SIMPACK - MODEL DEVELOPMENT PACKAGE FOR POWER PLANTS

1.0 OVERVIEW

SIMPACK is a totally integrated set of simulation software development modules for power plants. It is template based modeling tool and used by simulation engineers to configure, test, and document dynamic process simulation programs. These programs represent the power plant and are used in the operator training simulator. SIMPACK package consists of the following sections:

- Simulation Database
- Model Executive
- Process Algorithms Library
- Process Algorithms Coefficient Calculation Library
- Thermodynamic Property Algorithms Library
- General Algorithms Library
- Template based Model Configuration
- Automatic Calculation of Coefficients
- Interactive Process Monitor and Debugger
- User Manual

2.0 SIMULATION DATABASE

This is a pre-defined Structure or Common Storage area designed for access by all programs that formulate the Operator Training Simulator. The nomenclature used in defining the symbols is based on standard engineering practice. The symbols are generally one or two-dimensional arrays, defined by the following groups:

- Model Executive Variables
- Instructor Inputs
- Instrumentation Input/output Variables
- Control Variables
- Logic Variables
- Process Variables (flow, pressure, enthalpy, temperature, composition, etc.) for condenser, feedwater heater, deaerator, steam drum, superheater, coal pulverizer, combustion, pump, fan, turbine stage, motor, valve, etc.
- Coefficients for all of the above groups
- Time derivatives of process variables
- Execution “flags” for all time derivatives

3.0 MODEL EXECUTIVE

The Model Executive is the main program which executes the simulation model of the plant. The execution cycle is synchronized to represent real time. This program also interacts with the Instructor and Controls Programs. Additional features of this program include faster than and slower than real time execution upon request by the Instructor, suspending the model execution upon request by the Instructor, stepping the model one cycle at a time upon request by the Simulation Engineer during testing, and initializing the Database at the start of the simulation session.

4.0 PROCESS ALGORITHMS LIBRARY

This Library consists of the "building blocks" for the plant. Each algorithm simulates an equipment, such as condenser, feedwater heater, deaerator, steam drum, turbine stage, coal pulverizer, rotary air heater, pump, fan, valve, etc. The mathematical models in the Algorithms consist of time-based differential equations, representing dynamic heat balance, mass balance, steam-water equilibrium, and engineering correlations, where applicable. Each Algorithm has been tested thoroughly for proper responses for the complete range of operations, and numerical stability. The error-free Algorithm is then added to the Library. The following Algorithms are included in this Library:

- Sources (air, water, steam, coal, fuel oil, fuel gas)
- Sink
- Air heaters (2-zone rotary, 3-zone rotary)
- Condensers (main, gland steam)
- Feedwater Heater, Drain cooler, Heat Exchanger
- Steam drum, Deaerator, Drain Tank
- Waterwalls (natural circulation, forced circulation, once-through)
- Superheater, Economizer
- Combustion
- Coal Pulverizer
- Steam Turbine Stage
- Gas Turbine
- Compressor
- Turbine Supervisory (bearing temp., vibration, eccentricity, diff. expansion)
- Electrical Generator
- Pumps (options include centrifugal, and reciprocating)
- Fans
- Steam Jet Air Ejector
- Valves (control, on/off, motor-operated, safety, etc.)
- Mixing nodes
- Flow Conductances (options include parallel, and series)
- Pipe flow (options include laminar, and turbulent)
- Pressure nodes (options include single node, and multiple node matrix)

Description of Major Algorithms

CONDENSER

This algorithm simulates a condenser, which is a tank containing cooling water tubes. Streams of water and steam are inputs to the condenser. The mixture is assumed to condense over the cooling water tubes. The resulting condensate is accumulated in the tank and is taken out by the connected pumps. Non-condensable gas (air) is also considered as input by virtue of inlet steam and leak malfunction. The air is removed by vacuum pumps, or steam jet ejectors. Unsteady-state heat balance on the vapor envelope gives the enthalpy of liquid that is assumed to be in equilibrium with the vapor at saturated conditions.

Vapor pressure is then calculated as a function of this enthalpy from the available library of steam-water thermodynamic functions. Similarly, heat balance on the condensate gives the enthalpy. The temperature and density are then calculated from thermodynamic relationships. Mass balance on the condensate gives the liquid hold-up. Level is calculated as function of mass, density, and cross-sectional area of the tank Heat balance on the cooling tubes results in the calculation of the outlet cooling water temperature.

Effects on malfunctions, such as cooling water tube fouling are included in the model. This malfunction results in loss of cooling and consequently higher pressure.

SINGLE-PHASE HEAT EXCHAGER

This algorithm simulates a shell-and-tube heat exchanger in which heat transfer takes place between two single-phase fluids. Unsteady-state heat balance is performed on each side, which results in the outlet temperatures of the tube side fluid and the shell side fluid. The heat balance equation involves the mass flow rate, the heat capacity, the inlet and outlet temperatures, and the mass hold-up. The heat transfer coefficient is assumed to be a function of flow rate. The rate of heat transfer is calculated as function of log mean temperature difference. Malfunctions, such as tube leak and tube fouling are included as part of the model.

DEAERATOR

This algorithm simulates a deaerator, which is a tank with inlet streams of water and steam. The mixture is flashed at vapor-liquid equilibrium conditions. The resulting condensate is accumulated in the tank and is taken out by the connected pumps.

Unsteady-state heat balance on the vapor envelope gives the enthalpy of liquid that is assumed to be in equilibrium with the vapor at saturated conditions. Vapor pressure is then calculated as a function of this enthalpy from the available library of steam-water thermodynamic functions. Similarly, heat balance on the condensate gives the enthalpy. The temperature and density are then calculated from thermodynamic relationships. Mass balance on the condensate gives the liquid hold-up. Level is calculated as function of mass, density, and cross-sectional area of the tank.

STEAM DRUM

This algorithm simulates a steam drum, which receives a mixture of steam and water from the evaporator. The mixture is assumed to be at saturated conditions, and the steam and water are completely separated in the drum. The vapor pressure is calculated by performing mass balance on the vapor envelope. The steam outlet may discharges to the atmosphere through a vent passed through the Superheater during normal operation.

Heat balance is performed on the liquid pool which receives saturated liquid from the evaporator, and feedwater from the economizer. The liquid is discharged into the evaporator and the blowdown line. The heat balance gives the enthalpy of the liquid. Temperature is then calculated from enthalpy and vapor pressure, using thermodynamic property relationships. Mass balance on the liquid pool provides the level (density and cross-sectional area is used).

Drum metal temperatures are also calculated by Performing appropriate heat balances.

SUPERHEATER

It is a special tubular heat exchanger in which steam is flowing inside the tubes and flue gas is flowing on the outside. In this model, the heat exchanger is divided into five zones for the steam side, where as the flue gas and the tube metal is each considered as a single zone.

Heat balance is performed for each zone. This gives the temperature of the outlet flue gas, temperature of the metal, and the enthalpy of steam. The temperature of the steam in each zone is calculated from enthalpy and pressure, by using thermodynamic property relationships.

Heat transfer coefficients are assumed to be functions mass flow rate. Heat transfer rate is calculated as function of log mean temperature difference.

Malfunctions, such as tube leak, and tube fouling (inside and outside) are included.

EVAPORATOR (WATERWALLS)

In this model, the flue gas is one zone, the metal is one zone, and the steam-water mixture inside the tubes is divided into ten zones. Heat balance is performed for each zone. This gives the temperature of the outlet flue gas, temperature of the metal, and the enthalpy of steam-water mixture. The fraction of steam in each zone is calculated from enthalpy and pressure, by using thermodynamic property relationships. Mass balance provides the level (mass, density, and tube area is used).

Both radiation and convection heat transfer mechanisms are considered for heat exchange between the gas and the tube metal.

PULVERIZER

The pulverizer model consists of three zones: The feeder, the grinder, and the classifier.

Mass balance in each zone gives the hold-up of solid particles. The flow rate of solid particles leaving each zone is a function of the feeder speed, mass hold-up, and the flow rate of primary air. Heat balance on the air gives the temperature of outlet air. Latent heat of evaporation of moisture and heat of grinding are considered in the heat balance. Effects of temperature and moisture content on the grindability of solids are also included.

STEAM TURBINE STAGE

In this model, the stage power, the outlet steam properties (entropy, enthalpy), and metal temperatures are calculated. Given the inlet steam enthalpy and pressure, the entropy is determined from thermodynamic relationships. First assuming isentropic expansion, the "ideal" enthalpy at the outlet is calculated from the inlet entropy and the outlet pressure. The stage efficiency is determined at various flow conditions and stored in a table. Using the "ideal" enthalpy and the stage efficiency, the actual enthalpy at the outlet is then calculated. The product of flow and enthalpy difference gives the power.

Heat balances are performed to obtain the temperature of the rotor and the casing.

GAS TURBINE

This model assumes polytropic expansion in the turbine. Given the inlet temperature and the (pressure) expansion ratio, the outlet temperature is determined. Using the flue gas flow rate, inlet and outlet heat capacity, and temperatures, the power developed in the turbine is calculated. The heat capacity is determined from flue composition and temperature (from the thermodynamic properties library).

Heat balances are performed to obtain the temperature of the rotor and the casing.

COMBUSTION CHAMBER

The combustion chamber receives fuel flow and air flow as inputs. Given the composition of the fuel and air, stoichiometric calculations are performed to determine the availability of oxygen for combustion. The amount of heat produced by combustion is then calculated from the usual series of combustion reactions. Heat balance is performed to determine the adiabatic flame temperature. Another heat balance is performed to calculate the temperature of the flue gas leaving the chamber, accounting for heat loss to any heat exchangers and surroundings. The pressure in the chamber is calculated from the mass balance.

PUMP

The flow rate of a centrifugal pump is determined by the correlation between the dynamic head and flow. These curves are provided by the pump vendor. A parabolic equation is used to represent these curves at various pump speeds. The flow rate then becomes a function of inlet pressure, outlet pressure, pump speed, and pump characteristic constants.

COMPRESSOR

The flow rate of a centrifugal compressor is determined by the correlation between the

polytropic head and flow. These curves are provided by the compressor vendor. A parabolic equation is used to represent these curves at various compressor speeds. The polytropic head is a function of compression (pressure) ratio, inlet temperature, molecular weight of gas, and heat capacity ratio (Cp/Cv). The power used by the compressor is a function of polytropic head and flow rate. The temperature of the outlet gas is determined from the inlet temperature and polytropic pressure ratio.

VALVE

This model simulates the operation of a valve. Various characteristic equations are included, such as linear flow, equal percentage flow, etc. Valve ramp function is included. The final valve opening is based on availability of power or air (fail position) and any malfunction.

ELECTRICAL GENERATOR

The model for the electrical generator includes the simulation of the excitation system (Automatic Voltage Regulation). This provides the field current sent to the generator. The "no load saturation" curve (provided by the generator vendor) is used to determine the EMF, given the field current. The difference between the grid frequency and the generator rotor speed gives the "slip". The phase difference is calculated from the rotor angle and the terminal voltage angle. All these parameters are used to calculate the terminal voltage, active power, and reactive power.

5.0 PROCESS ALGORITHMS COEFFICIENT CALCULATION LIBRARY

This feature of the Model Development Package reflects the most significant enhancement in Dynamic Simulation Software Technology. For each Process Algorithm, there is a corresponding Coefficient Calculation Algorithm in this Library. In most common Model Development Procedures, the simulation engineer is required to manually calculate the coefficients, such as heat transfer coefficients, valve coefficients, engineering correlation coefficients, etc. from reference plant data. In the SIMPACK package, the coefficients for the entire plant are calculated online, automatically, and instantly. The simulation engineer simply enters the reference plant data and gives a command. The system calculates the coefficients, while checking the mass and energy balances, stores the results in ASCII and/or BINARY format, and produces automatic documentation.

In each of the Coefficient Calculation Algorithms, the mathematical equations which represent dynamic mass balance, energy balance, etc., are rearranged in steady-state format, and the respective coefficients are calculated from the given reference data. The thermodynamic properties of various components are utilized from the THERMODYNAMIC PROPERTIES LIBRARY. The simulation engineer also has the opportunity to check for any errors in the mass and energy balances, and correct these, even before testing the dynamics.

Using the Coefficient Calculation feature in this package, the simulation engineer saves significant amount of time required for calculations, error checking, testing and documentation of input data and calculated coefficients.

6.0 THERMODYNAMIC PROPERTY ALGORITHMS LIBRARY

The components in this Library are water (any state), steam (any state), water & steam mixture, air (oxygen, and nitrogen), flue gas (water vapor, oxygen, nitrogen and carbon dioxide). The thermodynamic properties of each component is calculated in the respective Algorithm by polynomial expressions. The Process Algorithms extensively use the Thermodynamic Property Algorithms.

Each of following properties is calculated with respect to one or more of the other properties:

- Temperature
- Enthalpy
- Entropy
- Pressure
- Density or Specific Volume
- Heat Capacity (air, flue gas, etc.)
- Heat of combustion

7.0 GENERAL ALGORITHMS LIBRARY

A number of General Algorithms are provided, to be used in the Process Algorithms, as required. The following categories are included:

- Integration with respect to time
- First order lag
- Ramp Function
- Maximum & Minimum Limits
- Scaling & Unscaling
- Interpolation
- Timers
- Pulse Generator
- Logical Functions, such as Flip-flops
- PID Controller

8.0 MODEL CONFIGURATION & CALCULATION OF COEFFICIENTS

The Model Configurator is a template based and an interactive program which works in the Windows environment. The simulation engineer invokes this program to configure or build the dynamic Model of the plant. The plant to be simulated is usually divided into smaller sections to enhance the flexibility in testing and debugging. Each section is represented by a sub-model. The Model Configurator opens as an Applications Window with a Function Menu to configure the sub-model.

To configure the sub-models, the simulation engineer follows procedure described below:

- Select the sub-model to be configured from the displayed table.
- Click on the ADD button on the Function Menu.
  A table of functional groups of Algorithms is presented.
- Select the appropriate group.
  A table of Algorithms is presented that belong in the functional group.
- Select the appropriate Algorithm.
  A template of connectivity parameters is displayed with descriptions and blank spaces to enter values. The connectivity parameters require equipment identification and input/output stream identification numbers. On-line Documentation and Help is available.
- Several other functions are available on the Function Menu to aid in the configuration process, for example,

  MODIFY (change the connectivity data)
  DELETE (remove selected Algorithm from the sub-model)
  LIST (display a list of all Algorithms used in the sub-model)
  REVIEW (display documentation of selected Algorithm)
  WRITE (save the configured file in the appropriate directory)
  HELP (select a subject and display contents of the Help file)
  EXIT (end of the configuration session)

The Model Configurator has another important function available on the Function Menu, CALCULATE:

- Select the sub-model from the displayed table.
- Select the Algorithm from the sub-model for coefficient calculation.
- A template of inputs, coefficients, and outputs is displayed with descriptions and blank spaces to enter values.
- The simulation engineer enters reference data in the input columns and executes the model.
- The coefficients are calculated and the results are displayed immediately in the template. The simulation engineer views the coefficients and outputs from the Algorithm, determines the results to be satisfactory, and saves the file in the appropriate directory. This file will be used later for dynamic testing and documentation.
- This procedure is repeated for all Algorithms in all the sub-models. The Composite results give all the required coefficients and a reference initial condition of the plant.

9.0 INTERACTIVE PROCESS MONITOR AND DEBUGGER

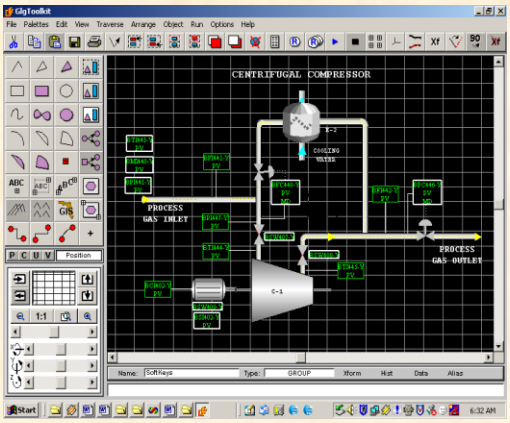
The SIMPACK Interactive Process Monitor and Debugger is a powerful, user-friendly, dynamic monitoring and debugging program. The program provides many functions to the simulation engineer which allow the interactive monitoring and changing of process variables and coefficients, while the simulation model is running. The program is designed to run stand-alone, accessing process variables via the simulation database shareable segment. This program includes the capability to:

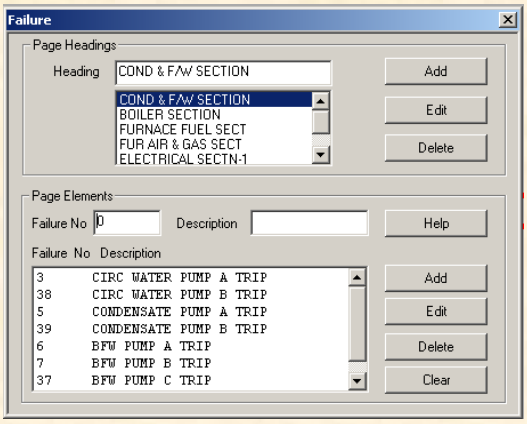
- Show, Enter, or Alter variables and coefficients on-line
- Turn individual integrators ON/OFF
- Turn all integrators ON/OFF
- Turn individual Algorithms ON/OFF
- Turn sub-models ON/OFF
- Create functional groups of variables to be viewed on the same screen
- Save/Restore functional groups of variables
- Create/Save/Restore display screens
- Run/Stop the simulation model
- Save/Restore the database in BINARY or ASCII
- "Step" through the simulation model one cycle at a time (very important debugging tool)
- Rename the commands for the convenience of the simulation engineer
- Change the simulation time scale (faster/slower than real time)
- Change the integration time step
- Execute commands from a file
- Help (on-line documentation, and helpful hints)

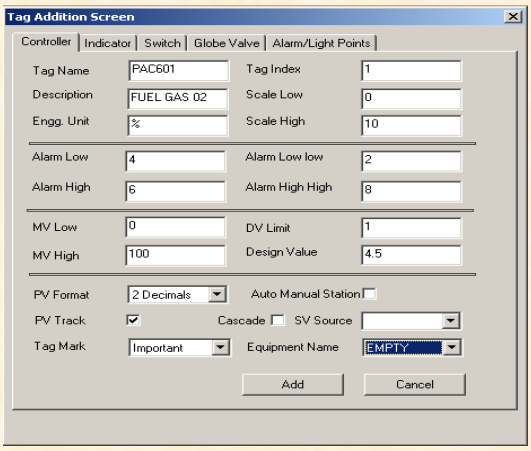
10.0 USER MANUAL

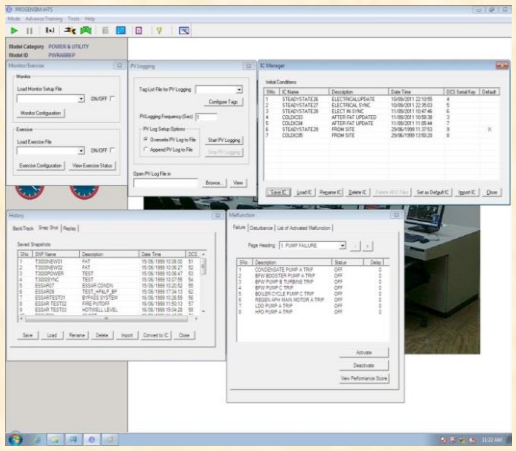
The SIMPACK User Manual provides complete information to the simulation engineer about the organization of the software package, description of all Algorithms in the Libraries, procedures and tasks required for the dynamic simulation project, and several examples. Each of the above nine topics is a chapter in the manual.

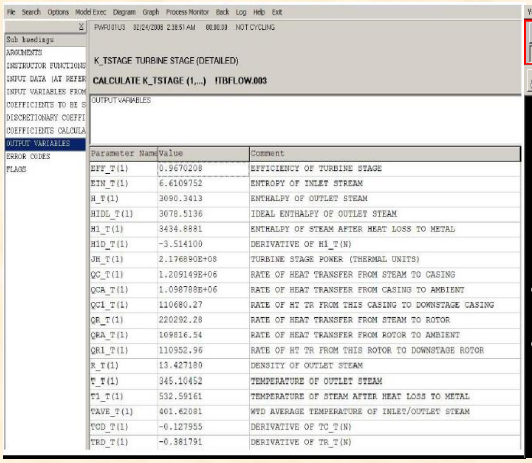
PS0030: POWER PLANT SIMULATOR DEVELOPMENT PACKAGE

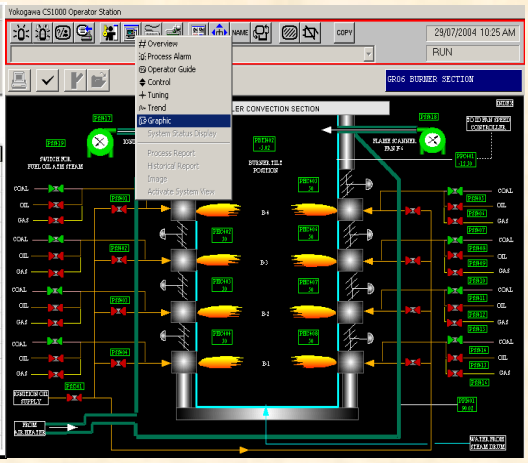
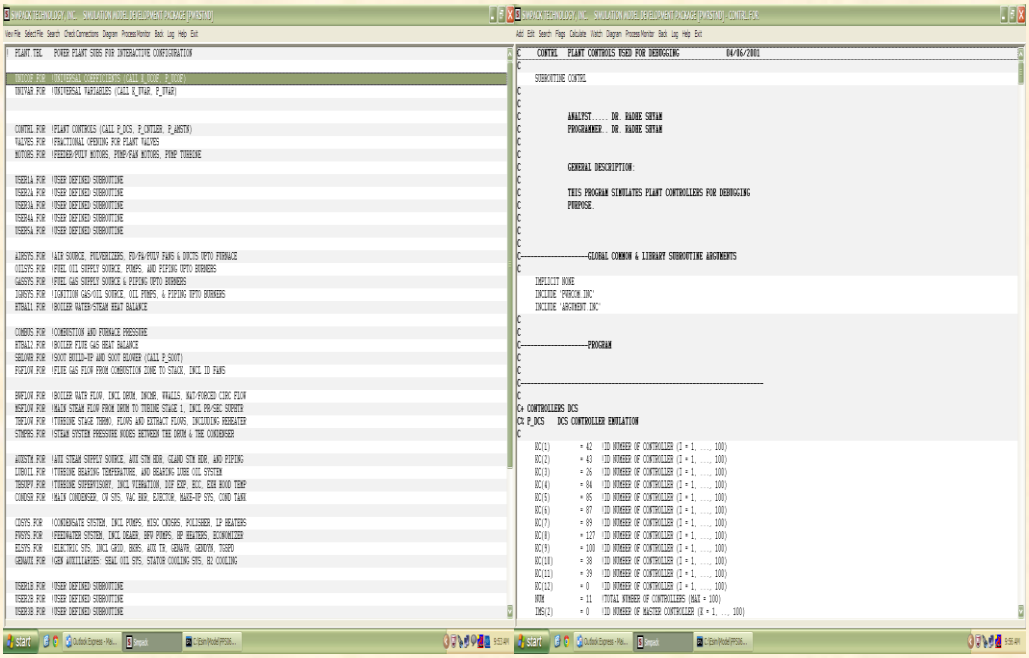
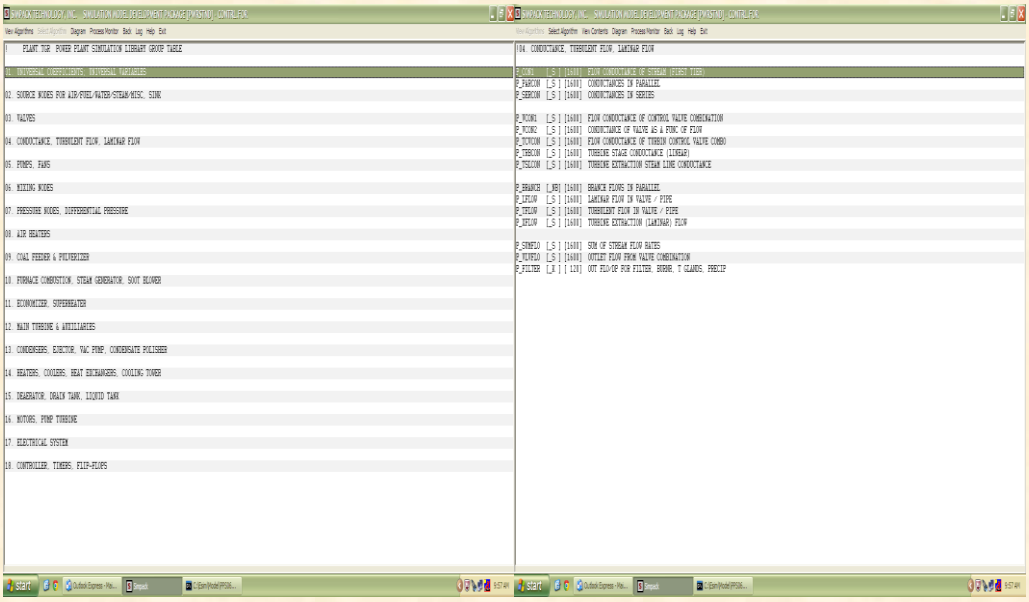












SIM INFOSYSTEMS PVT LTD, 11, 1st Cross St, Nehru Nagar, Kottivakkam, Chennai 600 041, INDIA
Phone: +91-44-24982617, Email: sales@siminfosystems.com. Website: www.siminfosystems.com