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SOLTES*

(Simulator of Large Thermal Energy Systems)

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ABSTRACT

SOLTES simulates the steady-state response of thermal energy systems to time-varying data such as weather and loads. Thermal energy system models of individual components and simple and complex systems can easily be modularly constructed from a library of routines. These routines mathematically model solar collectors, pumps, switches, thermal energy storage, thermal boilers, auxiliary boilers, heat exchangers, extraction turbines, extraction turbine/generators, condensers, regenerative heaters, air conditioners, process vapor, etc.; SOLTES also allows user-supplied routines. Model construction is a natural extension of the system analyst's schematic. A pre-processor aids the user in constructing and editing system models and automatically constructs a SOLTES program that uses only those routines in the system model; thus, computer core requirements are minimized. Fluid names need only be specified in order to instruct SOLTES to obtain the proper heat-transfer liquid property data and power-cycle/refrigeration working fluid

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constants from a fluid property data bank. Load management allows SOLTES to simulate total energy systems that simultaneously follow process heat and power loads and demands. Power, heating, and/or cooling requirements of each component in the system model can be satisfied by other components in the system or externally. Cooling, heating, electrical, mechanical, thermal, and/or hot-water loads may be read from a data file, combined by category, scaled and/or peak-shaved, and followed. Hourly weather data for typical meteorological years for 26 locations in the U.S. are used, or the user can supply weather data with any time increment. Generalized energy accounting is available and instantaneous and integrated values for systems performance parameters may be automatically determined. In addition to other data, system performance and energy accounting parameters may be written to a file for access by user-supplied programs for economic, rate, or auxiliary supply analyses, etc. Because of its modularity and flexibility, SOLTES can be used to simulate a wide variety of thermal energy systems such as solar power/total energy, fossil-fired power plants/total energy, nuclear-fired power plants/total energy, solar energy heating and cooling, geothermal energy, and solar hot water.

Introduction

SOLTES is a computer code that can be used to simulate a wide variety of thermal energy systems [1]. System models are natural extensions of the analyst's system schematic and are modularly constructed from routines in a routine library that may include user written routines. Due to its software structure, SOLTES can be used, without penalty, to simulate small systems, individual components, and subsystems as well as large systems that may include Rankine-type power generation. Input to SOLTES is proportional to the size and complexity of the system model. Generalized energy accounting [1] automatically calculates system performance parameters and categorizes and integrates significant energy transfer rates.

Philosophy

In thermodynamic texts [1,2], thermal energy systems are analyzed by placing control volumes around the components or devices in the system, and the first and second laws of thermodynamics are applied to these control volumes to determine changes in thermodynamic state and fluid flow rate as fluid flows through the components. The control volumes separate the state points in the system model, and a unique number is assigned to each state point. Values of the thermodynamic state variables such as pressure and temperature or quality and transport variables such as the fluid flow rate at the state points are designated by the number assigned to each state point. The first and second law analyses of these control volumes require fluid transport property data, thermodynamic data and the rates that energy as heat and/or shaft work crosses the control surfaces. Before the performance of the thermal energy system can be assessed, the unknown values of the independent thermodynamic state variables, fluid flow rates, and the rate that energy is transferred by heat and shaft work across the control surfaces are determined.

SOLTES system models are analogous to the method described above. State points are assigned unique numbers, and the analyst chooses from a library the routines that are appropriate models for the components in the thermal energy system. This library contains three types of algorithms -- information, component, and system performance routines. Information routines provide time varying data such as weather and loads (energy transferred as heat or shaft work across component boundaries). Component routines are mathematical models of controls or thermodynamic models of components in the thermal energy system. Controls may change the fluid flow rate but do not change the thermodynamic state of the fluids flowing through them. Thermodynamic models may change the fluid flow rate or the thermodynamic states of fluids flowing through them and may include heat transfer and fluid mechanics effects.

Fluid transport and thermodynamic data for heat transfer liquids are supplied as functions of temperature by polynomial curve fits [1], and the thermodynamic data for power cycle/refrigeration working fluids are provided by the methods for determining the change in thermodynamic state described in reference [2]. This method requires only the fourteen constants discussed in references [3 and 4]* as input.

The coefficients for the heat transfer fluid property data and the fourteen constants are provided in the fluid property data bank for many of the more commonly used fluids. This data bank can be easily

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* These data are available for 468 fluids in Reid et al. [5].

expanded. Once data for a particular fluid has been placed in the data bank, the analyst need only specify the fluid by name. The transport property and thermodynamic state calculations using these data are written in subroutines and functions so that transport and thermodynamic property calculations can be easily included in future component models.

The unknown values of the independent thermodynamic state variables (pressure, temperature, and quality), fluid flow rates, and the rates that energy is transferred by heat and shaft work across component boundaries are determined by iteration. Values of the pressure, temperature, quality, and fluid flow rate are stored at each state point in the system model. Sequential calls to the information, component, and system performance routines are repeated until values of the fluid flow rate and thermodynamic state variables at each state point for two successive iterations are within user supplied convergence criteria. Upon convergence, system performance calculations are made by the system performance routines and time is advanced by the constant user supplied SOLTES time step, and the procedure is repeated through the end of the simulation period.

Structure

SOLTES input includes fluid property data; fluid loop definition data (names of fluids used in the system); values for information, component, and system performance routine input parameters (includes routine name and state point and component number assignment); convergence criteria; time step; simulation period definition; and output control data.

SOLTES output is categorized as follows:

(1) System model description:

- routine names, component number designations, values for the component/information routine input parameters, component inlet and outlet state numbers, names of the fluids flowing through components, etc.

(2) Convergence criteria, time step, and simulation period definition data.

(3) Values of the fluid mass flow rate and thermodynamic state variables at each state point.

(4) Calculated values of significant variables from each routine, e.g., the thermal loss from a solar collector and the energy transferred to the fluid flowing through the receiver.

(5) Calculated values for energy accounting and system performance parameters.

Each of the categories is controlled by user input. The values of the significant variables from each routine, thermodynamic variables and fluid mass flow at each state point, and energy accounting and system performance parameters are available in tables and in a file that can be post accessed by user supplied programs that plot and/or perform economic, rate, or auxiliary supply analysis, etc.

The main SOLTES program is referred to as the "executive routine." The executive routine manages the numerical method by making the sequential calls to the information, component, and system performance routines, and checks for convergence. The executive routine also controls SOLTES output in accordance with user's instructions.

A preprocessor PRESOL aids the user in model construction; PRESOL can be used interactively or from card input. Figure 1 shows the relationships between PRESOL, SOLTES input and SOLTES output. PRESOL responds to interactive user commands to create system models, retrieve system models from a data bank, edit system models, store system models on a data bank, and create loop definition data and executive routine control data. PRESOL also creates an executive routine with calls only to those routines used in the system model and to a file that includes the fluid property and power/ refrigeration cycle constants for those fluids named in the loop definition data. The compiler/loader combines this executive routine with the required routines from the SOLTES library to construct a binary SOLTES program for the system model described by user input.

Current Capabilities

Information routines that supply time varying weather and loads are currently in the routine library. The loads may be read from a file and peak shaved and/or scaled. The weather data is supplied by reading the TMY tapes for the SOLMET [6] sites or by user supplied data in the TMY format. The routine library now includes system performance routines that can meter the energy transported between state points by liquids and that automatically calculate system performance and first law energy accounting. Thermodynamic models currently exist for several types of solar collectors (flat plate, two axes trackers, dishes, line focus), pipes, pumps, thermal energy storage, thermal boilers, auxiliary boilers, heat exchangers, extraction turbines, load management, air conditioners, space heaters, condenser heaters, boiler feed pumps, cooling towers, regenerative heaters, etc. Control models in the routine library are for switches and flow controllers that use time, temperature, pressure, quality, flow rate, and insolation as the control variables.

Simple or complex Rankine-type power generation cycles may be modularly constructed from component models that are now in the SOLTES routine library. The load management component manages these Rankine-type cycles so that thermal and power loads are simultaneously followed and insures that the first and second law of thermodynamic restrictions discussed in references [3] are not violated by user input. These cycles may also be instructed to satisfy none, selected, or all of the parasitics and other power demands of components in the system model. Energy accounting automatically credits and debits the system for following loads and satisfying demands and parasitics [3].

Although SOLTES does not exclude transient algorithms for components, currently only thermal storage components are modeled to include transient terms; all other component models use steady-state algorithms.

The time varying behavior of thermal energy systems such as solar energy systems are simulated by successive quasi-transient solutions. The quasi-transient solutions assume thermal energy storage components change very slowly and the steady-state response of the other components is very rapid compared to changes in weather, loads, and system operating modes.

Applications

Because of its modularity and flexibility, SOLTES can be used to simulate a wide variety of thermal energy systems such as solar power/total energy, fossil-fired power plants/total energy, nuclear-fired power plants, solar heating and cooling, geothermal energy, solar hot water, and solar irrigation.

To date, known applications of SOLTES include detailed studies of trough solar collectors, surface hydraulics for a strategic petroleum reserve site, buried pipe insulation studies, IPH systems simulation, and solar power system simulations. Comparisons with operating systems or components have not been made, but plans are underway to compare SOLTES predictions with the Barstow solar power facility.

Availability

CDC6600/7600 - Software and examples Contact:

Julie M. Pietrzak
National Energy Software Center
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439
Telephone: 312/972-7250

Documentation

Reference [3] is available from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
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References

1. Van Wylen, G. J., and Sonntag, R. E., Fundamentals of Classical Thermodynamics, 2nd ed., John Wiley and Sons, NY, 1973.

2. Reynolds, W. C., Thermodynamics, 2nd ed., McGraw Hill, NY, 1968.

3. M. E. Fewell and N. R. Grandjean, User's Manual For Computer Code SOLTES-1 (Simulator of Large Thermal Energy Systems), SAND78-1315 (Revised), Sandia National Laboratories, Albuquerque, NM, February 1979.

4. M. E. Fewell, "A Method for Determining Values of Thermodynamic Properties Without Tabular or Graphical Data Following Thermodynamic Processes Between Subcritical Thermodynamic States," to be published.

5. R. C. Reid, J. M. Prausnitz and T. K. Sherwood, The Properties of Gases and Liquids, 3rd ed., McGraw Hill, NY, 1977.

6. Hall, I. J., Prairie, R. R., Anderson, H. E., and Boes, E. C., Generation of Typical Meteorological Years for 26 SOLMET Stations, SAND78-1601, Sandia Laboratories, Albuquerque, NM, August 1978.

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