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Challenges In Grid Level Electrical Energy Storage

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ABSTRACT :

The energy availability has increased while the peak demand met has increased in the same period .Despite the increase in availability, world is facing an energy deficit and a peak deficit. It is expected that energy deficit and peak deficit will rise in near future

To meet the requirement of the electricity market, combined with the international pressure to reduce CO2 emissions, lead to new architectures of the future electricity networks with a large penetration of Renewable Sources (RES) such as wind and solar power.

Due to the unpredictable nature of wind and solar energy, the ability to store this energy when it is produced is essential for turning these resources into reliable sources of energy.

Energy storage can provide various services such as

(i) Improved cost and Technical adaptation
(ii) Improved power quality and smooth load curve
(iii) Maximize the production by shifting the energy

Electrical energy is stored during times when production (from power plants) exceeds consumption and the stores are used at times when consumption exceeds production.

In this way, electricity production need not be drastically scaled up and down to meet momentary consumption. Production is maintained at a more constant level.

The current energy grid system is used predominantly for distributing energy and allows little flexibility for storage of excess or a rapid dispersal on short notice.

One of the foremost challenges is not only the ability to store the energy when it is produced and disburse it when it is needed but also issues such as technical requirements, especially interconnection issues, tariff structures and more generally economical aspects and test procedures for selecting storage.

This paper addresses the challenges in grid level electrical energy storage.

KEYWORDS: *Battery, Ultra capacitor, Fuel Cell, and Hybrid Energy Storage Systems*

INTRODUCTION: Modern Economy depends upon the availability of cheap and clean energy. Today, the world depends upon the fossil fuel for energy supply, a major source of co_2 emission. The use of fossil fuels raises serious environmental concerns. New technologies for generating electricity such as solar and wind power do not generate co_2. Electrical energy storage is the obstacle preventing more widespread use of wind and solar power.

Why Energy storage is needed in Electrical grid system?

Grid energy storage refers to the methods used to store electricity on a large scale within an electrical power grid.

In an electrical power grid without energy storage, energy sources that rely on energy stored within fuels (coal, oil, gas) must be scaled up and down to match the rise and fall of energy production from intermittent energy sources.

Thus, grid energy storage is one method that the operator of an electrical power grid can use to adapt energy production to energy consumption, both of which can vary over time. This is done to increase efficiency and lower the cost of energy production, or to facilitate the use of intermittent energy sources.

Energy storage can supply more flexibility and balancing to the grid, providing a back-up to intermittent renewable energy.

It can improve the management of distribution networks, reducing costs and improving efficiency. In this way, it can ease the market introduction of renewables, accelerate the decarbonisation of the electricity grid, improve the security and efficiency of electricity transmission and distribution (reduce unplanned loop flows, grid congestion, voltage and frequency variations), stabilise market prices for electricity, while also ensuring a higher security of energy supply.

ENERGY STORAGE SYSTEM FOR TRANSMISSION AND DISTRIBUTION

Grid energy storage system is a bidirectional device, connected to the grid, controllable and able to communicate. It is connected to the distributed network.

Electrical energy in ac system cannot be stored electrically. However, energy can be stored by converting the ac electricity and storing it electromagnetically, electrochemically, kinetically and as potential energy.

Each energy storage technology usually includes a power conversion unit to convert the energy from one form to another

Different forms of Energy storage available:

Liquid air:

One electricity storage method is to compress and cool air, turning it into liquid air, which can be stored, and expanded when needed, turning a turbine, generating electricity, with a storage efficiency of up to 70%.

Compressed air:

Another grid energy storage method is to use off-peak or renewably generated electricity to compress air, which is usually stored in an old mine or some other kind of geological feature. When electricity demand is high, the compressed air is heated with a small amount of natural gas and then goes through turbo expanders to generate electricity.

Batteries:

Battery storage was used in the early days of direct current electric power. Where AC grid power was not readily available, isolated lighting plants run by wind turbines or internal combustion engines provided lighting and power to small motors. The battery system could be used to run the load without starting the engine or when the wind was calm. A bank of lead-acid batteries in glass jars both supplied power to illuminate lamps, as well as to start an engine to recharge the batteries.

Electric vehicles:

Plug-in hybrid or electric cars could be used for their energy storage capabilities. Vehicle-to-grid technology can be employed, turning each vehicle with its 20 to 50 kWh battery pack into a distributed load-balancing device or emergency power source. This represents 2 to 5 days per vehicle of average household requirements of 10 kWh per day, assuming annual consumption of 3650 kWh. This quantity of energy is equivalent to between 40 and 300 miles (64 and 480 km) of range in such vehicles consuming 0.5 to 0.16 kWh per mile.

Flywheel:

Mechanical inertia is the basis of this storage method. A heavy rotating disc is accelerated by an electric motor, which acts as a generator on reversal, slowing down the disc and producing electricity. Electricity is stored as the kinetic energy of the disc. Friction must be kept to a minimum to prolong the storage time. This is often achieved by placing the flywheel in a vacuum and using magnetic bearings, tending to make the method expensive.

Pumped water:

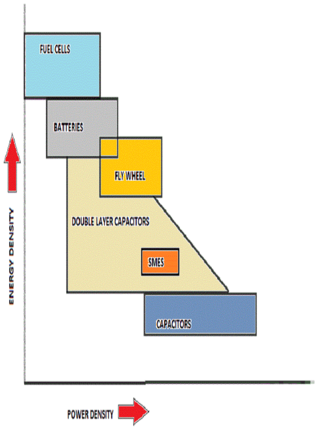
In many places, pumped storage hydroelectricity is used to even out the daily generating load, by pumping water to a high storage reservoir during off-peak hours and weekends, using the excess base-load capacity from coal or nuclear sources. During peak hours, this water can be used for hydroelectric generation, often as a high value rapid-response reserve to cover transient peaks in demand. Pumped storage recovers about 70% to 85% of the energy consumed, and is currently the most cost effective form of mass power storage.

Superconducting magnetic energy : Superconducting magnetic energy storage (SMES) systems store energy in the magnetic field created by the flow of direct current in a superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature. SMES systems are highly efficient; the round-trip efficiency is greater than 95%. The high cost of superconductors is the primary limitation for commercial use of this energy storage method.

Super Capacitors: Electrical double-layer capacitors (EDLC) are, together with pseudo capacitors, part of a new type of electrochemical capacitors called super capacitors, also known as ultra capacitors. Power density combines energy density with the speed at which the energy can be delivered to the load. This makes charge and discharge cycles of super capacitors much faster than batteries. Additionally, they will tolerate many more charge and discharge cycles than batteries.

Comparisons

The plot shows the energy storage and power handling capacity of some alternative storage techniques.



Factors characterize the application of an energy storage technology

(i) One is the amount of energy that can be stored in the device.

(ii)Another is the rate at which energy can be transferred into or out of the storage device.

The main energy storage functionalities such as Energy time-shift, Quick energy injection and Quick energy extraction are expected to make a large contribution to security of power supplies, power quality and minimisation of direct costs and environmental costs.

The storage systems have a number of characteristic parameters:

1. Minimum and maximum power available,
2. Energy content,
3. Efficiency in load and supply modes,
4. Response time for availability (load & supply modes),
5. Size/area needed, weight,
6. Possible safety issues,
7. Variation of the parameters values with time, temperature

These parameters, even if they are quite basic, can be difficult to evaluate because the energy Storage system is different from the conventional power plant.

The differences are:

1. They can operate in two different modes: energy generators (supply function) and energy receptors/consumers (storage function),

2. The technologies on which they are based can be very different, and the energy can be stored after transformation to chemical, mechanical, thermal energy.

3. Even if the assessment criteria have to be common to all storage systems, independently of the Technology they are based on, the measurement methods may differ.

4. For some technologies, the characteristic parameters have a strong variation during the life of the storage system.

5. Some of these criteria are very difficult to measure.

6. The energy available varies a lot when changing the discharging rate, the "ageing" of the system.

CHALLENGES IN GRID LEVEL ENERGY STORAGE BASED ON DIFFERENT CHARAECTERISTICS AND PARAMETERS:

(i) Maximum power Throughput :

Storage systems in most cases include a transformation of electrical energy into a different medium. Batteries store the energy chemically; compressed air and pumped hydro use the transfer of air and water from one place to another. In any conversion step, some of the energy will be lost and converted to heat. Especially for batteries, maximum throughput is strongly related to the maximum power generated in the storage medium which may lead to overheating and degradation of the storage system up to catastrophic consequences. Batteries may have different power ratings for charging and discharging which should be taken into account when designing a storage system.

In mechanical storage systems the maximum throughput depends on the size of the generators and electric motors used to transfer the medium, both with their maximum power rating.

Maximum power can be a matter of cooling or a more physical limit of the conversion process, being it chemical conversion rate or generator size.

Thus Measurements of the maximum power of a storage system is a combination of assessing the maximum power of the individual components and determine whether the cooling capacity of the system can sustain the heat generation in the conversion.

For different applications, restrictions arise with respect to the weight or size.

(ii) Safety System :

Different applications require different safety precautions. Any storage system contains a large amount of potential energy and most systems are inherently capable of releasing that energy in a short time. This might be through fire, explosion or electrical short circuiting. Storage systems in the vicinity of people will require more stringent precautions but in any case care should be taken to identify possible risks, and assess the possibility and the effect of the said risks to quantify them.

(iii) Operator safety :

A major difference from an operator/maintenance point of view is the effect that storage systems (and especially batteries) have no off-switch. Any other piece of grid equipment can be powered down for maintenance. Additional care should be taken as batteries are always active and can pose serious high voltage exposure risks to operators and maintenance workers. Additional protocols and education is needed in the field.

(iv) Efficiency :

Efficiency is a major parameter to determine. When half the energy is thrown away for transfer from and to the storage medium, storing energy quickly becomes expensive. Efficiency for storage system is usually measured as the roundtrip efficiency, taking into account the losses for both transfer between electricity and the storage medium. The higher the value, the better.

Efficiency is measuring the total energy going into the storage system while charging a fully empty energy storage system and the total energy extracted out of the fully charged energy storage system.

(v) Temperature dependency :

Most storage systems and especially batteries have a significant temperature dependency. Depending on the application, this is something that could have a big impact on the performance. For batteries it is common to publish test data for the entire applicable temperature range, which can differ from a wide range of -40 to +85 °C to much smaller ranges. Also for charging and discharging different temperature ranges can apply.

As a chemical system, batteries are prone to self-discharge due to unwanted side reactions that take place all the time in the battery. These reactions are also temperature dependent and generally will have an Arrhenius-like temperature rate relation.

This means that even if the storage system is not actively used, e.g. transferring power in or out of the system, it will still consume energy due to self-discharge.

(vi) Electromagnetic compatibility :

Energy storage systems, being large DC systems with low voltage per cell, will generate significant electric fields through all interconnections and DC bus-bars. It is a recurring problem in designing a battery system that temperature probe signals or per cell voltage measurements used by the battery management system, are disrupted by the fields generated by the large currents flowing nearby the measurement lead.

(vii) Availability :

Any battery can be discharged down to the low voltage limit set by the manufacturer. It is a fact that for most chemistries, large cycles (between fully charged and fully discharged) cause more degradation of the cells (i.e. more capacity loss and more increase in internal resistance) than small cycles. The battery will be worn down more quickly.

(viii) Cycle life :

The battery will degrade with a rate depending on the use. On the other hand, a battery will also degrade when not used, similar to the self discharge. As soon as a battery is in operation, different clocks start to tick and any one of those clocks could signify the end of the battery. For some chemistries it is already determined that because of the rate of degradation in storage, it is purely a matter of 'use it or loose it'.

The different clocks will tick with different rates depending on the chemistry of the battery, the design, the operating conditions and the actual materials used. To determine the merit of implementing an energy storage system depends largely on in-depth knowledge of the degradation rates, which can even differ between different generations of batteries from the same manufacturer.

(ix) Dynamic performance :

Typically a storage system, transforming electrical energy to and from chemical or mechanical energy, has a non-linear power versus efficiency behaviour. This behaviour also depends on the state-of-charge of the system. As such, modelling the impact of implementing a storage system in the network should take into account these parameters. Measuring the dependency could be done by performing micro cycles at different state of charge with different power draws.

(x) Short circuit behaviour :

A short-circuit, or a fault, could occur either within the storage system (internal fault) or within the grid (external fault). The behaviour of the system and its corresponding reaction differ depending on the location of the fault. During a fault situation the energy storage system is disconnected from the grid and therefore not operational until the fault has been cleared. With severe faults, (human) intervention is typically required to reset the system after the fault has been cleared. External faults in the grid result mainly in a voltage dip on the AC terminals of the grid-inverter. Other phenomena include voltage unbalance and frequency variation. The severity and duration of the voltage dip depend on the nature of the fault and the distance there of from the terminals of the grid inverter. The closer the fault is to the terminals of the grid-inverter, the more severe the voltage dip would be; a fault exactly on the terminals would lead to a 100% voltage dip (residual voltage of 0 V).

(xi) Fault ride through :

Fault ride through is a concept that is mandatory for large generators in power systems. It requires that such generators remain active during an external fault and support the grid during the fault and subsequent recovery period. Due to increasing levels of DG penetration, the trend is that also smaller generators and storage systems will need to satisfy such criteria.

If the contribution of the grid inverter towards balancing of the grid is small, the storage system would be allowed to disconnect during an external fault and be reconnected after the external fault has been cleared and the voltage has been restored to its nominal value. However, as the contribution towards grid balancing of such systems increases, its significance in supporting the grid becomes larger and the connection requirements dictate that the grid-inverter should support the grid during a fault. This is commonly performed by the grid inverter remaining connected to the grid during an external fault and providing reactive power to the grid in order to stabilise the grid voltage quicker. For this purpose, the storage system itself is actually not required as the grid-inverter is capable of controlling the reactive power.

(xii) Communication system :

A grid connected storage system comprises a number of different communication levels. The primary level is the battery management system (BMS), with communication and information exchange on component level between the storage medium (either cell or battery level) and its direct supervisory equipment. Typical measurement values here are battery temperatures, actual voltage and current levels and cooling unit parameters such as air-flow or cooling water temperatures.

The energy management system (EMS) complements the BMS by incorporating the management of many BMS systems together, including their overall protection systems.

Typical measurement values here are system availability, grid usage load profiles, curtailment information and market signals.

(xiii) Control validation :

The services that can be provided by grid-connected storage systems are largely ensured by intelligent software control of the system. In grid applications it is vital to validate, if not certify a system before any connection to the public grid is allowed. This validation covers both the hardware and the software aspects of the system. To validate the control architecture and algorithms, also during worst-case conditions, control systems are extensively tested in simulation as well as laboratory or factory testing. The control system also has different levels, starting from the primary control of the active elements (for the grid-inverter this would be the semiconductor devices) up to the higher level control, responsible for system stability.

Typical measurement values here are controller bandwidths, controller speed on grid disturbances or set-point variations and controller stability under all circumstances.

(xiv) Economic aspects :

Different storage devices, used in combination with other distributed generation energy
sources in a variety of grid connected or stand alone applications.

An intelligent energy management system functions in order to optimize generation in accordance with forecasting of the renewable energy resources, and optimizing demand of controllable and switchable loads in accordance with demand forecasts. The best scheduling of energy, and ecological and economic constraints will define the optimized storage scheduling. The goal of the module is to optimize energy flows between generation, supply and points of use, to minimize the operating cost or to maximize the profit on systems with DG. The goal function usually compromises the cost of generation, the cost associated with the grid, and penalty costs.

Conclusion

Storage systems are the only grid-connected devices capable of being a load and a power supply: they have very high potential for grid management and operation and can be envisaged in a large number of configurations.

However, important features are to be known for grid operation:

- electrical features may change according to the charging/discharging operation,
- some technologies will change smoothly from one mode to another, whereas other technologies will need a delay between the two operating modes,
- or some technologies, the available power can depend on the state of charge of the storage, while the available energy can depend on the requested power

Their complexity requires the setup of an appropriate methodology for the system design and sizing. This paper addresses the challenges in grid level electrical energy storage based on different characteristics and parameters.

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