Determination of Specification Criteria for Large Scale Battery Systems

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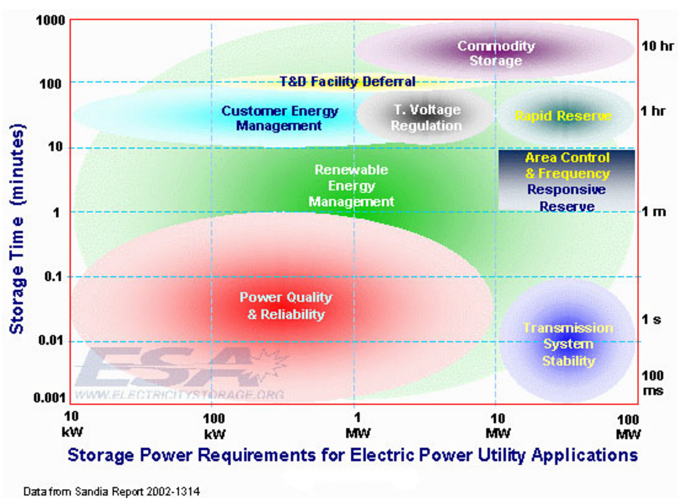
Abstract: Energy storage for management of electrical grids is becoming increasingly important and attractive. A number of changes in the landscape of the electrical power network are contributing to this popularity, including the increased cost of both the upgrade of existing power system assets as well as placement of new assets; the need to reduce CO2 emissions and a corresponding increase in the desire to integrate renewable energy sources; and new market mechanisms that allow efficient transfer of energy and provision of other services with low transaction costs. These changes coincide with new innovations in energy storage technologies that have lowered costs while improving performance. It is important for those implementing such technologies to appreciate the many and varied types of performance parameters involved in specification of such systems. For instance, the Ragone plot, often used as the most important characterization of a battery system's performance, is by no means sufficient to specify a battery system for reliable and continued use. Parameters including temperature, state of system charge (how much energy is in the system), the charge and discharge rate capabilities at different states of charge, cycle life at various temperatures, and many others will strongly affect the ability of a battery system to meet a given set of application requirements. These parameters can be represented as a multidimensional matrix, with each parameter having an effect on the "total life cycle" cost of an energy storage system. In this paper we propose to evaluate the parameters needed to specify an energy storage system and focus on their interrelationships. This analysis allows a sophisticated approach to specifying storage systems, which in turn ensures that the users get the maximum value from their investment.

Introduction: In the electrical storage arena, one size doesn't fit all. Each application necessitates different operational characteristics and as a consequence, different economic metrics. An overriding metric may be $/Mega Watt Hour transferred. All of the operational criteria are then rolled into the many operational parameters for each application. ESA, (Electricity Storage Association), provides a map of applications on a modified Ragone plot.



Power and Energy should be differentiated and many storage systems are now highlighting these differentiated parameters. There is a continual gradation of the abilities of super capacitors to power storage batteries to energy storage batteries. Along with this gradation of characteristics are both efficiency and economic aspects.

Important characteristics for power storage and energy storage units are shown in the following chart:

Energy Storage Characteristics

	Safety	Control	Optimization	Physical	Business
Max V	***	**	*	**	
Max I	***	**	*	**	
Protocol	*	***	**		*
% of total capacity	*	***	***	**	*
Round Trip Efficiency		*	***	*	***
$/MWh transferred			***	*	***

As one can see, the characteristics in the first vertical column fall into various parameters in later columns. A look at the column headings gives an understanding of some of the issues associated with applications. One can think of the chart as a number of hurdles that need to be jumped to get on to the next set. The final hurdle as mentioned above is the **$/MWh transferred** for a total life cycle cost. Ancillary services are bid in $/MW for a time period (usually an hour), so an assumed "dispatch cycle" is necessary for a total life cycle cost calculation. For many battery storage systems, the depth of discharge determines the total life of the system, so the "dispatch cycle" is critical to this calculation. In many battery systems the life is not a linear function of depth of discharge, giving rise to significantly longer life times at low percentage depth of discharge.

Safety: The first consideration must be safety. Most systems have an Achilles heel and energy storage systems are no exception. Either the National Electrical Code or the National Electrical Safety Code will have jurisdiction in the USA. Normal operational controls and safety disconnects rely on Max V and Max I for specification, as well as operational frequency and voltage. There may be need for seismic and fire protection, as well as there are transportation issues with some technologies. Needless to say, there may be no compromises on safety.

Control: Communication to the energy storage device will have various levels of integrity. For example, an ISO dispatch will have to be a two way communication with a variable output from the energy storage system. The ISO must know the SOC (State of Charge) of the system to determine if energy can be called for or stored in the system. For Frequency Control, the dispatch can be on a short time period. Testing has been done on a 4 second dispatch, but faster dispatch is being investigated. For one system, the battery stack voltage can vary from approximately 750 volts to 1075 volts. Consequently, the current will vary to provide the nameplate power of 1 megawatt. The owner of the system needs to permit the ISO to use the resource, having determined whether both the day ahead bidding was successful and there is no scheduled maintenance. The third system would be a "read only" history of use for vendor warranty information.

Optimization: A vision of the "smarter grid" is also a "Learning Grid". Optimization will take place as the "learnings" from data analysis of grid operation are realized. Energy storage will be categorized by power capabilities, round trip efficiency as a function of state of charge, temperature and other parameters. Also an expert system will determine if the same charge algorithms are applicable on Sunday with significant power requirements on Monday morning vs. on Friday with a light load expected on Saturday. As the expert systems learn the usage on a local basis, the algorithms will be changed to maximize both economic and climatic variables.

Transmission line loadings and base load availability will be integrated with renewable sources such as wind and PV solar. There are many "axes being ground" in the renewable industry, especially by wind advocates who are claiming wind as a "negative load". The ramp rates necessary for grid stability using over 10% renewable wind or

PV solar are incompatible with most hydrocarbon generations systems which need 20 to 30 minutes to obtain full name plate capacity. The best gas turbines need a ramp rate of .5% per second, which means the full power takes up to 200 seconds to be achieved.

Physical: The physical parameters also are important. The Community Energy Storage (CES, 50 kWh) initiative (AEP and Duke Power) have significantly different requirements compared with a 1 MW, 250 kWh frequency regulation system sited at a substation. In both cases the duty cycle and temperature parameters are significant. Altitude, condensing humidity, seismic and ease of installation are all important. The I^2R heating in an energy storage system is very important for determining whether ancillary cooling or heating is needed. Some systems, such as NaS storage systems, need to operate a high temperatures. Lithium Ion likes 35 ° C and some systems don't operate below 0 ° C. Each storage technology will have specific physical issues.

Business: While business issues are not specifically technical, they do have the final trump card on the application of a technology. Here the "total life cycle cost" is the ruling parameter. Here we can use the metric of $/MWh transferred. Here we must put brackets on the life parameters. Also the end of life parameters need addressed. Some systems fall off a cliff at 80% of original capacity while others still have significant life at the 80% mark. For example, PHEV (Plug-in Hybrid Electrical Vehicle) battery packs can be repurposed when they reach 80% of capacity and operate to very low capacities (as low as 10%) in stationary applications with no additional expense other than relocations.

Metrics: The above categories form a system of "hurdles" that each storage system must pass. It must be safe and protect the grid from interruption. This is a purpose of IEEE 1547 and does an excellent job for various distributed energy systems. Next there will be a complex system of controls as enumerated above. These systems will be continually optimized as learnings evolve and expert systems are applied to the control algorithms. The optimization will be technical, operational and economic. The physical is dependent on location and many site considerations, which will be location dependent. But the overriding metric will be the **$/MWh transferred**.

Conclusion: We have reviewed the categories but little has been learned about each type of energy storage system except there are many variables. How they interact will depend on the specific application, the physical environment and the needs of the grid stability requirements. A multi dimensional matrix can be developed to bring some rationality to the situation. The logic is to assume the safety requirements will be satisfied. Then an application from the ESA chart will be selected and an optimum set of characteristics for an energy storage system will be specified. The applications will be separated into either an energy storage application (hours of supply duration) or a power storage application (cycles to seconds to minutes). This paper is the first attempt in trying to separate the conventional thinking of energy storage in terms of $/MW or $/kWh stored to a total "energy transferred" metric in the form of **$/MWh transferred**.

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