TOWARD INTEGRATING ENERGY STORAGE SYSTEMS WITH MARINE AND HYDROKINETIC ENERGY RESOURCES

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INTRODUCTION

Energy Storage Systems (ESS) can be used for a variety of power system benefits, including mitigating intermittencies of renewable resources (e.g., solar and wind). With abilities to provide fast and on demand capacity to store excess energy and make up for energy shortage, storage devices are of significant interest to complement emerging types of nature-sourced variable generation resources, including marine and hydrokinetic (MHK) energy resources [1-2]. While there are continuous improvements in MHK device designs and component technologies, due to the intrinsic nature of ocean waves and tides, power output of MHK devices will still vary [3]. Despite the relatively higher predictability of MHK resources in comparison to solar or wind, due to predictable cyclical and swell-induced variabilities, practical usage of MHK energy would be challenging, particularly due to grid integration and load-serving constraints. ESS could offer great benefit in this regard by mitigating these intermittencies and may be suitable for device integration. However, integration of ESS with MHK resources itself needs research attention due to the nature of deployment constraints [4]. Learnings gathered from ESS deployment projects could provide valuable insight to some of the challenges that need to be addressed for effective integration of ESS with MHK resources.

Pacific Northwest National Laboratory (PNNL), under its engagement with Washington Clean Energy Fund (CEF) program [5], a state sponsored initiative to advance renewable energy technology, is studying technology aspects and economics of a number of grid scale ESS deployment projects. This work will first review grid integration challenges with respect to MHK resource variability issues, and then will draw from PNNL's lessons learned through CEF program on ESS capabilities and challenges in relation to integration with MHK devices.

MHK RESOURCES VARIABILITY CHALLENGES AND ESS OFFERINGS FOR MITIGATION

The fact that wave and tidal energy is originated through natural phenomena and may not coincide with the energy use cycle in the built environment brings ESS into consideration to turn these resources into practically useful source of clean energy. MHK energy resources experience both long and short term intermittencies. Long term intermittencies (in the range of hours) are caused by daily tide cycles that could be semidiurnal, diurnal, or a mix of both depending on the location and short term intermittencies are caused by underwater swells [4] in the range from seconds to minutes and is a direct challenge for grid integration. A few specific challenges caused by these variabilities are discussed below.

Over/under Generation

While the variations in tidal power extracted by an MHK device could be accurately predicted, the wide variation from zero to the peak power level itself is a challenge for serving consumers. Electricity demand profiles vary with customer types, such as residential, commercial, industrial. Depending on the proportion of different types of customers being served by a network, the demand profile peak may or may not be concurrent with MHK generation peak. This could result either surplus or shortage of generation. Surplus generation can cause typical issues related to reverse power flow (e.g., voltage rise, unwanted operation of control and protection devices) while shortage of generation, depending on network configuration and operational strategy, can cause low voltage, increased line loss, and even load shedding at the worst case. An appropriately sized and controlled ESS can mitigate over and under generation by appropriately charging and discharging. ESS support would also be essential for MHK integration in a microgrid setting, particularly for islanded mode of operation.

Fluctuating Generation

Unacceptable voltage fluctuations, and hence deterioration of power quality, could be caused by short term variations in MHK power generation. Severity of the event depends on the grid's "stiffness" (the strength to oppose change in voltage due to change in power), and the magnitude and frequency of power variations. IEEE standard 1547 [6] has specific limits on rapid voltage fluctuations which will need to be observed when MHK-based resources are interconnected with the grid. Depending on the penetration rate at bulk power system level, variability of MHK resources could also lead to system operation challenges in the future, which is now being observed with solar PV resources causing difficulties in managing high ramp rates of system net load [7]. With adequate response time and suitable control strategies, ESS could alleviate these challenges at distribution level and beyond, through appropriate coordination and aggregation.

Dispatchability Issue

Combined long and short term intermittencies could make it difficult to operate MHK resources as dispatchable generation. Using its power and energy capacity in an effective manner, ESS would be able to deal with moment-to-moment surplus/shortage of generation and enhance the dispatchability of MHK resources' output.

ESS INTEGRATION QUESTIONS

While ESS offers solutions to different challenges associated with practical use of MHK resources, there are a number of issues that need to be addressed to facilitate widescale integration of ESS with MHK devices. Based on PNNL's experience on working with ESS and variable generation issues, a few of those questions are reviewed and presented below.

Suitable ESS Technology

It is important to understand what type of ESS technologies would be most suitable considering technological maturity and cost-effectiveness, the power and energy requirements, and also the physical installation challenges at onshore or offshore sites. ESS technology for mitigation of short term fluctuations need to be power intensive, fast, and should be able to withstand a high number of charge/discharge cycles. Among different energy storage technologies, supercapacitors [8] feature very high cycle life (up to 100,000) and fast response time (< 1 sec). Flywheels [8] also have similar cycle life and response time, however the power density (W/liter) is lower compared to supercapacitors which is important due to physical installation constraints of MHK systems. Long term intermittency mitigation needs substantial energy storage capacity with moderate cycle life and reasonably fast response time. Electrochemical battery storage technologies [8] (e.g., Lithium-ion, Lead-acid) feature high energy density (up to 400 Wh/liter) and reasonably high cycle life (up to 10,000), and therefore are suitable for long term intermittency mitigation. Among a variety of ESS technologies, only a few (e.g., flywheel [4], supercapacitor [9], battery energy storage [10]) have been studied. Different ESS technologies with various technical characteristics need to be explored in relation to the long and short term intermittency characteristics of MHK energy resources to determine the most suitable technologies for field deployment.

Effective ESS Location

Depending on the power harnessing architecture used, there could be different options for selecting the point at which an ESS interacts with an MHK project site. Electrical components for MHK power conversion, such as generators, power electronic converters, transformers, and switchgear, can be located subsea (e.g., in a turbine nacelle), offshore above the ocean surface (e.g., on a hub, collecting a group of MHK devices' output), and onshore (e.g., at a substation, collecting multiple hubs' output) [11]. Power generated from MHK devices can be collected at variable (voltage and frequency) AC, fixed AC, or DC. ESS can be integrated either at DC side or fixed AC side of the power conversion systems. In combination, these configurations could provide different ESS placement layout options having advantages and challenges in regard to type, number, and rating of equipment (e.g., power electronics, AC/DC switchgear), AC/DC cable length and connector type (e.g., dry-mate, wet-mate), infrastructure (e.g., offshore platform, onshore substation). It is important to consider which option would allow storage capabilities to offer the greatest benefit for MHK resources, from electrical production perspective, and also from a system design perspective (e.g., technical suitability, capital and maintenance expenditure).

Appropriate ESS Control Strategy

Another significant consideration is how to maximize economic benefits of ESS in an integrated operation with MHK devices through appropriate control of ESS. Given the very nature of the intermittencies associated with MHK resources and the ESS technology characteristics, it is essential to understand how should ESS be designed and controlled to meet the needs of a contract, a utility, or a direct energy consumer.

WASHINGTON CEF LEARNINGS FOR MHK-ESS INTEGRATION

Washington Clean Energy Fund (CEF) was created in 2013 by the Washington state legislature for statewide advancement of renewable energy technologies. PNNL is leading ESS use case analytics effort under this program that provided opportunities to learn about ESS technical performance requirements and economic benefits in bulk energy, transmission, distribution, and behind the meter customer level applications. Lessons from field testing of a wide variety of applications, particularly the ones related to fast variations of ESS power profile (which would essentially be required for short term smoothing of MHK power), could be beneficial for MHK applications. A few specific examples relating CEF learnings with MHK integration are discussed below.

Specific CEF Learning Examples

Under the CEF use case analytics task, PNNL designed and implemented variety of ESS control duty cycles for grid ancillary services (e.g., frequency regulation, load following). Lessons learned while practically implementing these duty cycles through commercially available control systems might be useful for understanding ESS control requirements to limit MHK power variations. ESS capacity constraints experienced during CEF use case tests related to firming of renewable resources could provide valuable insights on ESS sizing requirements for MHK intermittency mitigation. Fast command tracking performance of ESS is assessed in a number of use cases under CEF analytics task which could help understanding the merits of current technology, particularly power electronics and control, for intermittency mitigation. CEF analytics task also focuses on performance degradation of ESS as a result of charging/discharging operation under various use cases and lessons learned would be useful to understand asset management requirements for ESS integrated with MHK resources.

From a holistic viewpoint, lessons from the CEF program would be able to provide useful information for ESS and MHK community to understand if the current status of ESS and MHK technology is suitable for wide scale integration between each other and to identify the areas needing further development.

CONCLUSION

MHK energy resources, though predictable, will not necessarily generate in concert with consumers' or grid's consumption pattern due to its hydrodynamic variation. ESS, with its offerings of flexible capacity to absorb intermittencies in MHK power output, would be of great interest to the MHK industry. However, ESS integration by itself could be challenging given the practical deployment issues. This presentation will reflect on PNNL's learnings achieved through field deployment experience under Washington CEF program and relate the findings to some of the MHK-ESS integration questions addressed herein. It is anticipated that sharing PNNL's findings on the current technology and economics aspects will be useful for both MHK and ESS communities to identify the future development needs toward achieving better integration between these two technologies.

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