DOE Global Energy Storage Database – A Platform for Large Scale Data Analytics and System Performance Metrics

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***Abstract*— The U.S. Department of Energy (U.S. DOE) Global Energy Storage Database (GESDB) is an openly accessible archive of electrical energy storage projects across the electric grid infrastructure and a global repository of relevant policies. The data included in the archive has been fully validated. The GESDB represents a dynamic catalogue with a continuously updated dataset. This is essentially a global industry platform for dissemination of project and performance metrics on the growing fleet of energy storage installations. Over the last four years, the database has been utilized to help shape the development of new projects, improve existing systems and to help develop policy and regulatory framework.**

***Index Terms*—Energy Storage, Electric Grid, Grid Storage Technology**

I. INTRODUCTION *(HEADING 1)*

The U.S. Department of Energy (DOE) Global Energy Storage Database (GESDB) began as a public archive that provided free, up-to-date data about grid-connected energy storage projects through the world, along with relevant state and federal energy storage policies. The information included in the archive is independently verified for data quality and accuracy. The chief objective of the database is to enable advances in energy storage technologies and wide spread deployment.

As of August 2016, the database contains information about 1,591 operational projects in 69 countries divided into five technology categories: electro-chemical, electro-mechanical, hydrogen storage, pumped hydro storage, and thermal storage. This represents a total 171 GW of operational energy storage capacity deployment.

The database has three principal components: system platform, services provided, and validated content [1]. The database offers open access with extensive data visualization tools and ability to export data in usable formats, including Microsoft Excel and Abode PDF. In this paper, we highlight the features of the database and the usefulness of the information for developing new energy storage projects and provide a platform for greater data dissemination for the worldwide energy storage community.

II. DATABASE DEVELOPMENT

A major challenge in creating a reference grade data repository is access to quality data with usable performance metrics over its operational life. We used an iterative design process in creating this database, starting with extensive stakeholder input and engagement with the global energy storage industry.

A. Defining Use Cases and Data Granularity

To start with, we conducted extensive background research, including interviews with over 50 stakeholders from the utilities, project developers, and energy storage system providers. These interviews led to a greater understanding of the industry needs as well as identified key users, use cases, and the level of granularity needed for the information to be useful for the community. This was followed up by the development of initial prototype database and a framework to generate "fuse case" scenarios to be tested with key user segments and selected stakeholders. The final product is a result of extensive refinement in system architecture, improved user-interface and ease of navigation for user experience.

B. Development of the Application Architecture

The application stack for this project is based on a standard programming language Ruby on Rails [2], with a *postgreSQL* database that relies on a three-layered architecture to protect data and prevent data scraping. The technical tools associated with this programming language are well established to ensure the long-term viability of the database. We have successfully implemented automated program interfaces that are based on commonly used data sharing protocols. We decided to use Ruby on Rails for its model-view-controller (MVC) architecture, with a structure particularly well suited for database applications. The MVC architecture contains specific criteria for the following components:

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1) User: Ability to search and view database entries or input new data into database from a web browser.

2) View: A user interface (UI) that emulates the front-end aspects of the website. The database front-end was built using HAML, HTML5, CSS3, JQuery, and JQgrid, with Tableau used for data visualizations.

3) Controller: A logic based controller that allows bidirectional data verification and validation. The controller was built in Ruby on Rails.

4) Model: The back-end of the database that has robust data flow architecture for seamlessly accessing data from the controller. Again, this model was built in Ruby on Rails.

5) User: Data is stored in a PostgreSQL database, which is an open source object-relational database system.

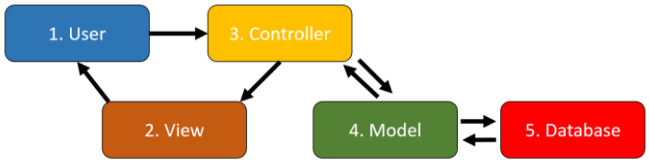

Figure 1 GESDB model-view-controller (MVC) architecture

The flexibility of the DOE GESDB platform allows for new entry fields to be made readily available. In the most recent version, we have added features to include updates on "Energy Management Software," features that are becoming common. We make continuous improvements to the database to improve the front end user experience. For example, we have recently added features to allow drag and drop functionality for images for project entry. We also reduced, then grouped the primary energy storage systems use case categories as follows:

Figure 2 Primary energy storage use case categories

In many cases off-the-shelf tools and plug-ins are available to build new front-end applications like Tableau Public to enhance data visualizations. As an example, Fig. 3 is a visualization display of the annual deployed capacity of non-hydro energy storage:

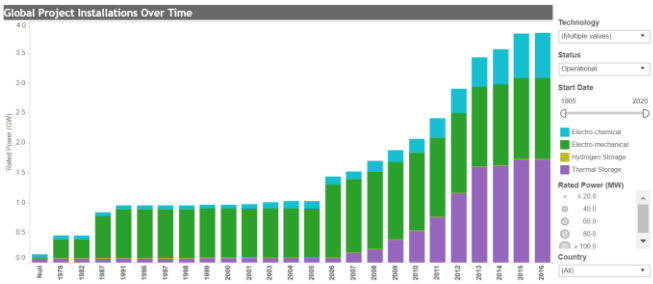

Figure 3 Non-hydro energy storage deployment

III. CURRENT STATUS

Upon accessing the database at http://www.energystorageexchange.org/ one finds the following: (a) the image of a global map with balloons pinned to specific locales; and (b) two major options for searchable records – either storage projects or policies. This is a menu-driven tool according to the user's interest.

A. Navigating Current GESDB Content: Projects & Policies

Clicking on the global map balloons does not engage the site. One must choose from either "Projects" or "Policies" to advance into the site. Should the selection be for the "Projects" option, then the next page is populated with a more detailed map that serves as a summary of projects around the globe, against the backdrop of a map. Filters are offered according to the table below.

Technology Type	Rated Power	Ownership Model
Country	Duration	Status
State/Province	Service/Use Case	Grid Integration

Table I - Filters to search projects on the GESDB site

Selection of balloons after the opening page does render data about the name and size of the project, the country, the technology type, and operational status. Options exist to export data, perform an advanced search, to further filter the data, or add new projects.

When the selection is "Policies", then a 2011 map of North America and its Regional Transmission Organizations (RTOs) is the page default. See Fig. 4.

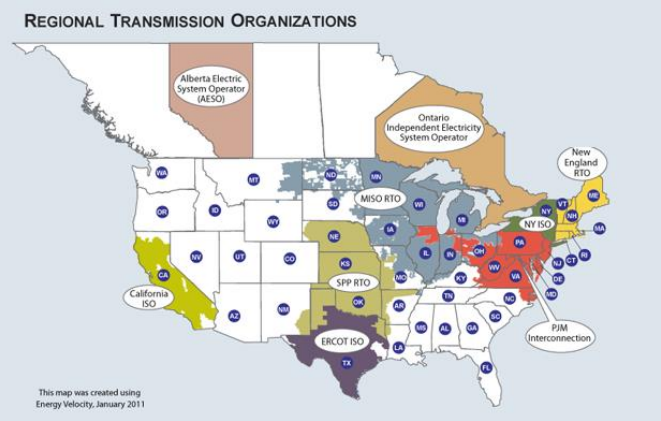

Figure 4 North American Regional & Independent Service Organizations

There are two Canadian (Alberta Electric System Operator and Ontario Independent Electricity System Operator) RTOs and seven U.S. RTOs represented on the map: California Independent System Operator (CalISO), Electric Reliability Council of Texas (ERCOT), Southwest Power Pool or SPP RTO, Midcontinent Independent System Operator (MISO), Pennsylvania, New Jersey and Maryland (PJM) Interconnection, New York ISO, and New England ISO. Currently, only Texas' ERCOT has a list of state policies listed. If one selects a state or region where there is no RTO, then the search returns empty.

B. GESDB and Unique Partnerships

The current list of database partners is diverse: (1) The California Energy Storage Alliance, a membership-based advocacy group made up of technology manufacturers, project developers, systems integrators, consulting firms, and others in the clean energy industry; (2) The China Energy Storage Alliance (CNESA), a not-for-profit member-based energy storage association in China, composed of energy storage (ES) technology developers, renewable energy manufacturers, venture capitalists, and ES research institutions; (3) The India Energy Storage Alliance (IESA), whose stakeholders promote ES and micro grid technologies; (4) New York Battery and Energy Storage Technology (NY-BEST) Consortium, motivated by ES applications for transportation, grid storage, and power electronics; (5) The Australian Energy Storage Alliance, an information sharing and networking platform to promote the wide range of existing and emerging energy storage solutions that are available in Australia; and (6) Strategen, a clean energy markets consulting firm.

These unique partnerships contribute to the exclusive content for the database. Energy storage systems owners and developers are key players, providing dynamic data that is not centrally available at any other single website. The website developers track use of the services and users of the site, including pages viewed and length of page viewing to gauge current data needs.

Since its launch in June of 2012, the GESDB has received over 2 million page views from users across 205 different countries, islands, and territories.[3] The GESDB has grown from 10,868 users in its first year to 98,392 users over the past four years. This growth tracks the development of global energy storage projects during this time period: the total capacity of energy storage installations (not including pumped-hydro) that are operational or under construction expanded from 3.2 GW in 2012 to 6 GW as of March 2016.

Visitors to the GESDB typically spend over five minutes visiting the website. Further, while the average session duration for all users on the GESDB is 5.5 minutes, over 8,000 sessions have lasted over 30 minutes, suggesting deeper engagement. The most popular page on the database website is the "Projects" page, which provides an overview of energy storage projects across the globe. This page has received 14.5% of total page views – even more views than the homepage itself, which received 13.34% of total page views.

Geographically, 39.8% of visitors to the GESDB are located in the United States. Visitors from India represent the second highest source of traffic, at 6% of all visitors. The top ten countries delivering website traffic to the database are (from highest percentage of traffic to lowest): United States, India, Germany, United Kingdom, Canada, South Korea, Japan, France, Australia, and Spain. This list is roughly aligned with the locations in which the world's energy storage is currently installed or under development. The country with the most storage currently installed is the United States, followed by Spain, Germany, Japan, and China.

Over the past four years, the GESDB has become a popular and trusted resource for information on energy storage technologies and projects. As the database has grown, so too have energy storage markets across the globe. The growth in user interest in the database reflects steadily increasing interest in energy storage projects, technologies and markets from users throughout the world.

Figure 5 GESDB "Projects" page

C. Technical and Legal Considerations

The GESDB offers a comprehensive glossary of the technical nomenclatures used for each of the filters as well as associated terminology. Where possible, an example of the term is also shared. As an example, for the ancillary

service “black start”, the broad description of a technical term like “performance” or legal references like “policy number”, the website shares the following:

Term	Definition	Example
Black Start	A black start is the process of restoring a power station to operation without relying on the external electric power transmission network.	An energy storage system is used to re-start turbines of a generation facility after a large blackout causes generators to go offline.
Performance	Any performance statistics or results available on the project.	The system performed at a capacity factor of 90% during the year of 2010. Other examples of performance statistics include: - Round Trip Efficiency (RTE) - Ramping Rate - Greenhouse Gas Emissions - Noise (decibels) - Availability Number of maintenance visits
Policy Number	The assigned tracking number for a given policy.	R. 11-09-011

Table II – Example of GESDB glossary of terms

The database shares with users the legal terms of data use and reproduction along with its Digital Millennial Copyright Act (DMCA) and the applicable Download Disclosure Terms of Use Agreement.

D. Project Data Type, Use, and Format

Let us look at a case in particular to understand the data that is available to inspect. Take for example the projects in New Mexico. Currently the database lists five different energy storage projects in New Mexico. One would find specific elements in common to all the projects – a description, technology type, rated power (in kW), duration of rated power (in Hours: Minutes), siting, any associated RTO, ownership, benefits, funding, research partners and performance link(s). The project of interest is the Public Service Company of New Mexico’s Prosperity Energy Storage Project.

In 2009 the U.S. Department of Energy provided $185M in federal matching funds from the American Recovery and Reinvestment Act (ARRA) to support energy storage research and development projects in five categories: battery storage for utility load shifting, ancillary services, distributed storage for grid support, compressed air energy storage and promising storage technologies. The Public Service Company of New Mexico (PNM) won one of those grants for its Prosperity Project.

The database report summary indicates the PNM Prosperity ESS to be a demonstration project that was installed with a 0.5MW Smoothing Battery and a 0.25MW/0.99MWhr Peak Shifting Battery that uses Ecoult/East Penn Manufacturing Advanced Lead Acid Batteries.

The PNM ESS database performance link in this instance is a series of analyses and methodologies folded into the Final Technology Performance Report [4]. The analyses are described in terms of cost and technical performance.

For economic performance, the PNM project used the Energy Storage Valuation Tool (ESVT) from the Electric Power Research Institute (EPRI) to establish baseline data from specific system parameters (i.e., feeders, photovoltaic (PV) generation, SCADA data, etc.) to produce pro forma dispatch schedules for peak shaving. EPRI simulated firming; then used another DOE simulation tool to validate the ESVT outputs. The technology analyses were performed to assess smoothing and shifting results: validation of the feeder model, smoothing simulation, validation of the shifting model. These data complement earlier reports on the PNM ESS project [5, 6].

Experimental data important to a researcher or an engineer appears in these reports. For example, the initial algorithm was not accurate in forecasting how to shave the peak. The efforts resulted in residual peak that appeared after the batteries finished discharging. Thus there was no benefit gained by using the battery. See Fig. 6.

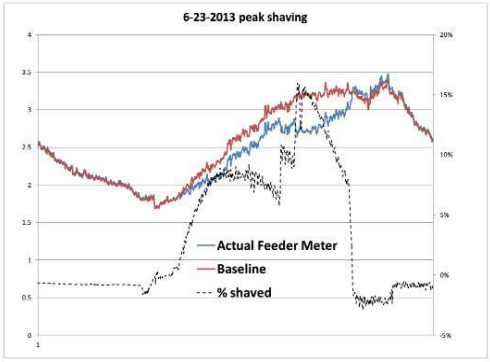

Figure 6 PNM Prosperity ESS prior to peak shaving optimization

Fig. 7 is an illustration of how better tuning the feeder profile improved the shifting algorithm. In this instance, the batteries were properly dispatched.

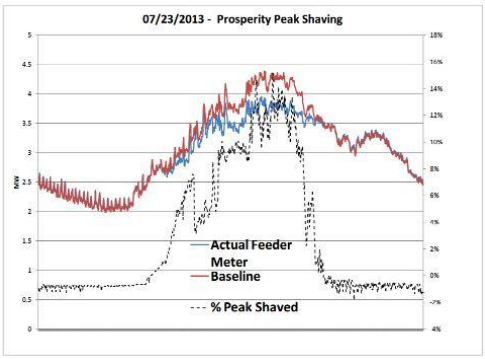

Figure 7 PNM Prosperity ESS peak shaving after optimization

There were four other projects in New Mexico listed in the database. None of those projects have (a) formal cost and performance metrics reports in the links provided or (b) electro-chemical technology type with at least a four-hour duration profile. Two other electro-chemical projects with a 4-hour duration option are featured in the database. Only EnerVault has a cost-performance report available.

The EnerVault Redox Flow Battery Demonstration Project was also funded through a DOE ARRA grant. The project engineers designed, developed, deployed and tested a 250kW/1MWhr (4-hour duration) iron chromium redox flow battery system to integrate a 150kW dual-axis tracking PV system that would manage peak demand. The end-user benefits from this ESS by having access to full-rated power and energy as well as full-rated discharge that matches the application.

After completing the installation, the EnerVault team completed field system performance testing. Figure 8 shows the system performance profile and uniformity over three short duration charge and discharge cycles at 220kW [7].

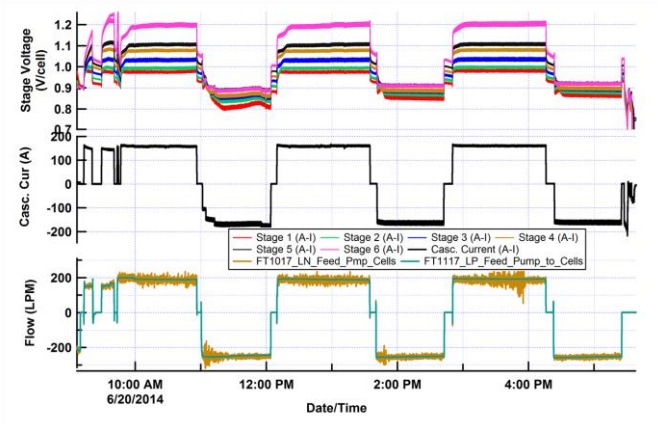

Figure 8 EnerVault field demonstration testing system at 220kW

The multi-colored lines show voltage from each (120-cell) stage, normalized to the cell count. Each color has plot points for each of the nine cascades that comprise the system. According to the system analyst, the narrow width of each plot indicates exceptional electrical and chemical uniformity in the stages and cascades as well as system stability. The black line plots the cascade current for the nine cascades. The blue line shows the system flow rate as measured at multiple points within the hydraulic system.

The GESDB has access to the publicly available information from this and similar projects. In the next phase of data-sharing, the database project manager will need to make decisions about the data type and format to present for the end user.

IV. Planned Improvement

The five immediate areas to improve the existing body of work provided by the GESDB are the following:

1) *Build on the policy section,*
2) *Work with an agency to expand the scope of the data,*
3) *Develop the platform to share applicable codes and standards for energy storage systems,*
4) *Improve data visualization and social media tools, and*
5) *Establish an advisory board.*

The policy section will retain landmark decisions like FERC Orders and post up-to-date DOE policy mandates that affect energy storage. However, there is also the opportunity to include current docket information for state and regional jurisdictions in the United States. If there is something similar with other countries that implicate major changes in energy storage, then that data will also be posted.

A primary goal of the GESDB is that it provides accurate data for comparison and analysis by many different users. Strategen is teaming with Sandia National Laboratories to develop the inquiry construct with respect to energy storage projects at 1MW or greater to become part of the data collected by the U.S. Energy Information Agency (EIA). The EIA serves as the U.S. authority on energy statistics based on its comprehensive data collection program.

The science of energy storage is proven. However, the applications and technological advances are still emerging. The narrative about safety, industry codes and standards relate directly to the many varied applications of energy storage. The Sandia Labs and Strategen team members are working toward creating a tool within the database that can be a useful reference of codes, standards, and regulations for energy storage systems.

An advisory board of approximately 10-15 people is planned. The board would include partners from around the world, with Dr. Imre Gyuk of the U.S. DOE-OE taking the lead role. An agency, however, would be the U.S. representative on the panel. Lastly, a newsletter is planned to highlight new projects and new policy developments and to engage the broader community of GESDB users.

V. Conclusion

The DOE GESDB is a unique tool that provides data for energy storage systems (ESS) users, researchers, and other stakeholders based on exclusive input from global partners. It can provide better value by improving its information about relevant energy policies, expanding the scope of its technical data, developing a platform to share ESS codes and standards, improving data visualization and establishing an advisory board.

The challenge to the researcher is how to define the data that is needed across regional projects, availability of that data, and permission to share more than a press release. The challenge for the database provider is how to establish a set of standard metrics to present cost, environmental impact, and technical performance data.

ACKNOWLEDGMENT

The authors thank the United States Department of Energy, Office of Electricity Reliability and Delivery for funding the Global Energy Storage Database and making available data from ARRA-funded projects. Special thanks also go to Bill Ehrlich for his assistance with this paper and his work on the Global Energy Storage Database.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administrator under contract DE-AC04-94-AL8500.

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REFERENCES

[1] Peter Weill, Woerner, S.L. "Optimizing Your Digital Business Model", MIT Sloan Management Review, Spring 2013 Vol 54, No, pp 71-78.

[2] http://rubyonrails.org/

[3] Google Analytics: www.energystorageexchange.org

[4] Steve Willard, Final Technology Performance Report: Smart Grid Demonstratation Project/ Public Service Company of New mexico, PV Plus Battery for Simultaneous Voltage Smoothing and Peak Shifting; Submitted to U.S. Department of Energy/ NETL; April 8, 2014

[5] J. Johnson, A. Ellis, A. Denda, K. Morino, T. Shinji, T. Ogata, and M. Tadokoro, "PV Output Smoothing using a Battery and Natural Gas Engine-Generator," Sandia National Laboratories, Tech. Report SAND2013-1603, February 2013, pp 21-22.

[6] J. Johnson, K. Morino, A. Denda, J. Hawkins, B. Arellano, T. Ogata, T. Shinji, M. Tadokoro, and A. Ellis, "experimental Comparison of PV-Smoothing Controllers Using Distributed Generators", Sandia National Laboratories, Tech Report SAND2014-1545. February 2014.

[7] http://www.sandia.gov/ess/docs/pr_conferences/2014/Thursday/Session 7/01_Nevins_Sheri_IRON-CHROMIUM_REDOX.pdf