Alaska Hybrid Simulator Model (Hybsim v1.0)[1]

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1.0 Abstract

The Alaska Hybrid Simulator Model (Hybsim v1.0) was developed to analyze the economic and environmental benefits of combining or replacing a typical fossil-fuel generation system with renewable energy and energy storage methods. The purpose of this task was to test and hone the Hybsim v1.0 model as an effective assessment tool for real-world applications.

The model was successfully validated against a real system. The first round trials revealed areas of concern and unacceptable variations in component responses. These variations were investigated and eliminated where possible. By the end of the validation process, two of the three simulated components had a response variation of less than 1% compared to their real system counterparts. The battery in the simulated case was discharged 15% more than the real battery, the reasons for which are identified in section 4.0.

The Hybsim v.1.0 model is now considered to be validated for its designed purpose: To perform a first-cut analysis on the economic and environmental benefits of adding renewable energy and energy storage to an existing fossil-fuel generation mix. The predicted fuel consumption of the simulated system matched well with that of the real system[3].

2.0 Introduction

The Alaska Hybrid Simulator Model (Hybsim v.1.0) was developed as a tool to model the economic and environmental outcomes of adding renewable energy and energy storage to a standard fossil fuel (typically diesel) generation system. This effort was preceded by a Validation Plan that established the criteria for successfully validating the model. However, the Validation Plan could not be used in its entirety due to its dependence on fuel consumption data,[4] which was unavailable during the validation process.

To confidently validate the model, a variation of +/- 5% in the component response compared to the real system was established as the maximum threshold. If variations in the comparative results were beyond the acceptable range, the failed parameters would be identified and the divergence investigated. Any unacceptable and uncorrectable variations would be documented, and a correction plan would be developed.

3.0 Model Validation Methods & Validation Data

In order to validate the model, it was tested against a real system. Recorded data was obtained from a hybrid system installed at Carol Springs Mountain, Arizona. The Carol Springs Mountain (CSM) hybrid system, the specifications of which are tabulated below, is composed of a diesel generator, photovoltaic panels, and a battery bank for energy storage. This system was installed in October, 1995[5], and is currently being maintained by Arizona Public Services (APS), a utility company operating in Phoenix, AZ. The system provides power to two communication towers installed at the top of the mountain.

Prior to the installment of the hybrid system, two diesel generators (60 kW and 55 kW) consuming 11,000 gallons of diesel per year were the source of power at the site. Fuel transportation via trucks, especially in winter months, and fuel spills prompted the transition to renewable energy and energy storage.

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[2] Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

[3] Approximate fuel consumption for the real system was extracted from APS fuel invoices from 08/04 – 08/05.

[4] Recorded fuel consumption for the duration of the simulation.

[5] http://www.sandia.gov/ess/publications/conferences/2002/hammond 20- 20pv-hybridsysmonitorstar.pdf

Component	Manufacturer	Size
Generator		50 kW
Photovoltaic Panel		24.6 kW
Battery	GNB Absolyte IIP	2880 Ahr
Inverter	AES	30 kVA

3.1 Data Specifications

A month's worth of data recorded at 10-minute intervals was obtained from APS. Data for load, plane of array irradiance, wind speed, ambient temperature, and a corresponding time-stamp were some of the several parameters measured in the CSM hybrid system. This information was formatted as per the data input requirements of the model before being used in the model.

3.2 System Operation Specifications

John Wiedner, a representative from Arizona Public Service (APS), revealed that the real system installed at the site was being operated in a 'cycle charge' mode and the decision points for operating the generator and battery was strictly based on the battery voltage. The battery was considered to be fully discharged at 2.0 volts/cell and fully charged at 2.3 volts/cell. Setting the discharge cut-off voltage to 2.0 volts/cell ensured that the battery was restricted to 50% Ahr depth of discharge (DOD) thereby prolonging the life of the battery.

3.3 Data Modification

In the model, a simulated battery is designed to be "fully charged" at the beginning of a simulation. Since the data obtained from the CSM system was a subset of the recorded data for the real system, the battery was not at a 100% state of charge (SOC) at the beginning of the obtained data set. To compare the two battery banks, the real system's battery must be at the same SOC as the battery in the simulated system. Consequently, a few data points at the beginning of the real system data were deleted until the real battery was at maximum charge.

4.0 Real System Response vs. Simulated System Response: A Comparison

A simulation system emulating the real system at Carol Springs Mountain was created and stored in the model. Extracting relevant data from the real data file generated the input files (the load data file and the weather data file) to the model. Specifications of components were obtained from manufacturers' websites, and system information was obtained through conversations with John Wiedner of APS**.**

The simulated system was run to imitate the response of components in the real system. The simulation result, i.e. response of the components in the simulated system was compared to that of the real system. The total energy generated by each component and consumed by the batteries during the simulation was calculated and compared. The response of the real and simulated system components were plotted to observe the time-based variation between the two.

4.1 First Run Results

The variance in total energy generation between the real system and the simulated system observed in the first run is tabulated below. Except for the diesel generator, variations in all the components were beyond the established limit of acceptability for model validity.

Component	Real (kWhr)	Simulated (kWhr)	Diff (%)
Photovoltaic Panels	20,700.20	23,040.71	11.31%
Diesel Generator	40,058.70	38,413.43	-4.11%
Battery – Charging	-27,646.30	-30,509.47	10.36%
Battery – Discharging	25,563.68	30,833.86	20.62%

4.1.1 PV Response

The PV panel in the simulated case produced 11% more energy than the PV panel installed at Carol Springs Mountain, AZ. This deviation in response was a result of the simulated PV panel power peaking consistently higher than the real PV panel (See Graph 1 in appendix). Communications with PV experts and calculations revealed that the performance of the real PV panel, which was about 10 years old, had degraded about 1% per year. Not accounting for performance decline due to age in the simulated model resulted in a falsely high PV power peak.

4.1.2 Generator Response

The total energy generated by the simulated model diesel generators is 4 % less than their real counterparts. However, the variance between real and simulated diesel generators is within the acceptable variation limit (+/- 5%).

4.1.3 Battery Response

The simulated model's battery did not match well with the real battery installed at Carol Springs Mountain, AZ. According to the simulation results, the simulated battery was being charged 10% more than the real battery while being discharged 20% more than the real battery. According to battery experts at Sandia National Laboratories and SENTECH, INC., the major technical contributors to the mismatch of the two batteries were:

a) *Absence of temperature compensation in the model* – According to the data obtained from the validation site, the temperature at the location varied from a minimum of 50°F to a maximum of 90°F during the course of simulation. The absence of temperature compensation in the model's battery algorithm and observed temperature variation at the site are major reasons for variation in battery response.
b) *Frequency of equalization of the real battery* – As per conversations with the APS representative, the real battery was being equalized once a month. Since the DOD of the battery is dependant on the SOC of the battery at the beginning of each discharge cycle, the DOD of the real battery varied from 40 – 50% during the simulation period. In contrast, the simulated battery was being discharged to a DOD of 68 – 75% during the simulation. This consistently deeper discharge is another major reason for the observed variation in the battery response.

4.2 Second Run Results

The sources of the deviations (identified in the previous section) were eliminated by modifying the code in the model, and the simulated case was rerun. The validation results from the second run improved considerably compared to the results from the previous run. Accounting for performance degradation due to PV panel age and implementing temperature compensation in battery code reduced the variation in most of the component response to acceptable levels. The new results are tabulated below:

Component	Real (kWhr)	Simulated (kWhr)	Diff (%)
Photovoltaic Panels	20,700.20	20730.09	0.14%
Diesel Generator	40,058.70	39862.43	-0.49%
Battery – Charging	-27,646.30	-29094.66	5.24%
Battery – Discharging	25,563.68	29334.46	14.75%

The results of the second run compared much better to the real system than those of the first run. The variation in the PV response reduced from 11% to 0.14% and the diesel generator variance came down from -4% to -0.49%. Improvement in battery response was also observed, though not to the extent of the previously mentioned components. In the second run results, the simulated battery was charged 5% more than the real battery, rather than 10% as observed in the previous run, and the excess discharge of the simulated battery was reduced from 20% to 15%.

Aside from the battery equalization frequency issue (see 4.1.3b), factors contributing to the observed variation in battery response included:

a) The efficiency curve for the inverter is a 'best-guess' curve as opposed to manufacturer's data. The model has been discontinued by Advanced Energy Systems (AES) and a basic search, including phone calls to the company representative and the internet, did not produce in any references to manufacturer's data on the efficiency curve for the particular inverter model under consideration.
b) Unlike the real system at the validation site, the simulated system gives priority to charging the battery over meeting the load in the 'cycle charge' mode. As a result, the simulated battery is charged faster by the power available from the PV panel as well as the generators (excess after meeting the load). This can be observed in Graph 4 in the appendix, where each charge cycle ends with a tail representing a significantly higher charge at the end of the cycle than at the beginning.
c) Performance degradation due to overall age of the system: Similar to the performance degradation observed in the case of photovoltaic panels, other components lose efficiency as the system ages. The loss of performance due to age, especially in the case of the battery bank, is not accounted for in the model.

Since the factors contributing to the variation in battery response were specific to the system installed at Carol Spring Mountain, they were not modified or rectified to minimize the battery response variation to less than 5%.

The time variations between the simulated system and its real system counterpart were negligible for all components (See Graph 2 – 4 in appendix). Although the power curves for the two systems are not identical, the graphs indicate all components in the simulated system generally react like the real system components in response to the same load profile.

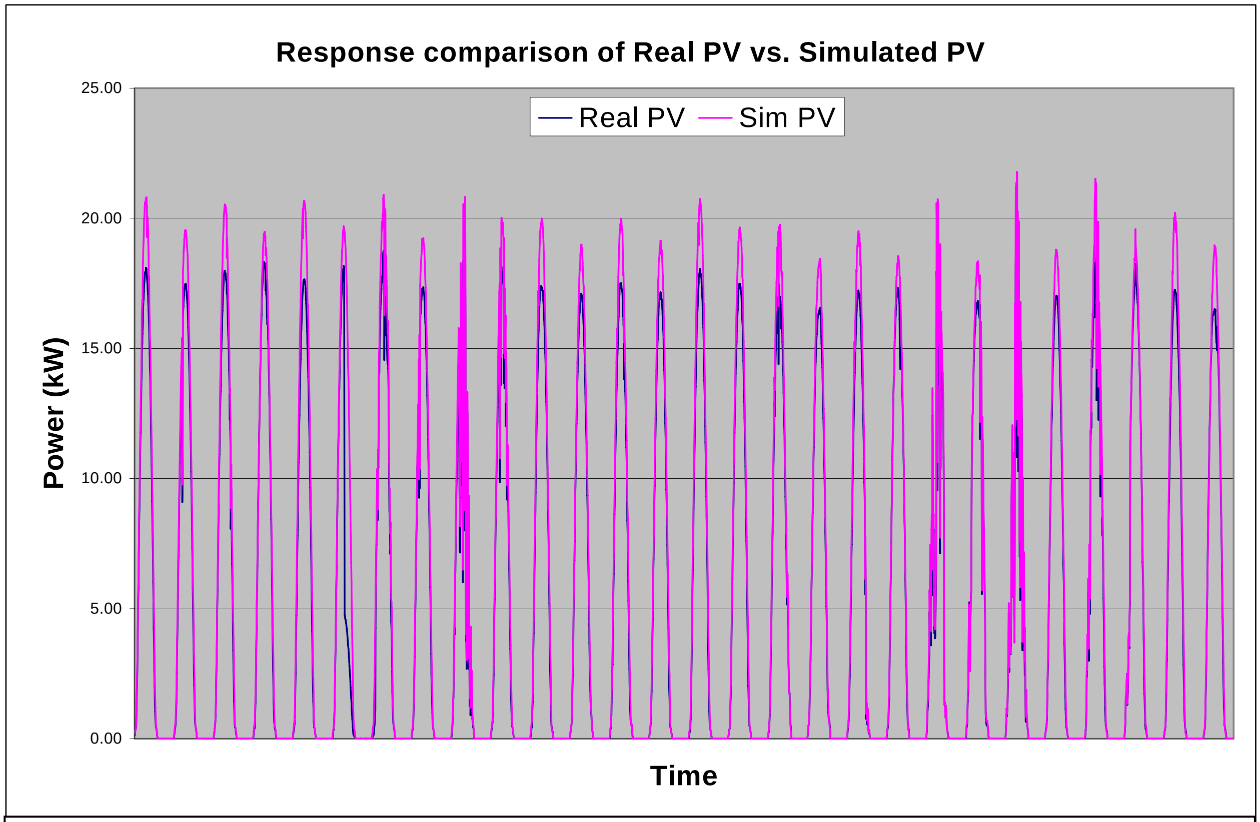
5.0 Conclusion

The response of the simulated case in the model was very similar to that of the real system. Although recorded fuel consumption data was unavailable for the course of the simulation, the predicted diesel consumption of the simulated system on a daily basis (14 gallons/day) was almost exactly equal to the average fuel consumption per day of the real system (14 gallons/day).

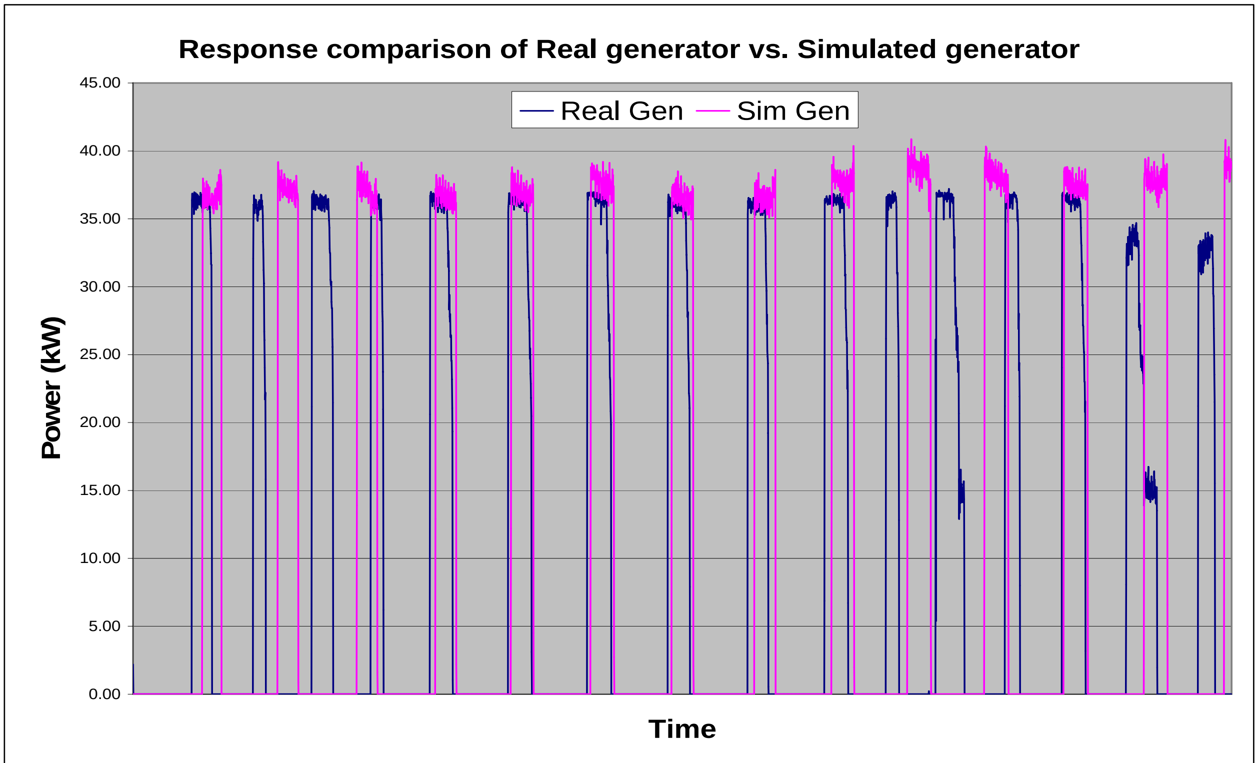
Criteria	Value
Annual Fuel Savings (gde)	5,020
Annual Fuel Savings (%)	49.10%
Annual Fuel Savings ($)	15,060
Avoided NOx (kg)	1,084.30
Avoided SOx (kg)	12.3
Avoided CO (kg)	288
Avoided PM-10 (kg)	33.9
Avoided CO_2 (kg)	55,458

The results tabulated above confirm the validity of the model in predicting the response of a system and its associated economic and environmental benefits. Hence, Hybsim v1.0 can be used by decision makers in analyzing the potential benefits of adding renewable energy and energy storage to an exclusively fossil fuel generation system.

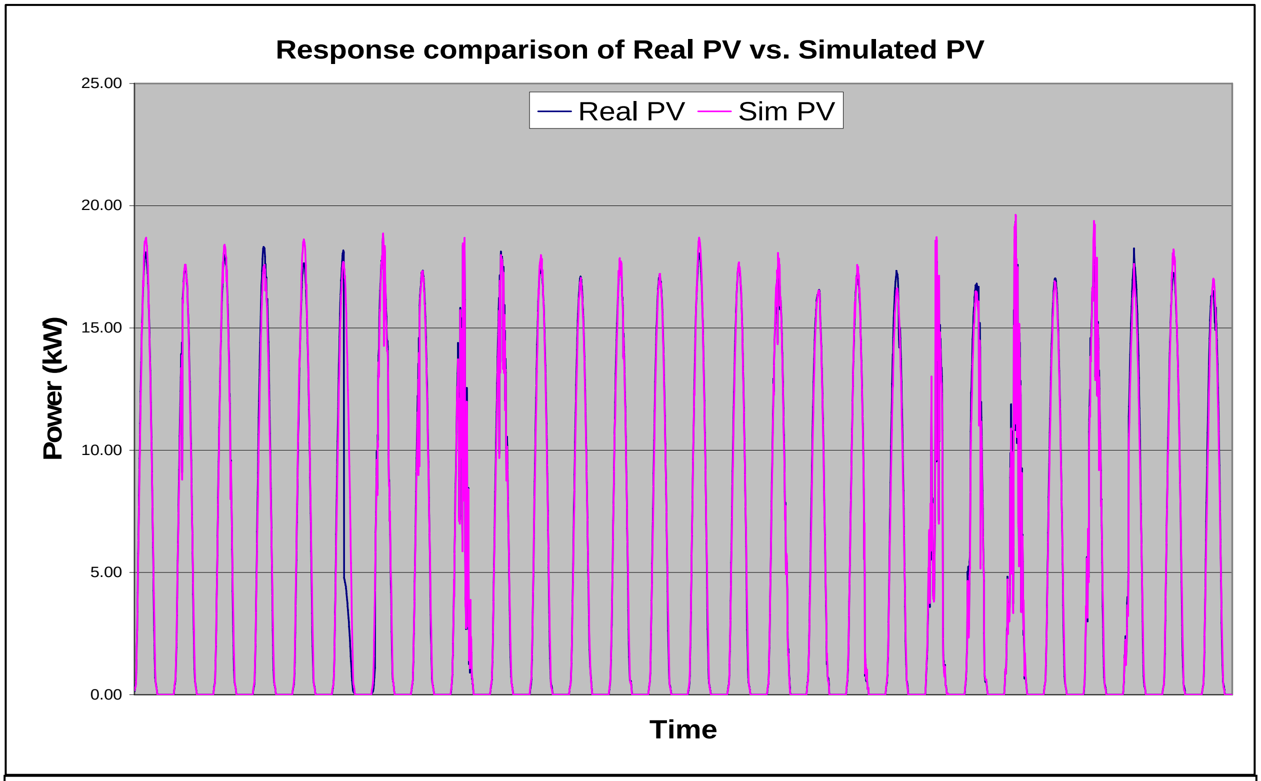
6.0 Appendix



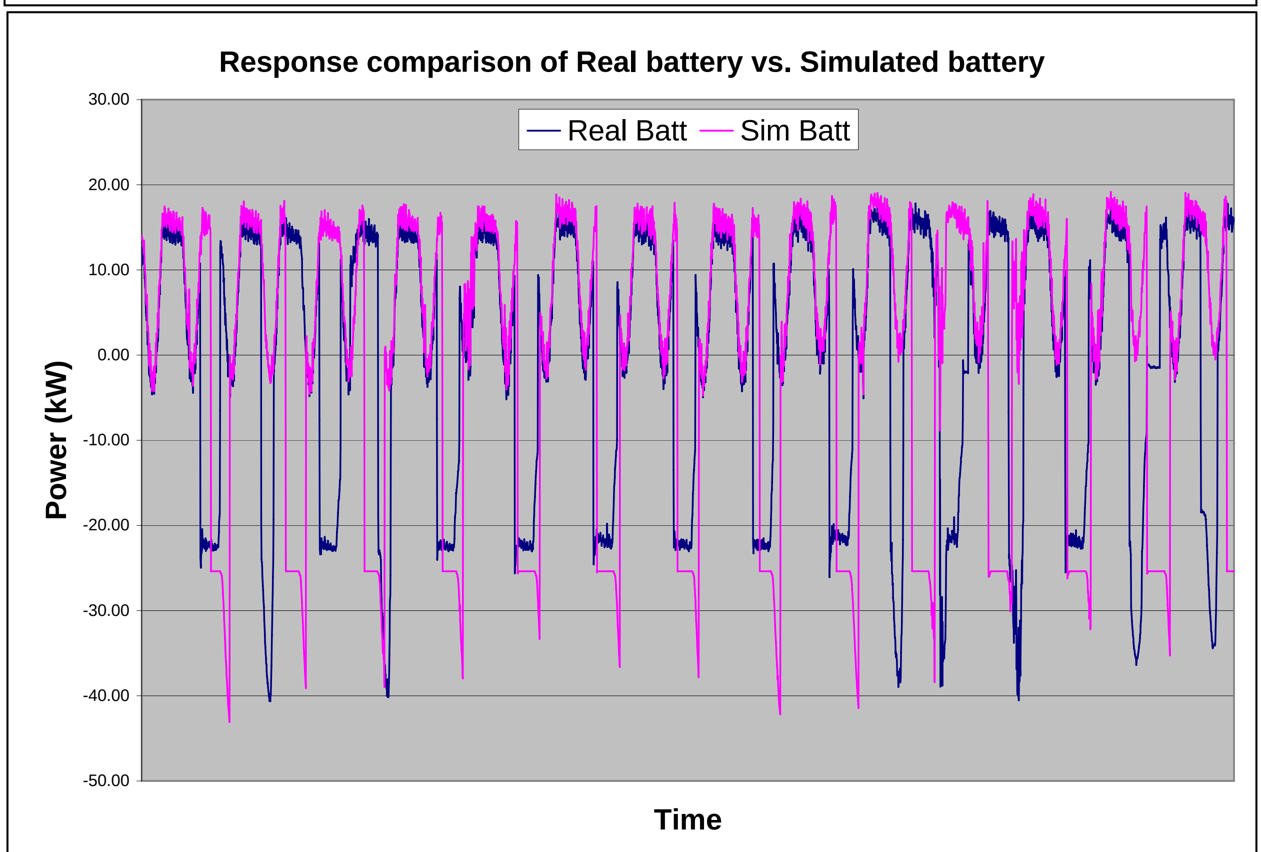
Graph 1: Graph displaying the response of PV panels in the real and simulated system – Run 1



Graph 2: Graph displaying the response of diesel generators in the real and simulated system – Run 2



Graph 3: Graph displaying the response of PV panels in the real and simulated system – Run 2



Graph 4: Graph displaying the response of the battery bank in the real and simulated system – Run 2