BATTERY STORAGE INFLUENCE ON ELECTRIC SYSTEMS WITH EMBEDDED RENEWABLE: A TECHNOLOGY OUTLOOKFOR ROMANIAN POWER NETWORK IMPROVEMENT

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Abstract – High penetration of variable renewable energy sources (especially wind and solar) in electrical grids rises o series of balancing and regulating issues. One of the most important one is the need for increase of grid flexibility. Battery storage systems represent a mature technology for enhancing grid flexibility by managing electricity supply fluctuations both at electrical systems and insulated week grids.This paper analyzes the influences of this technology from technical point of viewto an international level, conclusions referring to the Romanian national grid level being drawn at the end.

Keywords: variable renewable energy sources, battery storage system, renewable resources, grid flexibility

1. INTRODUCTION

Safe and secure operation of an electrical system involves dispatching of a large number of power plants so that, after an extensive process of forecasting, scheduling and operating, the electrical energy produced should meet the demand at any given time. The demand pattern presents significant variations which can be hourly, daily or seasonally. To maintain the equilibrium between electricity produced and load, the system operator has several types of power plants:

- Baseload plants (on fossil fuels or nuclear) are destined to assure a constant demand of electricity. Due to high operating costs there are designed to function at full power on an extended period of time;
- Load following, or "cycling" plants (usually hydro and plants on gas or oil) cope with the variation in load, the day to day one and peak demands;
- Operating reserve plants had to deal with random fluctuation of the load both in normal condition and contingencies (unscheduled power plant or transmission line outages) [1].

Renewable energy deployment started to penetrate the electrical systems, the growth being unprecedented in the last decade both in number and in installed power [1]. This is particularly significant for variable renewable energy sources (VRES) such as wind and solar: only in 2006-2012 periods, the installed capacity of wind generators has increased with 40% and for PV systems with 190%, representing the fastest growth among all renewable sources [10]. However, at the country level, out of 170 countries that has established renewable energy targets, only in 26 of them the installed power in VRES are expected to grow by 30%, according to [7]. In case of insolated consumers, the installed capacity of VRES is expected to grow by 50%, in case of supporting renewable energy policies are maintained[7].

Unlike renewable power plants based on geothermal, biomass or hydro energy, the wind and solar plants presents the unique characteristic of supplying electrical energy only when renewable resource is available. The variation in time of their output power has an impact of the electrical system which is more significant as the installed power is higher. Due to this fact, maintaining the equilibrium between supply and demand request operational maneuvers, the most commonly used being curtailment at generation level and disconnections at consumer level. To reduce the curtailment and disconnection percentage, the electrical systems need to be more flexible.

The flexibility of an energy systems are defined as *the capability to respond, in economic limits, at large fluctuation between supply and demand, both predicted and random*[8]. In case of energy systems with renewable embedded, its flexibility can be translated as the capability to "absorb" a significant quantity of variable energy and to cost effectively "dispose" it[8]. In fig. 1. are presented the source of flexibility of a power system.

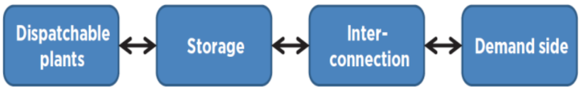


Fig. 1. Flexibility resourcesin a power system [9]

Synchronous generator from classical power plants has the capability to automatically react to sudden frequency modification in the system but only on short period of time. The state of the art VRES, which incorporates subsystem capable to adjust automatically the output power (such as storage and power electronics), have the capability to emulate the classical synchronous generation and so, between a certain limits, to assure a reduction in flexibility demand [9].

Interconnections between networks allowexporting the energy surplus ant to import in case of energy deficit.

Consumers have “the potential to alter their electricity use in response to supply abundance or energy shortage”[9].

Storage availability translates in the capacity of a storage system to supply / store a certain amount of electricity, depending the installed power and time duration. Storage systems consist in technologies that currently are in different stages of development. The most mature storage technology is represented by pumped hydropower, about 99% of existing storage systembeing in operation worldwide [9].

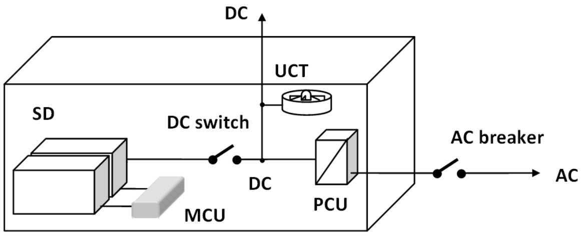
By contrast, battery storage systems (BSS) belong of a relatively new technological sector, alongside with compressed air, inertial and super capacitor systems. In addition, the thermal storage is cheaper then above mentioned systems, but presents the disadvantage of difficulty to produce electrical energy from thermal stored energy [9].

2. BATTERY STORAGE SYSTEMS

A BSS is defined as a power generation unit which is based on a chemical storage of electricity having the capability of charging and discharging.

There are two type of BSS currently used at power network scale: cell based and flux based.

Cell based BSS are modular units of various powers, by combining them can be obtain varying installed capacity (up to tens of MW), the main components being presented in fig. 2.



SD = Storage device;
MCU = Monitoring and control unit;
TE = Temperature control;
PCU = Power conversion unit.

Fig. 2. Primary power components of a cell based battery unit[9]

The SD consists in a set of individual cells connected into modules, a number of modules connected to each other resulting into packs such that it may be obtained the required installed battery capacity.

The MCU has the role of assuring the power management of the BSS (preventing the overcharge and the battery over discharge) as well as to integrate the needed software for remote monitoring and control.

The TE unit is often integrated in BSS to assure the adequate operation of the BSS in various temperature conditions, especially for the BSS based on Li-Ion battery, which is prone to overheating.

Te PCU is part of the BSS providing an integrated unit ready to be connected in the needed network area. Usually this unit consists in a bidirectional inverterwhich permits both power flow to the network and recharging the battery when needed.

Flux based BSS consists in a reaction unit in which one or both of the electrodes are immersed in solution and two separate reservoirs from which the electrolyte is pumped in reaction unit, fig.3.

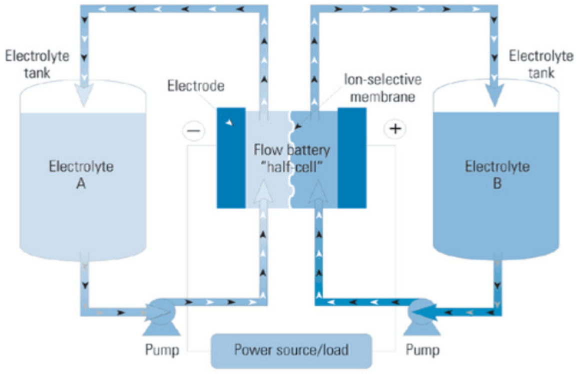


Fig. 3. The main diagram of a flux based battery unit[10]

A unique characteristic of such BSS is that the installed power [kW] depends on the number of cells connected in reaction unit packs and the energy delivered [kWh] depends on the electrolyte quantity circulated by pumps. Due to storage of the electrolyte in separate tanks, this BSS can handle many charging and discharging cycles without significant degradation in performances, the main disadvantages consists in the higher cost of the pumping system (plumbing and additional energy to the pumps)and also the danger of accidentally spilling of the electrolyte.

There are three main technical indicators which characterize a BSS [9]:

- Depth of discharge (DOD), defined as the percentage form full battery capacity which is effectively utilized;
- Ambient temperature, having a major impact on battery performance: higher values of this parameter can cause corrosions and gases emissions while extreme lower values may slow the chemical reaction to even a complete stop;
- Cycle of life, represents the number of charging/discharging which battery can cope without significant performances reduction. This parameter depends strongly on DOD and ambient temperature.A battery at the end of its life cycle is considered when it deliver only (60-80)% of its original capacity.

Generally, in choosing a BSS type the defining criteria are technical performances and costs, but often it leads to a wrong choices due to the fact that each applications has unique characteristics of climate, locations, infrastructure, operating conditions and so on. To make an adequate choice, it is needed an outlook which take into account all the factors that may influence BSS implementation in a certain system, a comprehensive diagram for this purposebeing the one presented in fig. 4.

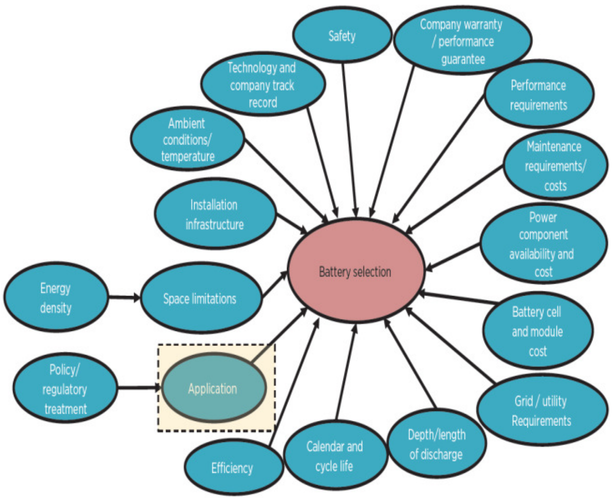


Fig. 4. The main criteria in choosing a BSS [3]

The main BSS utilized in electrical networks which belong either to the power system or to insolated consumers are: Lead-acid, advanced Lead-acid, Li-ion, Sodium-sulphur and flow battery, the technological maturity of these being presented in fig. 5.

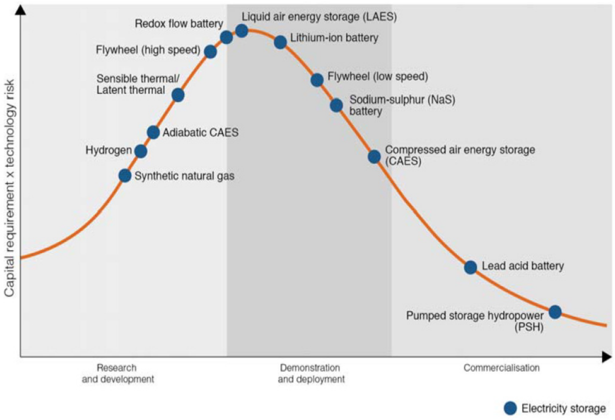


Fig. 5. Current maturity level of BSS technology [3]

Lead-acid battery is the most mature between available technologies being the first choice in UPS systems and renewable integration due to proven cost effectiveness and in spite of their shortcomings: low energy density (59 Wh/kg), short life cycles (maximum 7 years) and necessary maintenance and ventilation.

The need for maintenance was eliminated with *advanced Lead - acid* batteries, being the peak of Lead-acid technologies and having a higher energy density (70 Wh/kg) and life cycle.

Nickel-cadmium batteries have longer round trip efficiency, high energy density and a long life cycle, but it proved to be very toxic and operates at a temperature range only between -20^0C and $+40^0$C, a total of only 27 MW units being installed worldwide [4].

Lithium – ion battery is currently being used at a larger scale due to high energy density (up to 140 Wh/kg), longer life cycle (over 5000 charging/discharging) and low standby losses. The main disadvantage is represented by the over temperature tendency in certain operating conditions, but with proper temperature management, the risk of fire may be reduced to zero.If its price will come down in time, it may be the first options for a widely deployment in short term, fig. 6.

Fig. 6. Possible Li-Ion BSS for wind farm grid integration in China [4]

Sodium – sulphur battery has a relatively high energy density (120 Wh/kg), long life duration (15 years) but it is very costly (up to 800 EUR/kWh) and can be operated only at temperature of 300^0C. [2]. The largest NaS installation belongs to Tokyo Electric Power company having 6MW unitwith 8h discharge time [2].

Redox flow battery are developed mostly in Japan, and some demonstrator units of vanadium RFB are commissioned: one of 5 kW installed power with 10 hour discharge time and one of 3 MW with 1,5 s reaction time [2].

3. VRES IMPACT ON ELECTRICAL NETWORKS

VRES implementation in electrical system presents unique challenges due to, first of all, the renewable resource (RR) characteristics: intermittency and unpredictability, especially true in case of wind farms and PV units.

These results in a totally different operating mode of the electrical system, the power in VRES being produced in a different mode than the classic generation units. Thus, to evaluate the impact of VRES on electrical system, instead “to see” these units as a source of electrical generation it is better to consider as a *reduction in load*, so that the remaining load to be covered from classic generation unit (called here the “net load”)may be calculated as a difference between normal demand and electricity produced from RR [1].

The benefits of net load covering for electrical system are, first of all, in reducing the number of conventional generating units, as a result reducing the conventional fuel used and associated emissions with positive impact for environment and, somewhat in volatility of fuel prices on international markets [1].

On long term, there are four main impact of VRES penetration in electrical systems [1] shown in fig.6:

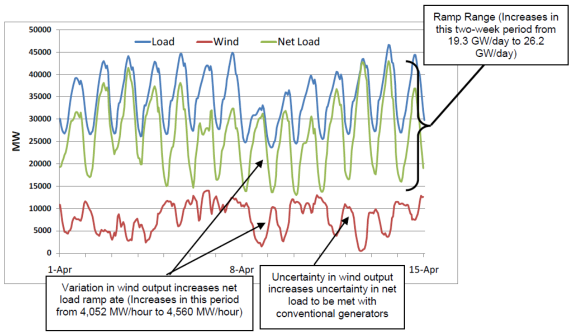


Fig. 6. The impact of VRES on electrical systems [1]

1) *Increased need for frequency regulation*, due to the fact that these units may present abrupt variation in produced power in very short time;
2) *Increase in hourly ramp rate*, having the result of increasing the speed at which the load following generation unit must increase and decrease their output;
3) *Increase in uncertainty of net load*, due to the unpredictability of the RR;
4) *Increase in ramp range*, forcing thus the base load plants to reduce its output power and, in extreme cases to costly cycle between on and off state.

On short term, VRES impact on electrical systems may translate into mitigation in minute by minute regulation of the produced power [1]. This is happening because VRES may present a significant spatial distribution in the grid (especially in case of wind farms and PV), the total produced power from these units presenting smaller variations and thus being easier to counter at the system level. Additionally, the newest generation wind turbines have the capability of a stable short term power supply, being so capable to contribute in frequency regulation in electrical system [1].

Having the above considerations, the increased penetration of VRES in the electrical systems leads to an increasing in variability of the net load and thus the necessity in grater electrical network flexibility as well as greater storage capabilities, so that both predictable and random variations of loads can be met at any given time [1].

3. BSS INFLUENCE ON ELECTRICAL SYSTEMS WITH RENEWABLE

Accommodating the increased variability of the net load and the limited coincidence of VRES power supply with the demand in order to ensure the generation mix matches the net load requirements is done by a number of techniques and technologies described as *flexibility resources* [1].

Electricity storage is one of the many technologies utilized to increase grid flexibility leading to enable a greater use of VRES [1].As shown in fig. 7.there are a supply side source of flexibility and a demand side one and as the VRES penetration increases the flexibility costs also increase.

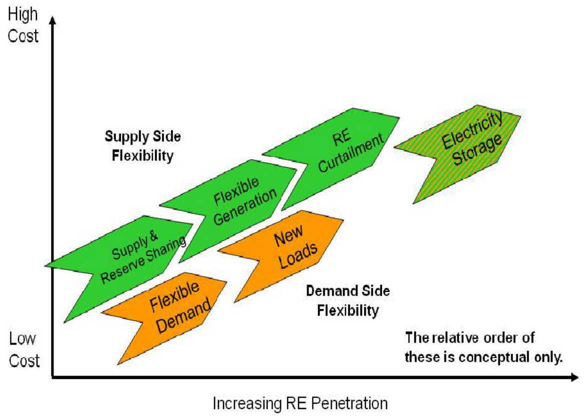


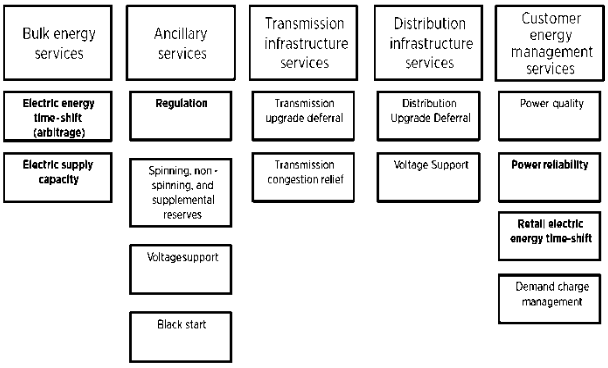
Fig. 7. The flexibility supply curve [3]

The VRES need two type of grid flexibility [1]:

1) *Ramping flexibility*, described as the "ability of the electrical system to follow the variation in net load, both in minute-by-minute timescale needed for frequency regulation and minute-to-hours timescale needed for load following";
2) *Energy flexibility* type, described as "the ability to increase the coincidence of VRES supply with demand".

Electrical storage represents an important step in achieving flexibility but only when other options are saturated or unavailable [1]. Among the electrical storage technology the BSS units are included in three categories clustered by different points of view:

A. By services provided in different parts of the system, fig. 8.



Bulk energy services	Ancillary services	Transmission infrastructure services	Distribution infrastructure services	Customer energy management services
Electric energy time-shift (arbitrage)	**Regulation**	Transmission upgrade deferral	Distribution Upgrade Deferral	Power quality
Electric supply capacity	Spinning, non-spinning, and supplemental reserves	Transmission congestion relief	Voltage Support	**Power reliability**
	Voltagesupport			**Retail electric energy time-shift**
	Black start			Demand charge management

Fig. 8. Classification of electrical storage by servicing provided [12]

B. By classes which energy storage may contributes to system regulations, tab. 1.

Table 1. The classes of energy storage [1]

Regulation	Applications	Discharge time required
Power Quality	Transient stability, Frequency regulation	Seconds-minutes
Bridging Power	Contingency reserves, Ramping	Minutes -1hour
Energy Management	Load leveling, Firm capacity, T&D Deferral	Hours

C. By technologies and applications within BSS are used, fig. 9.

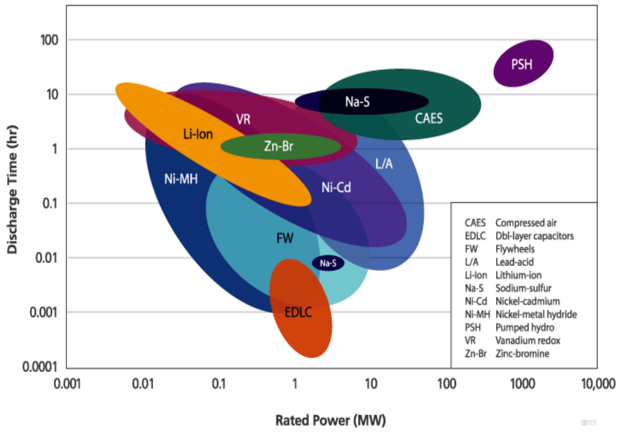


Fig. 9. Classification of electrical storage by discharged time and rated power [1]

As shown in table 1, **power quality** in electrical systems requires a rapid response from the storage systems (often less than 1s), thus storage technologies utilized consist mainly form flywheel, condensers, superconducting magnetic storage units. But if the response time reach 10-20s, BSS based on Lithium and Zinc-Bromine are commercially available [2].

In case of electrical network belonging to the insolated consumers, they have an increased vulnerability to the sudden fluctuation of RR (especially solar and wind). It is known the fact that, for instance, shadowing the PV system by a cloudleads to a sudden drop of produced power with 90% in seconds [1]. In this case, for frequency regulation, the BSS is the obvious solutions because these units are already integrated in the power supply systems of the consumer, providing energy on the time when RR is not available [1]. The technologies used within BSS of the hybrid systems are mainly Lead-acid deep cycle but there are cases on gel and Lithium utilization [2].

Additionally, BSS for fast regulation in grids with high renewable penetration offers a 100% full regulation capacity both positive and negative, unlike the dedicated regulation power plants which can provide only a positive one and even this being limited by operational constrains, fig. 10.

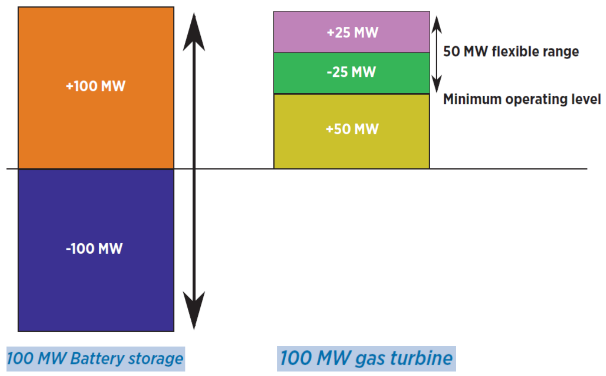


Fig. 10. Fast regulation from BSS units versus a gas power plant [4]

Frequency regulation in grids requires an increased charging discharging cycles, limiting thus the battery life cycle of the regulation unit.

Bridging power includes all the necessary applications for assuring the electric energy reserves, load following and additional reserves to cover the electric energy gaps in case of forecast errors and unit commitment errors [3]. In this case, the response time varies from seconds to minutes, when the discharge time reaches 1 hour [3]. BSS units require a lower charging/discharging cycles than the units that assured frequency regulations, so it operates with a longer life cycle the technology used being: Lead-acid, Nickel-Cadmium, Ni-Metal-Hybrid and the most recently, Li-ion [1].

Energy management in power systems includes the applications which require moving power on a certain period of times, BSS needed in this case discharging rates of several hours or more [1]. This operating mode overlay on the previous ones, due to the fact the BSS units should offer fast response time and long period of discharge. For the BSS serving insulated consumers, its multiple utilization results in the fact that these units have to combine long and short term storage, covering both period with unavailable RR and peak loads [3], as example from fig. 10. shows.

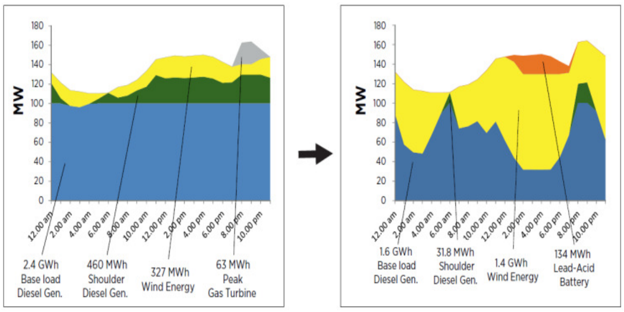


Fig. 11. Impact of BSS unit on an insulated consumer powered by a wind - Diesel hybrid system [5]

Batteries within BSS from electrical networks for power management are of two types: high temperature units and liquid electrolyte flow ones [1].

High temperature batteries commercially available are the ones with sodium-sulfur, worldwide being installed a total of 270 MW capacities and the sodium-nickel-chloride batteries are in the development stages [3].

The flux based battery has the advantage that both produced power and energy delivered can be independently sized, commercially available units being vanadium-redox and zinc-bromine [1].

The BSS units for insolated consumer electrical networks are based on lead-acid technology due to the costs and proven operational performances [1].

Another important factor of influence of the BSS represents the deploying mode of these units within the electrical systems. There are two possibilities: individual and aggregating deployment [1].

The most common implementation of the BSS is the individual one: in this case, these units are placed close to the VRES being operationally tided with them. The main reasons for that deployment consists in smoothing the produced power (especially in case of wind farms) and covering short term peak or gap in power (due to RR or loads variations). On the electrical system level, this approach supplying the same applications regarding power regulation with the electrical network, as shown in table 2, so overall it results in a decrease in efficiency [1].

Table 2. Dedicated BSS applications at the VRES and their whole grid counterpart [1]

Specificapplications	Whole grid applications
Transmission curtailment	Transmission deferral
Time shifting	Load leveling/Arbitrage
Forcast hedging	Forecast error
Frequency support	Frequency regulation
Fluctuation suppression	Transient stability

Furthermore, individual BSS deployment eliminates the benefits of the resources aggregations. This means that aggregating multiple VRES on the entire grid leads in diminishing the overall storage capacities, meaning BSS implementation being done at a lower cost. This is especially true in case o f a high spatial dispersions of the VRES which can significantly mitigate power variability over multiple timescales [1].

In addition, VRES aggregation at the whole grid allows the system operator to dispose of all storage systems available, leading to an increase of network flexibility [1].

There are of course cases in that individual deployment of the BSS makes more sense,namely if the VRES are situated in areas with weak transmission networks. In this case, the BSS units decrease the need for new transmissions capabilities and relieve probable congestions issues in the grid [1].

All these impact factors must be taking into account both technically and economically when considering BSS units deployment in the electrical networks.

CONCLUSIONS

Stable operation of the electrical network involves constantly keeping the power balance between supply and demand. In ordinary power systems it is done by well established technologies and operational habits.

Until late nineties this constitutes the case for Romanian power network when electricity was generated mainly from thermal and hydro power plants.As a result of National Action Plan for Renewable Energy Sources implementation, there has been an exponential growth of power plantbased on renewable resources which has led to an increasein VRES penetration.

With increasing penetration of the wind and PV power plants in electrical systems, the power fluxes modifies with the RR variation and being more significant than that VRES installed power increases. The first consequence of increase penetration of VRES in power systems is the need for increase flexibility of the electrical network.

One of the options for reaching this goal is represented by BSS. Although this storage technology is relatively new, at international level there are done important steps forward both in operational performances and in cost effectiveness, so this technology could be a solution for Romanian network. The main problem is representing how to choose the appropriate BSS system. Choosing a BSS for an application only by performances and costs criteria often leads to improper system operation due to the fact that each applications has unique characteristics of climate, locations, infrastructure, operating conditions and so on. To make a right choosing decision it must take into account the entire specific characteristic on site that can influence the correct operation of the BSS.

From a technological perspective the BSS technology is mature, worldwide being operational such reliable systems both ant the electrical systems level and insulated consumers level.

Utilizing the BSS at the Romanian national power network level could leads to smoothing the transition to a even higher penetration of the VRES due to two facts:

- Can provide required network flexibility when other options are saturated or unavailable:
- Can provide a series of applications at the electrical system level such as: power quality, bridging power and energy management.

The electrical networks of the insolated consumer have proven to be particularly vulnerable to sudden variation of the RR, thus utilizing the BSS at this level is critical.

Utilizing the BSS for multiple purposes can lead to an increase of its attractiveness. In case of Romanian electrical systems, the multiple purpose use results from operational practice, BSS units providing both fast response time and long period of discharge. In addition it can provide full regulation capacity both positive and negative. In case of insolated consumer electrical network, BSS must cover multiple requirements such as: power reserve, load following, power quality, black start.

Implementing BSS in Romanian electrical system must be done taking into account the two possibilities of deployment: overall and individual. Overall deployment has the benefit of decreasing in storage capacity and costs, but it can be cases when individual deployment makes more sense, especially when VRES are situated in week transmission networks.

Although in many countries there are well proven source of systems that can accommodate VRES at high penetration level, the versatility of the BSS, operational experience and proven cost effectiveness indicates the fact that such systems may have an important impact in energy management and it is worth exploring its technological potential at Romanian network level.

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