Maui Electrical System Model Development: Data and Assumptions

Prepared for the

U.S. Department of Energy
Office of Electricity Delivery and Energy Reliability

Under Award No. DE-FC-06NT42847
Task 8 Deliverable –
Report on System Model Development

By

GE Global Research
Niskayuna, New York

And

University of Hawaii
Hawaii Natural Energy Institute
School of Ocean and Earth Science and Technology

July 2008

Acknowledgement: This material is based upon work supported by the United States Department of Energy under Award Number DE-FC-06NT42847.

Table of Contents

1. Introduction

This document presents the conclusions concerning the databases of the GE MAPS™ and GE PSLF™ models that were developed based on the data provided by Hawaiian Electric Company (HECO) and the Maui Electric Company (MECO). The potential modifications to the existing databases and the assumptions used for selecting models and parameters, as accepted by the utilities, are described.

The data provided to GE and HNEI by MECO and HECO are covered under a non-disclosure agreement (NDA) between HECO, MECO, HNEI, and GE. After initial review by HECO and MECO, a meeting was held on June 16, 2008 to obtain approval for the use of information employed in the models. This document was then reviewed by HECO/MECO in order to ensure that any information covered under non-disclosure agreements (NDAs) is not included in the document.

Therefore, this report covers the acceptance by the utilities concerning how all information provided by them has been incorporated into the models for the development of the validation process. This process will be captured in the next report of this series of reports about the HNEI/GE work with MECO. This document presents the results for Task 8.

2. Simulation Data and Assumptions

2.1 Economic Data and Assumptions (GE MAPS™ analysis)

Input data for GE MAPS™ analysis, as presented in the preliminary results presentation on June 16th, are summarized in this section.

2.1.1 Thermal Plants

Definitions for each of the input variables as listed in the tables(s) are as follows:

<u>PLANT_NAME</u>
Name of the power plant
<u>FUEL_TYPE</u>
OIL-Distillate Oil (No.2); RENEW - zero cost fuel used for modeling Wind & Geothermal plants
<u>Full Load Heat Rate (btu/kWh)</u>
Fuel Input at Max rating/Max rating (Analogous to the Efficiency of the unit at full load)
<u>Max Capacity (MW)</u>
Maximum rating
<u>Fuel Input @ Min Power (mmBtu/hour)</u>
Fuel needed for the unit to operate at minimum power rating
<u>Power Point (MW) 1</u>
MW Operating level 1 (the min rating of the unit)
<u>Power Point (MW) 2</u>
MW Operating level 2 (between min and max ratings)
<u>Power Point (MW) 3</u>

MW Operating level 3 (between min and max ratings)
Power Point (MW) 4
MW Operating level 4 (between min and max ratings)
Power Point (MW) 5
MW Operating level 5 (the max rating of the unit)
Incremental Heat Rate (btu/kWh) 1
Incremental heat rate - rate of fuel burned (in Btu/kWh) between MW Operating level 1 and 2
Incremental Heat Rate (btu/kWh) 2
Incremental heat rate - rate of fuel burned (in Btu/kWh) between MW Operating level 2 and 3
Incremental Heat Rate (btu/kWh) 3
Incremental heat rate - rate of fuel burned (in Btu/kWh) between MW Operating level 3 and 4
Incremental Heat Rate (btu/kWh) 4
Incremental heat rate - rate of fuel burned (in Btu/kWh) between MW Operating level 4 and 5
Planned Outage Rate (pu)
Scheduled maintenance
Forced Outage Rate (pu)
Random outages
Percent of Capacity Available to contribute to Spinning reserve (PU_SPN_RES)
Percent of capacity that contributes to spinning reserve
Variable O&M ($/MWh)
Cost for Variable Operation and Maintenance
Variable Cost ($/FiredHour)
Cost for Variable Operation and Maintenance per Fired hour
NOX Rate (lbs/mmBtu)
NOX emissions rate from the unit in pounds per unit of fuel burned
SOX Rate (lbs/mmBtu)
SO2 emissions rate from the unit in pounds per unit of fuel burned
CO2 Rate (lbs/mmBtu)
CO2 emissions rate from the unit in pounds per unit of fuel burned

2.1.2. Independent Power Producers

The following decisions about how to implement the IPP hourly production in the models were made by the HECO/MECO project team during weekly conference calls. Hourly wind power production for the Kaheawa Wind Power Plant (KWP) was obtained from 2007 historical data (post-curtailment) and implemented in the model. The data were obtained from the "2007 actual wind generation" tab in "Pmonth Data_mar08GP_031708mm.xls." Hourly power production from the HC&S power plant was obtained from 2007 historical data. The historical data were not used in the model, rather a schedule of power production based on the HC&S contract and the past performance of HC&S were implemented in the model. The details are described later in this report. There was no power production from the Makila hydro plant in 2007, therefore no power production from the hydro plant was included in the GE MAPS™ or PSLF models.

2.1.3. Load Demand

The actual 2007 hourly demand was used in the GE MAPS™ simulations. The data were obtained from the "2007 load shape" tab in "Pmonth Data_mar08GP_031708mm.xls."

The unit input table and the data provided by HECO/MECO are outlined in Deliverables under Tasks 6 and 7. The entries in the table below were obtained from the historical data and input from the HECO/MECO working group during the weekly meetings. Entries in the table can be revised based on further inputs from HECO/MECO prior to the finalization of the baseline model, which is present here. The 2007 data were used in the model in order to validate an entire year of recent power production. The fuel cost data is outlined in Table 1.

Table 1. MECO Thermal Plant Fuel Cost Projection from "Power Supply Reports ('07)_031708mm.xls"

	FUEL ($/mmBtu)	
	RESIDUAL	DISTILLATE
1/1/2007	8.14	14.69
2/1/2007	8.35	16.25
3/1/2007	8.01	15.09
4/1/2007	8.43	15.62
5/1/2007	8.78	15.96
6/1/2007	8.97	17.18
7/1/2007	9.91	16.93
8/1/2007	9.91	17.52
9/1/2007	10.19	18.12
10/1/2007	10.05	17.51
11/1/2007	10.38	17.58
12/1/2007	11.32	18.92

In order to develop a detailed model, general assumptions were made. These decisions were made during the weekly meetings between HECO/MECO and GE. A summary of these assumptions is provided in Table 2.

Table 2. MECO Generation assumptions

HC&S 9MW output Hour 1 to Hour 7
13MW Hour 8 to Hour 21
9MW output Hour 22 to Hour 24
$182/MWh (in 2007)

Units that provide Spin
generally, units M10, M11, M12, M13, M14, M15, M16, M17, M18, M19

Assume regulating reserve equals 6 MW plus 50% of the wind output

K1 runs 6:00 hours to 22:30 hours
K2 runs 7:00 hours to 22:00 hours
K3 & K4 run all hours

M17,M19 2 starts per day

M17/18/19 operates at DTCC from 6am to ~10:30pm
M17/18 10:30pm-6:30am
M4, M5, M6, M7, M8, M9 available 6:30am to 10:00pm

2.2 Dynamics (GE PSLF™ Transient Stability and Long-Term Simulations)

2.2.1 Load Flow

2.2.1.1 Database Conversion

The Transmission Planning Division of HECO provided load flow databases in PSS/E format for the scenarios presented in Table 3 below.

Table 3: Load flow cases

File	Load	Year
m08pmv1.raw	peak	2008
m08minv1.raw	min	2008

The PSS/E datasets were converted to GE PSLF™. The GE PSLF™ results match the PSS/E results. The results were presented to HECO and MECO at weekly meetings and at a review meeting on June 16.

2.2.1.2. Modification to Database

The only modification to the database was a modification of the generator reactive power limits according to discussion with MECO operations:

- Maximum reactive power limits to meet power factor of 0.85 at full load.
- Minimum reactive power limit of zero.

2.2.2. Basic Stability Model Data

2.2.2.1. Database Conversion

The Transmission Planning Division of HECO provided available dynamic databases in PSS/E format. The database was partially validated against field tests. The database included:

- Generator models for main generating units;
- Governor models for main generating units ;
- Automatic Voltage Regulator (AVR) models for main generating units;
- Dynamic Load Model;
- Under Frequency Load Shedding (UFLS); and
- Wind farm models.

The database did not include:

- AGC model (Related information was provided by MECO operation)

The PSS/E models were converted to GE PSLF™. Simulations to verify individual models against engineering practices were performed. Improvements made to the database are described in the following sections.

2.2.2.2. Governor/Turbine Models

The governor models and their parameters provided were the same for units of the same type as described in Table 4. Models had different minimum and maximum power limits; the rest of the parameters are mostly common among units of the same type.

Table 4: Governor Models in provided database / applied to database

Type of Unit	Model provided (PSS/E)	Model GE PSLF™)
Diesel Engine	Tgov1	Tgov1
Steam Turbine	IEEEg1	IEEEg1
Combustion Turbine	User model	Ggov1

The results indicate the units using the bus numbers and unit identifier according to Table 5.

Table 5: Units and bus numbers

MAALAEA	BUS NUMBER	ID
X1	110	1
X2	110	2
M1	105	1
M2	105	2
M3	105	3
M4	106	4
M5	106	5
M6	106	8
M7	107	6
M8	107	7
M9	107	9
M10	108	0
M11	108	1
M12	109	2
M13	109	3
M14	301	1
M15	303	3
M16	302	2
M17	304	4
M18	306	6
M19	305	5
KAHULUI		
K1	101	1
K2	102	2
K3	103	3
K4	104	4
IPPs		
HC&S	804	4

A number of modifications were performed to the PSS/E dynamic database based on these tests and experience with similar units.

- The models that represent LM2500 combustion turbines were replaced by models and parameters obtained from field test validation of LM2500 in other systems. GGOV1 models replaced the provided user models for the CT's.
- According to usual practice in the industry, the governor model of the steam turbine in combined cycle plants were not modeled in provided data. For LT simulations, the fact that the steam generation will follow exhaust gas variations of the CTs in the minutes range was captured in a simplified way with a 100-sec time constant in an IEEEG1 governor model. This assumption can only be applied in case the main steam valve is operated fully opened. This will be verified with the historical data.
- Steam turbine models and parameters in the original database correspond to single-stage steam turbines and include limitations in the power output and ramp rate. These models were not modified. Based on discussions and initial analysis of KPP units, it would seem that they are normally not performing frequency control in the way the models represent. This will be analyzed in Task 9.

- Diesel engines have fast-acting governor models. These models were not modified. Inertias also have impact in the observed response. The values of inertia were not modified.

2.2.2.3 Wind Farms

The Kaheawa wind farm is rated at 30 MW. GE 1.5 MW technology was assumed. The wind farm is featured with a wind farm management system and performs voltage control at the 69 kV bus. .

2.2.2.4 Dynamic Load Characteristic

The dynamic load characteristic representation is based on PSS/E data. This model includes load dependency on voltage and frequency.

2.2.2.5 Under Frequency Load Shedding

The UFLS models in GE PSLF^{TM} were converted from PSS/E data. UFLS was represented by a definite time under a frequency load-shedding relay (lsdt1) acting at each load.

2.2.2.6 AVRs

AVR responses for all units were tested for a step change in voltage reference under non-synchronized conditions.

Four different cases are presented.

- Case 1 is based on provided model parameters.
    a) The four steam turbines K1 – K4 have realistic responses.
    b) The two large diesels M-11 and M12 have an oscillatory voltage response and are unstable. This behavior seems unrealistic.
    c) The voltage responses of the combined cycle plant AVRs are relatively slow (settling time > 4sec). This is a feasible response, but slower than usual performance standards.
- Case 2 includes a modification of the parameter KE from 0.1 to 1 in the excitation system model of M11 and M12. The oscillatory response of the original model is due to the high time constant associated to the exciter generator (TE/KE in the model exac1 of 8 seconds). By modifying KE to 1, a realistic time constant of 0.8 seconds is obtained. The response with new parameter set is still oscillatory, but significantly better damped.
- Case 3 shows the response of the CTs for a modification of the parameter KF (model exdc2 from 0.09 to 0.045). The settling time is reduced.
- Case 4 shows the response of the diesel units M-11 and M-12 for a modification of the parameters TB/TC (model exac1 from 10/1: to 30/3). The response is further damped as compared to case 2.

2.2.3 Long-Term Dynamics Model

2.2.3.1 AGC

AGC modeling for stability and long-term simulations is not standardized by the industry. The AGC was modeled based on the information gathered during a GE visit to MECO, several related discussions with MECO operations personnel, and on engineering judgment. The proposed model is not intended to reproduce every detail of the actual

AGC, but to capture behavior relevant for the objective of this study. The block diagram of the AGC model is divided into two sections: regulation function and pulsating logic.

Regulation function:

The bias is set to 2.0 MW/0.1Hz. The bias is independent from load level fixed. T_f is disabled (set to zero) for MECO.

Pulsating logic

All regulating units under AGC share the power request from the regulation function. The priority levels of the units (Table 6) and the value of the parameter "factor" are used to define the reaction of each unit to the regulation function output. Priority levels for normal/assist/emergency modes are dependent on the ACE value.

The economic dispatch representation consists of a linearization around the point of operation. The limits of the economic dispatch (vamin and vamax) and of the regulation function (vumin and vumax) are set according to provided information for each unit. The unit frequency bias (UFB) is also represented. The pulse lengths are set in accordance to provided ramp rates for each unit.

Table 6. Units under AGC control

Bus	Unit	ID	ID	Priority	Comments
106	MGS-458	4	M4	2	
106	MGS-458	5	M5	3	
106	MGS-458	8	M6		Request input from MECO
107	MGS-679	6	M7	3	
107	MGS-679	7	M8	3	
107	MGS-679	9	M9		Request input from MECO
108	MGS-1011	0	M10	2	
108	MGS-1011	1	M11	2	
109	MGS-1213	2	M12	2	
109	MGS-1213	3	M13	2	
301	CT-1 M14	1	M14	1	
302	CT-2 M16	2	M16	1	
304	CT-3 M17	4	M17	1	
305	CT-4 M19	5	M19	1	
303	ST-1 M15	3	M15		In AGC to calculate CT-exhaust heat to steam turbines
306	ST-2 M18	6	M18		
101	KGS-1	1	K1	Basepoint	
102	KGS-2	2	K2	Basepoint	
103	KGS-3	3	K3	Basepoint	
104	KGS-4	4	K4	Basepoint	

2.2.3.2 Load Profile

For contingency analysis and transient stability, the load provided in the load flow databases will be used. The loads are represented at the buses presented below. The values in Table 7 correspond to peak load 2008.

Table 7: Loads for 2008 peak case

Bus-Nr	Name	kV	P (MW)	Q (Var)	Bus-Nr	Name	kV	P (MW)	Q (Var)
13	KULA 12	12.47	6.16	1.8	301	CT-1 M14	13.8	0.3	0.17
44	DET 03	0.48	0.69	0.2	302	CT-2 M16	13.8	0.3	0.17
45	HALEKALA	4.16	0.27	0.08	303	ST-1 M15	13.8	0.4	0.23
108	MGS-1011	6.9	0.3	0.17	304	CT-3 M17	13.8	0.3	0.17
109	MGS-1213	6.9	0.3	0.17	305	CT-4 M19	13.8	0.3	0.17
112	MAKA 12	12.47	6.29	1.83	306	ST-2 M18	13.8	0.4	0.23
123	PUUKB 12	12.47	4.88	0.76	325	WAILEA C	12.47	9.61	3.16
125	WAILEA A	12.47	6.41	2.11	335	KIHEI C	12.47	7.26	2.39
127	CONCRETE	0.48	0.32	0.16	336	WAIINU C	12.47	3.15	1.15
129	NAPILA12	12.47	2.71	0.42	343	PMCO1-2	12.47	0	0
134	LAHAINA1	12.47	8.69	2.54	403	WLUKU A	4.16	0.76	0.25
135	KIHEI A	12.47	7.69	2.53	404	WLUKU B	4.16	1.33	0.44
136	WAIINU B	12.47	3.15	1.15	405	WLUKU C	12.47	5.33	1.75
139	MAALA A	12.47	7.82	2.57	407	WAI WELL	4.16	1.28	0.42
141	HANA 1	2.4	0.51	0.15	415	WLUKU D	12.47	6.47	2.13
142	KEANAE	2.4	0.19	0.06	418	WLUKU HT	4.16	2.14	0.7
148	MAUIBLOC	0.48	0.06	0.02	422	WSCO PMP	2.4	0.54	0.18
150	MAHINA12	12.47	6.51	1.02	430	MOKU PMP	2.4	0.64	0.21
155	KULA AG	12.47	0.41	0.2	431	KAMOLE 4	4.16	0.91	0.27
161	HOSMER	2.4	0.11	0.03	436	WAIINU A	4.16	0.41	0.2
164	PUUNENE	7.2	0.11	0.05	440	ONEHEE 4	4.16	1.5	0.72
173	KUAU A	4.16	0.77	0.19	443	WAIEHU12	12.47	5.34	1.76
174	HUELO 1	2.4	0.12	0.04	493	PAIAMKA1	4.16	1.07	0.26
175	NEWHDWD	12.47	1.71	0.83	501	AUX K1	0.48	0.3	0.45
176	CAMP MAU	2.4	0.57	0.17	502	AUX K2	0.48	0.3	0.45
177	WAIKAP12	12.47	0.11	0.04	503	AUX K3	0.48	0.7	1.05
182	AMERON	0.48	0.11	0.05	504	AUX K4	0.48	0.7	1.05
188	AMERBLDG	0.48	0.11	0.05	534	LAHAINA5	12.47	7.45	2.17
192	SPRECK	4.6	1.01	0.25	723	PUUKA 12	12.47	8.55	2.49
203	KANAH A	12.47	7.55	3.66	729	NAPILB12	12.47	4.27	1.25
204	KANAH B	12.47	5.98	2.89	750	MAHINB12	12.47	3.2	0.93
205	KANAH C	12.47	6.76	3.28	803	KAHUL 3	12.47	5.34	1.76
206	PAIA B	4.16	0.86	0.21	817	PUKLN A	12.47	4.27	1.25
209	KAILUA A	2.4	0.1	0.03	834	LAHAIN 4	12.47	6.83	1.99
216	HAIKU 2	12.47	4.46	1.3	844	KAHUL 4	4.16	1.07	0.35
225	WAILEA B	12.47	8.55	2.81	845	KAHUL 5	4.16	1.07	0.35
235	KIHEI B	12.47	8.55	2.81	846	KAHUL 6	4.16	1.07	0.35
241	HANA 2	2.4	1.26	0.37	917	PUKLN B	12.47	5.34	1.56

For variability analysis with LT simulations, the total system load will be obtained from historical data provided by MECO. Individual loads in the load flow database will be scaled to match the total system load of historical data.

2.2.3.3 Wind Profile

Individual wind profiles of wind farms are used to introduce variability in the system model. GE will use the following sources of wind profiles:

- Historical data with different resolutions provided by MECO (active power output).

2.2.3.4 Initial Commitment and Dispatch

Commitment and dispatch is based on the provided load flow database, historical data and production cost analysis.

2.2.3.5 Generic Energy Storage

An energy storage model suited for LT and stability simulations was created for consideration in future scenarios. The model is generic and can be used to represent different energy storage technologies, depending on the selected set of parameters. In this study the main objective is to estimate the impact of energy and power ratings on system frequency behavior. The model includes a frequency control loop and a voltage control loop. Rate limits and efficiency are represented.

2.2.4 Performance Criteria

Comparisons of simulation performance to data have been limited to reporting of frequency, voltage and stability. No specific performance criteria have been applied.

2.2.5 Limiting Stability Events

The analysis of this effort is mainly focused on variability, and its impact on system regulation and operation. It is important to note that this work is not intended to substitute the transmission planning activities of HECO for the MECO system. A few (up to 5) critical limiting stability events will be also considered to verify the performance criteria for different scenarios.

A subset of the following contingencies will be considered.

1. Loss of MPP-Waiinu line (39-636);
2. Loss of MPP-Kihei line (39-35);
3. Loss of MPP-Puunene line (39-402);
4. Loss of Waiinu tie transformer (636-236) and loss of Puunene tie transformer (4-4002);
5. Loss of MPP-Lahaina line (39-34) and loss of KWP-Lahaina line (97-34);
6. Loss of MPP-Kealahou line (39-655) and loss of MPP-Kihei line (39-35);
7. Loss of KPP-Kanaha 1,2,3 (200-202,1,2,3);
8. Loss of Waiinu-Wailuku 23 (236-3); and
9. During minimum load, loss of KPP (K3 and K4).

3. Potential Model Refinements

3.1. Dynamics (for GE PSLF™ transient stability and longer-term simulations)

3.1.1. Load Flow

The load flow model will not be modified.

3.1.2. Dynamic Model Data

3.1.2.1 Governor/Turbine Model

GE will compare simulated responses based on the provided PSS/E database with historical data (1-min power outputs). This assessment is particularly focused in identifying if all units are actually operating continuously performing droop frequency control as assumed in the data base. With limited accuracy, deadbands can also be identified.

3.1.2.2 AVRs

No additional changes are planned to AVR models. GE requests MECO/HECO review of the AVR models, including modifications suggested by GE.

3.1.2.3 AGC

As noted above, the AGC was modeled based on the information gathered during a GE visit to MECO, several meetings, and on engineering judgment. Further refinements of the AGC will be attempted based on historical data.

4 Conclusions

The engineers and operators at HECO and MECO have reviewed detailed information that contains further data and assumptions used to populate the GE MAPS™ and GE PSLF™ models. As was mentioned earlier, these data are covered under an NDA between the utilities and HNEI and GE. The next task of the program will focus on the calibration and validation of both models. The results of the next task will be summarized in the next deliverable.