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Guidelines for Modeling of Energy Storage Devices

Energy Storage Modeling Task Force

January 2021

Introduction

This modeling guideline for Energy Storage Devices (ESDs) is intended to serve as a one-stop reference for the power-flow, dynamic, short-circuit and production cost models that are currently available in widely used commercial software programs (such as PSLF, PSS/E, PowerWorld, ASPEN, PSS/CAPE, GridView, Promod, etc.). It will also address the ongoing model development efforts/proposals within the industry that may result in future new model additions to be commercially available.

Importantly, this guideline's scope *does not* include proposing/developing any new model structures or providing recommended parameters for use with existing models.

Further, at this time the scope of this guideline is limited to the following ESD technologies:

1. Pumped Storage Hydro (PSH)
2. Battery Energy Storage System (BESS)
3. Compressed Air Storage (CAS)
4. Hydrogen Storage (HS)

These ESD technologies are either already mature (that is, already in-service or at the tipping point of near-term widespread implementation in the Western Interconnection) or nearing maturity (that is, pilot projects have been conceptualized/proposed in the Western Interconnection).

Power Flow Modeling

ESDs with Synchronous Machine Interface – Pumped Storage Hydro Plant

Applicable to Pumped Storage Hydro (PSH) and potentially to CAS and HS also.

Power flow model structure and parameters (Pmax, Pmin, Pgen, Qmax, Qmin, Vscheduled, etc.) would not be any different than the representation for traditional fossil-fuel generating plant having synchronous machine interface. Depending on operation mode – generating or pumping – selected parameter values in the power flow model would change from positive to negative. Additional information on PSH power flow modeling and simulations is available in the technical references listed in *Appendix A* to this report.

ESDs with Inverter Interface – Battery Energy Storage & Hybrid Plants

Applicable to Battery Energy Storage System (BESS) plant and potentially to CAS and HS plants also. Also applicable to Hybrid Generating Plants comprising of BESS plus Inverter-Based Resources (IBRs).

Power flow modeling for BESS plant would not be any different than the recommended representation for IBR-based generating plant (see Figure 1 below). Similar to wind/solar IBRs, the BESS plant is represented by an equivalent single generator. Charging capability should be modeled by setting the

equivalent generator with an appropriate negative value for the active power limit, *Pmin*. Discharging capability should be similarly modeled by setting an appropriate positive value for the active power limit, *Pmax*. These *Pmin* and *Pmax* limits in the equivalent BESS generator record should be set to reflect the power output limits imposed by the plant and inverter controllers in coordination with the capability of the inverters.

Depending on the operation mode – discharging or charging – as well as the battery's state of charge (SOC), some model parameter values would change when performing power flow simulations.
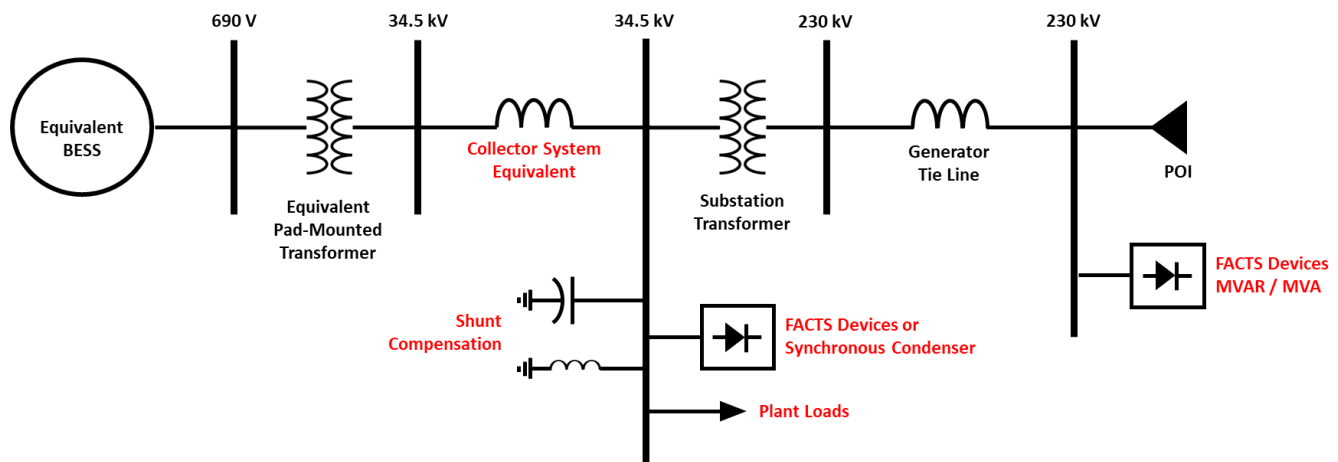

Figure 1: Generic Power Flow Model Example for BESS Plant or DC-Coupled Hybrid Plant [Source: NERC]

Hybrid Generating Plants may either be DC-coupled or AC-coupled, depending on how the BESS is coupled to the IBR in the plant. Power-flow model for DC-coupled hybrid plant is the same as shown in Figure 1 for BESS plant. Power-flow model for AC-coupled hybrid plant is shown in Figure 2 below.

Following aspects may be considered for power flow modeling for AC-coupled hybrid power plants:
- Plant Configuration
- Output Coordination of BESS and Generating Components
- Maximum Overall Plant Power Output (i.e. Plant Pmax)
- Source for BESS Charging – Plant Generating component or Grid
- Voltage Control Coordination of BESS and Generating Components

The WECC Renewable Energy Modeling Task Force (REMTF) has developed a White Paper on *Modeling Hybrid Power Plant of Renewable Energy and Battery Energy Storage System*[1] which provides

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[1] Available at:
https://www.wecc.org/_layouts/15/WopiFrame.aspx?sourcedoc=/Administrative/WECC%20White%20Paper%20on%20modeling%20hybrid%20solar-battery.pdf

recommendations for software vendors to improve the modeling capability for BESS and hybrid plants, particularly for representing overall plant-level active power limits as well plant-level coordinated voltage controls in the power flow base case. This will enable more effective modeling of hybrid plant dispatch scenarios as well as overall plant voltage control when performing power flow simulations.
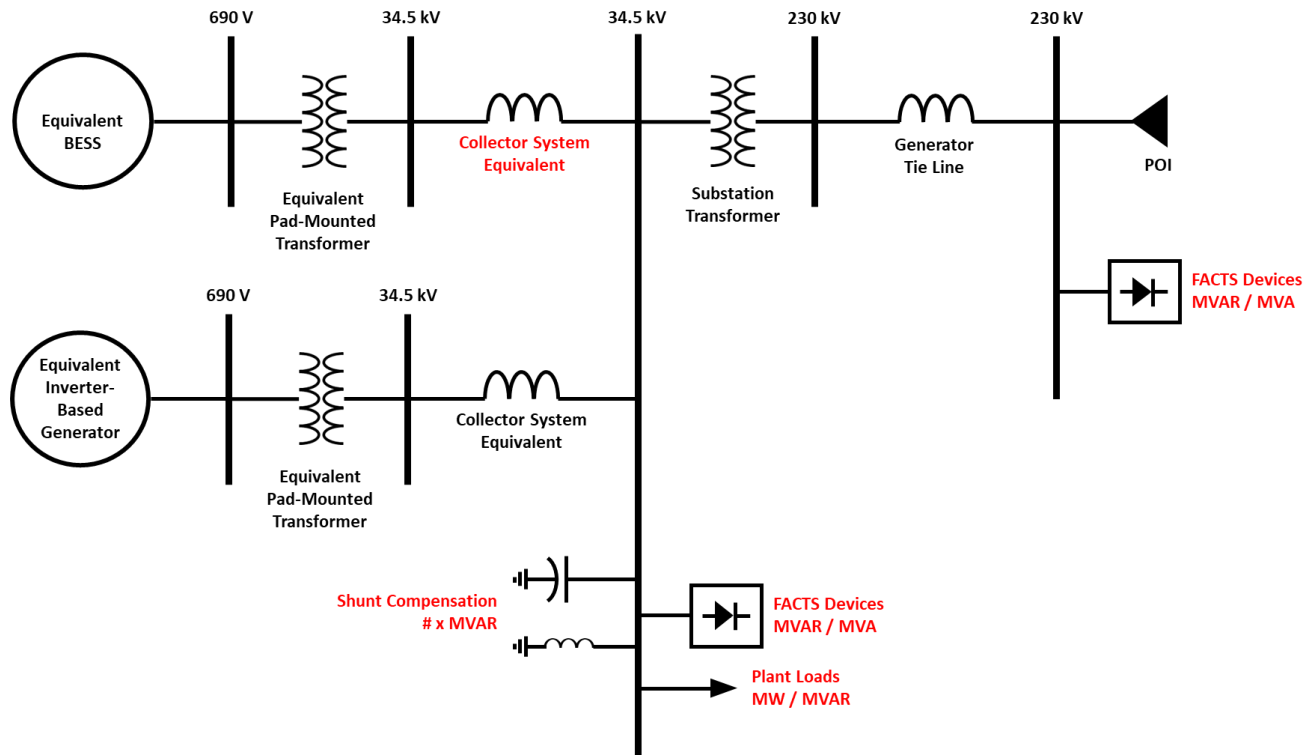
Figure 2: Generic Power Flow Model Example for AC-Coupled Hybrid Plant [Source: NERC]

For detailed power flow modeling guidance, refer to Chapter 2 in the *NERC Reliability Guideline on Performance, Modeling and Simulations of BPS Connected Battery Energy Storage Systems and Hybrid Power Plants* [2].

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[2] Available at:
https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_BESS_Hybrid_Performance_Modeling_Studies_2020-12-15%20(003).pdf

Dynamic Modeling

ESDs with Synchronous Machine Interface – Pumped Storage Hydro Plant

Fundamentally, the dynamic modeling of ESDs with Synchronous Machine Interface is no different than the traditional practice for dynamic modeling of synchronous machines by using the standardized dynamic models available for machine, exciter, stabilizer and governor. The dynamic model parameters remain unchanged for both generating and pumping operating modes. While representing dynamic behavior in charging mode, care should be taken with regard to application and parameterization of governor models.

However, due to the Pumped Storage Hydro (PSH) technological advances in recent years, several development efforts are underway for more accurate dynamic models capturing the dynamic behavior of the variety of PSH turbine configurations – ternary, quaternary, etc. Additional information on PSH dynamic model development efforts is available in the technical references listed in *Appendix A* to this report.

ESDs with Inverter Interface – Battery Energy Storage & Hybrid Plants

Dynamic modeling practices for BESS and hybrid plants are similar to those of other inverter-based resources; however, some unique characteristics of BESS such as four-quadrant operation and state-of-charge (SOC) must be captured in its dynamic model. Although the implementation may be different among equipment manufacturers, in principle the modeling structure of BESSs is the same as solar PV and Type 4 wind plants.

The level of dynamic modeling accuracy needed depends on the purpose of the study and the system short-circuit strength at the point of interconnection. Typical studies are:
  a) localized system performance (i.e. grid code performance) evaluation study needed for BESS or hybrid plant interconnection (i.e. interconnection system impact study),
  b) regional (wide-area) system performance assessment study,
  c) plant dynamic model verification/validation study, etc.

For most dynamic simulations, it is adequate and appropriate to use positive-sequence dynamic models – either the standardized (aka generic) dynamic models or the user-defined dynamic models – that are available in widely used software platforms such as PSLF, PSS/E, PowerWorld, etc. Standardized dynamic models are considered adequate for use in regional system performance assessment studies whereas the user-defined models are most often utilized in interconnection system impact studies. When using standardized models, care must be taken with regards to parameterization of the model gains, time constants, and settings. However, for certain study objectives (such as positive sequence dynamic model validation, weak-grid interconnection system impact evaluation) the

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additional use of detailed three-phase dynamic models within EMT (ElectroMagnetic Transient) programs is recommended, and is perhaps even necessary.

The dynamic representation of a large-scale battery energy storage (BESS) plant for system planning studies is achieved by modeling the power inverter interface between the storage mechanism (battery) and the grid. The overall structure generally consists of a converter control module, an electrical control module, and a plant control module. Frequency ride-through and voltage ride-through settings are modeled with the generator protection modules. Figure 3 below depicts standardized library dynamic models used for each module in the overall structure.
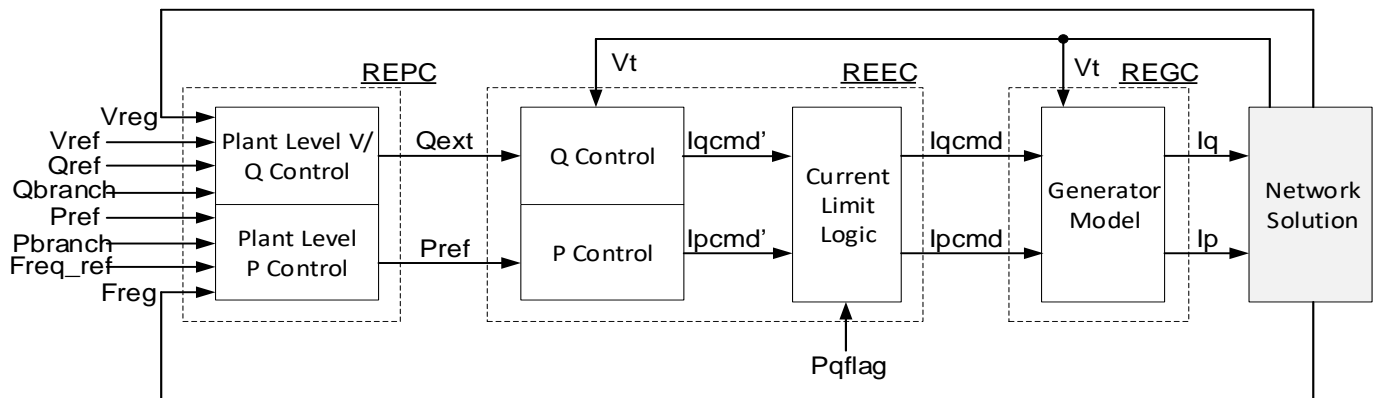
Figure 3: Block Diagram Structure for Dynamic Modeling of BESS Plant [Source: NERC]

Following generic/standardized dynamic models available in two commonly used software platforms are recommended for the BESS plant representation:

Dynamic Models used to Represent BESS in PSLF and PSSE		
Module	**GE PSLF Modules**	**Siemens PTI Modules**
Inverter/Grid interface	regc_a/b/c	REGC A/B/C
Electrical controls	reec_c or reec_d	REECC1 or REECD1
Plant-level controller	repc_a/b	REPC A/B or PLNTBU1
Voltage/Frequency protection	lhvrt/lhfrt	VRGTPA/FRQTPA

The plant-level V/Q control module (Figure 3) allows for the following reactive power control modes:

Reactive Power Control Options for BESS Standardized/Generic Models					
Functionality	Required Models	pfflag	vflag	qflag	refflag
Plant-level V control	REEC + REPC	0	N/A*	0	1
Plant-level Q control & local coordinated Q/V control	REEC + REPC	0	1	1	0
Plant-level V control & local coordinated Q/V control	REEC + REPC	0	1	1	1
Plant-level PF control & local coordinated Q/V control	REEC + REPC (repc_b and above)	0	1	1	2

* "N/A" indicates that the state of the switch does not affect the indicated control mode.

The plant-level P control module (Figure 3) allows for the following real power control modes:

Active Power Control Options for BESS Standardized/Generic Models				
Functionality	BaseLoad flag*	frqflag	ddn	dup
No frequency response	2	0	0	0
Frequency response, down only regulation	1	1	> 0	> 0
Frequency response, up and down	0	1	> 0	> 0

* BaseLoad flag is set in the power flow model.

The BESS plant is expected to provide frequency response in both upward and downward directions. Therefore, the "no response" and "down only regulation" options are greyed out (usage is unlikely to be approved by the transmission planning entity). In the WECC recommended modeling enhancement for hybrid power plants (WECC White Paper on *Modeling Hybrid Power Plant of Renewable Energy and Battery Energy Storage System* [3]), the base load flag in the power flow model could override the frqflag setting in the dynamic model. The frqflag/ddn/dup are meant to reflect the inverter capability while base load flag represents the availability of the operational headroom. It is important to set base load flag to 0 for BESS plants regulating frequency.

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[3] Available at:
https://www.wecc.org/_layouts/15/WopiFrame.aspx?sourcedoc=/Administrative/WECC%20White%20Paper%20on%20modeling%20hybrid%20solar-battery.pdf

For additional BESS plant dynamic modeling guidance, refer to the BESS Dynamic Modeling section in Chapter 3 in the *NERC Reliability Guideline on Performance, Modeling and Simulations of BPS Connected Battery Energy Storage Systems and Hybrid Power Plants* [4](available in Q4-2020).

Frequency and voltage ride-through are needed for transmission-connected BESS and/or Hybrid plants. Because they are simplified, the generic models may not be suitable to fully assess compliance with the voltage and frequency ride-through requirement. Voltage ride-through is engineered as part of the plant design and needs far more sophisticated modeling detail than is possible to capture in a positive-sequence simulation environment. It is best to use a standardized (existing) protection model with voltage and frequency thresholds and time delays to show the minimum disturbance tolerance requirement that applies to the plant. Also, as per the WECC White Paper on *Understanding Frequency Calculation in Positive Sequence Stability Programs* [5], the frequency calculations in a positive-sequence simulation tool is not accurate during or immediately following a fault nearby. It is best to use the frequency protection relay model in a monitor-only mode and always have some time delay (e.g., at least 50 ms) associated with any under- and over-frequency trip settings.

The dynamic modeling approach to hybrid power plants depends on whether they are ac-coupled or dc-coupled. For detailed discussion of the additional considerations unique to both ac-coupled and dc-coupled hybrid power plants, refer to the Hybrid Plant Dynamics Modeling section in Chapter 3 in the *NERC Reliability Guideline on Performance, Modeling and Simulations of BPS Connected Battery Energy Storage Systems and Hybrid Power Plants* [6].

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[4] Available at:
https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_BESS_Hybrid_Performance_Modeling_Studies_2020-12-15%20(003).pdf

[5] Available at https://www.wecc.org/Reliability/WECC_White_Paper_Frequency_062618_Clean_Final.pdf

[6] Available at:
https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_BESS_Hybrid_Performance_Modeling_Studies_2020-12-15%20(003).pdf

Short Circuit Modeling

ESDs with Synchronous Machine Interface – Pumped Storage Hydro Plant

Fundamentally, the short circuit modeling of ESDs with Synchronous Machine Interface cannot be different than the traditional practice for short circuit modeling of synchronous machines. The short circuit model parameters remain unchanged for both generating and pumping operating modes.

ESDs with Inverter Interface – Battery Energy Storage & Hybrid Plants

At a high-level, short circuit modeling of ESDs with Inverter Interface is no different than the short circuit modeling of full-converter inverter-based resources (e.g., Type 4 wind, solar PV, voltage source converter HVDC, and other FACTS devices). The modeling guidelines described in this section are intended to help develop/use standardized approaches for short circuit modeling of ESDs with Inverter Interface (i.e. BESS & Hybrid plants) that are similar to those recommended for inverter-based resources.

In general, inverters are voltage-dependent current sources, meaning the amount of active and reactive current injected by the inverter during a fault is dependent on its terminal voltage. The inverter's control logic dictates the voltage dependency (e.g., K-factor or closed-loop response) and is typically non-linear. As with full-converter IBR's, the fault current from a BESS plant depends on the pre-fault current. But unlike IBR's, a BESS plant's fault current also depends on whether the BESS was in charging or discharging mode prior to the fault. However, the fault current is relatively independent of the BESS's State of Charge (SOC) since the SOC does not modify any control loops or affect inverter overload current capability.

The IEEE Power System Relaying and Control (PSRC) Committee Working Group C24 led the development of state-of-the-art inverter-based resource short-circuit modeling practices, and recently published Technical Report #78: Modification of Commercial Fault Calculation Programs for Wind Turbine Generators[7]. This report advises industry on necessary modifications to commercial short-circuit programs to allow accurate modeling of wind turbine generators and wind power plants. While this report does not specifically discuss modeling solar PV, BESS, or other inverter-based resources, the recommendations for modeling Type 4, full-converter wind resources also apply to solar PV and BESS facilities. Presently, the software vendors for commercial short-circuit programs have incorporated the

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[7] IEEE PES Technical Report TR78: Modification of Commercial Fault Calculation Programs for Wind Turbine Generators: https://resourcecenter.ieee-pes.org/technical-publications/technical-reports/PES_TP_TR78_PSRC_FAULT_062320.html

new modeling approach of representing voltage-dependent current sources into their respective programs.[8]

The IEEE PSRC WG C24 report recommends that fault current injection information be provided for inverter-based resources in a tabular form, one for each type of fault. The information may be provided in the sequence domain (positive, negative, and zero sequence) or in the phase domain (phase A, B, and C). Further, considering the dependence of converter response on the voltage amplitude, the information is necessary at various voltage levels. Since inverter controls take time to reach a steady-state fault current level, the report further recommends that fault current data be provided for several time instants after fault initiation (e.g., 1, 3 and 5 cycles). If the inverter-based resource provides unbalanced fault currents for unbalanced faults, then additional set of tables will be needed for the negative sequence current contribution. Further, for BESS plants, two separate sets of tables are needed that correspond to the charging and discharging operating modes of the BESS.

Similar to the recommended steady-state and dynamics modeling of hybrid plants, the short-circuit modeling depends on whether the hybrid plant is DC-coupled or AC-coupled. Since the fault behavior of an inverter does not change even if there are multiple energy sources behind it, the short-circuit model of DC-coupled plant is the same as that of inverter-based resource. However, for AC-coupled plant, the IBR generating plant and the BESS plant must have its own separate short-circuit model.

For further guidance on short circuit modeling, refer to Chapter 4 in the *NERC Reliability Guideline on Performance, Modeling and Simulations of BPS Connected Battery Energy Storage Systems and Hybrid Power Plants* [9].

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[8] See "Siemens Technical Bulletin - Inverter-Based Generator Models with Controlled Power and Current – 2019 PSS CAPE User Group Meeting" and "ASPEN Technical Bulletin – Modeling Type-4 Wind Plants and Solar Plants" for more details.

[9] Available at:
https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_BESS_Hybrid_Performance_Modeling_Studies_2020-12-15%20(003).pdf

Production Cost Modeling

Pumped Storage Hydro Plant

Pumped storage hydro plant is usually represented by an equivalent single generator. Production cost models generally include an explicit representation of the energy limitations for the reservoir through minimum and maximum reservoir limits, and the start and final (or target) reservoir levels. Furthermore, the pump/turbine set may be modeled as two separate injectors, one pump and one turbine for each PSH plant. This separation allows for the enforcement of commitment constraints on individual turbine/pumps.

The following characteristics are important for appropriately modeling the dispatch of pumped storage hydro plant. Refer to *Appendix B* of this report for the description of these terms.

- Pumping Maximum Capacity
- Pumping Minimum Capacity
- Generating Capacity (Min and Max)
- Pondage Size (Min and Max)
- Plant Efficiency
- Pumping Blocks
- Schedule Mode (e.g. weekly or daily, load following, price following, fixed dispatch)
- Price $/MWh

Additional information on PSH market value studies based on production cost modeling is available in the technical references listed in *Appendix C* to this report.

Battery Energy Storage and Hybrid Plants

Federal Energy Regulatory Commission (FERC) Order 841 issued in early 2018 to enhance participation of BESS plants in RTO/ISO energy, ancillary services, and capacity markets established a participation model that recognizes their physical and operational characteristics. Consequently, BESS plants are now generally represented by an equivalent unique resource that can act as an injector (or a generator) and a withdrawer (a load) of power and energy[10].

While charging, battery operates as a load and following characteristics needed to be modeled:

- Maximum charge limit: represents the maximum power at which a BES plant can receive energy (i.e., charge) from the grid,

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[10] *Independent System Operator and Regional Transmission Organization Energy Storage Market Modeling Working Group White Paper: A report on current state of art in modeling energy storage in electricity markets and alternative designs for improved economic efficiency and reliability*. EPRI, Palo Alto, CA: 2017. 3002012327.

- Charge ramp rate: the rate, expressed in MW per minute, at which a BES plant can move from zero output to its maximum charge limit,
- Maximum state of charge: represents a state-of-charge value that should not be exceeded when a BES plant is receiving electric energy (i.e. charging) from the grid
- Charge cost,
- Charge efficiency

While discharging, battery operates as a generator and following characteristics need to be modeled:

- Maximum discharge limit: represents the maximum power at which a BES plant can inject (i.e. discharge) to the grid
- Discharge ramp rate: the rate, expressed in MW per minute, at which a BES plant can move from zero output to its maximum discharge limit
- Minimum state of charge: represents a state-of-charge value, below which a BES plant should not discharge when injecting electric energy (i.e. discharging) to the grid.
- Discharge cost
- Schedule Mode (e.g. weekly or daily, load following, price following, fixed dispatch)

Some production cost models and market clearing software (i.e., unit commitment and economic dispatch software) may include (or modify) rules to prevent its software from selecting the BESS plant to simultaneously charge and discharge in the same time interval. Given that BESS plants have limited energy, the allocation of how they supply and consume energy must account for how their state-of-charge is managed – this is to ensure that electricity is provided when it is needed, and that the schedules determined can feasibly be met. State-of-charge represents the amount of energy stored at a particular time, in proportion to the limit on the amount of energy that can be stored, typically expressed as a percentage. Based on the responsibility of the entity that schedules the BESS plant and manages its state-of-charge, there exist different state-of-charge management options, e.g. self-scheduling, self or BES asset owner state-of-charge management and operator state-of-charge management.[11] Some software may also include maximum daily energy limits that can be used for a number of different technologies and not just BESS plants (e.g., for emissions limits).

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[11] *Integrating Electric Storage Resources into Electricity Market Operations: Evaluation of State of Charge Management Options*. EPRI, Palo Alto, CA: 2019. 3002013868.

Appendix A – Pumped Storage Hydro (PSH) Power Flow & Dynamic Modeling References

Modeling and Simulation of Advanced Pumped-Storage Hydropower Technologies and their Contributions to the Power System

Vladimir Koritarov, Argonne National Laboratory, U.S.A.
Tao Guo, Energy Exemplar, LLC, U.S.A.
Erik Ela, National Renewable Energy Laboratory, U.S.A.
Bruno Trouille, MWH Americas, Inc., U.S.A.
James Feltes, Siemens PTI, Inc., U.S.A.
Michael Reed, U.S. Department of Energy, U.S.A.

Impacts of Ternary-Pumped Storage Hydropower on U.S. Western Interconnection with Extremely High Renewable Penetrations

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Modeling of Quaternary Pumped Storage Hydropower (Q-PSH) for Power System Studies

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Development of Dynamic Model of a Ternary Pumped Storage Hydropower Plant

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Development of Dynamic Model of a Ternary Pumped Storage Hydropower Plant

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Presentation at the IEEE-ICIEA 2018 Conference, Wuhan, China, May 31-June 2, 2018
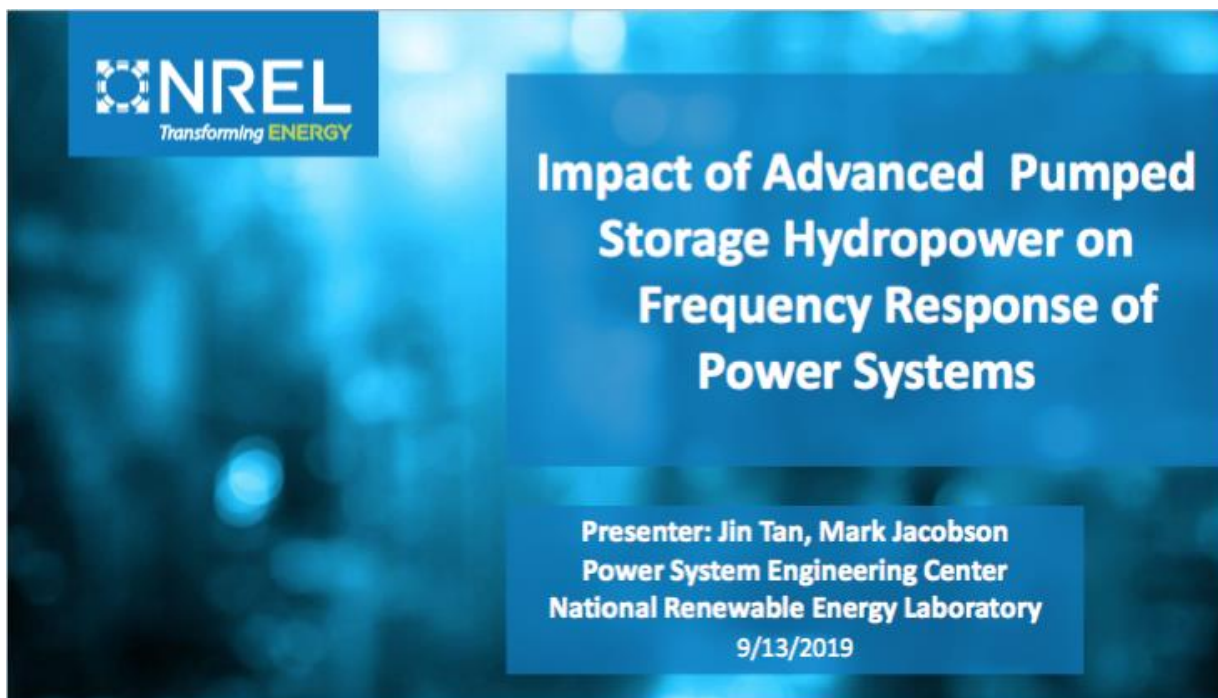
Appendix B – Pumped Storage Hydro (PSH) – Primer & Glossary

Pumped Storage Hydro (PSH) plants include two reservoirs, one at the bottom and one at the top of hill. The PSH pumps water up the hill that can then later come down and drive a turbine generator to produce energy. PSH plants have large reservoirs (tens of hours to days of continuous operation) and round-trip efficiency levels in the range of about 65-80%. PSH plants typically have commitment constraints similar to those of thermal steam plants, including minimum run times, start-up times, minimum operating levels, and unique to PSH, transition times between pumping and generating modes. The most common PSH technology includes fixed speed pumping, such that while the PSH is in pumping mode, it must operate at a fixed level. More advanced technologies include fast-acting variable speed pumping technology such that the plant can vary its consumption level while pumping, allowing it to provide flexibility, energy dispatchability, and ancillary services like regulation while in pumping mode. Fast-acting PSH technology (ternary and quaternary) is capable of achieving ramp rate of 20 MW per second. Although this technology has not yet been deployed in the United States, such PSH plants do exist in Europe and in Japan[12].

Pumping Maximum Capacity: typically, the PSH have a name plate rating, for the reversible type units the pumping and generating are the same piece of equipment. The reversible turbine type units can be either pumping or generating. For the fast-acting PSH units (Ternary and Quaternary) there is a turbine unit and a pumping unit. They can both be running at the same time. The maximum pumping does not change but the transition from zero to maximum output is along a curve and not a step function. Using a step function may work best for modeling.

Pumping Minimum Capacity: pumping can typically operate from zero to full nameplate capacity. For reversible or variable speed units it is a single or at most a couple of steps for the variable speed units. Again, for the fast-acting units it is along a curve and can go from zero quickly (a matter of seconds) or operate anywhere along the curve up to the maximum. For the reversible turbines there is a stop and reverse from generating to pumping.

Generating Capacity (Min and Max): The turbine/generating units will typically operate from zero to full name plate capacity. For PSH facilities when you are pumping at full name plate capacity you will be using energy – when you stop pumping you will go to zero – then you can generate at full nameplate capacity. If you have 400 MW facility you would move from negative 400 MW through zero to positive 400 MW resulting in a full range of 800 MW.

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[12] *Integrating Electric Storage Resources into Electricity Market Operations: Evaluation of State of Charge Management Options*. EPRI, Palo Alto, CA: 2019. 3002013868.

Pondage Size (Min and Max): Each project is designed a bit differently. Typically, the storage is described as "X" many MWhs of storage. The trend is at least a minimum of 4 hours at maximum output to compete with batteries, most PSH projects are at least 8 -12 hours to help with daily usage changes. There are projects that are season storage facilities. The two key issues discussed around PSH are dealing with ramping such as addressing the duck curve issue in California, dealing with peak demand period that happen either in the summer or winter that can last for 20 hours (how much can the PSH contribute to help solve the problem). For modeling purposes, you typically are discussing the "state of charge" which is the amount of stored water available for immediate use.

Plant Efficiency: The cumulative efficiency of the pump/motor and the turbine/generator – it also considers mechanical losses in the water flow and penstock, as well as the electrical losses in the facility and the transformers. The efficiency is optimized near the top of the operating range. The plant will typically be in the 80% range at the high end and in the 70% range at the low end.

Pumping blocks: For fixed speed or variable speed reversable turbines it is basically either pumping or generating with little variation in input or output. For the fast-acting PSH facilities they can operate from minus (full pumping) to plus (full generating) along a curve. Therefore, you could have a unit step from minutes to hours at any output level of ramping, holding at any point depending on the system need.

Schedule mode: With reversible turbines, operation schedule is driven by the number of starts and stops allowed on the equipment. The current fleet of PSH in the United States is limited to two starts and stops per day. Doing more than that will tear up the equipment. Newer variable speed units are being designed for more starts and stops but it still is an issue. The fast-acting PSH can handle multiple starts and stops per day with an infinite number of mode changes (moving from pumping to generation within the range of the facility). Most fast-acting PSH facilities will have multiple reversible units to provide output flexibility and they can handle any dispatch mode. Reversible units are either pumping or generating at full output.

Price $/MWh: Most of the information published will provide PSH as $/KW for the capital cost of the units. The $/MWh will be related to the cost of the stored energy and the efficiency lost (turn-around efficiency). The pumps are less efficient than the generating units. The range of efficiency will run from 70-80 % probably averaging in the 73% range. If you are buying energy at 20 $/MWh when you generate you will need 25.40 $/MWh to break even on the energy based on the efficiency losses, the O&M which is very small number, and the capital cost of the project is not include in the 25.40. The amount of stored water will weigh on the number of hours of operation per year.

Appendix C – Pumped Storage Hydro (PSH) Market Value Studies (Production Cost Modeling) References

Market Opportunities and Challenges for Pumped Hydro in an Evolving Power Grid

Preprint

Greg Stark
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Presented at HydroVision International
Charlotte, North Carolina
June 26–28, 2018

Transforming the U.S. Market with a New Application of Ternary-Type Pumped-Storage Hydropower Technology

Preprint

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