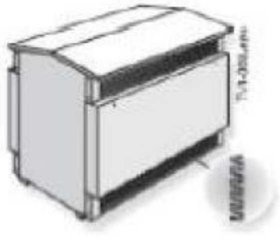
The grid connection transformer for LV applications has to be Dy – type, with the y on the grid side. In this case, a star-point can be connected at the grid side.

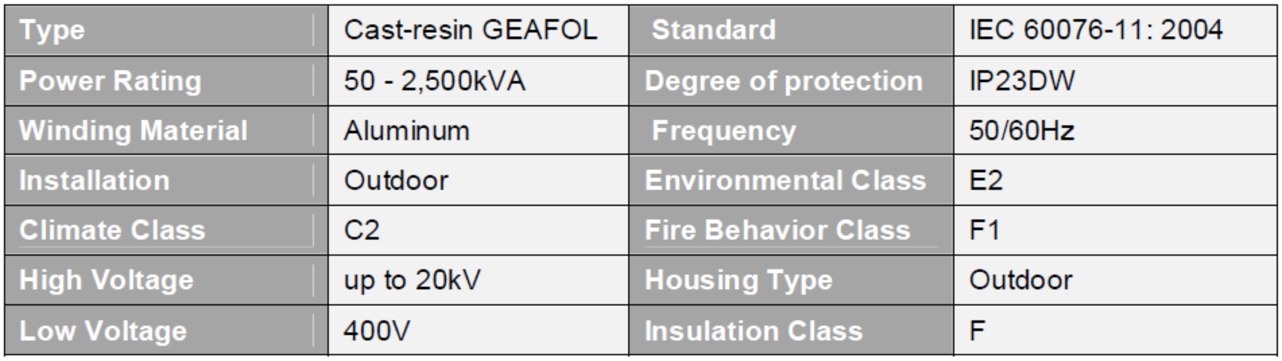
Heavier dynamic and thermal stresses due to the rapid changes in load require special transformers to work with static converters. Siemens cast-resin dry-type transformers GEAFOL has its windings properly designed to cope with the stress and the current curves generated during the operation of the SIESTORAGE static converters.

Besides its mechanical design, a key advantage of the utilization of GEAFOL transformer is that it can be easily integrated anywhere – directly at the site, regardless of whether a commercial or residential building is involved, or an industrial plant.

Requirements stipulated in regulations such as those for fire protection or water conservation can be easily satisfied using GEAFOL cast-resin dry-type transformers. The design employed is not only flame-retardant and self extinguishing, humidity-proof and tropic-proof, but is also low-noise.

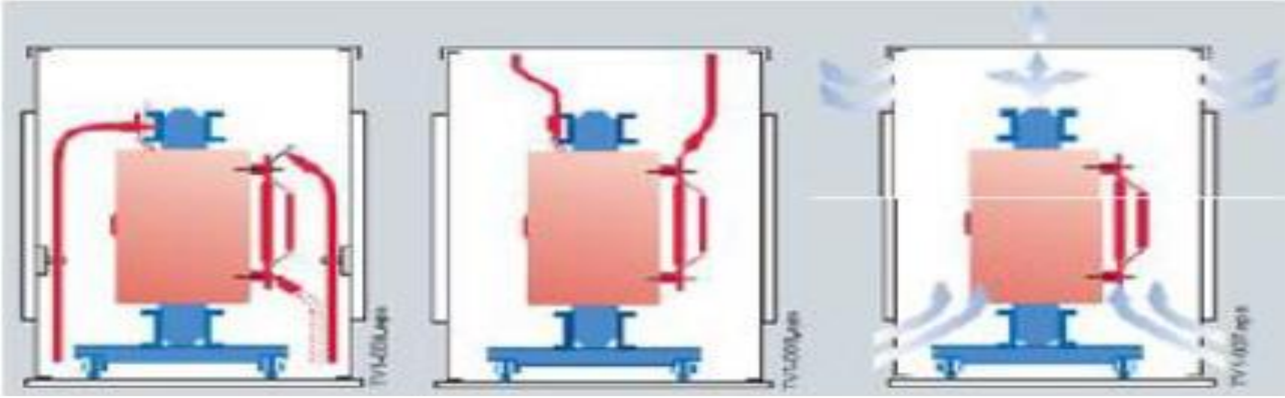
The following specification represents the typical technical data sheet for the transformers applied on SIESTORAGE Projects.





Type	Cast-resin GEAFOL	**Standard**	IEC 60076-11: 2004
Power Rating	50 - 2,500kVA	**Degree of protection**	IP23DW
Winding Material	Aluminum	**Frequency**	50/60Hz
Installation	Outdoor	**Environmental Class**	E2
Climate Class	C2	**Fire Behavior Class**	F1
High Voltage	up to 20kV	**Housing Type**	Outdoor
Low Voltage	400V	**Insulation Class**	F

The GEAFOL presents variable connection techniques. The cables can be brought in through the bottom, the cover or one of the sides (Fig. 7a and 7b). No reduction in output thanks to natural ventilation inside protective housing (Fig. 7c).



Cabling details A & B, ventilation C

Next table includes the technical descriptions for a transformer of 1.250 kVA

Technical description **Item ID: 1250kVA 33/0.36kV rectifier**

Type designation	4GD6176-1DG
Design:	GEAFOL® Three-phase cast-resin rectifier transformer
Transformer acc. to …	IEC 60076-11:2004 / VDE 0532
Environmental class	E2
Climatic class	C2
Fire behaviour class	F1
Installation	Indoor
Altitude installation	1000 m
Ambient temperature	40 °C
Temp. rise windings HV / LV	**80 K / 80 K**
Thermal class HV / LV	F / F
Frequency	50 Hz
Type of duty	continuous **
Type of cooling	AN
Protection	IP 00
Rated power	1250 kVA
Vector group	Dy5
High voltage	33000 V
tappings	±2,5; ±5%
tappings at …	Front
insulation level	LI 145 AC 70
Low voltage (U2)	360 V
insulation level	LI - AC 3
No load losses*	3600 W +15 %
Load losses (PK 75)*	10000 W +15 %
Load losses (PK 120)*	11500 W +15 %
Total losses tolerance	+10 %
Impedance voltage	6 % ±10 %
Winding material LV / HV	Alu / Alu
Terminals:	
High voltage	Top
Low voltage	Top
Dimensions, approximately	
Length x width x height	2050 mm x 1100 mm x 2050 mm
Distance between rollers	820 mm
Total mass	4100 kg
Painting scheme	
Color RAL… , thickness	RAL 5009 , 80 µ
Accessories:	
Transport rollers	4 pcs
Thermal protection	3 x Pt100 in the windings + 1xPt100 on the core
Thermal protection relay	1 x T154
Other accessories 1.	Elektrostatic shield between HV and LV windings
Other accessories 2.	Earthing ball on HV (3 pcs.) and LV side (4 pcs.)
Surge arrester or holder	without!
Remark:	***The guaranteed values are valid in case of sinusoidal induction.**
	**** Max. overload: 1390kVA (+11%) during 120 min per day.**

- **MV Switchgear**

The MV Switchgear is located in the Substation of the wind farm. As MV Switchgear we select the Siemens NX Plus Indoor Gas Insulated, rated for applications up to 40,5 kV and 31,5kVA. The technical characteristics are:

- Use of vacuum circuit-breakers.
- Three-pole hermetically sealed enclosure per panel, made of stainless steel.
- Small type of construction due to SF6-insulation of medium-voltage part.
- Insulation properties of SF6-gas constant throughout the operating life.
- Independent of environmental influences.
- Medium-voltage part absolutely maintenancefree.
- Use of ring-core current transformers outside the enclosure (free from dielectric stress).
- Voltage transformers are of the metalenclosed, plug-in type.
- Switchgear installation without gas work.
- The specified switchgear is a factory-assembled, type-tested, threepole metal-enclosed SF6 mediumvoltage switchgear.
- The entire switchgear is designed safe-totouch from the busbars down to the cable connection. Furthermore the switchgear is conceived in such a way that no gas work is required for panel replacement.
- Individual panels are interconnected by solid-insulated, plug-in busbars outside the SF6-gas compartment. The busbars are located in a metal-enclosed compartment..
- The three-position disconnector reduces the functional elements inside the enclosure and has to be used for make-proof earthing in combination with the circuit-breaker.
- Current transformers are designed as exchangeable ring-core current transformers located outside the SF6-enclosure, which are therefore not subjected to dielectric stress.
- The medium-voltage part are maintenance-free and independent of environmental influences.
- The switchgear are resistant to arc faults, i.e. it must satisfy Criteria 1 to 5 of IEC 62 271-200, arcfault duration: 1 second. The resistance to internal arc faults to protect the operating personnel has to be proven for all accessible sides of the switchgear according IEC 62271-200. A corresponding IACclassification has to be submitted.
- All switching devices are to be operated from the panel front. It permits to control the vacuum circuit-breakers from remote.

- All medium-voltage components of the switchgear are hermetically enclosed and safe-to-touch.
- Capacitive dividers in the bushing to the cable connection compartment are enable the verification of safe isolation from supply at the panel front.
- The closed gas compartment haves its own pressure relief, which prevents uncontrolled bursting of the gas compartment in case of an internal arc fault.

- **Siemens SIPROTEC Relay**

As protection relay we select SIPROTEC from Siemens. This relay are consistently used throughout all applications in medium and high voltage.

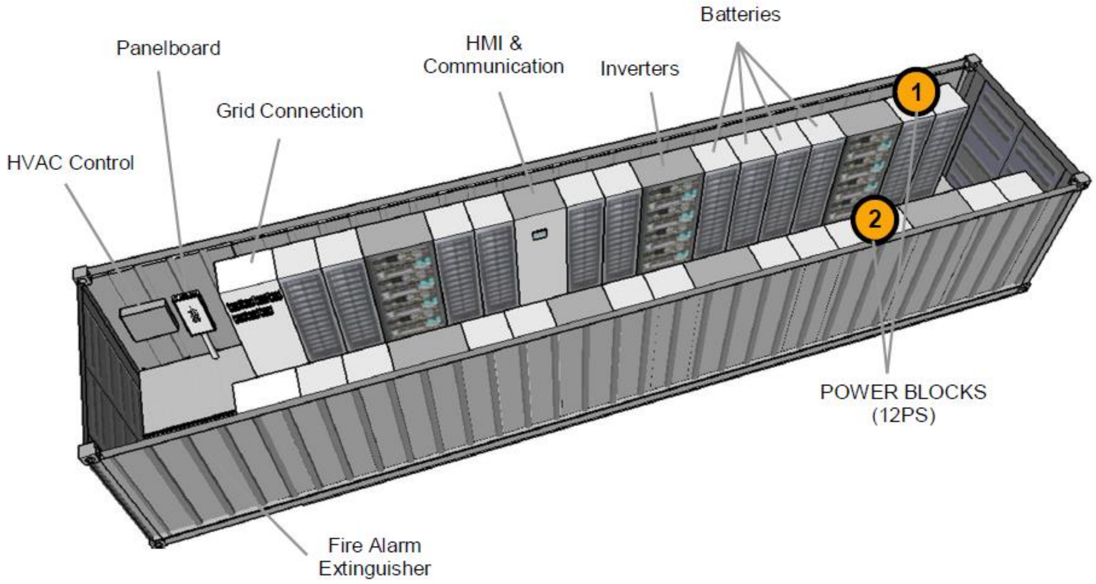
The diversity of SIPROTEC protection technology – with its unique technology and intelligent algorithms – reliably protects all equipment, ensuring selective fault tripping even under the most difficult circumstances. Owing their CFC logic, SIPROTEC protection devices can be adapted to the different requirements and demands.

Highlights:

- Just one SIPROTEC device handles all tasks in the feeder circuit: protecting – controlling – measuring – automating
- Just one operating program (DIGSI 4) is sufficient for all protective devices and all configuring and operating tasks
- User-friendly, easy parameterization
- Cheap engineering owing to the direct data exchange between the engineering tools of the bay control units and the substation control system
- Remote communication permits fast fault clarification and thus targeted service missions on site

- **Container**

The integration of the cabinets into a containerized enclosure ensures a particularly easy application as per the following illustration.



The SIESTORAGE integrated containerized solution permit integrates 30 battery cabinets and 3 bank BMS cabinets into only a single container.

The batteries and power electronics have an optimum and maximum operating temperature range. Thus, a HVAC system is part of the SIESTORAGE container to ensure safety and promote the best asset utilization. To avoid environmental impacts such as dust and moisture, the HVAC system was standardized on the “Split Unit” type. To provide a hermetically sealed design, the inner and outer modules are physically separated, and only connected by a coolant pipeline.

The SIESTORAGE container is also equipped with fire alarm and fighting system (oxygen reduction) is chosen for the fire fighting system. Frequent applied fire detection components are optical smoke detectors, temperature rise detectors, main fire alarm system, fire alarm (manual) on each door, pressure sensor to activate the fire suppression system on each door, door contacts (fire fighting system activation), optical and acoustic alarms.

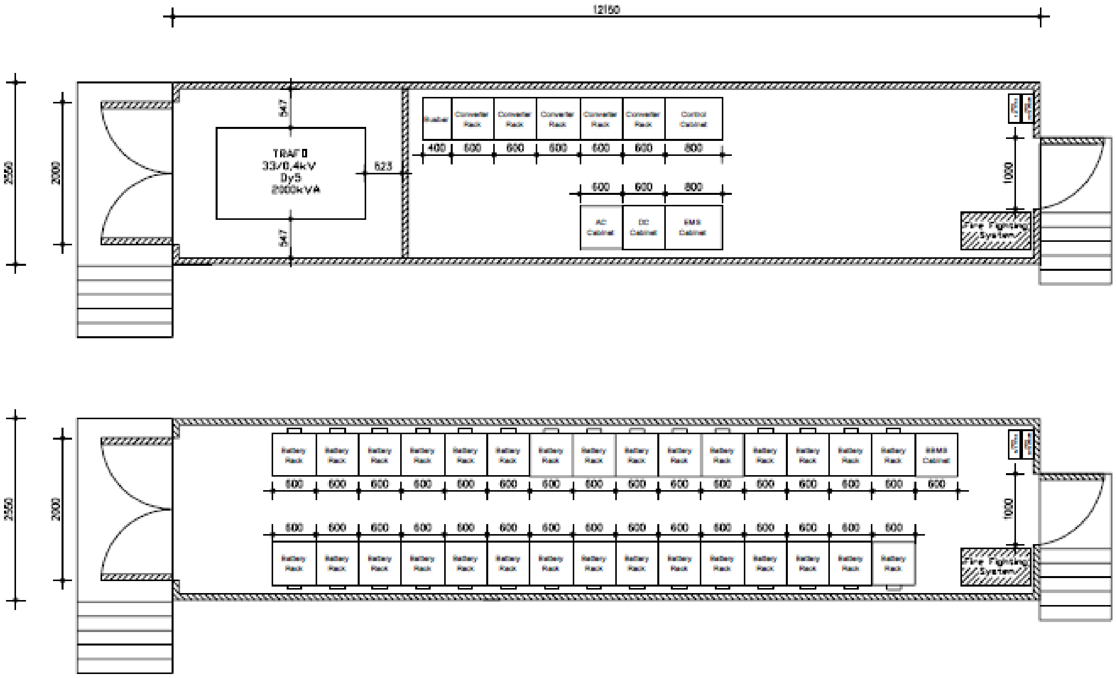
The access to the SIESTORAGE container is monitored through the supervision of positioning switches mounted on each access door. A status contact from every door positioning switch is hardwired to an I/O module connected to the master control system. By using the same communication infrastructure of the power inverter and battery systems, the access monitoring of the container can also be performed remotely

3.2.3 Solution Layout

Our BESS will be installed in two containers that will include:

- **Container 1:**
    - 30 Battery racks.
    - 3 bank of BMS
- **Container 2**
    - 5 Converters panels.
    - 1 Control cabinet.
    - 1 LV panelboard.
    - 1 Transformer 33/0,36 kV of 1250 kVA
    - Aux serv. panel BT
- **Wind farm Substation**
    - 1 Switchgear MV and the protection relay

In order to allocate all these elements, and also using commercial containers, 2 containers of the series SIESTORAGE are necessary in which the different cabins would be installed as indicated in the enclosed figure:

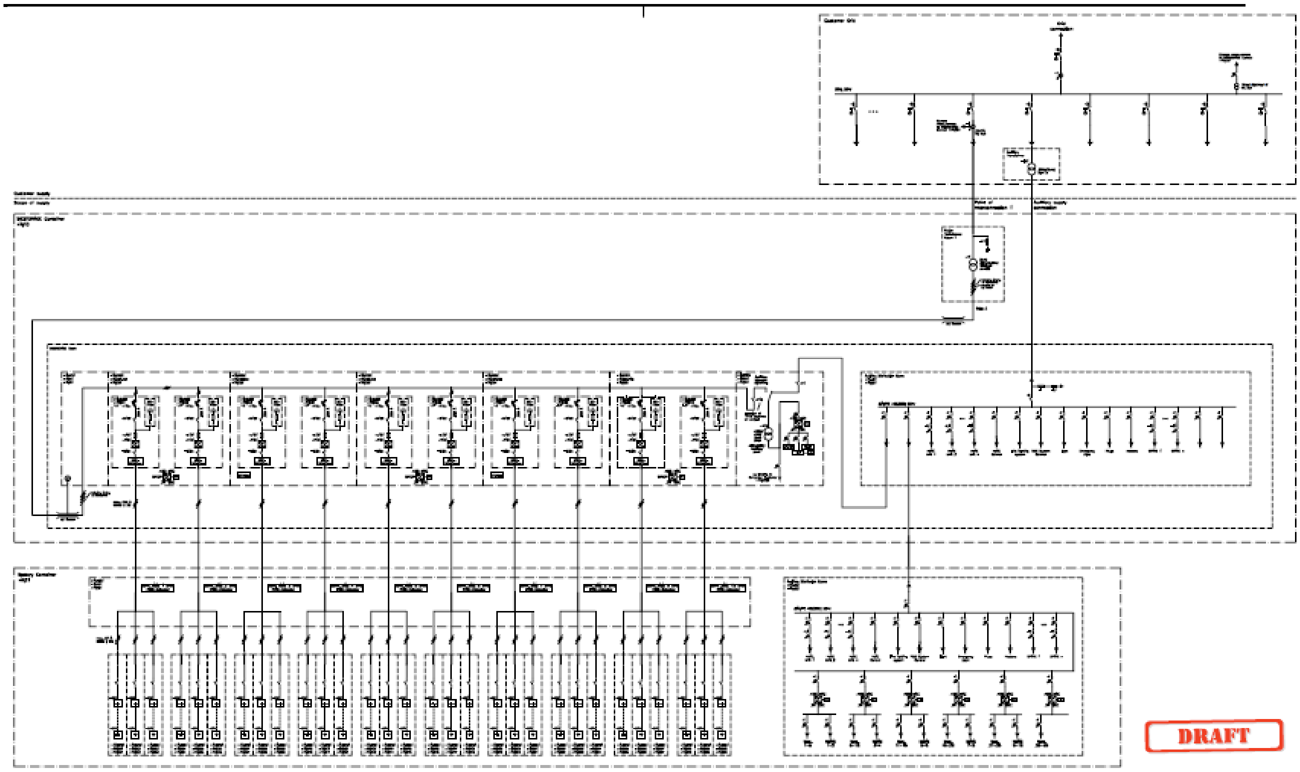


Solution layout

To locate both containers, facilitating access and maintenance work, will have a plot of 21 m * 14 m. Closed perimeter with a protective fence.

3.2.4. Single line diagram

The attached figure includes the electrical diagram of the BESS



Single line diagram

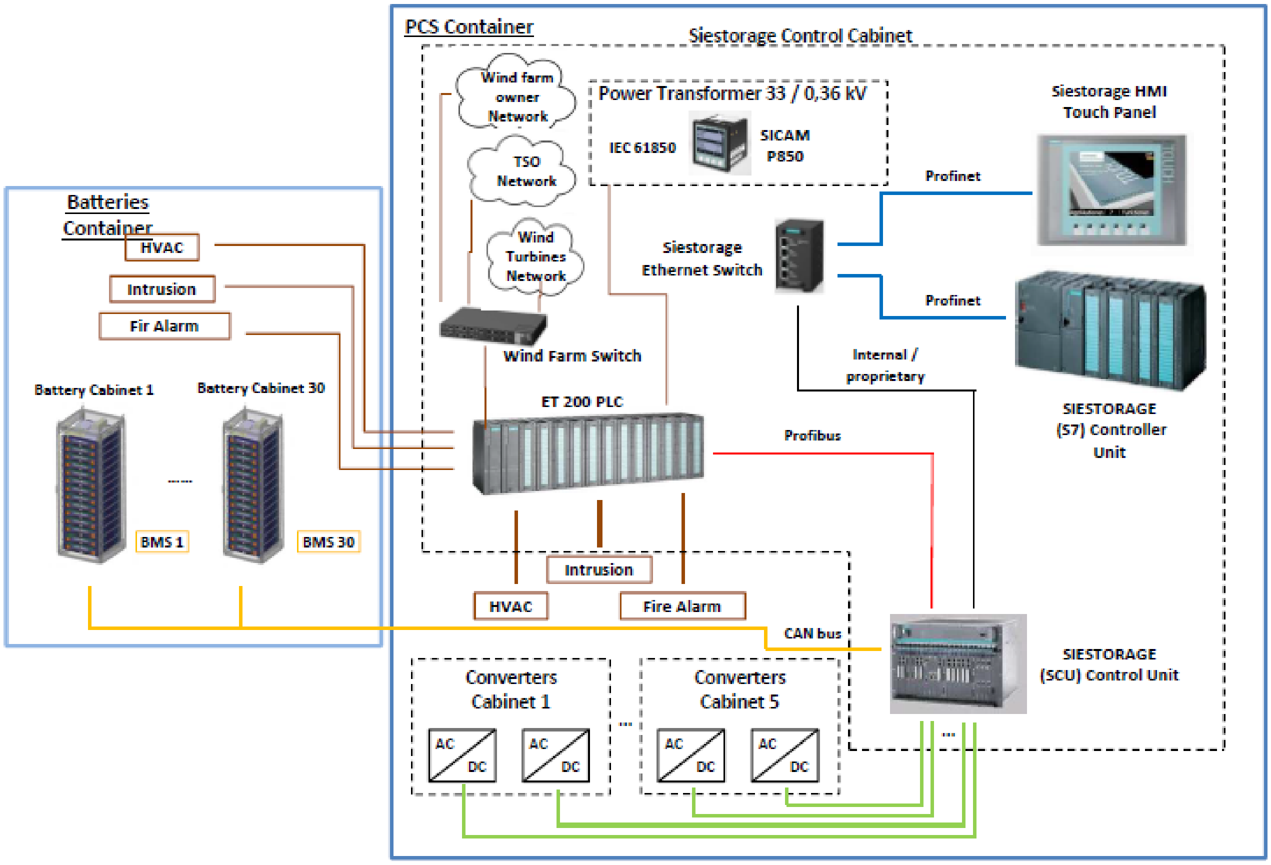
3.2.5 Control System and Communication Architecture

Storage applications can range from a simple turn on/off command to the quite sophisticated applications such as optimitation of renewable integration.

SIESTORAGE communication architecture allows power system management to quickly take place at the lowest levels possible.

El sistema gobierna los ciclos de carga y descarga de las baterías ajustando la energía vertida ala red a la consigna programada en el forecast diario. Igualmente tomalas señales decontorno y seguridad en el emplazamiento para garantizar un funcionamiento seguro de la instalación

The arrangement illustrated below represents a topology with the major components of a SIESTORAGE communication system.



4. ALGORITHM OF MONITORING

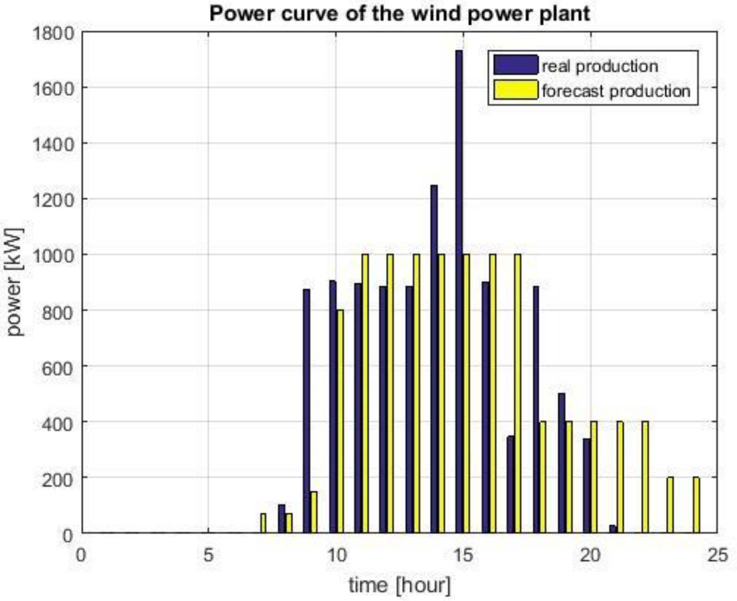
Once the installation is finished we will need an algorithm that allows us to monitor the operation of the battery in the moments of excess or lack of power generated.

For this we will start with three variables or "imputs":

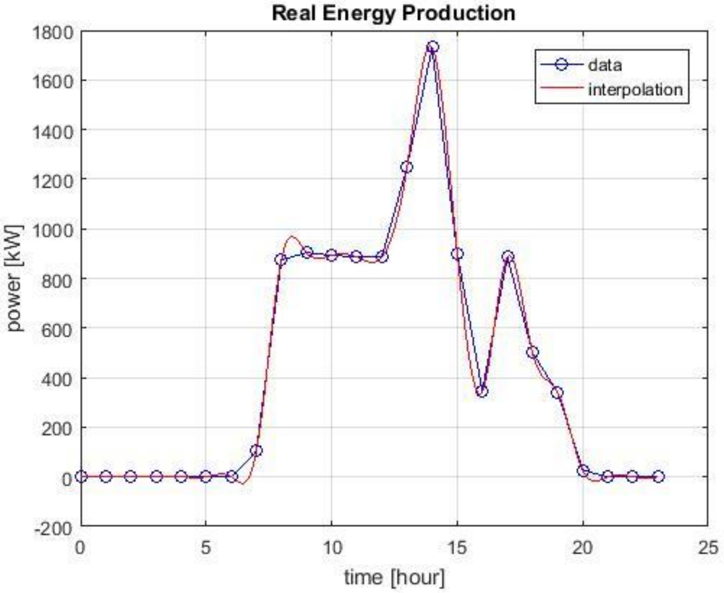
- The actual power generated at any moment by the wind turbines, which will depend directly on the wind speed at a given time. This input table is being updated by the plant control system every 10 minutes.
- Forecast or forecast of daily generation that the control system of the plant will use as a reference to adjust the net production of energy to the maximum possible, and in this way, adjust the energy delivery curve to the established forecast and minimize the penalties for deviations .
- The state of battery charge since the battery could not be used to give energy once exhausted nor to accumulate that energy in case of being fully charged.

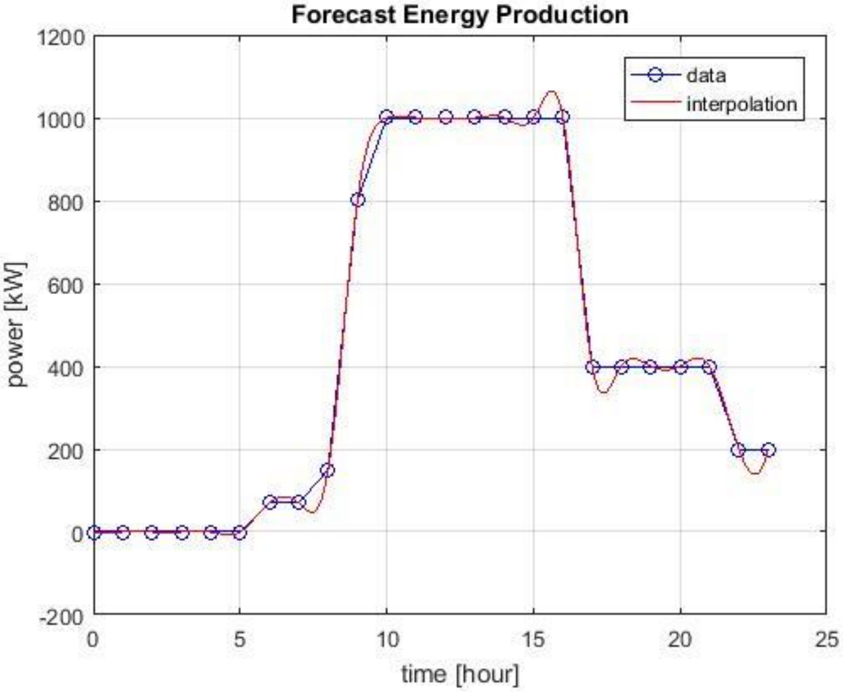
To construct the algorithm we will use logical functions in the Matlab program so that once the algorithm is finished, it will be able to tell us the operating state of the battery in each moment, besides the energy that gives or accumulates. In this case we have used for the explanation both the production and the forecast of a supposed day. In the same way we can adjust the monitoring to weekly, monthly etc., and the algorithm would be able to generate results in other periods of time.

To begin this algorithm it is necessary to initially read the input variants of the actual energy production and the forecast. Once read it will generate a comparative graph that will give us an estimated idea of the moments of maximum need of the battery, that is to say, the moments in which the real generation of energy of the aerogenerados have greater deviation of the forecast. Attached example that includes the 24 hours of a day.

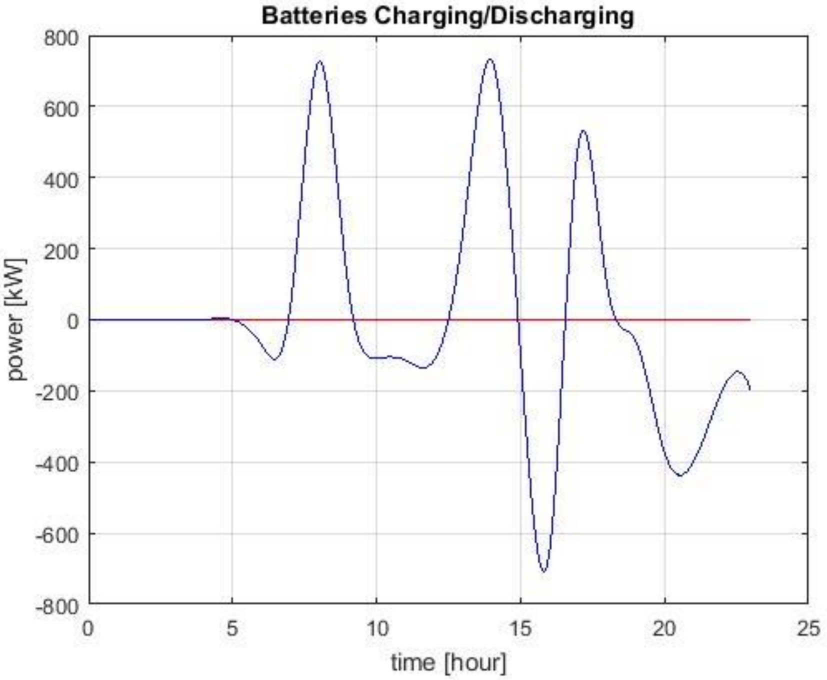


Once this graph is generated, the algorithm will perform a data interpolation of both the actual energy produced and the assumed energy in the forecast to achieve a function that will continuously describe the curve of the energies. This interpolation is necessary since in addition to helping us to treat the data allows us to obtain from a series of measures (every 10 min aprox) a continuous function that allows us to know the energy at any time.


Real Energy Production
data
interpolation
power [kW]
time [hour]
1800
1600
1400
1200
1000
800
600
400
200
0
-200
0
5
10
15
20
25


Forecast Energy Production
data
interpolation
power [kW]
time [hour]
1200
1000
800
600
400
200
0
-200
0
5
10
15
20
25

Once the algorithm ends the interpolation and shows the graphs of the functions described above will begin to generate graph that will show the state of the battery at each moment, for this by means of logical functions will compare the actual energy produced with the estimation of the forecast, So that if the energy produced is less than what was estimated in the forecast the system will rely on the batteries to compensate for the difference, likewise when the energy produced is greater than the estimated, the system will surplus the surplus in The batteries to recharge them. There are also boundary conditions (battery temperature, energy losses, weather conditions ...) of both the batteries and the system in general that would ensure the system stops in case of failure but these conditions would already be programmed in the control systems of both the batteries and the park so that no It will be necessary to include security measures in this algorithm.



Finally the algorithm will show us a graphical diagram of the use of the batteries where they will highlight the moments in which the batteries are more necessary, thus being able to know the most critical moments of production of the wind farm.

5. CONCLUSION

Once the assembly is complete we can see how the installation of batteries despite their current development is a way to increase the performance of a wind farm, when we talk about the performance improvement we mean both the improvement economically and that by adjusting the curve of Production in the forecast would save penalties, such as the increase in the use of wind, as this would take advantage of cases of surplus wind and reduce the loss in case of insufficient production.

On the other hand, the monitoring algorithm would allow us to make a parallel control of the system since in addition to the relevant control that the internal control systems give us, we would have a parallel study with the monitoring and the results delivered by said algorithm

6. REFERENCES

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Optimizing for Least Cost Configurations of Renewable Energy Generation, Princeton, New Jersey, Luke L. Cheng (June 2014).

A review of energy storage technologies for wind power applications, Universitat Politècnica de Catalunya EU d'Enginyeria Tècnica Industrial de Barcelona, Francisco Díaz-González, Andreas Sumper (February 2012).

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Battery Energy Storage System Catalogue, Siemens (2015)

7. ANNEX

Algortimo programado (Código Matlab):

```
% 10MW Wind Farm - Battery. Energy Production
%

% Hour Real Produc. Forecast Produc.
%
clc
close all
clear all

energy1=[0 0.0 0
1 0.0 0
2 0.0 0
3 0.0 0
4 0.0 0
5 0.0 0
```

```
6 0.0 70
7 103.4 70
8 875.2 150
9 903.7 800
10 893.0 1000
11 886.4 1000
12 886.4 1000
13 1247.3 1000
14 1730.5 1000
15 901.4 1000
16 346.4 1000
17 886.4 400
18 500.8 400
19 340.2 400
20 26.7 400
21 0.0 400
22 0.0 200
23 0.0 200];
```

```
[m,n] = size(energy1);

hour = energy1(:,1);

real_produc = energy1(:,2);

forecast_produc = energy1(:,3);

product = [real_produc';forecast_produc']'

figure

bar(product)

grid on

title('Energy Production');

xlabel('time [hour]')

ylabel('energy [kW]')

legend('real production','forecast production')




min_hour=min(hour);

max_hour=max(hour);

x = linspace(min_hour,max_hour,86400);

real_produc_interp = interp1(hour,real_produc,x,'spline');

forecast_produc_interp = interp1(hour,forecast_produc,x,'spline');
```

```
figure
plot(hour,real_produc,'-bo',x,real_produc_interp,'-r')
xlabel('time [hour]')
ylabel('energy [kW]')
grid on
title('Real Energy Production');
legend('data','interpolation')

figure
plot(hour,forecast_produc,'-bo',x,forecast_produc_interp,'-r')
xlabel('time [hour]')
ylabel('energy [kW]')
grid on
title('Forecast Energy Production');
legend('data','interpolation')

figure
battery_interp=real_produc_interp-forecast_produc_interp;
```

```
zero_interp=zeros(24,1);
plot(hour,zero_interp,'-r',x,battery_interp,'-b')
xlabel('time [hour]')
ylabel('energy [kW]')
grid on
title('Batteries Charging/Discharging');

x_hour=input(' Give a hour : ');
x_min=input(' Give a minute : ');
x_sec=input(' Give a second : ');
x_readeng=3600*x_hour+60*x_min+x_sec;
real_produc_str=num2str(real_produc_interp(x_readeng));
if real_produc_interp(x_readeng) > 0
    type_energy='  - charging'
else
    type_energy='  - discharging'
end
real_produc_str=[real_produc_str ' kW' type_energy]
```