TECHNOLOGY DEVELOPMENT NEEDS FOR INTEGRATED GRID-CONNECTED PV SYSTEMS AND ELECTRIC ENERGY STORAGE

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Abstract-**Modernizing the electric system will help the nation meet the challenge of handling projected energy needs—including addressing climate change by integrating more energy from renewable sources and enhancing efficiency from non-renewable energy processes. Advances to the electric grid must maintain a robust and resilient electricity delivery system, and energy storage can play a significant role in meeting these challenges by improving the operating capabilities of the grid, lowering cost and ensuring high reliability, as well as deferring and reducing infrastructure investments. Finally, energy storage can be instrumental for emergency preparedness because of its ability to provide backup power as well as grid stabilization services. At present, the U.S. has about 24.6 GW (approx. 2.3% of total electric production capacity) of grid storage, 95% of which is pumped storage hydro.1 Europe and Japan have notably higher fractions of grid storage. Pursuit of a clean energy future is motivating significantly increased storage development efforts in Europe and Asia, as well as the U.S. Energy storage technologies—such as pumped hydro, compressed air energy storage, various types of batteries, flywheels, electrochemical capacitors, etc., provide for multiple applications: energy management, backup power, load leveling, frequency regulation, voltage support, and grid stabilization. Importantly, not every type of storage is suitable for every type of application, motivating the need for a portfolio strategy for energy storage technology. This paper summarizes the status of various storage technologies in the context of PV system integration, addressing applications, benefits,**
costs, and technology limitations. It then discusses **further research and development needs, with an emphasis on new models, systems analysis tools, and even business models for high penetration of PV-storage systems on a national scale.**

Index Terms- **VRLA,EPRI**

I. INTRODUCTION

Several efforts are currently underway to define and establish the electric grid of the future, such as EPRI's Intelligrid, the DOE's Smart Grid, the Galvin Perfect Power Initiative, and others. These initiatives work to improve grid flexibility, reliability, load management, power quality,
and other features of our electricity generation and delivery system through the improved application of information and control technologies. This paper focuses
on the use of PV-storage as part of the overall "modern grid" system, while focusing on smaller, distribution-scale applications on the order of 1MW or less. Figure 1 illustrates the intermittent nature of PV generation. The plot shows voltage and power produced by a small residential PV system over the course of a day with frequent passing clouds. Both the magnitude and the
rate of change in output are important: in seconds, the PV system can go from full output to 20% output or less and back again. At high levels of PV penetration, this intermittency can wreak havoc on utility operations and on load-side equipment due to fluctuations in grid voltage and power factor. Stated simply, fluctuations on this scale will not be allowable. Figure 2 is a graphical representation of the current need for a utility to add storage or spinning reserve backup capacity as the penetration of PV on its system increases.

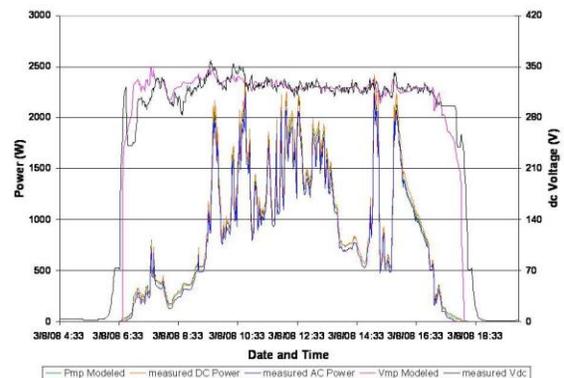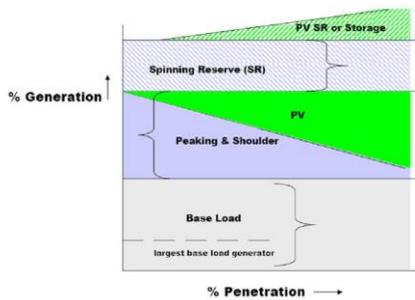Figure 1: Measured and modeled PV system output on a day with frequent passing clouds.

Figure 2: The need for spinning reserve or storage at increasing levels of PV penetration

As more PV is used to meet intermediate or peaking loads, and thereby offset such generation, additional backup is needed to assure these loads can be met during times of low PV generation. From an economic standpoint, this adds costs to utilities and electricity consumers that are not directly reflected in the up-front cost of the PV systems. Successfully integrating energy storage with distributed PV generation in grid-connected applications involves much more than selecting an adequately sized system based on one of the many commercially available technologies. Optimal integration of storage with grid-tied PV systems requires a thorough understanding of the following:

• The application for which the storage is being used and the benefits integrated storage provides for that application;

• Available storage technologies and their suitability to the application;

• The requirements and constraints of integrating distributed generation and electrical energy storage with both the load (residential, commercial, or microgrid) and the utility grid;

• The power electronics and control strategies necessary for ensuring that all parts of the grid-connected distributed generation and storage system work.

II. CURRENT DEVELOPMENTS AFFECTING THE ELECTRICITY GRID

The electric power grid is quickly evolving into a smarter, more sophisticated delivery system that incorporates new renewable, distributed generation, end-use, and communications and control systems. The changes will provide many benefits, such as the ability to respond to public policy goals, increase the diversity of generation options, and provide consumers with more choices; however, the challenges are several, including the following:

1. Variable renewable energy generation with limited dispatchability is rapidly growing in its overall contribution to the resource mix.
2. Variability in solar photovoltaic (PV) power output due to the diurnal solar cycle, passing clouds, and other events can lead to ramping events and unpredictable load management at

the system level. Likewise, variations in wind power output, whether short term (seconds) or longer term (minutes), may affect distribution voltage (in those cases in which wind is connected at the distribution level) and might create a requirement for additional regulation and ramping support at the system level.

3. State renewable portfolio standards, which require that a specified minimum fraction of the electricity supplied in a state be generated from renewable energy sources, will likely result in substantial increases in the penetration of these sources on the grid in the coming 10–20 years.

4. Bidirectional power flow created by distributed energy resources presents a challenge for distribution systems with voltage regulation and protection schemes originally designed for one-way power flow.

5. Smart Grid designs call for additional distribution automation and sophistication, such as islanding and self-healing designs aimed at improving user reliability.

6. Limited transmission capacity threatens to force existing clean energy wind resources to be curtailed during peak production times, but expansion of new transmission capacity presents regulatory and environmental challenges.

7. Utilities seek new ways to extend the useful life of existing capital assets to defer investment in capital upgrades and maintain reliable power at a reasonable cost to users while accounting for uncertainty in load growth.

III. POTENTIAL USES FOR ELECTRIC ENERGY STORAGE

In principle, all these issues can be addressed with appropriately designed grid-connected storage systems. Storage can be sized from the kilowatt range up to thousands of megawatts. It can be designed to discharge from sub cycle durations up to many days. Storage can be controlled locally or remotely and can be designed for extremely fast reaction in response to control signals. Storage can both absorb and inject active power and can be coupled with power electronics that can absorb and inject reactive power. Depending on the utility requirements, storage systems can provide voltage and frequency regulation, load and resource shifting, ramping, and dispatchability. They can be designed for the needs of distribution and/or transmission systems and for single-purpose or multi-purpose operation.

Figure 3:- Overview of energy storage use cases
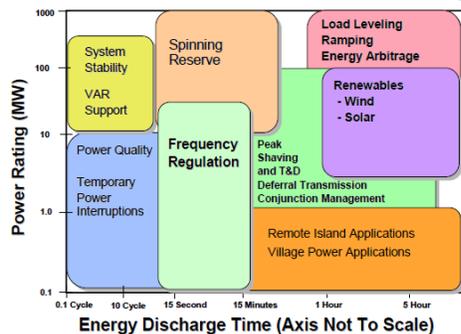
1V. ELECTRIC ENERGY STORAGE OPTIONS AND TECHNOLOGY NEUTRALITY

A wide range of technologies that have the potential to meet these application needs have been or are being developed, including the following:

1. Electrical. Capacitors, super-capacitors, and superconducting magnetic energy storage systems.
2. Electrochemical. Battery systems, flow batteries, and hydrogen with fuel cells
3. Mechanical. Pumped hydroelectric energy storage, compressed air energy storage, flywheel energy storage, and hydraulic accumulators

The process and this report were based entirely on utility requirements for specific applications, and not on the capabilities of underlying storage technologies. Although certain energy storage technologies might operate better in one application or area than another, it is not the purpose of this project to evaluate the suitability of specific storage technologies. To the extent possible, the descriptions of the functional requirements in this report are applicable across all possible technologies. However, on occasion, there are references to requirements that are expected to be relevant only to specific technologies. For example, the capacity of electrochemical batteries might degrade over time, so the rating of systems must account for this possibility, and this is addressed. Such references are provided merely for comparability and clarity; they are not intended to represent recommendations about the suitability of a given storage option. Figure. illustrates possible siting options for energy storage applications.

Figure 4:- Overview of siting energy storage applications
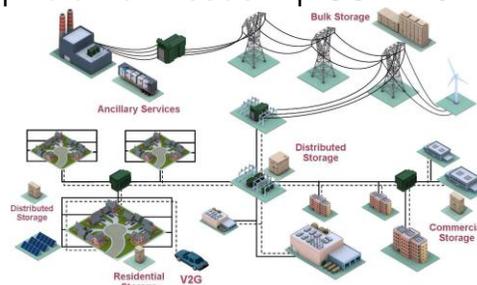
V. GRID SCALE ENERGY STORAGE APPLICATIONS

Until the mid-1980s energy storage was viewed by the electric utilities as a means to time

shift energy produced by coal and nuclear units during off-peak hours to displace energy

that would be produced from other more expensive fuels during on-peak periods. Several

factors, including environmental concerns in building large pumped hydro plants and emergence of other storage technologies using batteries and flywheels, introduced the viability of using storage to provide other grid services. The 2013 edition of the DOE/EPRI Electricity Storage Handbook describes eighteen services and applications in five umbrella groups, as listed in Table . The services and applications identified in this table show that energy storage can be used to support generation, transmission, and distribution, as well as customer-side-of-the-meter needs of the grid. This section describes some of the functions most commercially viable and relevant to the near-term future of the grid.

Table 1:- Electric grid energy storage services

VI. CURRENT ELECTRICAL ENERGY STORAGE TECHNOLOGIES AND COSTS

Energy storage devices cover a variety of operating conditions loosely classified as 'energy applications' and 'power applications'. Energy applications discharge the stored energy relatively slowly over a long duration (i.e., tens of minutes to hours). Power applications discharge the stored energy quickly (i.e., seconds to minutes) at high rates. Devices designed for energy applications are typically batteries of various chemistries. Power devices include certain types of batteries, flywheels, and electrochemical capacitors (ECs). Figure 3 shows several rechargeable technologies in relation to their

respective power/energy capabilities. The traditional lead-acid battery stands as the benchmark. The plot shows that significantly

greater energy and power densities can be achieved with several rechargeable battery technologies. To date, the advantages of lead-acid technology, such as low cost and availability, have made it the default choice for energy storage in most PV applications. New developments in valve-regulated lead-acid (VRLA) technology may revolutionize this well-established technology by using special carbon formulations in the negative electrode. The added carbon inhibits hard sulfation, which minimizes or eliminates many common failure mechanisms (e.g., premature capacity loss and water loss). In cycling applications, the new VRLA technology could dramatically lower the traditional battery energy costs by increasing cycle life, efficiency, and reliability.

Figure 5 : Specific power vs. specific energy of several energy storage technologies.
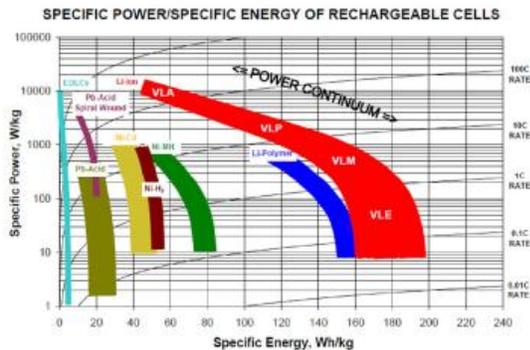
VII.   RESEARCH AND DEVELOPMENT NEEDS

The main research needs discussed in this section fall into three broad categories: storage technologies; controls; and comprehensive systems analysis, including the development of new models.

Storage Technologies: The main R&D needs for storage technologies address the following aspects of their use:
• Increasing power and energy densities;
• Extending lifetimes and cycle-life;
• Decreasing charge-discharge cycle times;
• Ensuring safe operation; and
• Reducing costs.

Batteries also do not typically work effectively under partial state of charge (PSOC) conditions. PSOC operation occurs when a battery is less than fully discharged and then less than fully recharged before being discharged again. PSOC operation is not fully understood for all battery chemistries. Charge and discharge profiles for grid-connected PV-Storage applications need to be tested on the most promising

technologies. Further development and optimization of batteries of various chemistries to improve PSOC operation is also needed.

Controls: To achieve long lifetimes, maximum output, and optimal efficiency from batteries, they must be charged and discharged according to the manufacturer's recommendations. For example, traditional lead-acid batteries require a long (multiple-hour), low-current finish charge to remove sulfation from the lead plates. If finish charging is not done properly, battery lifetime is shortened and capacity is reduced. For non grid-tied systems such as an islanded microgrid, the finish charge is very difficult to accomplish with only a PV-based generation source. Advanced battery management systems can be developed to address some of the charge/discharge issues. Energy storage devices themselves (batteries, flywheels, etc.) do not discharge power with a 60-Hz AC waveform (nor can they be charged with 60-Hz AC power); a power conditioning system is necessary to

convert the output. The DOE Solar Energy Program is currently developing integrated power conditioning systems for PV systems under the SEGIS initiative . These systems include inverters, energy management systems, control systems, and provisions for including energy storage. It is anticipated that charging and discharging control algorithms for different battery

technologies will be included in the SEGIS control package. In the case of lead-acid and NiCd batteries, this will be relatively straightforward. Other technologies (e.g., Li-ion, vanadium redox, and Zn/Br batteries or flywheels) require more complex safety and control systems. To achieve the most economical total system using these technologies, SEGIS system manufacturers and manufacturers of these energy storage products could cooperate to design a fully integrated product with minimal duplicated functionality.

Systems Analysis and Modeling Tools: Successful development of PV-Storage systems will require comprehensive systems analysis, including economic and operational benefits and system reliability modeling. This analysis must include a methodology for determining the life-cycle costs of PV-Storage systems using conventional industry metrics. This methodology will be used to determine benefit/cost tradeoffs for specific applications and system configurations. Software-based modeling and simulation tools represent a key component of successful systems analysis. PV system designers use various models to evaluate the needs for and effects of various technologies. For the most part, current PV system models do not accommodate storage well. Ideally, models and simulation tools for grid-tied PV-Storage systems will be able to accomplish the following:

• Fully evaluate the benefits of a given PV-Storage system by modeling solar energy production, building

loads, and energy storage capabilities relative to capital cost, maintenance, and the real-time cost of alternate energy sources (utility power).

• Accurately simulate residential, commercial, and utility systems and provide recommendations for how to operate, dispatch, and control the PV-Storage system to optimize its economic performance under various loads and rate structures.

• Provide detailed models of the interrelationships between the various system components and operating parameters including the physical relationships, operating rules, regulations, and business decisionmaking criteria to aid in comprehensive systems analysis and to identify relationships that might create unexpected vulnerabilities or provide additional robustness.

VIII. CONCLUSIONS

To address the technology gaps described above and to ensure that grid-tied PV-Storage systems meet the needs of customers, utilities, and all other stakeholders, a three-pronged approach is recommended:

• Comprehensive systems analysis and modeling;

• An industry-led R&D effort focused on new integrated systems; and

• Development of appropriate codes and standards that facilitate broader market penetration of PV-Storage systems and address all related safety concerns. These analytical studies will include

developed new modeling tools to address several aspects of PV-Storage system integration, including system

technical performance optimization; grid operational performance, stability, and reliability; cost/benefits; lifecycle costs; and overall energy systems management. Models will also address advantages and disadvantages of distributed versus aggregated storage systems (e.g., community-scale vs. residential), and the integration of PV-Storage systems with building loads, operating rules, and regulations and business decision-making criteria. Finally, new models are needed to explore the role and potential for plug-in hybrid electric vehicles (PHEVs) to provide grid and PV generation support.

REFRENCES

1. J. Maire, and D. Von Dollen, "Profiling and Mapping of Intelligent Grid R&D Programs", Report 1014600 to the IEEE Working Group on Distribution Automation,
December 2006.

2. D. Manz et al., "Enhanced Reliability of Photovoltaic Systems with Energy Storage and Controls", NREL/SR- 581-42299, National Renewable Energy Laboratory,
Golden, CO, February 2008.

3. J. Boyes, and D. Menicucci, "Energy Storage: The Emerging Nucleus", Distributed Energy. 5, January /February 2007.

4. C.J. Hanley et al., "Solar Energy Grid Integration Systems – Energy Storage", SAND2008-4247, Sandia National Laboratories, Albuquerque, NM, 2008.

5. H. Bindner et al., "Lifetime Modelling of Lead Acid Batteries", Riso-R-1515, Riso National Laboratory, Roskilde, Denmark, 2005.

6. K.D. Divya, and J. Ostergaard, "Battery Energy Storage Technology for Power Systems – An Overview", Electric Power Systems Research, 79, 2009, pp. 511-520.

7. O. Onar, M. Uzunoglu, and M. Alam, "Modeling, control and simulation of an autonomous wind turbine/photovoltaic/fuel cell/ultra-capacitor hybrid power
system", J. Power Sources, 185, 2008, pp. 1273-1283.

8. A. Urbina et al., "Probabilistic Analysis of Rechargeable Batteries in a Photovoltaic Power Supply System", SAND98-2635C, Sandia National Laboratories,
Albuquerque, NM, 1988.

9. A. Urbina, T. Paez, and R. Jungst, "Stochastic Modeling of Rechargeable Battery Life in a Photovoltaic Power System", 35th IECEC. 2, 2000, pp. 995-1003.

10. A. Urbina et al., "Inductive Modeling of Lithium-Ion Cells", J. of Power Sources. 110, 2002, pp. 430-436.

11. L. Kendrick et al., "Hybrid Generation Model Simulator (HYBSIM)", SAND2003-3790A, Sandia National Laboratories, Albuquerque, NM, 2003.

12. D. Sauer, and H. Wenzl, "Comparison of Different Approaches for Lifetime Prediction of Electrochemical Systems – Using Lead-Acid Batteries as Example", J. of Power Sources. 176, 2008, pp. 534-546.

13. H. Wenzl et al., "Life Prediction of Batteries for Selecting the Technically most Suitable and Cost Effective Battery", J. of Power Sources. 144, 2005, pp. 373-384.