CHAPTER SIX

HYBRID SYSTEMS MODELING

\The wind and waves are always on the side of the ablest navigators."

|Edward Gibbon, Decline and Fall of the Roman Empire

Hybrid power systems are designed to generate electrical power for isolated loads. They are composed of a diversity of components, and range in size from a few kW up to 1000 kW.

6.1 Description of Hybrid Systems

Figure 6.1 is a graphical representation of a hybrid system model. The hybrid system model developed as a part of this thesis, UW-Hybrid, is implemented in TRNSYS. The TRNSYS simulations environment makes use of several terms for describing components, etc. These are:

Type: The component model, such as a wind turbine. Each Type has a unique Type number in a simulation.

Unit: The nth copy of a type used in a simulation. Each Unit has a unique Unit number to distinguish it from the other Units of the same Type.

Deck: The input file used by TRNSYS to identify the Types used, the number of Units of each Type, and the interconnections between them. The deck can be either a simple deck describing the interconnections or it can be a TRNSED deck, which additionally describes a user-interface for the operation of the program.

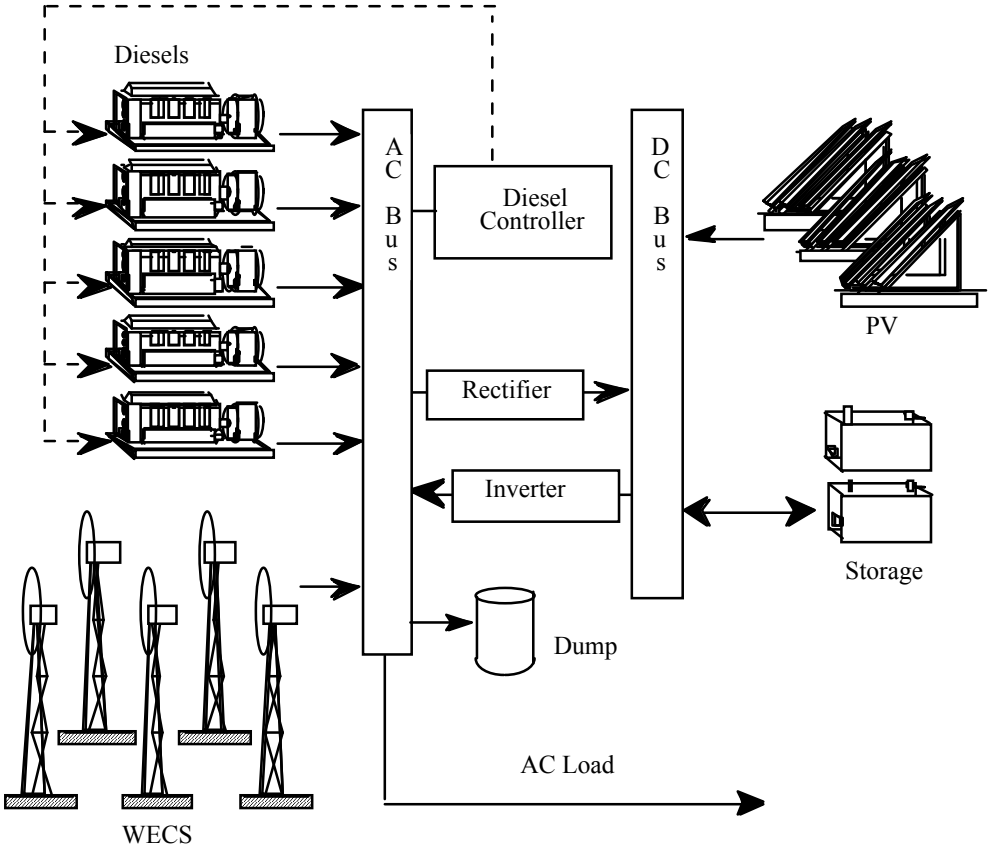

Figure 6.1 Example hybrid power system modeled by UW-Hybrid.

Hybrid system models are composed of Types which represent physical devices, control systems, and input and output devices. The components representing physical devices used in the UW-Hybrid program are:

Type 62: Photovoltaic Module: Multiple numbers of a single module model

Type 70: Storage Battery: Variable size

Type 71: Power Converter: Variable size

Type 90: Diesel Engine: Zero to five Units

Type 85: Wind Turbine: : Zero to five Units, or

Type 88: Wind Turbine Cluster: Two to 99 Units

In UW-Hybrid the renewable generators are not controlled; the energy produced by the wind turbines and PV modules is either transferred to the load, stored, or dumped. The diesel generators are controlled by the Type 92: Diesel Dispatcher, which also serves as the AC bus, where the output of the wind turbines and PV modules is collected in order to determine the reduction in apparent demand from which the turbine dispatch strategy is applied.

Dump energy is calculated using an energy balance equation in the deck. Data input and management functions (not shown in the graphic) are handled by:

Type 9: Data Reader: A universal text file reader used to read weather data, loads data and turbine data files.

Type 16: Solar Radiation Processor: A Type used to estimate the solar insolation the PV module, from horizontal solar insulation data.

Data produced during TRNSYS simulations are handled by data readers, which operate similarly to data loggers. Data readers are given the unit and output number of a variable of interest from other Types, for example wind turbine energy production. The readers then write the value of the listed output to disk per timestep. Prior to receipt by the data reader, several types are used to sum and sort the data. The Types used in UW-Hybrid for these data manipulations are:

Type 55: Periodic Integrator

Type 27: Histogram

Type 25: Printer

During a simulation, the on-line plotter displays the progress of the calculations as a running plot on screen. The data output of the simulation is stored in two files. The first file stores the monthly total output from each component. The second file stores the output from selected outputs in the form of histograms. The histograms are definable in terms of range and number of intervals.

6.2 Data and Data Files Used in Simulations

The UW-Hybrid simulator uses a variety of data, including weather data, loads data and device specifications. Device specifications are contained in *.dat files.

6.2.1 *Weather Data*

Weather data for UW-Hybrid are obtained from a variety of sources. The simulation deck is currently configured to make use of TMY data files representing each of the utility service areas in the state of Wisconsin. The TMY files used are:

Eau Clair, Wisconsin:	ECLAIR.WI
Green Bay, Wisconsin	GRNBAY.WI
Lacrosse, Wisconsin	LACRSS.WI
Madison, Wisconsin	MADISN.WI
Milwaukee, Wisconsin	MILWAK.WI

In addition to the Wisconsin TMY sites, other sites across the United States are included. These are:

Albuquerque, New Mexico	ALBUQE.NM
Miami, Florida	MIAMIF.FL
Washington, D.C.	DCWASHNG.DC

Weather data used by UW-Hybrid are not restricted to TMY data. The Type 9: Data Reader can be reconfigured to read in weather data in time series form from a variety of sources. The Type 54: Weather Data Generator can be used to generate weather data for 329 locations, including wind speed, from monthly average values.

6.2.2 *Loads Data*

UW-Hybrid is currently configured to utilize loads profiles from five utility service areas located in the state of Wisconsin. These data have been normalized to 300 kW peak in order to allow for convenient scaling.

Madison Gas & Electric	`MGE3.LOD`
Northern States Power	`NSP3.LOD`
Wisconsin Electric Power Corporation	`WEPCO3.LOD`
Wisconsin Power and Light	`WPL3.LOD`
Wisconsin Public Service	`WPS3.LOD`

In addition to the specific loads data from Wisconsin utilities, several regional loads data files are included. These are

Combined Wisconsin Power & Light and Madison Gas & Electric	`MGE3.LOD`
Combined Wisconsin Regional Loads Data	`NSP3.LOD`

UW-Hybrid employs diagnostic loads data in order to examine the impacts of constant or ramped loads on device performance. A ramped loads file is included, `RAMP.LOD`. The constant loads files are:

Constant 15 kW	`ANN15.LOD`
Constant 30 kW	`ANN30.LOD`
Constant 60 kW	`ANN60.LOD`
Constant 120 kW	`ANN120.LOD`
Constant 240 kW	`ANN240.LOD`

Constant 310 kW	ANN310.LOD

6.2.3 *Turbine Data*

UW-Hybrid includes a library of 14 wind turbines. The details of the wind turbine data files are provided in Appendix F. The wind turbines included with UW-Hybrid are:

AOC 15-50	AWT-26
Carter 300	BWC Excel
Jacobs Long	Jacobs Short
Jacobs 23-10	Jacobs 29-29
KVS-33	MHI 275
MHI 300	Tacke 600
Whisper 300	Vestas V-90

6.2.4 *PV Module Data*

The Type 62 component utilizes PV module data provided with the module. Details of the input files are provided in Appendix G. The six PV modules included with UW-Hybrid are:

EP-50	AEG
F-SEC	Kyocera LA361J45Y
Mobil RA30-12	Sharp NT-11H

6.2.5 *Diesel Engine Data*

Sixteen diesel generators are included with UW-Hybrid. The generator data are included in Appendix F. The generator data included in Appendix F list the diesel specifications including the generator and separately from the generator. The diesels listed are:

Petter AA1 2.3 kWe	Petter AB1 3.3 kWe
Petter AC1 4.3 kWe	Petter AC2 8.1 kWe
Generic 15 kWe	Hatz 2_L30 16.4 kWe
Hatz 3_L30 24.6 kWe	Hatz 4_L30 32.8 kWe
Generic 100 kWe	Cummins D34 161 kWe
Cummins D35 207 kWe	Volvo TDF120 238 kWe
Cummins D09 253 KWe	Cummins KT 1150 339 kWe
MB 6-190 577 kWe	

Note that the kWe designation is the *electrical* output rating of the generator.

6.3 Modeling Solar PV Systems in Hybrid Systems

The modeling of PV module performance involves considerable calculation, including the radiation processing equations and PV module relations. The modeling of PV output in UW-Hybrid is accomplished using the TRNSYS Radiation Processor and Type 62: Photovoltaic Module components. The size of the PV array is determined by

user input of the number of modules. Selection of parallel and series combinations of modules is not required. The user selects the array tilt, and module type to complete the PV preparation process.

Eckstein (1990) and Furler (1993) provide detailed analyses of the performance of the PV module Type 62. Within UW-Hybrid, Type 62 operates with peak power tracking.

6.4 Hybrid Systems Simulator Using TRNSED

UW-Hybrid simulations are designed to be carried out using the TRNSED interface. TRNSED allows the user to perform the simulations without the need to work with the underlying TRNSYS code. The TRNSED interface is graphical and relatively easy to use. The source code (deck) underlying the interface is included in Appendix C. The details of the TRNSED interface, as seen by the user, are presented in this section.

The TRNSED interface to UW-Hybrid is a single, long scrolling \page". The amount of the page seen at one time is determined by the size and resolution of the computer monitor. Figure 6.2 shows an example first page of the TRNSED interface.

The header of the simulation provides spaces for a user to enter in the Date, Name of System, and user name. Simulation parameters are then set. The user selects the month, day, timestep, and length of the simulation from scrolling menus. The user then selects weather and loads profiles for the simulation.

Figure 6.3 shows an example second page of the TRNSED interface. The storage type, charge control mode and total storage capacity are selected. A power conditioning

model is chosen from a menu, and wire losses can be assigned. The first device to be defined is the PV array. The model, number, tilt and azimuthal orientation of the array are selected. \None" can be selected for the number of PV modules.

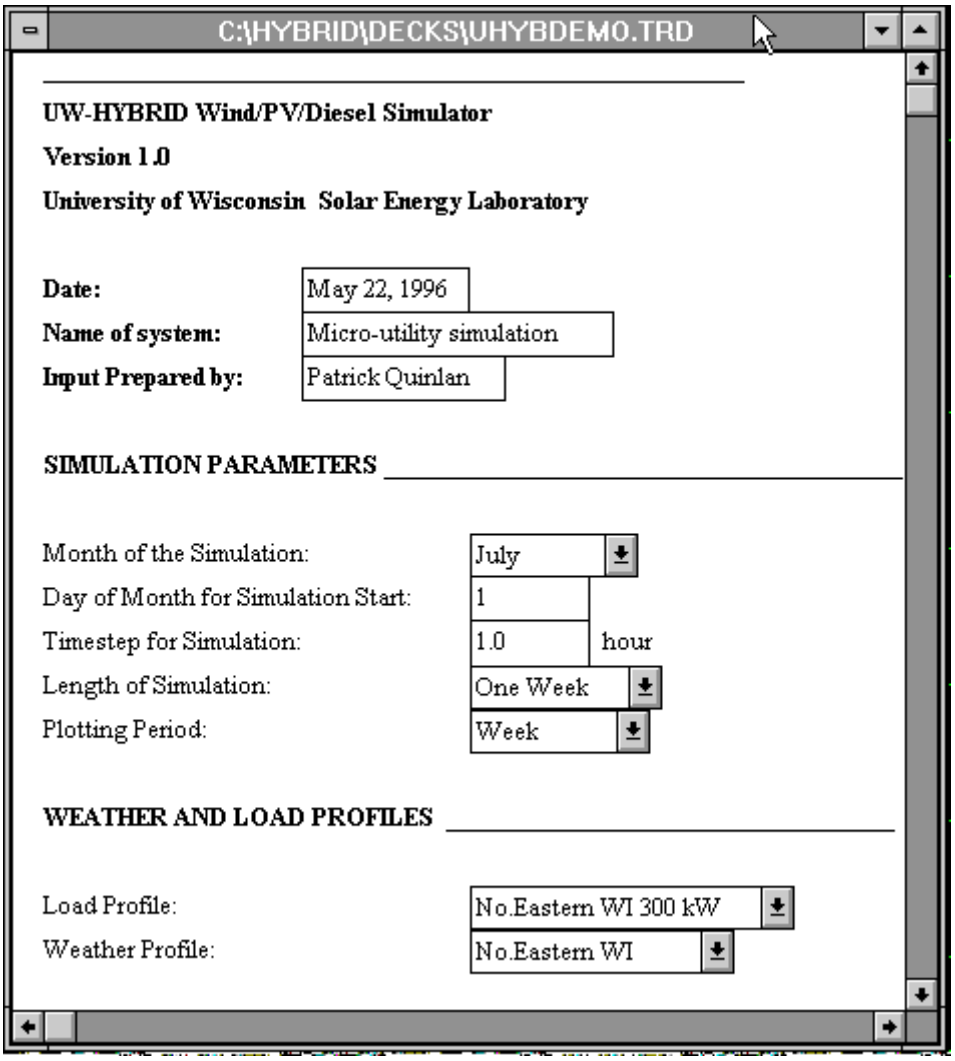

Figure 6.2 Example first page of the TRNSED interface.

Figure 6.4 shows an example third page of the TRNSED interface. Next to be described are the diesel generators. A cost of fuel is assigned. Five identical menus are provided for selection of the diesel generators. Each generator can be selected from a scrolling list. A single diesel generator can be assigned from any generator menu. \None" can be selected for the number of diesels in each case. Selecting \none" for all of the diesels allows UW-Hybrid to be configured as a wind or PV only system.

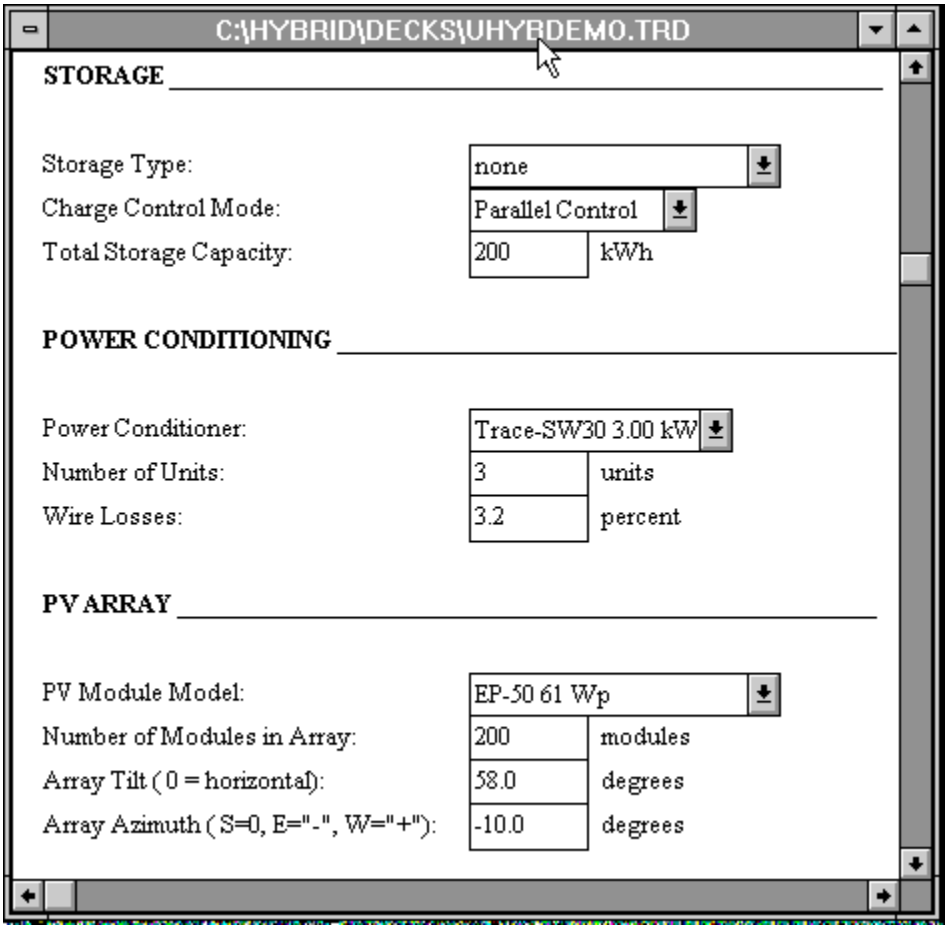

Figure 6.3 Example second page of the TRNSED interface.

Wind energy systems are the next category of device to be selected. Site elevation, data height above ground, and overall power losses are entered. The power

losses reflect miscellaneous operational losses assigned to the wind systems. For each of the five wind systems, its hub height, local shear exponent, and the number of similar turbines, is entered. Selection of no wind turbines is permitted. Figure 6.5 shows the next page of the TRNSED interface. The final set of selections are the output specifications. The user can select the number of on-line plots per run, and set up histograms for the following parameters:

Wind turbine output from all wind turbines selected

Total output of all diesel generators selected

PV output

Dump energy

Deficit energy

Fuel consumption

Demand energy per timestep (power).

The user elects to run a simulation by selecting the \Calculate" Menu item. At this point, the on-line plotter begins to present a running plot of the simulation as TRNSYS progresses across the time steps, as shown in Figure 6.6.

After a simulation has been completed, the results can be examined by utilizing the plotting functions available under the TRNSED interface. Most data variables are available for plotting, including device outputs and the variables portrayed on the on-line plotter. UW-Hybrid, using TRNSYS, creates a list file of the pertinent data to be archived over the course of the simulation. The data are saved in a text file, and can be viewed by selecting the list file as a menu item, or the file can be opened by another software application, such as a spreadsheet application, for later analysis.

TRNSYS analysts may wish to edit the TRNSED deck to modify the interface, or examine the construction of the interface. This is accomplished using the TRNSHELL editor available to licensed TRNSYS users.

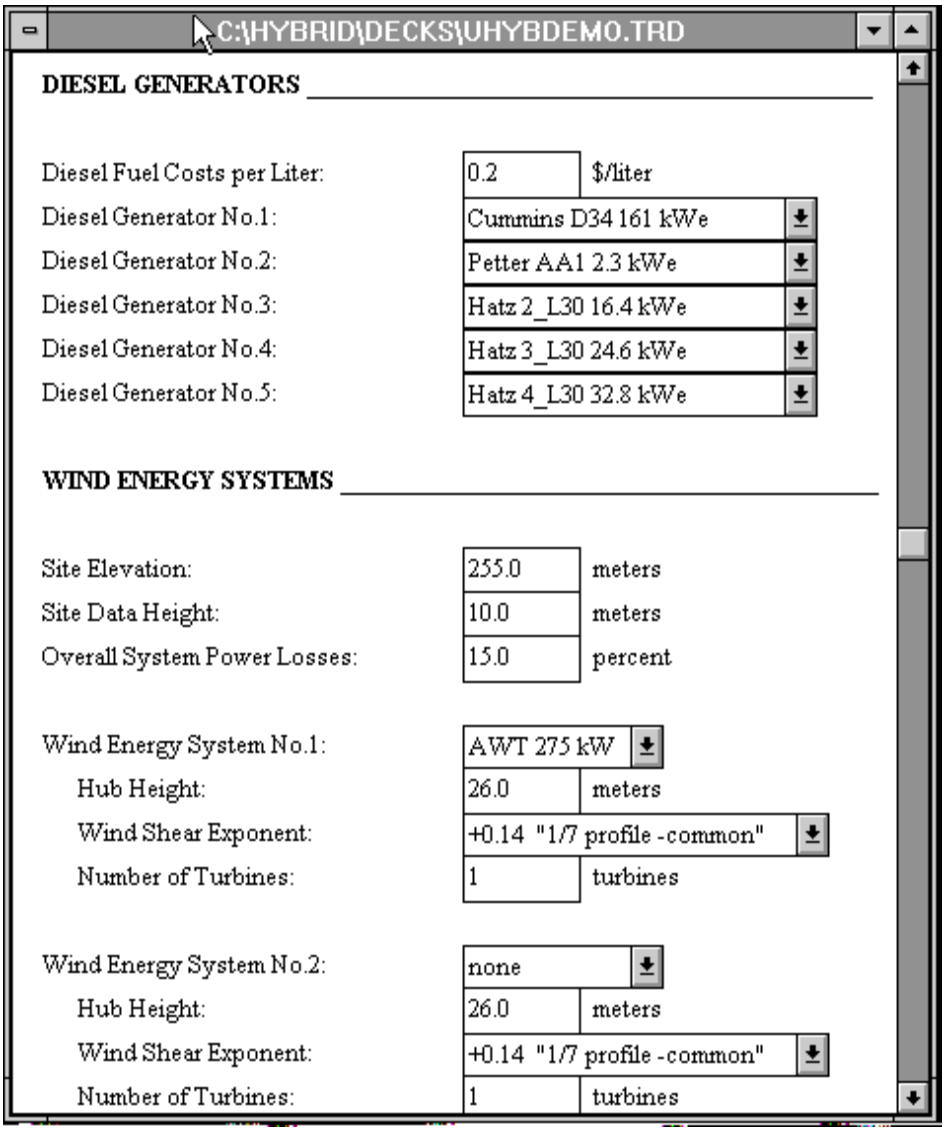

Figure 6.4 Example third page of the TRNSED interface.

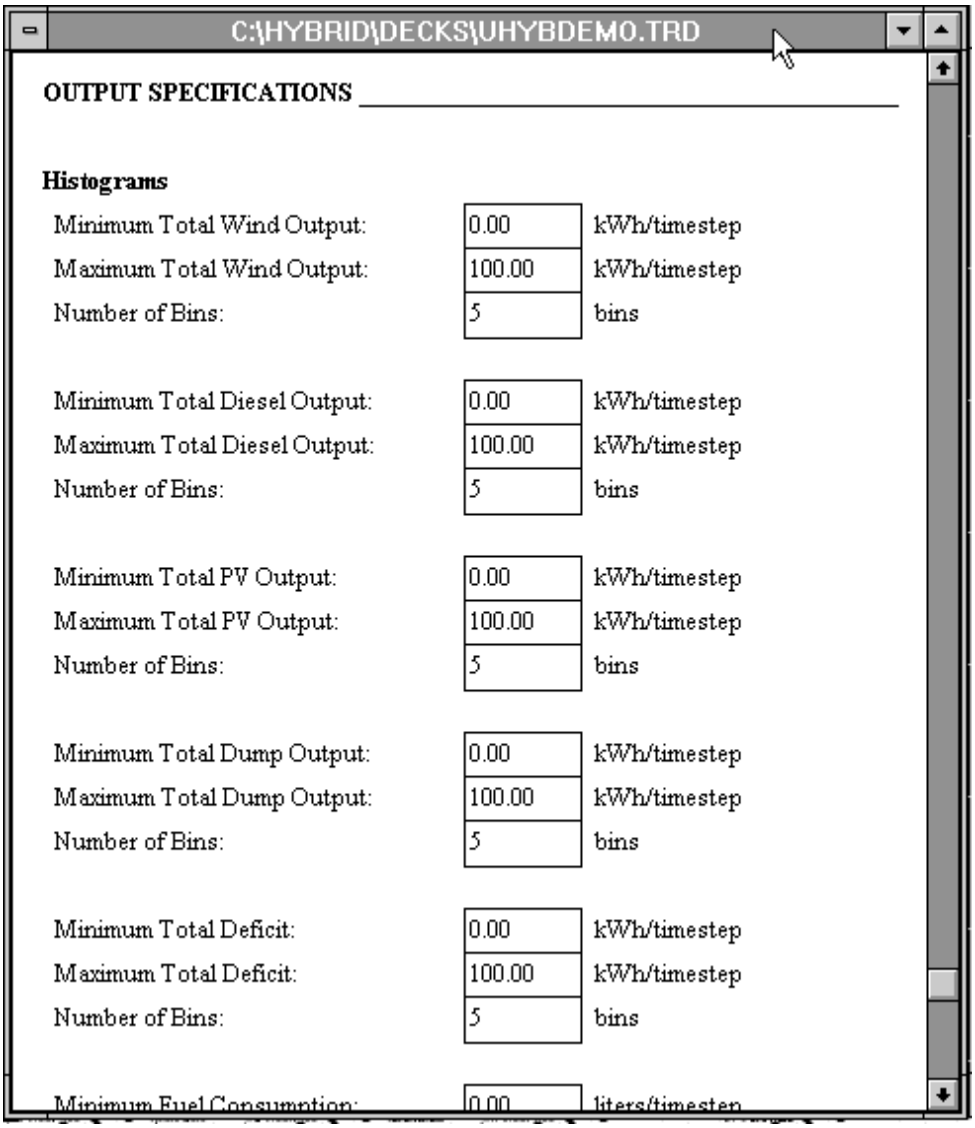

Figure 6.5 Example fourth page of the TRNSED interface.

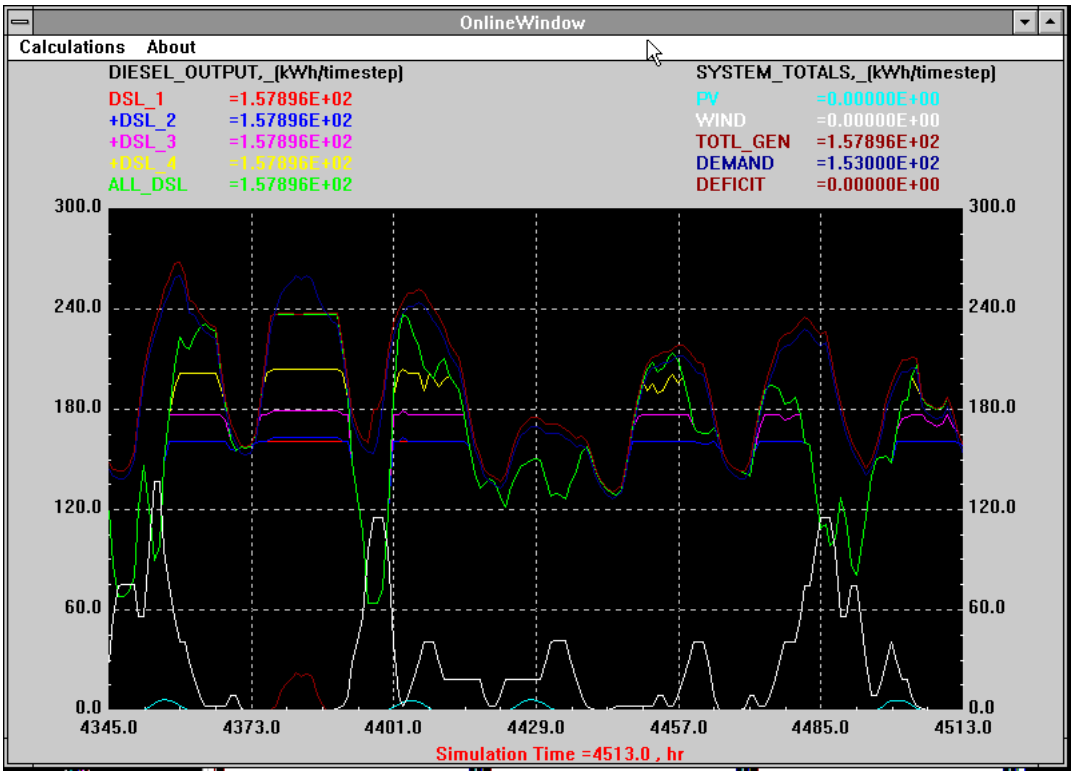

Figure 6.6 UW-Hybrid on-line plotting.