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The Grid Value of Ocean Current Energy in Florida

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***Abstract*—Ocean current energy technology has been proposed as a potential contributor to Florida's energy portfolio. There has been limited investigation of how this energy would be valued when integrated into the Florida electrical grid. This study assesses three future grid scenarios to evaluate the impact of adding zero-cost ocean current energy to each. The Resource Planning Model, a tool developed by the National Renewable Energy Laboratory, is used to identify the least-cost generation mix through 2050, with and without ocean current energy. The first scenario is a base case and assumes existing policies in which the addition of ocean current energy does not retire fossil-based technologies but variable generation technologies. In the second scenario, solar and storage technologies are lower cost, and the addition of ocean current generation enables those technologies along with wind to retire existing natural gas units earlier. In the third scenario, which requires a 95% reduction in carbon emissions from 2020 levels by 2050, ocean current energy can play a role in decarbonization along with other variable generation technologies. This analysis is intended to inform stakeholders on the opportunity, potential challenges, and overall value to the grid of ocean current technology from a reliability and availability focused perspective.**

***Index Terms*—Capacity Expansion Model, Ocean Current Technology, Renewable Energy, Grid Modeling**

I. INTRODUCTION

Power systems around the world are shifting towards cleaner technologies, including variable renewable energy. The potential of such technologies depends on regional resource characteristics, including resource potential, existing electricity mix, and transmission grid topology. Ocean current technology – which is a type of marine renewable energy technology that includes devices to harvest wave, tidal, and river current energy – has been proposed as a potential contributor to Florida's energy portfolio because of the proximity of the Florida Current to the shore near Miami, Fort Lauderdale, and West Palm Beach with average current speeds greater than 1.5 m/s [1].

To date, much ocean current research has focused on resource quality and not on how the technology could contribute to power grid reliability and emissions reductions. While a strong resource is a key factor for renewable energy deployment, it must be paired with a suitable demand. If ocean current technology is developed to a high enough technology readiness level (TRL) [2] to be deployed at the scale this study is investigating, our vision is that it would be deployed as an array of ocean current turbines submerged in the water column miles offshore. Given the low TRL of this technology, this study is not a deployment cost analysis, i.e., we are not assessing ocean current technology in terms of cost competitiveness with other technologies. Instead, we assume the cost of ocean current technology to be zero and investigate the value its generation provides in terms of firm capacity, energy, and displacement of other, including fossil-based, technologies. Hence, this feasibility study investigates how integrating ocean current technology (free of cost) on an intermediate- to long-term horizon would impact Florida's grid from a reliability point of view. In other words, this study focuses on informing stakeholders to what extent would ocean current technology contribute to the grid from a reliability perspective to impact future system buildout under different scenarios.

II. METHODOLOGY

A wide range of tools can be used to assess the grid value of a technology; therefore, it is important to know the temporal and spatial resolution that is of interest to choose the appropriate tool. For our feasibility study, we are interested in assessing the grid value of Florida ocean current technology at the utility-scale over an intermediate to long-term horizon. The National Renewable Energy Laboratory's (NREL's) capacity expansion model, the Resource Planning Model (RPM), has the capabilities needed to assess the impact of this regional resource, including its interactions with the transmission grid. The following sections provide further details about RPM, the model assumptions and the scenarios assessed in this feasibility study.

A. Resource Planning Model (RPM)

The NREL-developed RPM is a capacity expansion model (CEM) used for power system planning over an intermediate to long-term horizon [3]. CEMs simulate generation, storage, and transmission investments and operations accounting for future projections of demand, fuel prices, technology costs, and policies. One of the limitations of most CEMs is that they use

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[1] Brady Cowiestoll contributed to this project while working at the National Renewable Energy Laboratory.

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limited temporal resolution and are thus not suitable for detailed operational analysis (like production cost analysis)[2] or extensive resource adequacy assessment.

RPM solves the optimization problem to find the least-cost resource mix subject to reliability and policy constraints. Hourly dispatch is modeled for 5 days that represent low, mid, high, peak load, as well as low variable generation conditions throughout the year. RPM estimates capacity credits and curtailment impacts for variable generation and energy-limited resources (e.g., storage and PV+battery) using 8760 hourly data. These estimates are key inputs into the least-cost investment and dispatch problem because they improve the valuation of these resources as potential investments when only 5 days' worth of data are used to represent annual operations.

B. *Model Assumptions*

RPM runs in 5-year increments, from 2010 to 2050 and new resource builds starting in 2025. The existing generators, transmission and load are based on the 2024 case from the North American Renewable Integration Study (NARIS) [4]. In this study, the model is configured to not build any new fossil-based or hydropower units, so all such resources that appear in the results were built in 2020 or before. We allow new builds of renewable combustion turbines (RE-CTs) and hydrogen combustion turbines (H2-CTs). RE-CTs are combustion turbines fueled by, e.g., biogas, biofuels or hydrogen; and H2-CTs[3] are fueled by on-site electrolytic hydrogen generation with 340 hours of storage capacity and a round-trip efficiency of 45%.

The yearly load growth scenario is based on the Annual Energy Outlook 2021 reference scenario [5]. The fuel price assumptions are based on the 2022 Annual Energy Outlook [6] and the technology cost assumptions are based on NREL's 2022 Annual Technology Baseline [7], except for ocean current technology, which is modeled as zero cost. The variable generator profiles were created with the Renewable Energy Potential (reV) model and 2012 weather data [8]. We also include a production tax credit (PTC) that aligns with NREL's 2022 Standard Scenarios representation of the Inflation Reduction Act (IRA) [9].

RPM models Florida on a nodal level and all the non-Florida nodes in the Eastern Interconnection are aggregated to the state level. Although the model still assumes that Florida is electrically connected to Georgia and Alabama, we put a very high price on import and export interactions between these regions to incentivize Florida to plan to meet its own power needs, rather than rely on imports from other regions. This assumption allows us to narrow the scope of the analysis to assess the unique challenges and opportunities faced by Florida. In other words, it helps us assess the sensitivity of the model's outcomes to changes in Florida without the need for complex cross-regional considerations and to encourage Florida to meet its own renewable energy goals.

Ocean current technology is treated as prescribed in the model such that the model builds the technology without considering cost. We choose a prescribed approach for ocean current technology since we want to understand the feasibility of integrating ocean current energy into the system: what grid services it would provide and what assets it would displace. We add 500 MW of ocean current capacity in 2030 which remains on the system until 2050. We selected calendar years 2009 and 2012 as examples of ocean current energy profiles for this feasibility study; 2009 was selected because it represents a year with typical conditions (Figure 1). There are a few output dips below 90% in winter and spring but has a steady power output in the summer. In the fall, the resource is intermittent at between 40% and 100% output. The year 2012 represents a year where the output of ocean current energy generation is quite low. As Figure 1 shows, there are 50% dips in winter and spring, but the summer has a steady power output. In the fall, the output reaches zero for several days.

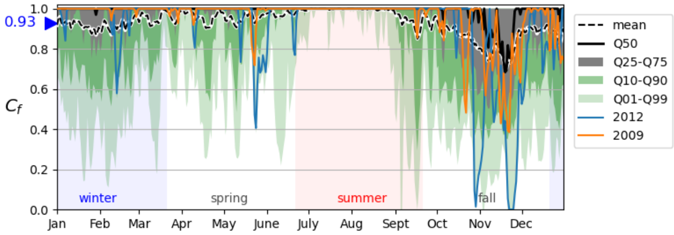

Figure 1. Ocean current power generation hourly capacity factor. The black line indicates the median value as a function of time. The gray (25%-75%), green (10%-90%), and light green (1%-99%) regions indicate the quantiles of the data across years 1994 to 2015.

C. *Model Scenarios*

In our analysis, we consider three scenarios with and without ocean current generation to assess the impact of ocean current generation on the grid. The scenarios are (1) Business as Usual - Base (BAU Base), (2) Business as Usual- High Solar and Storage (BAU hPVst), and (3) Florida 95-by-2050 (FL95by2050). For each of these scenarios we conducted two runs with ocean current energy to account for profile variability, one with a 2009 modeled ocean current generation profile and one with a 2012 profile. The BAU Base case is the least constrained. It assumes existing policies with no carbon policy interventions, and it allows new nuclear builds beginning in 2040. The BAU hPVst case has the same assumptions as BAU Base but assumes low solar and low storage costs. The FL95by2050 case is the most constrained because a carbon constraint is added to the Florida region, and the scenario prohibits new nuclear builds. Otherwise, all other assumptions of the FL95by2050 case match the BAU hPVst case. We assume that the national power sector carbon emissions decrease linearly to 95% below 2020 emissions by 2050, with the initial 2020 values taken from the 2021 Standard Scenarios [10]. The three scenarios' main assumptions are in Table I.

TABLE I. SCENARIO SPECIFIC ASSUMPTIONS.

BAU Base	**BAU hPVst**	**FL95by2050**
No carbon policy interventions		Carbon constraint on Florida and the Eastern Interconnection
Allow new nuclear builds in 2040		No new nuclear

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[2] Production cost models are used for detailed operational analysis.

[3] Although listed as H2-CTs, this functionality could be fulfilled by fuel cells, which do not produce NO_x emissions, instead.

BAU Base	**BAU hPVst**	**FL95by2050**
Midline solar and storage cost	Low solar and storage cost	
Florida islanded (high cost to import or export power)		

III. RESULTS AND DISCUSSION

The objective of this analysis is to evaluate the feasibility of integrating ocean current energy into Florida's grid, focusing on long-term planning reliability rather than cost considerations. The scenarios assume ocean current technology is cost-free and use realistic modeled resource profiles that demonstrate that Florida ocean current is expected to have a time-varying capacity factor (as shown in Figure 1). The analysis begins by presenting the energy mix without ocean current generation in Section A; Sections B and C delve into the effects of ocean current integration on Florida's power system.

A. Florida System Without Ocean Current Energy

To understand the impact of ocean current energy on the power system, it is important to understand the initial generation mixes of the three scenarios. Figure 2 shows the installed capacity (left) and generation mix (right) for the BAU Base, no ocean current energy runs. In the left-hand plot, the installed capacity in 2020 represents Florida's existing capacity, which is heavily weighted toward fossil-based technologies. Since the model is not allowed to build any new fossil-based technology, the system integrates more battery storage, H2-CTs, wind and solar, while retiring some oil and nuclear plants by 2050. The right-hand plot shows that the dispatch consistently uses natural gas throughout the study period but reduces coal use due to retirements. The H2-CTs are hardly dispatched, which indicates that they are built mostly for planning reserves. Although the model builds a significant amount of variable generation, more than 50% of the total demand is still met by fossil-based technologies (mostly natural gas combined cycle (NG-CC)) in 2050. Natural gas combustion turbines (NG-CT) are mostly used for peaking power (to respond quickly to changes in electricity demand).

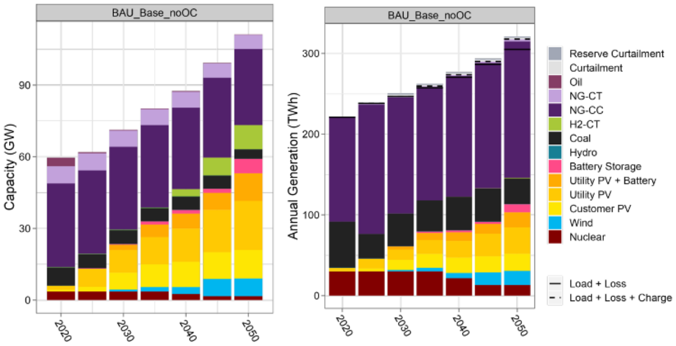

Figure 2. Installed capacity and annual generation of the BAU Base no ocean current run.

Figure 3 shows the installed capacity (left) and generation mix (right) for the BAU hPVst no ocean current energy runs. The left-hand plot shows increased solar and battery storage for this scenario due to low-cost assumptions compared to the BAU Base scenario, along with new nuclear plants built after 2040 to replace retired units. Wind builds are mostly delayed to 2050. Overall, while the total installed capacity doesn't significantly increase, the percentage of added technologies differs from BAU Base scenario. In the right-hand plot, fossil-based technologies, and variable generation (wind and solar) remain cost-effective for meeting demand, leading to a drop in coal dispatch as some units retire by 2050. In the right-hand plot, we see similar patterns as the BAU Base but with 40% of the demand met with clean (not-fossil) technologies in the BAU hPVst compared to 35% in the BAU Base case.

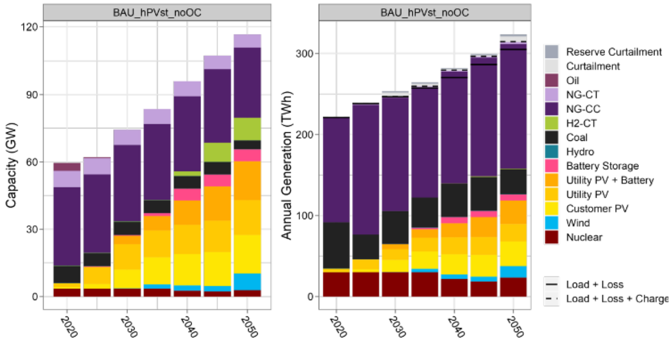

Figure 3. Installed capacity and annual generation for the BAU hPVst no ocean current run.

Figure 4 shows the installed capacity (left) and generation mix (right) for the FL95by2050 no ocean current runs. The left-hand plot shows that a significant portion of installed capacity, including 47% in 2030, 70% in 2040, and 87% in 2050, is built through RPM decisions. New builds of solar technologies, including PV tracking, fixed, and rooftop, constitute a major part of new builds, accounting for 55% in 2030, 64% in 2040, and 71% in 2050. Wind capacity, both onshore and offshore, also exhibits substantial growth due to these decisions. By 2050, solar technologies make up nearly 25% of the total installed capacity, PV+battery contributes 20%, wind contributes 5%, offshore wind accounts for 14%, and storage and H2-CTs together contribute 21%. Solar technologies, particularly PV-related ones, are identified as having the highest potential to meet the demand in 2050. The right-hand plot illustrates that dispatch in earlier years relies heavily on natural gas and that coal retires completely in 2025. The use of natural gas decreases as the system approaches 2050 due to retirements in compliance with carbon constraints.

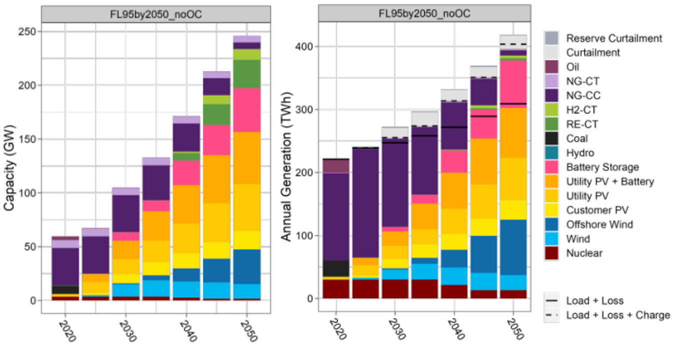

Figure 4. Installed capacity and annual generation of the FL95by2050 no ocean current run.

B. Use of Ocean Current Generation Over the Year

Capacity factor is a unitless metric that expresses how much energy a resource generates over a time period, usually a year, relative to its capacity. Figure 5 shows the post-dispatch capacity factors of ocean current energy for all three scenarios and both resource profiles. As expected, the 2009 profiles have a higher capacity factor than those for 2012. Comparing across scenarios, ocean current energy capacity factors are 10% higher in 2030 for BAU Base and BAU hPVst compared to FL95by2050 because FL95by2050 curtails some of the variable generation it builds to meet its carbon constraint (approximately double the variable generation of the other scenarios). The trend continues through 2050. Hence, ocean current energy dispatch competes with other variable generation in the FL95by2050 scenario, but this does not happen in the BAU scenarios with their relatively smaller variable generation builds, especially in earlier years. The system relies mostly on PV technologies to meet the peaking demand during the daytime in 2030 and curtails some of the ocean current energy generation and other variable generation technologies at those times. However, in later years, as some of the gas units retire and more storage is built, batteries charge during the day and dispatch at night. Hence, the amount of curtailment drops, and the Florida system takes (near-) full advantage of these zero cost and low emissions technologies.

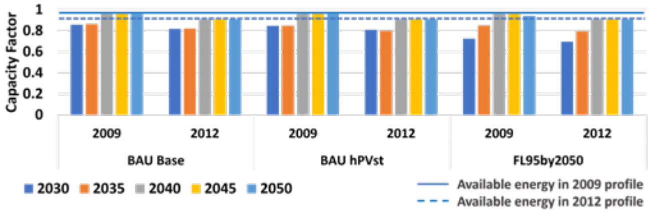

Figure 5. Ocean current technology capacity factors for all scenarios.

C. *Impact of Ocean Current on the Generation Mix*

For the next set of results, we introduce a cost-free 500 MW of ocean current technology into the previous runs. A comparison with the results in Section A allows us to determine which technologies ocean current technology might displace. We see that the capacity factor of ocean current generation is 3 times higher than the capacity factor for other variable generation sources (e.g., wind and solar), and significantly influences grid investment decisions. In BAU Base case, ocean current energy shifts the competitive balance between different clean generation technologies. The left two subplots of Figure 6 demonstrate that the prescribed ocean current energy build does not displace any fossil-based capacity, because it's cheaper to maintain that capacity in support of planning reserves when there are no retirement pressures, but does result in new builds of standalone PV, standalone batteries, nuclear, and H2-CT, rather than PV+battery and wind. This is the first indication, seen throughout Figure 6, that as a high-capacity factor resource able, unlike wind and solar, to provide large firm capacity contributions, ocean current has an outsized impact on capacity builds. With regards to energy (Figure 7), in this scenario ocean current generation mostly replaces natural gas dispatch, and usually (except for 2045) enables more clean generation on net, because of its influence on the capacity builds.

In the BAU hPVst case, the presence of ocean current technology allows gas to retire earlier, and leads the model to preferring new solar and battery installations to meet demand (Figure 6, middle subplots), typically reducing reliance on gas generation (Figure 7, middle subplots). In the FL95by2050 case (right two subplots of Figure 6 and Figure 7), starting in 2030 ocean current energy replaces natural gas and delays offshore wind builds, though there are some delays in gas retirements due to prior fossil retirements in 2025. Starting in 2040, ocean current energy displaces nearly ten times its capacity worth of offshore wind, PV+battery, standalone batteries, and RE-CT, highlighting its potential to provide firm renewable capacity (Figure 6). As carbon constraints tighten, the model is able to use nearly all of the available ocean current generation to replace other variable generation, some shifted to be used at times other than when it was generated (Figure 7).

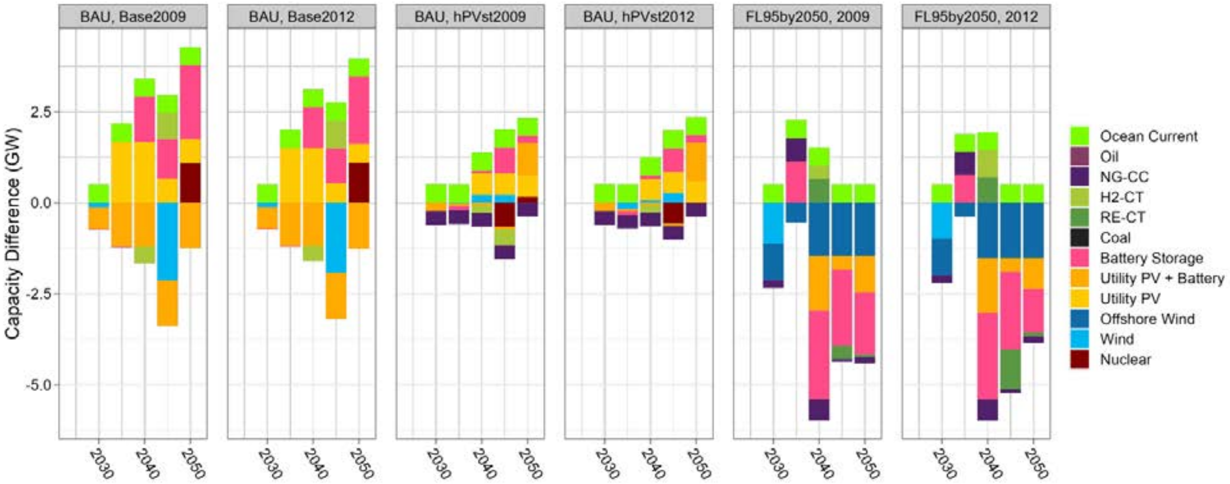

Figure 6. Installed capacity difference plots for the scenarios considered in this feasibility study.

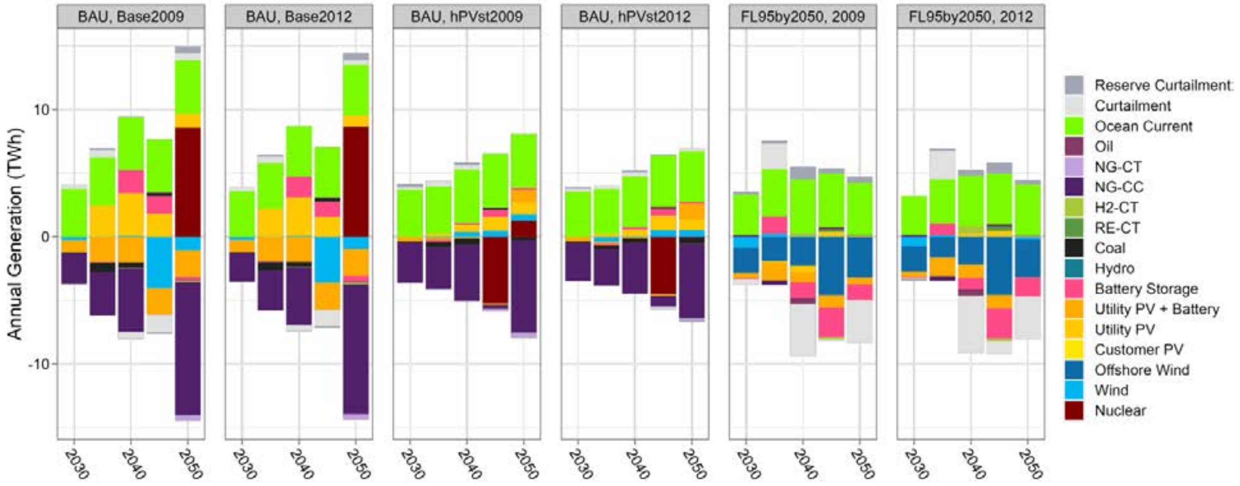

Figure 7. Annual generation difference plots for the scenarios considered in this feasibility study.

IV. CONCLUSION

This analysis studied impact of integrating ocean current energy into Florida's grid using NREL's capacity expansion model, RPM. Three Florida capacity expansion scenarios were studied through 2050. The study investigates how RPM's investment choices are influenced by various configurations and assumptions related to policies, solar, and storage costs assuming that ocean current technology is free of cost in the model. Although the ocean current technology being free is an unrealistic assumption, the analysis emphasizes the grid value of ocean current energy to assess the feasibility of the technology from a reliability perspective. The high-capacity factor of ocean current energy significantly influences capacity build-out, evident in scenarios like FL95by2050 where it delayed up to ten times its capacity worth of offshore wind, PV+battery, and battery, and RE-CT builds. Depending on the scenario, ocean current can replace different technologies' contributions to both firm capacity and energy as well as shift the competitive balance between other clean energy technologies.

For future work, assessing the cost range of ocean current compared to other technologies will give us insights as to whether ocean current technology is cost-competitive. Also, production cost model analysis is needed to understand how the variability of ocean current would impact its operation on the system. Though a full ocean current technology deployment analysis would assess the grid value from a capacity expansion perspective, many other assessments could possibly show economic infeasibility or other factors. This analysis can be used to inform stakeholders on the grid value of ocean current technology from a reliability perspective but opens a wide range of research questions that need to be addressed.

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