Community and Residential Energy Storage in Smart Grids

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Abstract. This paper reviews the most important energy storage systems for applications in residential environments. Normally, these systems are associated with renewable energy in order to achieve specific characteristics, although new possibilities and challenges are implemented over them in any residential places. Nowadays, the development of such kind of energy systems represents a technical challenge in the market. In residential and small building applications, energy storage solutions supply the demanded power by consumers of residential areas or small stand-alone buildings placed on isolated zones. In context of smart grids, energy storage management systems are not only concerned about energy storage, also inefficiency optimization and power consume. This work presents INTELEM, a new smart storage architecture which integrates the energy storage and the intelligent energy management in communities and in residential applications.

Keywords: Renewable energies, energy storage systems, residential and community applications, smart storage, smart grids.

1 Introduction

In coming years, the energy sector will have several challenges due to the demanded primary energy in the world producing an increase of the emissions and greenhouse effect. The International Energy Agency predicts that world primary energy consumption will increase from 2008 to 2035 by 36% [1]. The international community is supporting the use of renewables and efficient energy sources, and one important consequence of the European 20-20-20 targets [2] (The European Union's climate change package, including 20% reduced in emissions, 20% improvement in

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energy efficiency and 20% increase in renewable energy by 2020) is that thermal power generation must be reduced to boost the renewable power generation, ensuring the environmental sustainability [3].

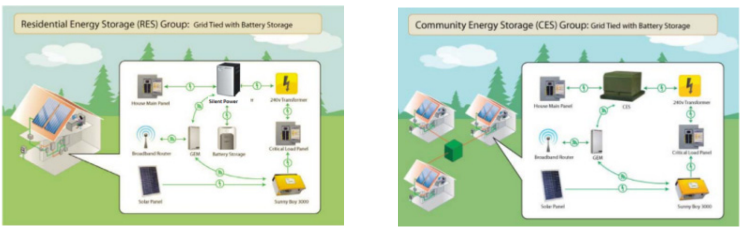
The most popular renewable resources are photovoltaic cells and wind turbines as they do not yield pollution and inexpensive primary energy are widely available in many areas. Actually, renewable energy resources are becoming cost competitive and are used instead of traditional fossil fuels as a second option to produce electric power to the local loads in remote areas.

The principal problems of renewable energies are the seasonal, daily or instantaneous variations due to dependence of weather conditions, so the power generation is stochastic. Therefore, the solution is the use of energy storage systems. These devices must feed the residential loads maintaining a low cost. They must also be so fast to produce a continuous supply to the loads. The advantages of energy storage devices are improved stability, power quality and reliability of power supply.

Renewable resources are integrated into the electrical grid as distributed generation taking advantages such as high reliability, high power quality, modularity, efficiency, low emissions, security and load management [4]. It has also some disadvantages, for example complexity of protections and variable power generation. Distributed generation allows the development of micro-grids, needing smart grids for an intelligent and efficient integration on the electrical systems.

In the same context, Virtual Power Plants (VPPs) are gaining a significant momentum within the energy industry. They have the ability to tap resources in real time, and with enough details, to control the load profiles of customers and to aggregate these resources hosting a trader’s desk.

In this paper, it will be shown different energy storage systems used for residential or community applications (community of residential energy storage, CRES) (Fig. 1). The main targets of this research work are a higher efficiency, lower cost and longer life.



(a) (b)

Fig. 1. Residential (a) and Community (b) Energy Storage systems

2 Contribution to Internet of Things

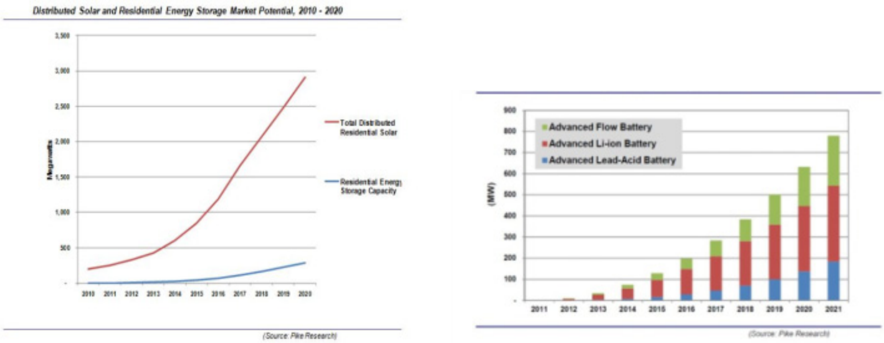
Many different battery technologies can be used in an intelligent device taking part of the future project INTELEM using it both concepts: energy storage and information and communications technology (ICT). It provides a new function to Internet of Things. This device is able to receive domestic power consumption data and send them through TCP to a central intelligent server. This server can manage the energy in an smart way, so this unit can control the demanded energy in a residential or community environment.

3 CRES on the Market

The market of batteries and other kinds of energy storage will gradually increase because the use of renewable energy and technologies mature will reach approximately € 10 billion annually in2020.

According to Pike Research, solar power systems will have3 giga watts in 2020 (Fig. 2a) [5]. If residential energy storage devices cover just 10% of this fact, it would reach annual 300 megawatt for energy storage. If this were accompanied by a decrease in price of lithium ion batteries until 345 $/kW, this market could represent a $ 100 million annual opportunity for lithium ion batteries by 2020.In coming decade the top technology in CRES systems will be lithium ion (Li-ion) batteries [6]. Nowadays, these batteries are the most important technology for energy storage in utility demonstration projects.

Some energy experts identify the CRES sector as one of the newest and least understood application areas for energy storage systems, where the market is still in situation of technical demonstration, and vendors are developing products. The implication for the CRES market is that purpose-built technologies are not expected to be commercialized in next two years [7] (Fig. 2 b).



(a) (b)

Fig. 2. (a)Distributed Solar and Residential Energy Storage Market Potential, 2010 – 2020 (Courtesy of Pike Research) (b)CRES Installed Capacity by Technology. World Markets: 2012-2022. (Courtesy of Pike Research).

Moreover, the company NEC is developing the Smart House [8], which is a house that uses information control technologies (ICT) to manage energy supply and demand. This makes houses more comfortable, saving energy and reducing the electricity receipt. This enterprise is one of a few vendors in the world that has both energy storage technology and ICT.

4 Energy Storage Technologies

At present, there are many incipient energy storage technologies, such as pumped hydropower, batteries, flywheels, fuel-cells, superconducting magnetic energy storage and electrochemical capacitors.

It should make a distinction between short and long-time responses in the energy storage technologies. Energy storage systems with long-time response can produce energy during minutes or hours and, therefore, they are used in many tasks, as for energy management, frequency regulation and grid congestion management. Short-term energy storage systems work during transient state from a few second to minutes to improve the power quality and maintain the voltage stability of the electrical grid [9].

The considered technologies in this paper for long-time response are pumping-hydro, batteries (electrochemical batteries and redox flow), compressed air and fuel-cells.

A. Pumping-hydro energy storage technology

In this case the energy is stored as potential energy, pumping water in tanks located in high places whenever electricity is cheap and there is low demand. If power consumption is high, the stored water is released to rotate hydroelectric turbines. Pumping-hydro energy storage technology has the great problem of requiring two tanks separated by a short distance and located at different heights. As a result, infrastructures are quite expensive and also depending on the availability of the water resources and the topography of the place.

B. Batteries technology

Battery is the most popular storage system. However, it is not ideal having the following physical properties as was analyzed in [10]. The first feature is the lifetime that depends on the number of times it is charged or discharged and the depth of discharge. Secondly, there are losses due to energy conversion during the charging or discharging process. This fact is characterized by the measure of charging/discharging efficiency. Finally, the battery will leak energy while is working.

There are many important factors to consider in batteries for distributed energy storage applications, such as energy density, energy capability, efficiency, cycling capability, life time, initial cost and modularity.

In general, there are two types of batteries, some are the electrochemical system and the others are redox flow system.

The first type, electrochemical batteries, is based on chemical reactions between anode and cathode to create ions electrically charged. In the charging process, a direct current is converted in chemical energy. In the reverse process, when the battery discharges, the chemical energy is converted back into a flow of electrons in form of direct current. Most popular material used in electrochemical batteries are lead-acid, nickel cadmium, sodium sulphur and lithium ion.

Lead-acid batteries are widely used as storage element in vehicles and stationary equipment, so that this technology is mature and stable. For residential environments, the lead-acid technology is the best option, in particular the type deep-discharge specially designed for stationary solar electric systems. Regarding to the aging processes in lead-acid batteries are anodic corrosion, positive active mass degradation, irreversible formation of lead sulfate in the active mass, short-circuits and loss of water [11].

However, there are better storage systems than lead-acid batteries for stationary applications that has higher energy density capability, but they are still expensive for higher power applications. As examples, may be named to nickel-cadmium and lithium ion batteries being its application in electric vehicles. In these cases, the cost is balanced by high energy density capability.

The second type, vanadium redox flow batteries (VRB), is an electrochemical system that converts chemical energy to electrical energy, and vice versa.

It uses the redox active substance which is stored in two tanks separately. The process consists of a solution flowing through the battery by an electric pump, then the oxidation-reduction occurs at the electrodes in both sides of an ion exchange membrane producing electricity. Many stacks connected in series through bipolar plates, resulting in batteries.

A VRB has three main parts: a stack where the conversion of electric energy and chemical energy takes place, tanks which hold liquid electrolyte and a power conversion system.

The VRB energy storage has four main features [12]. First, the arrangement and design of VRB are very flexible, allowing higher storage capacity. Second, the battery system can work at a high speed and output high power. Third, the battery system is safe, stable and easy to maintain. Finally, this storage system is clean because the electrolytic liquid of the battery can be reused and materials such as carbon dioxide, etc. do not appear.

C. Hydrogen fuel cells

A fuel cell is a solid state DC power generator that converts chemical energy into electricity with no pollution. There is a chemical reaction which is composed of two elements, hydrogen and oxygen. Due to fuel cells do not have moving parts and do not rely on combustion, they are easy to maintain, very efficient and quiet.

Fuel cells can be classified according to two features: operation temperature and used electrolyte. In the high temperature range (65ºC to 1050ºC), there are two technologies, molten carbonate fuel cell (MCFC) and solid oxide fuel cell (SOFC). For low temperature (65ºC to 250ºC), it can be distinguished some types, proton exchange membrane fuel cell (PEMFC), alkaline fuel cell (AFC) and membrane phosphoric acid fuel cell (PAFC) [13].

The used fuel is mainly hydrogen in the high and low temperature technologies, although high temperature fuel cells use carbon monoxide and some hydrocarbons as well. One company that offers this technology is Idatech [14].

D. Other energy storage technologies

There are other energy storage technologies that they are mainly used for short-term response energy storage systems:

- Flywheels.
- Supercapacitors or ultracapacitors.
- Magnetic superconductors.

Flywheel energy storage systems operate mechanically in a rotating flywheel. Electrical energy is stored by using a motor which rotates the flywheel, thus converting electrical energy into mechanical energy. The energy that can be stored depends on its angular velocity and inertia. More energy can be stored if the flywheel rotates at higher angular speed. The main advantages of flywheel energy storage system are fast charge/discharge, high energy storage density, high power density, low risk of overcharge or over-discharge, wide range of operation temperature, very long life cycle and environmental behaviour [15]. A problem with flywheel systems is large vibration of the rotor when it is rotating, so it is difficult to increasing the angular speed. Companies that offer this technology are EATON [16] and Beacon POWER [17].

Supercapacitors, also called ultracapacitors, are a new technology employed for energy storage systems. These devices store energy in form of electric charge between two metallic or conductive plates, separated by a dielectric medium. Supercapacitors operate in DC allowing enough power and high energy density. They have a long life cycle and a short charging-discharging time [18]. Nowadays, the company Maxwell Technologies manufactures and sells energy storage and power delivery solutions through supercapacitors [19].

Superconducting magnetic energy storage (SMES) is a large superconducting coil capable of storing electric energy in the magnetic field generated by DC current flowing through it. System converts the AC current supplied by power system into DC current [20]. The superconductor operates at low temperatures (cryogenic) without resistive losses, so that the energy can be stored all the necessary time. The main advantage of this system is that the charging-discharging time is very short.

5 Conclusions

In residential applications there are many energy storage technologies and some are available in the market being the main problem the charge-discharge efficiency. Lead-acid batteries are devices chosen for any new project because they are cheap and having high availability. These batteries are widely used as storage element in vehicles and stationary equipment, so this technology is mature and stable. For residential environments, the lead-acid technology is the best option, in particular the deep-discharge ones specially designed for stationary solar electric systems.

Normally, energy storage systems are related to renewable energy applications to improve the stability, power quality and reliability of power supply. Moreover, the word ICT is used by smart home more and more to control energy supply and demand. In other words, it refers to a residential building equipped with embedded intelligence and communication infrastructure.

If the two previous concepts, energy storage systems and ICT, are mixed appears the term “Smart Storage” that would enable store energy when it was cheaper and deliver energy when it is needed, thus reducing the electricity receipt. To achieve this, the consumers must become active customers and they must understand and accept this. Therefore, active customer participation plays a key role.

6 Future Work

In the context of smart grids, future smart houses will have DC loads, pv systems, evs and energy storages (mainly based in batteries)connected with power and control systems by means of power lines and communication infrastructures. The control system has to send control commands to the smart-house according to system conditions and the smart house determines the operation of controllable loads.

In this scenario is defined a new concept named smart storage which are concerned not only about the energy storage (that has been discussed previously) but also about energy management systems (EMS).

EMS will be able to adapt to the environment, grid and user requirements. In this context, it can be referred the project INTELEM (Fig.3) that implements ideas related with the smart storage. In this project the smart storage is based in two systems implementing a master/slave configuration that integrated electric grids and communication networks.

Fig. 3. Schematic diagram of INTELEM Project

One system is a device placed in a house or in a community of houses, able to store energy and to connect or disconnect different loads in order to control the power consumption, implementing in this way energy saving functions. This device will operate take into consideration the guidelines received from the central server.

The other system is an Artificial Intelligent Central Server that receives data from different INTELEM devices (consume profiles, load turned on/off …). The central server optimizes the overall performance of all devices, and is sensible to environment (temperature, irradiance, energy prices by time period, forecast of DG generation if exists, forecast of consume at controlled houses …) using commands. The central server will send information back to INTELEM devices, that could include the priority for connecting or disconnecting loads in houses if it is necessary, the maximum power that the house could demand from the grid, and INTELEM devices will operate locally according to these commands.

References

1. International Energy Agency. World Energy Outlook, Executive summary (2010)
2. European Commission. Climate action, http://ec.europa.eu/clima/policies/package/index_en.htm
3. Bedir, A., Ozpineci, B., Christian, J.E.: The impact of plug-in hybrid electric vehicle interaction with energy storage and solar panels on the grid for a zero energy house. In: 2010 IEEE PES Transmission and Distribution Conference and Exposition, pp. 1–6 (2010)
4. Roggia, L., Rech, C., Schuch, L., Baggio, J.E., Hey, H.L., Pinheiro, J.R.: Design of a sustainable residential microgrid system including PHEV and energy storage device. In: Proceedings of the 2011-14th European Conference on Power Electronics and Applications (EPE 2011), pp. 1–9 (2011)
5. PikeResearch. Residential Energy Storage, http://www.pikeresearch.com/blog/articles/residential-energy-storage
6. PikeResearch. Investment in Community and Residential Energy Storage Systems to Total $4.2 Billion through 2022, http://www.pikeresearch.com/newsroom/investment-in-community-and-residential-energy-storage-systems-to-total-4-2-billion-through-2022-2
7. Globe-Net. Community and Residential Energy Storage Systems Investment to Soar, http://www.globe-net.com/articles/2012/february/29/community-and-residential-energy-storage-systems-investment-to-soar/
8. NEC. Smart Houses, http://www.nec.com/en/global/environment/energy/house.html
9. Angheliță, P., Chefneux, M., Balaban, R., Trocan, L.: Energy storage systems for buildings equipped with photovoltaic cells. In: 2010 3rd International Symposium on Electrical and Electronics Engineering (ISEEE), pp. 332–335 (2010)
10. Urgaonkar, B., Neely, M.J., Sivasubramaniam, A., Urgaonkar, R.: Optimal power cost management using stored energy in data centers. In: ACM International Conference on Measurement and Modeling of Computer Systems, SIGMETRICS 2011, San Jose (2011)
11. Sun, Y.-H., Jou, H.-L., Wu, J.-C.: Aging Estimation Method for Lead-Acid Battery. IEEE Transactions on Energy Conversion, 264–271 (2011)
12. Zhang, X., Wei, Y., Xu, S., Zhang, Y.: Optimizition design of all-vanadium redox flow battery energy storage system. In: 2010 China International Conference on Electricity Distribution (CICED), pp. 1–4 (2010)
13. Weickgenannt, M., Sawodny, O.: Efficient Hydrogen Production for a Stationary Fuel Cell System: Two-Degree-of-Freedom Control of a Steam Reformer Unit. Control Systems, 54–69 (2012)
14. Idatech. Power for the long run, http://www.idatech.com/products-and-services-electragen-h2-i-system.asp
15. Nguyen, T.D., Tseng, K.J., Zhang, S., Nguyen, H.T.: On the modeling and control of a novel flywheel energy storage system
16. EATON, http://www.eaton.com/Electrical/USA/index.htm
17. Beacon Power, http://www.beaconpower.com/
18. Guerrero, M., Romero, E., Barrero, F., Milanés, M., González, E.: Supercapacitors: Alternative Energy Storage Systems. Przegląd Elektrotechniczny (Electrical Review) (2009)
19. Maxwell Technologies, http://www.maxwell.com/
20. Ali, M.H., Dougal, R.A.: Comparison of SMES and SFCL for transient stability enhancement of wind generator system. In: Energy Conversion Congress and Exposition (ECCE), pp. 3382–3387 (2010)