MEASURING AND EXPRESSING THE PERFORMANCE OF ENERGY STORAGE SYSTEMS

David R. Conover[1] and David Schoenwald[2]

[1]Pacific Northwest National Laboratory, Great Falls, VA USA
[2]Sandia National Laboratories, Albuquerque, NM USA

Until late 2012, there was no uniform methodology to measure and express the performance of energy storage systems (ESS). A void in this area can affect the acceptance of ESS in the marketplace because different systems cannot be equitably compared and ESS cost-benefit analysis may be challenging due to a lack of verified and relevant ESS performance. The lack of such criteria also furthers the probability that each ESS customer or user will make up their own; necessitating "custom validation" to a unique set of criteria each time an ESS is to be considered or installed.

To address this need and foster the acceptance of ESS, the U.S. Department of Energy's (DOE) Energy Storage Systems Program facilitated the development of a protocol to measure and express ESS performance and is supporting its updating, enhancement and use in formal consensus standards development. Of particular interest is the development of the document through an open and transparent process that saved considerable time.

Keywords: Performance, Standards, Protocols, Measurement, Testing

INTRODUCTION/BACKGROUND

The U.S. Department of Energy's Office of Electricity (DOE-OE) supports an Energy Storage Systems (ESS) Program that is intended to foster the development and deployment of ESS. A key to deployment of ESS is the timely and confident use of the technology. One issue that had challenged ESS proponents and stakeholders was the lack of a uniform way to measure and express ESS performance. The lack of a uniform method to assess performance was resulting in no uniformity, comparability or reliability of performance information; leading to confusion in the market. In addition, some customers and potential users were creating 'home grown' methods of testing; resulting in the need to conduct a different set of tests for each possible ESS installation. The immediate need was to provide a uniform way of measuring, quantifying, and reporting the performance of ESS in various stationary applications; something that did not exist until the protocol development effort was undertaken and, as such, was hampering the consideration and use of this technology at a time when there was considerable emphasis on and support for getting ESS into the marketplace.

DOE wanted to address this issue through standardization in measurement and reporting of ESS performance in an open and engaging manner that would involve all relevant stakeholders. The availability of an application-specific protocol for use in measuring and expressing performance-related metrics of ESS allows technology developers, power-grid operators, and other end-users to evaluate the performance of energy storage technologies on a uniform and comparable basis. This helps differentiate technologies and products for specific application(s) and provides transparency in how performance is measured. It also assists utilities and other consumers of ESS to make more informed decisions as they consider the potential application and use of ESS, as well as forming the basis for documentation that might be required to justify utility investment in or utility commission support for such technologies. DOE realized time was an important factor and sought to address this issue through an innovative process that could lead to consensus standards being available in a more timely and collaborative manner.

In early 2012, DOE, through PNNL and SNL, initiated the development of a protocol (pre-standard) to craft a document that addressed the most urgent needs in the industry related to measuring and expressing performance characteristics of energy storage technologies in various applications. The goal of this effort was to produce a document by the end of 2012 that addressed the most pressing needs associated with measuring and expressing the performance of ESS as determined by those participating in the development of the protocol. In addition, the protocol was to serve as a foundation for addressing the performance of future ESS applications and technology advancements. It was felt that criteria for measuring and expressing system performance could be developed much faster through an open, collaborative, and less formally structured process as can be the case with formal standards development. Then, the results can be made available for initial use in the marketplace and can, in parallel, be used as a basis for more formal standards development.

The protocol is intended to be used to foster the uniform measurement and expression of performance of ESS used for peak shaving and frequency regulation applications. For each of those applications, a specific duty cycle is presented and relevant metrics to be measured and reported for each application provided. Use of the protocol by manufacturers of ESS on a voluntary basis or as required by customers of ESS will result in each ESS, via a permanent label and/or specification document providing relevant data about the performance of the ESS, being uniform in nature and comparable amongst ESS technologies intended for the same application. It is recognized that in addressing only two applications, and a limited set of metrics (5 or 7) for each, there are other applications and metrics that need to be addressed. The intent with the initial protocol effort was to address the most pressing needs in a short period of time as determined by those participating in the development of the protocol, while building a foundation for consideration of additional applications and metrics in the future.

Protocol development and enhancement is intended to be a dynamic process that will occur over time through a phased approach to address enhancement and consideration of all applications and relevant performance metrics. Through application and use of the protocol, it was hoped that the resultant information will serve short term needs and that needed refinements can be identified and addressed in a more formal standards development process by one or more voluntary sector standards development organizations. Both of those goals are being realized through application of the protocol on actual ESS installations and its consideration in U.S. and international standards development.

RELATED WORK

There are a number of activities being conducted by both public and private sectors that relate to methods of testing for ESS performance and the development of formal consensus standards. Relevant to the process undertaken to develop criteria for ESS is the work conducted in the 1990s associated with stationary fuel cell power plants. With the development of stationary fuel cell technology, manufacturers undertook the development of their own criteria for performance assessment associated with not only energy efficiency but also safety. These 'home grown' activities helped to foster the evaluation of a particular vendor's technology. With respect to performance from a safety standpoint they could also be used as 'bench standards' by third party agencies that would test and certify the equipment (fuel cell power plant) as to its acceptability to the criteria. These activities were successful in fostering initial acceptance of the technology but they did not support comparability and uniformity associated with fuel cell performance. Standards and codes requirements were needed to foster acceptance of the technology.

In the absence of an industry association or other private sector lead organization, the U.S. DOE supported efforts to work with relevant stakeholders on the development and deployment of standards and codes for stationary fuel cell technology. Starting with a process similar to that used in development of the protocol stakeholders developed criteria that were then processed through a consensus standards developer resulting in ANSI Standard Z21.83 (now known as ANS/CSA America FC1-2012[2]). In addition, recognizing there was a need to address the installation of the technology in relation to the built environment efforts were fostered by DOE to assist stakeholders in the development of NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems. The latest edition of that standard is 2010 and it will be updated in 2015[3]. Through these activities, what was initially being addressed by some technology proponents on an individualized basis was organized and focused leading to standards and codes to foster a uniform assessment of the technology and its deployment in the built environment. In addition, this activity helped in the creation of Technical Committee (TC) 105 within the International Electrotechnical Commission (IEC) to address international standards for fuel cell technology, which based subsequent IEC standards on these initial efforts in the U.S.

There do not appear to be any activities in the U.S. or internationally that conflict with those being conducted through the protocol effort. The protocol is currently a target for use in U.S. standards development by standards developers such as NEMA and IEEE. It is also likely to be used as the basis for an IEC Standard to be developed by IEC TC 120, which was recently formed to develop standards for ESS.

DEVELOPMENT OF THE PROTOCOL

The protocol development process was initiated in March 2012 and open to anyone who wanted to participate. It was widely representative of ESS industry leaders, developers, users, government, research, and other interested stakeholders; involving over 100 individuals representing over 60 different entities. This process included a project introduction and many varied communications. Anyone who responded became a member of the protocol working group, which had four web-based and one face-to-face meeting over a period of eight months. In addition the working group was broken into four subgroups working on specific details associated with the protocol; specifically criteria for peak shaving and frequency regulation applications, the desired performance metrics, and definitions. Through those efforts and numerous correspondence, drafts, re-drafts, etc., the protocol was completed in the fall of 2012.

The establishment of this process is similar to consensus standards development in that a purpose and scope of the document and all criteria were developed by a group of interested and affected parties (stakeholders). Key differences though are the protocol development process allowed all interested parties to equally participate and provide input, voice their opinions and while there were no formal votes every effort was made to ensure no participant had any major issues with the content in the protocol. Another key difference was its relatively informal nature compared to consensus standards development, which at times can be challenging and controversial where varied interests and agendas conflict. Of particular importance the working group understood that there was considerable work that needed to be accomplished and to cover everything in a year would be impossible. This resulted in setting up a process to address the most pressing needs first and then circle back in an organized manner to address other needs in order of priority in the future.

PROTOCOL CONTENT

Because the intended use of the protocol is as a pre-standard as well as providing a starting point for formal standards development the protocol is written like a standard; that is there are clear directions for applying the criteria in the document. It is intended that varying entities applying the protocol will do so in the same manner and the results secured for different systems will be comparable. The purpose and scope of the protocol were developed first and clearly establish what was (and was not) to be covered in the protocol. Of key importance, they were written to be as broad and inclusive as possible, something that ensures their continued validity and ability to respond to change over time. Given that the intent of the protocol work, as covered above, was to create a dynamic process and living document having a very broad purpose and scope was even more important in fostering additional work after the first version was completed to address more ESS applications and relevant metrics.

The purpose of the protocol is to provide a set of "best practices" for characterizing energy storage systems and measuring and reporting on their performance. It is intended to serve as a basis for assessing how individual ESS will perform with respect to key performance attributes relevant to different applications. It is also intended to provide a valid and accurate basis for the comparison of different systems. In achieving this purpose it was envisioned the protocol would enable more informed decision-making in the selection of ESS for various stationary applications.

The scope of the protocol is the establishment of a set of test, measurement and evaluation criteria with which to express the performance of ESS that are intended for energy intensive stationary applications and/or power intensive stationary applications. When using the protocol the energy storage system includes the storage device and any power conversion systems installed with the storage device and can also include battery management systems when the user of the protocol chooses to include them. This ensures that all users include the same components when they assess the performance of their ESS. The protocol is agnostic with respect to the storage technology and the size and rating of the energy storage system. The protocol does not apply to single use storage devices and storage devices that are not coupled with power conversion systems, nor does it address safety, security or operations and maintenance of ESS, nor does it provide any pass/fail criteria.

Recognizing that the purpose and scope were by design very broad, those involved in development of the protocol recognized that it could take considerable time to develop criteria to fully address the purpose and scope; especially considering that because ESS technology and applications are continually evolving there would always be work to be done. A decision was made to approach the work based on which systems and applications were the most critical in the short term and then after writing the criteria for those to circle back and address other system metrics and applications. Figure 1 provides an overview of the 'design' of the protocol.

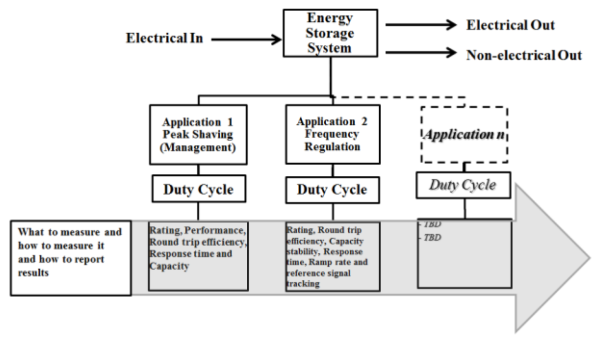

Fig 1. Overview of protocol development effort.

The initial work was focused on electrical storage systems and to two applications of those systems: peak shaving (management) and frequency regulation. For each of those applications a duty cycle was established, recognizing that for system performance to be comparable all systems would have to be subjected to the same identical operational demands. In addition metrics relevant to the performance of the system for each application were also identified. The end result, as discussed in more detail below, is the selection of the system application, what is to be measured based on the data needed to address the relevant metrics and then operation of the system consistent with the applicable duty cycle.

One other important consideration was the definition of the system boundaries; that is the points where measurements would be taken. This recognized that the intent of the protocol was to address system performance. Within the system, component to component communication and interaction and the performance of the individual components was not considered to be of key importance. In short, the system is defined pursuant to the scope of the protocol and then delineated by the entity making the system; and as noted above all systems were required to have certain components inside the boundary to ensure comparability of different ESS. Within that boundary, the ESS manufacturer is required to identify and provide a schedule of all ESS subsystems and major components by make and model number, their input and output and the standards used in taking those measurements.

The metrics to be determined for both peak shaving and frequency regulation applications are discussed below. The reporting of the results for each metric is intended to be from the manufacturer of the ESS. There are no specific criteria in the protocol addressing the qualifications of those conducting the tests or their affiliation with the ESS being tested. Generally speaking those issues, which are associated with conformity assessment, would be addressed by those adopting or referencing the standard. For instance a utility or building developer customer would likely require testing to be performed by an independent testing entity having satisfied certain qualifications applicable to entities conducting testing (e.g. ISO standard 17025[4]). That said, in applying the protocol to initially addresses the performance of ESS it is logical to expect first party testing (e.g. the ESS manufacturer) to be acceptable with the customer having access to review the test results and competency of the entity conducting the testing.

Peak Shaving Applications

One of the two applications covered by the protocol is peak shaving (management). Such an application involves an energy storage system that requires discharge duration during the daily on peak period (on the order of 2 to 12 hours) and is intended to recharge in the daily off-peak period and be available again the following day.

Five metrics associated with performance of ESS for peak shaving were considered very important to address in the short term; recognizing that future work could allow those working on peak shaving applications to circle back in the future to address other metrics. Those metrics are the system rating, stored energy capacity, roundtrip efficiency, response time, and duty cycle round trip efficiency. Also within this application the system is required to be classified as to its intended use. Such uses are energy time shift, electric supply capacity, load following, transmission congestion relief, distribution or transmission system upgrade deferral, wind or PV energy time shift, renewable capacity firming, of base load generation time shift.

The protocol requires measurement of specified data during the operation of the system in conformance with a specific duty cycle. That 24 hour duty cycle is shown in Figure 2 and in turn that duty cycle must be applied (repeated) over at least seven continuous days as shown in Figure 3.

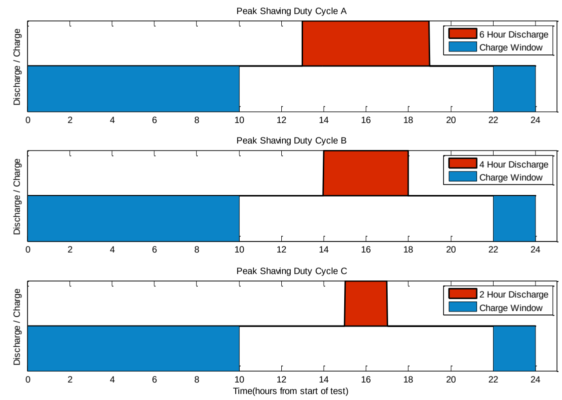

Fig 2. Peak shaving duty cycle.

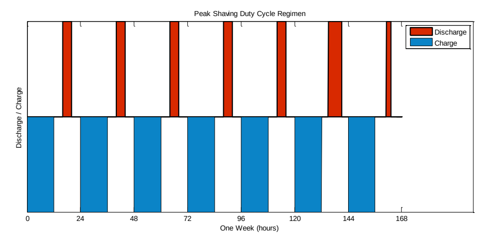

Fig 3. Peak shaving duty cycle regimen.

System Rating

The system rating (power in volts DC) is determined using operating conditions set by the ESS manufacturer and then performance is determined at those operating conditions at the beginning of the life of the ESS based on IEEE Standard 1679[5].

Capacity (size)

The capacity test determines the energy performance at the rated power (capacity in Ah). After the initial charge to the ESS, the system is discharged to the minimum storage level specified by the manufacturer. Values of energy input to the system are recorded at regular intervals of time or at step or percentage variances at a rate that is documented by the manufacturer as providing adequate resolution.

In conducting the capacity test, the manufacturer describes a detailed and documented charging procedure within the specifications of the ESS for charging the system in less than 12 hours to full state-of-charge. In addition, the manufacturer selects a discharge time at constant power output. For devices intended for peak shaving (management) application the discharge time selected must be as recommended by the system manufacturer but between 2 and 12 hours. Once this discharge time is selected, all capacity tests conducted on the same system are intended to remain consistent to properly track performance degradation.

A summary of the test, which must be performed at least eight times, is shown below. The resultant efficiency is calculated as the mean of the second through X^{th} values of the energy input while charging the ESS, with the standard deviation also calculated and reported. At the end of this test the ESS is recharged and left at a fully charged state but that particular energy charge is not considered in determining the efficiency of the ESS.

- The ESS is discharged to its minimum state-of-charge level in accordance with the system manufacturer's specifications and operating instructions.
- The ESS is then charged in accordance with the system manufacturer's specifications to full state-of-charge. The energy input into the system during system charging, including all parasitic losses, is measured and recorded.
- The system is left at rest in an active standby state for 30 minutes.
- The system is discharged in accordance with the system manufacturer's specifications and operating instructions to the minimum state-of-charge associated with the practical state-of-charge range as defined by the system manufacturer and provided in the system manufacturer's specifications. The energy output from the system is measured and recorded during discharge.
- The system is left at rest in an active standby state for 30 minutes.

Roundtrip Energy Efficiency

A roundtrip energy efficiency test is conducted to determine the amount of energy that an ESS can deliver relative to the amount of energy injected into the system during a charge. This test is performed as part of (e.g. concurrent with) the reference performance capacity test covered above using the energy test routine and the applicable duty cycle for the intended application of the system. The roundtrip energy efficiency is determined in accordance with Equation 1 based on the data secured during the capacity test.

$$Round\ trip\ efficiency = \left(\left(\frac{\sum_2^X (Wh_{DX})}{\sum_2^{X1} (Wh_{IX})} \right) \right. \qquad (1)$$

In Equation 1, X represents the number of test repeats, WhDi is the Watt hour rated power (AC) delivered (output) by the system measured and recorded as WhDi, where i is the cycle number, WhIi is the Watt hour input (AC) into the system during system charging, including all parasitic losses, where i is the cycle number and WhI is the Watt hour input WhI1, into the system during system charging, including all parasitic losses.

Response Time

Response time is reported in seconds and addresses the amount of time required for the system to transition from no discharge to full discharge and from no charge to full charge. The response time test is measured in accordance with Figure 4 starting when the signal is received at the ESS boundary to when the system begins to discharge within two percent of the ESS rated power. The data collected are then applied where response time is determined by subtracting the end time stamp when the output of the system maintains a value within two percent of its rated power, in seconds from the initial time beginning when a change in set point of output is sent to the system, in seconds. These tests must be repeated at the maximum and minimum state-of-charge levels with a charge input signal sent to the ESS.

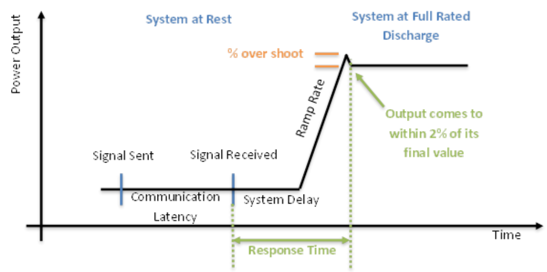

Fig 4. Response time test.

Duty-cycle Round Trip Efficiency

In determining the duty-cycle round trip efficiency the ESS is operated as outlined below in accordance with the peak shaving duty cycle.

- The ESS is fully charged in accordance with the manufacturer's specifications and then is brought to the initial desired state-of-charge by removing the necessary amount of energy at the rate provided in the system specifications provided by the manufacturer or alternatively brought to the desired starting state-of-charge in accordance with a vendor specified procedure.
- The ESS is then subjected to the duty cycle.
- At the end of the duty cycle, the system is returned to the initial state-of-charge just prior to the application of the duty cycle.

The roundtrip efficiency is then determined as the total energy output divided by the total energy input measured between the same state-of-charge end points associated with the application of the duty cycle during the test.

Frequency Regulation Applications

The second application covered by the protocol is frequency regulation. Frequency regulation is defined as an energy storage application that regulates the electric power frequency provided by generating units that are online and increase or decrease power as needed and where the power is provided by an ESS that provides "up" regulation by discharging and "down" regulation by charging. Frequency regulation is also considered the use of generation, loads, and energy storage to control system frequency within a predetermined bandwidth and the inclusion of local devices that continuously measure frequency such as a generator governor or a relay or a phasor management unit and then send a control signal to a device to increase or decrease the amount of energy injected into the grid or the amount of load on the grid.

Seven metrics associated with performance were considered important to address in the short term; recognizing that the working group could circle back in the future to address other metrics. Those metrics are the same as those described above for peak shaving applications, other than in assessing how the ESS performs in a frequency regulation application, as opposed to peak shaving application; a different duty cycle would have to be applied. The two additional metrics applicable to frequency regulation applications are the ramp rate and reference signal tracking.

The protocol requires measurement of specified data during the operation of the system. The system is required to be operated under duty cycle as shown in Figure 5. The duty cycle is power normalized with respect to the system rated power over a 24-hour period. Positive on the X-axis represents change into the ESS and negative on the X-axis represents discharge from the ESS, both as a function of time in hours. This duty cycle was based on the PJM balancing signal for calendar year 2011. The standard deviation over a 24-hour period was used as a metric for aggressiveness of the signal. The signals were grouped into low, average, and high standard deviation days. A representative 2-hour average standard deviation signal was chosen, and a representative 1-hour high standard deviation signal was chosen. It was also noted that 24-hour signals were energy neutral. The average and high standard deviation signals were chosen such that they were energy neutral and had the same standard deviation as the average and high deviation signals. The PJM duty cycle consisted of three 2-hour average signals, followed by two 1-hour high deviation signals, three 2-hour average signals, two 1-hour high deviation signals and four 2-hour average signals. The data that support the duty cycle are in 4-second intervals and are provided in an Appendix of the protocol.

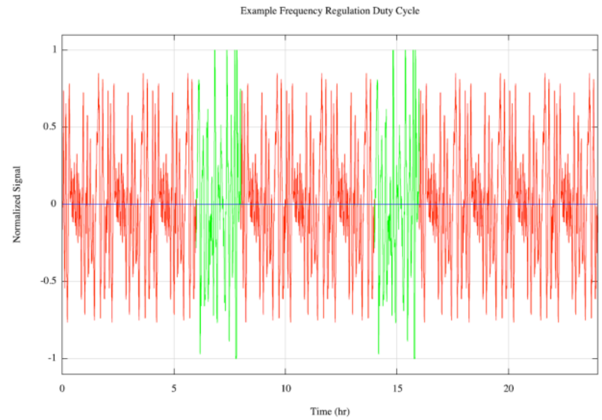

Fig 5. Frequency regulation duty cycle.

Based on application of this duty cycle to an ESS intended for a frequency regulation application selected performance metrics are reported based on data gathered at the established ESS boundary. As noted above the system rating, stored energy capacity, roundtrip efficiency, response time and duty cycle round trip efficiency would be determined as described above for peak shaving applications except that the duty cycle for frequency regulation would be applied instead of that for peak shaving. Ramp rate and reference signal tracking would also be determined as covered below.

Reference Signal Tracking

The ability for an ESS to respond to a reference signal is recorded during the roundtrip efficiency test. Signal tracking is based on the sum of the squares between the balancing signal and the power delivered to or absorbed by the ESS. The result is an indication of the inability of the system to track the signal as a decimal less than one.

Ramp Rate

Ramp rate is reported in watts per minute and addresses the rate at which power output can be changed due to the system charging or discharging or whether it is initially beginning at a low or high state-of-charge. A charge and discharge test routine are required to be performed and based on the rated power in MW and time in seconds it takes to reach rated power from a 50% state-of-charge the ramp rate is determined.

DISCUSSION

The Process

There is no 'one size fits all' recipe for the development of standardized methods of test, or for that matter any standards. Clearly the objective is the availability of criteria that can be readily adopted and implemented. In the U.S. that generally means a standard developed through a consensus process and internationally through very much the same process with participating countries each having a vote as opposed to a balanced committee of interested parties as is the case in U.S. standards development. Achieving consensus and ensuring all interested parties have a voice and their views are considered takes time. Because the process is more formalized, those participating can tend to approach the effort with an objective of protecting their particular interests, which can add additional time and complexity to development of the standard.

To streamline this process it is not unusual to develop pre-standards, however, that is generally done by a singular party such as a third party testing agency for a technology client or a technology customer or proponent as a basis for testing a particular product. While this helps one example of the technology it does not generally support that technology industry as a whole. When more than one proponent or client of the technology undertake parallel efforts it can create confusion in the market and adversely affect the acceptance of the technology. One way to eliminate the probability of duplicative and conflicting efforts and develop standards in a timelier manner is to establish a more informal and open pre-standards development process.

The protocol was developed with this in mind. By establishing an open, transparent and less formal process it created a situation where any individual efforts that had already been started could be channeled to the betterment of the ESS industry at large. Simply announcing this effort was being initiated with a goal of producing a protocol in less than a year garnered significant interest and the involvement of over 60 companies and organizations. The collaborative nature of the process also fostered success in that participants understood this was simply an initial body of work that would serve on an interim voluntary basis and then serve as a resource for further U.S. and international standards.

With the first protocol completed in late 2012, it was then available for use; addressing the need for uniformity and comparability and eliminating the need for any separate, parallel or competing activities. Its availability also meant that both U.S. and international standards efforts that were just getting underway to address ESS performance had a ready-made draft from which to work. As covered below under future work this process allows for refinement of the protocol based on its application and use on real systems that can then feed into standards development. It also means there is a process under which additional ESS applications and metrics can be addressed in a timelier manner in the future.

The Purpose and Scope of the Protocol

In development of standards the purpose and scope not only drive what is in (and is not in) the standard but can also take considerable time to hammer them out. If they are too narrow then interested parties feel left out and may be justified in opposing the development and/or adoption of the standard. If too broad then there is simply too much on the plate to be done before the standard can be approved. In formal standards development whatever the purpose and scope cover must be addressed in the standard. That is the criteria in the standard cannot address portions of the purpose and scope and then include a foot note indicating that 'we will get back to the rest of the standard later'.

The purpose and scope of the protocol were very broad by design to match with the process as discussed above. Because this effort was not a formal standards process, but a pre-standards process intended to feed into formal standards the purpose and scope could be broad. This eliminated the need to restrict the purpose and scope to only what could be done initially in one year, which would have meant leaving out certain ESS technologies, applications and metrics and likely drawing criticism from advocates for those items that were left out. By having the broad purpose and scope coupled with the ongoing protocol development process it allowed the effort to set a long term vision and then approach reaching that vision in steps. The first step was to address electric storage technologies, two applications and selected metrics for those applications. As discussed under future work below, the vision established in the purpose and scope creates the foundation for that future work without having to go back and broaden a purpose and scope that may have been limited to only what was done in 2012.

The Criteria

Once the purpose and scope were established the task was to identify the key ESS applications and metrics that needed to be addressed first. Based on input from all those involved in the process peak shaving and frequency regulation were chosen, the focus was on electric only systems and metrics that were felt most important identified. From there it was simply a case of determining how to best structure the presentation of the technical criteria and then determining what those criteria should be.

It was recognized that a system boundary needed to be established and that the protocol needed to focus on what passed across that boundary, as opposed to what was happening between the various components within the system boundary. This greatly simplified the development of the criteria. A duty cycle was chosen for each application. It was recognized that the duty cycle chosen needed to be defensible but also that any ESS in actual operation might not be subjected to that exact duty cycle. Given the purpose of the protocol was to allow for a uniform comparison of different ESS for the same application it was recognized that a singular duty cycle generally representative of how such systems would operate was appropriate. There was discussion about the application of alternative duty cycles and that is something that was recognized could be considered in the future along the lines that both auto efficiency and sound level have a singular metric such as mpg or db but then multiple variants such as highway/city and A/B.

Once the boundary, duty cycle, and metrics were chosen, the development of the actual testing and measurement guidance was undertaken. During this effort, it was recognized that an ESS can address multiple applications. Where an ESS can serve to address peak shaving and frequency regulation, the measurement of performance can be facilitated by instrumenting the ESS and conducting the peak shaving tests as outlined in the protocol. Because there are five tests common to both applications then simply applying the frequency regulation duty cycle to the ESS and re-testing for the five common metrics and the two additional metrics only applicable to frequency regulation applications provides performance information for both applications.

CONCLUSIONS

The experiences to date in taking on the challenge presented in early 2012 to develop and deploy criteria for measuring and expressing the performance of ESS in a timely manner that will be readily accepted and deployed support the following observations:

- Creating an open and transparent process where all interested stakeholders can participate at whatever level they deem appropriate is important to building a critical mass and the credibility needed to ensure the resultant product is accepted in the marketplace. Conversely having a singular third party undertake a similar effort and presenting it to interested stakeholders does not generate the needed and critical by-in.
- The establishment of an effort to develop a protocol establishes a stake in the ground early on that minimizes the probability that any one company undertakes such an effort. While that can foster their initial success in the marketplace it generally comes at the expense of others in the same industry. Moreover such development can be costly; something better approached in a collaborative fashion by all stakeholders.
- New technologies are more apt to get to market in a timelier manner if their industry at large is collaborating on standards development as opposed to one or more members of the industry using standards to gain market share.
- Organization and operation of an effort to develop an initial protocol is best hosted and led by entities that are familiar with the technology, the standards development and deployment process and who can be seen as having no particular agenda other than to get the task at hand accomplished in a timely, organized, open and collaborative manner.
- Establishment and buy-in to a broad vision, goals and objectives is critical for both short term and longer term success. Recognizing that the scope of this effort and the dynamic nature of technology change could clearly bog things down it is important for all involved to 'visualize the entire farm and from there determine the most important seeds to plant first; and from which future success could be based while being able to use the fruits of those seeds in the short term'.
- Once the long term vision and short term activities are identified it is important to break down the needed efforts into related but smaller tasks. This allows an opportunity for interested parties to 'get into the weeds' if they so choose. Coordinating those separate efforts and keeping all involved appraised of those efforts ensures there are no surprises.
- Development of a protocol or pre-standard, in being less formal than consensus standards development, can be less confrontational. This fosters collaboration and better use of time moving forward rather than debating opposing viewpoints. That said when different views surface making everyone aware of them and trying to mediate a compromise is much easier since the expected outcome is not a formal standard but a more informal protocol intended for initial use and further enhancement based on the results of such use.
- The availability of more formal consensus standards is facilitated because when those activities are initiated there is a document available that looks, feels and can be used as a standard. Those familiar with the development of a brand new consensus standard know the process needed to establish a committee, title, purpose and scope for a standard and then develop a first draft suitable for public review and comment is likely to take at least two to three years. In this instance the basis for a draft international standard covering the subject of the protocol was available to the international committee (IEC TC 120) developing standards for ESS immediately upon their formation.
- Paralleling initial application and use of the protocol with its initial consideration in more formal standards development results in valuable information that can inform the standards development process and further enhance the initial standard. This is something not likely to occur until the first edition of a standard has been out for a while and is not then considered until the standard is updated, which in the U.S. can be as long as five years (ten with extensions).
- In the interim until more formal standards are completed the protocol serves its intended purpose – to provide a means to measure

and express ESS performance. This fills a very important need. While not necessarily as refined as possible the lack of any such criteria means that there is nothing to go on. That perpetuates the window of time that the effort was intended to 'shut'; namely provide some basis for system comparison and eliminate the need for each ESS customer to make up their own criteria in the absence of some accepted criteria.

- During the development of any protocol or pre-standards efforts keep all relevant standards development organizations apprised of the effort as opposed to choosing any particular standards developer to work with at the expense of others. While stakeholders are also likely to do this as well it appears better to let standards developers choose to engage (or not) in using the results of the effort for standards development. When they do choose to engage then clearly work with them to apply the protocol in their efforts.

RECOMMENDATIONS

As covered, the need for a uniform method of test to measure and express the performance of ESS was identified. A process was established to fill that need in a timely, transparent and collaborative manner that resulted in a protocol that could serve immediate needs. Since the energy storage field is very dynamic the resultant document and process also needed to serve as a foundation to address additional storage technologies, applications, metrics and issues beyond the immediate needs identified in 2012. The following recommendations relate to what can and should be done right now with the protocol. Work beyond that is covered below under future work.

- The protocol is published and available for adoption and use. It is recommended and utilities are encouraged to reference the protocol as a basis for system performance measurement. Concurrently manufacturers are encouraged to conduct testing and report performance in accordance with the protocol on a voluntary basis.
- Through use of the protocol as recommended above confirmation of the validity of the protocol and/or needed enhancements and revisions can be identified and addressed in the future. Manufacturers, utilities and others applying the protocol are encouraged to participate in the Protocol User's Group being led by PNNL in collaboration with SNL.
- Through use of the protocol technical enhancements and revisions can be identified as suggested above. It is also recommended that protocol users identify any issues associated with usability, cost, time and other non-technical issues as well. Clearly the protocol should be as technically sound and accurate as possible but applying it must also not be a time consuming, costly or overly challenging endeavor.
- As discussed above the lack of standards can adversely affect technology acceptance and deployment. Such a lack of standards can be from doing nothing or in doing something the scope of the effort, complexity, volatility and the intended rigor of the standards development process simply takes time. The protocol was developed with the intent that it could serve as a starting point for formal standards development. It is serving that purpose and is finding its way into U.S. and international standards. Manufacturers, utilities and other stakeholders are encouraged to become involved in those efforts and when completed use the resultant standards as a basis for performance measurement and reporting.
- As noted the efforts to date have been transparent and open, but they have been less structured than is generally the case when industry comes together and creates a roadmap and takes the lead. In the absence of leadership from the DOE Office of Electricity Energy Storage Program the protocol would not likely have been developed and the more traditional standards development process may have started to develop a standard but it would likely have taken a few more years to be approved and published. Either way the key stakeholders have individually participated in these efforts. Future efforts could be fostered, including taking a large role in organization and management of these efforts, through the associations and organizations representing the key stakeholders in the energy storage field.

FUTURE WORK

The success of this collaborative process and eight month effort to develop the protocol will be realized through the voluntary application and use of the protocol by ESS manufacturers, or the request for its use by ESS customers as they consider adoption and use of the technology. As supported in the above recommendations, it is hoped that the effort undertaken to develop the protocol proves to be a good investment in technology acceptance by realizing such a successful adoption and use of the protocol.

Concurrent with any efforts to develop consensus standards, the process for ongoing use of and further enhancement of the protocol is expected to continue through the protocol working group. These efforts will focus on additional applications and metrics for those new applications as well as additional metrics for the two applications addressed in the initial protocol. In addition they will also consider how to ensure that the protocol can also be used for ESS that are not all electric (e.g. electric/thermal). In like manner, the next version of the protocol that contained those enhancements, supported by experiences in applying the protocol in the field, could feed into updates and revisions to any consensus standard whose provisions are based on those in the protocol. As noted, this process, compared to starting with formal standards development, saves time and money and most importantly provides a document that, while not having an official consensus designation, is available for application and use in a timelier manner to fill the immediate needs previously discussed.

To further foster acceptance and use of energy storage technology the following future standards-related efforts are envisioned and would be coordinated through an 'energy storage codes and standards forum' facilitated through a public/private collaboration of energy storage stakeholders and interested parties.

- Continued enhancement of the protocol to address new storage technologies, applications beyond the current activities to address micro-grid and PV smoothing applications.
- Continued enhancement of the protocol to ensure it will be applicable to both all electric ESS and electric/non-electric ESS.
- Continued enhancement of the protocol to address additional metrics as deemed appropriate by those participating in the process.
- Increase the number of entities involved in the protocol effort; ideally through the efforts to date, more will choose to become involved and be more active.
- Ongoing 'test driving' of what is developed as protocol content as a basis for refining the criteria and validating their usability.
- Facilitating use of the protocol in more formal standards activities and adoption and deployment of the protocol and subsequent standards.
- While the protocol addresses the measurement and reporting of system performance, it is recognized that ESS do not necessarily act alone but instead may be a component in a larger system whether that be with renewable energy systems or simply as a component of the energy systems in a building or complex of buildings. Future work must be undertaken to effectively integrate the work done to date and that will be done in the future on energy system performance with similar work on other components in the energy generation, delivery and use environment.
- Beyond system performance as covered by the protocol, there are a number of other issues that must be addressed. One key issue is to foster the acceptance of storage technology in front of and behind the meter to ensure the safety of the systems; both the system itself and its installation within the built environment. Future work, through the forum mentioned above, must identify current codes and standards that would apply to storage systems and develop revisions to those documents as well as new documents that can guide the acceptance of safe system installations.
- Once necessary and appropriate codes and standards criteria are available, then concurrent with their adoption, a cohesive, robust and coordinated effort must be undertaken to develop and deploy the infrastructure to support the assessment, acceptance and approval of such systems. This includes education, training, outreach, communications and relevant support for all those in the built environment from electrical inspectors to building facility managers and elected officials.

In summary, the current protocol effort yielded a protocol in a short amount of time to address the immediate needs of the energy storage industry. More importantly, it jump started a process to foster future development and deployment of criteria to facilitate the acceptance of energy storage technology. Future work should build on that by enhancing the process, getting more stakeholders involved, and having the storage industry collaborate to address codes and standards. Since the technology and possible applications are dynamic, the work on performance should continue to evolve, but in addition the scope of the work should be extended beyond performance to cover other issues such as safety. Concurrent with the development and deployment of appropriate codes and standards, the industry will need an infrastructure that can readily support the timely adoption, application, approval, and continued operation of ESS regardless of where they are located, what applications they serve, and how they may be integrated with other components of the built environment.

REFERENCES

[1] PNNL 22010-2012, Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems, Kathy Bray (PNNL), Summer Ferreira (SNL), David Conover (PNNL), David Rose (SNL), Michael Kintner-Meyer (PNNL), David Schoenwald (SNL) and Vilayanur Viswanathan (PNNL), November 2012, Pacific Northwest National Laboratory, Richland, Washington 99352
[2] ANS/CSA FC1-2012, Fuel Cell Power Systems. 2012 Edition. CSA America, prior edition 2004.
[3] NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems, 2010 Edition, National Fire Protection Association, prior editions: 2000, 2003, 2007, next edition: 2015.
[4] ISO 17025, General Requirements for the Competence of Testing and Calibration Laboratories, 2005 edition. International Organization for Standardization.

[5] IEEE 1679, Recommended Practice for the Characterization and Evaluation of Emerging Energy Storage Technologies in Stationary Applications, 2010 Edition. Institute of Electrical and Electronics Engineers.