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Energy balance modeling of tidal and river current generation devices in Alaska

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Abstract

Energy balance models have been used to help size and predict viability of wind generation integration into microgrid communities and can provide comparable analyses for marine resources as well. HOMER is a leader in techno-economic modeling software for microgrids allowing for component comparison and cost optimization over project lifetime based on hourly resource availability and demand. MiGRIDS offers a greater management of generation control and scheduling than HOMER, as well as higher temporal resolution, but lacks project lifetime analysis. These software tools will be used to analyze benefits and impacts of marine energy integration into Alaska microgrids using two sites as a case study for two types of marine energy converters. Igiugig on the Kvichak River will be simulated with a river current energy converter and Tyonek on the Cook Inlet will be modeled with a tidal energy converter. It is demonstrated that both models yield similar results, but each is designed to focus on different aspects of microgrid simulation.

Keywords: Alaska Microgrids; Energy Balance Modeling; Marine Energy;

Nomenclature

CEC	Current Energy Converter
MEL	Minimum Efficient Loading
MiGRIDS	Microgrid Renewable Integration Dispatch and Sizing
TEC	Tidal Energy Converter

1. Introduction

Alaska has immense potential for marine energy resources, with over 230 TWh/yr of untapped tidal and river power [1]. As the technology develops it will be necessary to analyze the impacts that additional resources have on the existing electrical grids. HOMER and MiGRIDS (**Mi**cro **G**rid **R**enewable **I**ntegration **D**ispatch and **S**izing) are two energy balance modeling software tools which have been used for analysis of wind and energy storage integration into microgrids [2], [3]. This case study demonstrates these tools for analyzing marine resource integration into microgrids.

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Two sites have been selected to test marine energy devices in Alaska using energy balance models: one for a river current energy converter (CEC) device and one for a tidal energy converter (TEC) device. Additionally, each site represents a different type of microgrid typically found in Alaska. Igiugig, a population of 68, sits along the Kvichak River at the outlet of Iliamna Lake and is a permanently islanded microgrid which relies primarily on diesel generators for electricity generation. Tyonek, a population of 152, lies on the North Forelands of Cook Inlet and is connected via transmission to the Railbelt, Alaska's largest electrical grid.

2. River Current Device

2.1. Time Series

Yearlong electrical load and river speed data [4] have been collected and processed for the community of Igiugig, AK. The electrical load time series data were obtained directly from the local utility operators. The time series for MiGRIDS use five-minute time steps, while the HOMER time series use hourly time steps. On average the data sets are very similar, but the extremes are more accurately represented in the higher resolution series. This can be seen in Figure 1 showing the load time series used in MiGRIDS and HOMER for one week starting February 12. The maximum load seen by HOMER in this time window is 64.8 kW while the maximum load seen by MiGRIDS during the corresponding time is 70.6 kW.

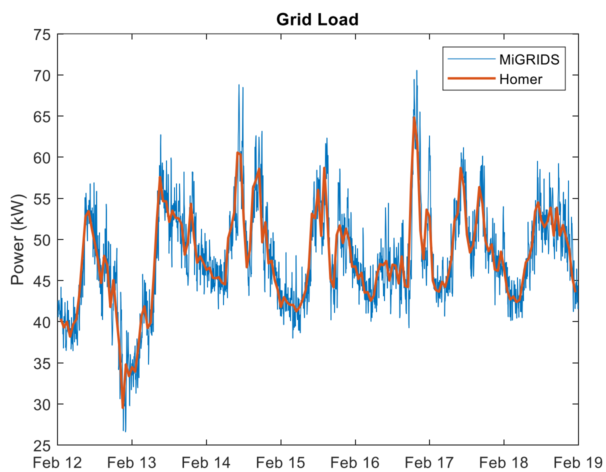

Figure 1 Electrical load of Igiugig using five-minute time steps for MiGRIDS and hourly time steps for HOMER.

2.2. Microgrid Parameters

To convert river-speed data to available power, the modeling tools used the same power curve of a 5 kW New Energy current energy converter (CEC) river turbine, seen in Figure *2*. Figure *3* shows the river-speed plotted alongside the available power from the turbine throughout the year. The models assume three John Deere 4045TMF75 diesel engines with a rated electric output of 65 kW. The generators have a minimum loading of 25% and maximum loading of 110% of the rated capacity in both HOMER and MiGRIDS.

As well as running at a shorter timestep, MiGRIDS also has a more detailed representation of the system dispatch and scheduling. This includes multiple load thresholds, each with their own time, which would cause a transition from one combination of online generation to another. These settings replicated the operation of an actual system and needed to be adjusted to get the desired behavior of switching the online combination of generation fast enough to avoid over or under-loading, while also avoiding switching too often. This was an additional set of model tuning that was not required when running HOMER at hourly averages.

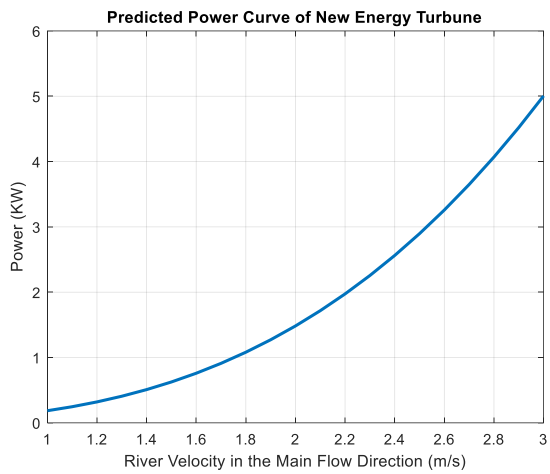

Figure 2 Power curve of 5 kW New Energy turbine for operational water velocities.

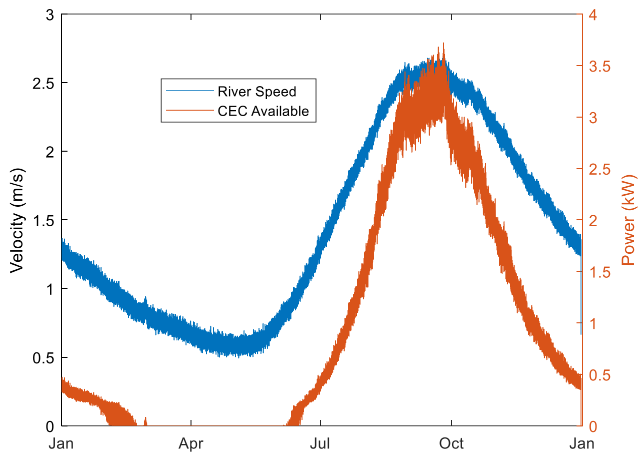

Figure 3 River speeds at Igiugig (blue) and available power for a 5 kW turbine (red).

2.3. Results

Over the course of a full year the two models performed similarly. Table 1 compares several performance factors of MiGRIDS and HOMER over the course of one year. These factors include total load served (kWh), the CEC production (kWh), diesel generation (kWh), diesel fuel consumption (Gal), and average electrical production per unit of fuel (kWh/Gal). The annual production values show the performance of MiGRIDS is similar to that of HOMER. While the extremes are greater in the higher resolution load and resource data, they average out over the year.

Table 1 Comparison of MiGRIDS and HOMER yearlong simulation results.

	MiGRIDS	HOMER	% Diff
ANNUAL LOAD (KWH)	339,909	339,814	0.028
CEC PRODUCTION (KWH)	8,310	8,257	0.64
GEN. PRODUCTION (KWH)	331,599	331,556	0.012
GEN. FUEL (GAL)	27,750	27,311	1.6
AVG. FUEL RATE (KWH/GAL)	11.95	12.1	1.6

The difference in fuel consumption between the MiGRIDS and HOMER simulations is slightly larger than the electrical production. This is due in part to the greater control over generator scheduling and dispatching in MiGRIDS. The controls in the MiGRIDS simulation are set to reduce frequent generator switching, as shown in

Figure 4, but this leads to slightly more fuel usage over the course of the year. Tuning of the MiGRIDS control parameters would allow a more similar operation to that seen in HOMER.

A baseline case without a CEC was also simulated in both MiGRIDS and HOMER, with the annual performance factors shown in Table 2. The addition of a 5kW CEC turbine led to a fuel reduction of 647 gallons in MiGRIDS and 634 gallons in HOMER, although both models had the generators operating slightly more efficiently without the CEC.

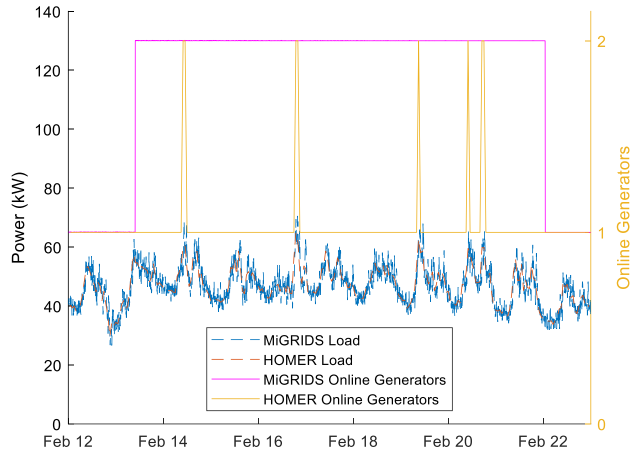

Figure 4 Comparison of MiGRIDS and HOMER load (kW) and online generators.

Table 2 Comparison of MiGRIDS and HOMER yearlong simulation results for a baseline without a CEC.

	MiGRIDS	HOMER	% Diff
ANNUAL LOAD (KWH)	339,909	339,814	0.028
CEC PRODUCTION (KWH)	NA	NA	NA
GEN. PRODUCTION (KWH)	339,909	339,814	0.028
GEN. FUEL (GAL)	28,397	27,945	1.6
AVG. FUEL RATE (KWH/GAL)	11.97	12.2	1.6

The area plot in Figure *5* shows the relative portion of CEC production and diesel production over the year. Adding more or larger CEC devices could increase the proportion of renewable energy on the grid and provide a greater reduction in fuel usage, but only for a portion of the year with sufficient flow. The river only saw velocities less than the device's cut-in speed during the spring. A different renewable resource would be needed to displace electricity from the diesel generators for that time of year.

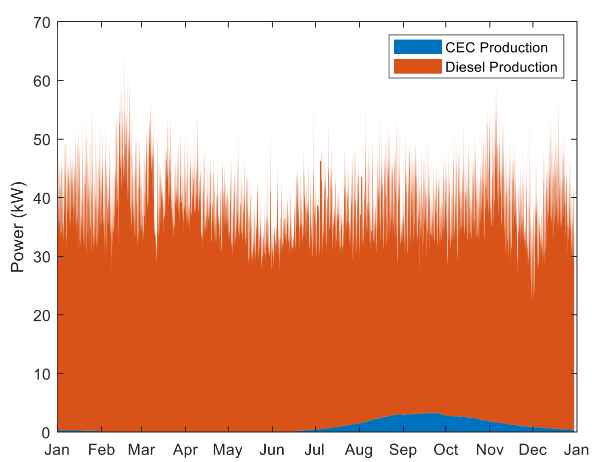

Figure 5 Area plot of electrical production from a CEC device (blue) and diesel generators (red).

3. Tidal Current Device

3.1. Time Series

A community load time series for Tyonek, AK was not able to be obtained. Instead, the Igiugig load time series was scaled up by the relative population of the two communities. For the resource profile, hourly tidal energy capacity factors for the Cook Inlet were scaled to 1 MW comparable to the Reference Model 1 tidal current turbine developed by Sandia National Laboratory [5]. Since there is not higher time resolution data available for the resource time series, only HOMER was used to simulate the site.

3.2. Microgrid Parameters

The HOMER model assumed a grid connection capable of supplying the entire load. The baseline only used the electrical grid. The test case included the tidal energy resource as well.

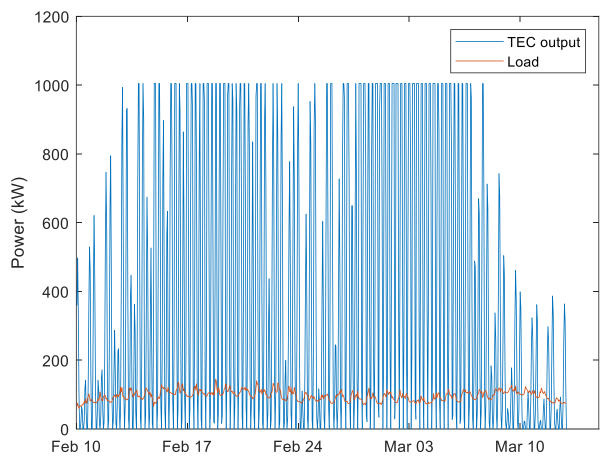

Figure 6 Power output of TEC (blue) and load demand of Tyonek (red).

3.3. Results

In the base case, all 760 MWh of the load was powered by the grid. With the addition of the 1 MW tidal energy turbine, a total of 3590 MWh of energy was produced. Of that 560 MWh were used to power the community load and 3030 MWh were exported onto the Railbelt grid. Additionally, another 200 MWh were imported from the Railbelt during the times of the high and low tides when the tidal current changes direction. Figure 6 shows a snapshot of the TEC power generated and the community load. The tidal behavior of the system is demonstrated as the current reverses direction between high and low tide with an approximate 6-hour cycle, as well as the bi-weekly and monthly cycles which correspond to the lunar cycle.

4. Conclusion

As marine energy technology matures, MiGRIDS and HOMER modeling tools can both be effective resources to analyze new deployments into microgrids. The river CEC analysis shows MiGRIDS and HOMER yield similar results over the course of a year. However, the two software tools are not interchangeable. HOMER has greater economic and optimization features used to compare costs over the lifetime of a project. MiGRIDS is better used when examining how shorter time scale dynamics and microgrid control methodologies impact grid behavior. The TEC analysis shows significant potential of tidal power in the Cook Inlet, but that it must be complemented with other resources during periods of slow current when the flow changes direction and when the tides are less extreme.

References

[1] L. Kilcher, M. Fogarty, and M. Lawson, "Marine Energy in the United States: An Overview of Opportunities," National Renewable Energy Laboratory, TP-5700-78773, 2021.

[2] T. Lambert, P. Gilman, and P. Lilienthal, "Micropower System Modeling with Homer," in *Integration of Alternative Sources of Energy*, F. A. Farret and M. G. Simões, Eds., Hoboken, NJ, USA: John Wiley & Sons, Inc., 2006, pp. 379–418. doi: 10.1002/0471755621.ch15.

[3] J. Vandermeer, M. Mueller-Stoffels, T. Morgan, D. Broderson, and N. Green, "MiGRIDS." [Online]. Available: https://github.com/acep-uaf/MiGRIDS

[4] J. Kasper, P. Duvoy, N. Konefal, and A. Cannavo, "Next Generation RivGen Power System: Kvichak River, AK Overwinter Ice Study." Marine and Hydrokinetic Data Repository (MHKDR); Igiugig Village Council, p. 3 files, 2017. doi: 10.15473/1492960.

[5] V. Neary *et al.*, "Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies," SAND2014-9040, 2014. [Online]. Available: https://energy.sandia.gov/wp-content/uploads/SAND2014-9040-RMP-REPORT.pdf