

Modelling and Optimization of Dual Purpose Power and Desalination Plants

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Abstract

In recent years several large-scale combined power & desalination projects have been implemented in the Middle East and the list of additionally required projects to meet growing power and water demand in the region has been announced.

The maximum capacity of individual projects tendered is increasing continuously and the significant increase of power generation and desalination capacity has also increased the number of options for plant configurations and technology integration. The use of hybrid desalination processes (combination of thermal distillation and membrane desalination) has further increased the complexity involved in designing and optimizing dual purpose plants.

Several simulation software packages are available to optimize the power island but so far no sophisticated simulation tool has been found for the optimization of the entire power & desalination plant including hybrid systems, flue gas desulphurization system and the seawater intake and outfall system.

This paper describes the application of the OPUS™ simulation program for the conceptual design and NPV based optimization of any kind of integrated power and desalination plant.

The main modules of the OPUS™ simulation program comprise Thermodynamic Simulation, Capex estimation, Opex estimation and financial model.

The program has no restrictions with regards to defining new configurations and/or adding new technologies. Efficient optimization methods are applied to the model in order to find the most cost-effective solution. The results of configuration options modelled are expressed as power and water tariff.

I. GROWTH AT AN UNPRECEDENTED RATE

As we all know, this motto of the annual POWER-GEN Middle East conference became true and continues to keep us busy. We face a continuously growing number of projects combined with increasing plant sizes and complexities. A delightful situation for the region but it also leads to several bottlenecks in each phase of a project.

To overcome the global lack of experts (which means reducing the number of bottlenecks) ILF has started to integrate the power plant and desalination plant optimization process into one single, easy to use software system. With OPUS™ the optimization process of all kinds of conventional plants, combined plants and even incineration plants will be done more efficiently and quickly. This will result in an increasing number of multi-disciplinary engineers having the tool on hand to respond rapidly and efficiently to the market's requirements. This is not only applicable to the planning phase of new plants but also to the extension or improvement of existing plants.

OPUS™ will be able to run optimization calculations taking consideration of capital costs, operating costs and the corresponding economic and ecological aspects.

II. COMPUTER MODEL

The core to the optimization of power plants, desalination plants and the combination of power and desalination plants is a rigorous computerised mathematical model of the process mass and energy balance, including thermodynamic calculations. The model must be capable of accurately modelling all of the plant configurations being considered so as to determine the economic consequences of each option.

The OPUS™ simulation software has been developed using the IPSEpro software suite. This suite includes the Process Simulation Environment (PSE) software, which is used by the engineer to simulate process configurations; Model Development Kit (MDK), which is used by the simulation specialist to provide the required thermodynamic and process simulation process unit models; and PSEconomy, which is a capital and operating cost estimation package.

IPSEpro provides an integrated program framework with only one physical model library. This single model library provides all the unit process models required to simulate power generation and desalination processes via a easily accessible graphical user interface. These models can be combined in any manner which the engineer desires to create overall models of any option being considered for the combined power and desalination plant.

In this manner, the goal of optimising all kinds of technologies and combinations of power generation, desalination and flue gas cleaning systems is realised.

IPSEpro's Model Development Kit

IPSEpro's Model Development Kit (MDK), provides the capabilities that are required to define new models and to translate them into a form that can be used by PSE. MDK consists of two functional units:

- Model editor
- Model compiler

These allow the user to design icons that represent the unit process models and to describe the unit process behaviour mathematically in the form of model equations.

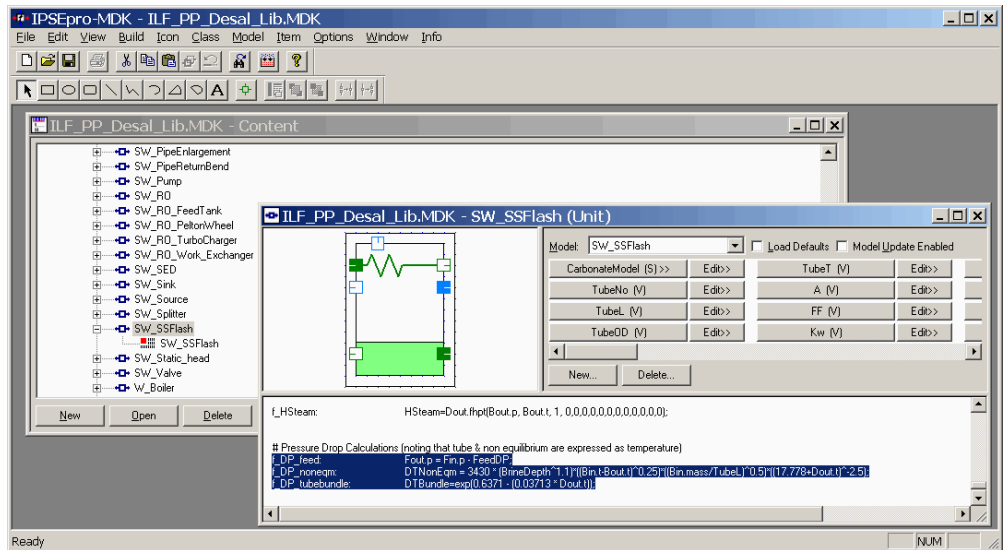


Figure 1: Typical MDK screen

IPSEpro Process Simulation Environment PSE

PSE is used to create and solve process models based on components from a library. PSE provides a graphic flowsheet editor for setting up process models. The user selects the required components from the library menu and arranges them appropriately. All process data is entered directly in the flowsheet. The results are directly displayed on the scheme. PSE generates output protocols automatically, at the end of a simulation run.

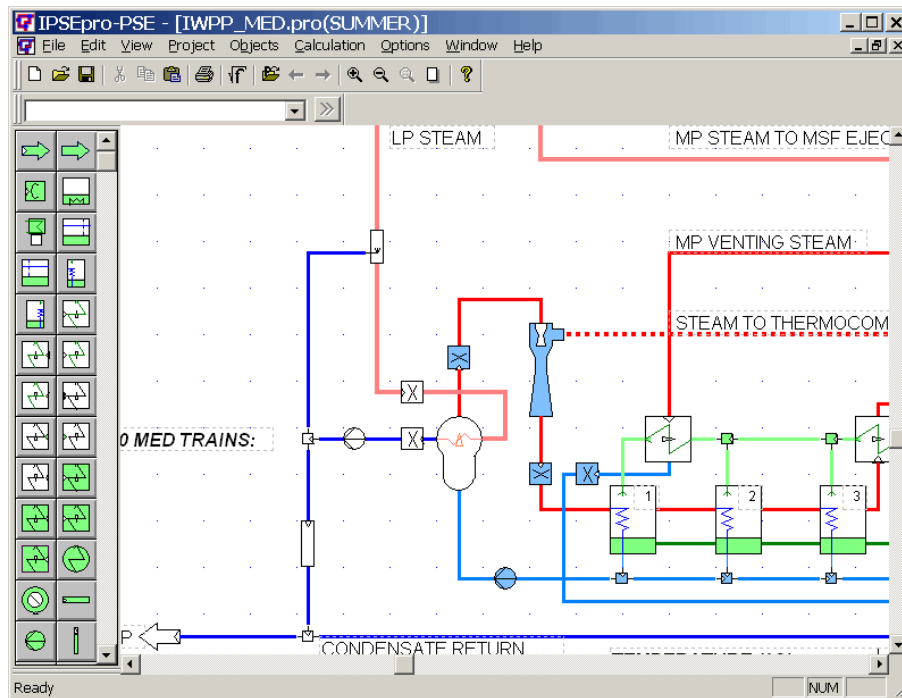


Figure 2: Typical PSE screen

Mathematical Formulations and Solvers

IPSEpro uses an equation oriented approach. Mathematically, a process model is a system of algebraic equations. This system is set up implicitly by drawing the flowsheet and entering data. Although accessible, there is no need for the user to deal with the mathematical formulations explicitly. However, the source code is readily available to the expert user, allowing the system to respond to the requirement to model unforeseen process configurations. Once configured, the system of equations is solved by the respective solver.

Besides a standard solver for steady state solutions, IPSEpro also contains an optimizer for optimizing process parameters and a validation module. The data validation module allows the user to systematically validate measured data against process models.

The solvers are shared by all modules to ensure consistent results.

Examples of physical model of combined plants

IWPP WITH MED DESALINATION

CRUDE OIL-FIRED BOILER WITH INTEGRATING BACK-PRESSURE STEAM TURBINES WITH MED @ 2.885MW, PSD (1.2% S)

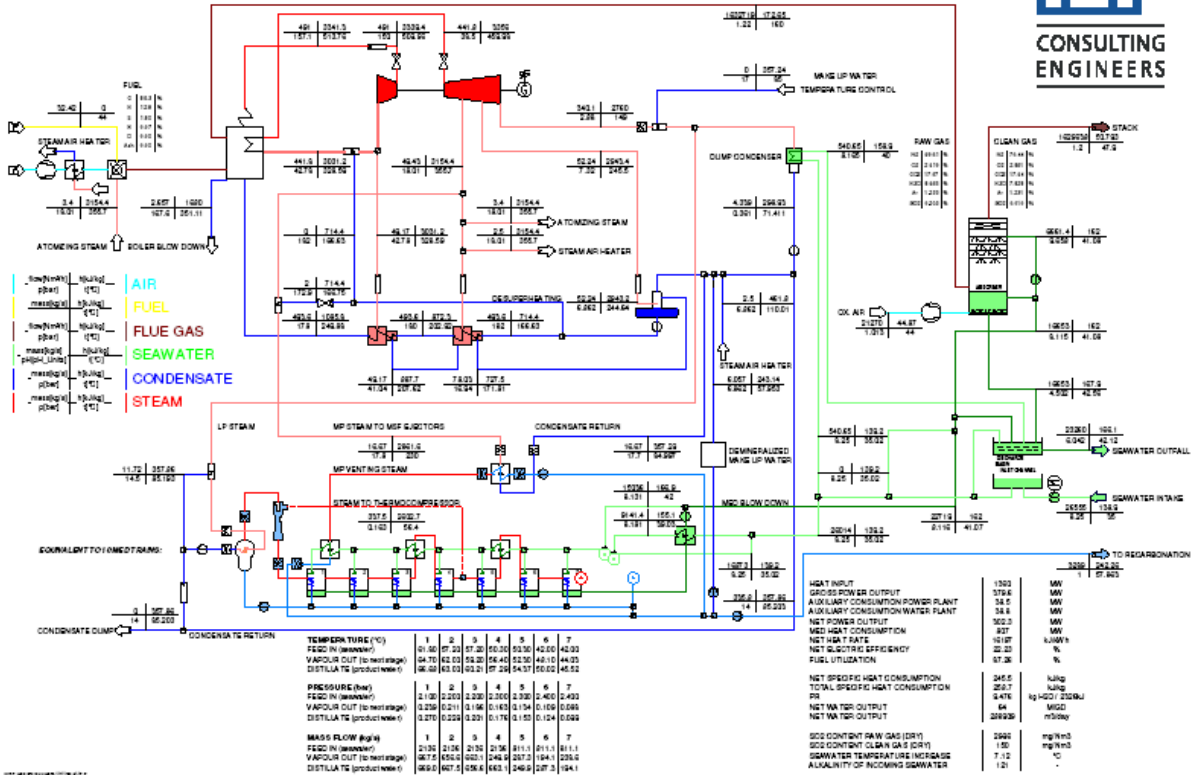


Figure 3, 4 and 5 show the output flowsheet generated by IPSEpro for different combinations of power and desalination technology.

IWPP WITH MED DESALINATION

CRUDE OIL-FIRED BOILER WITH REGENERATING BACK-PRESSURE STEAM TURBINES WITH MED @ 2.885MW, PSD (1.2% S)

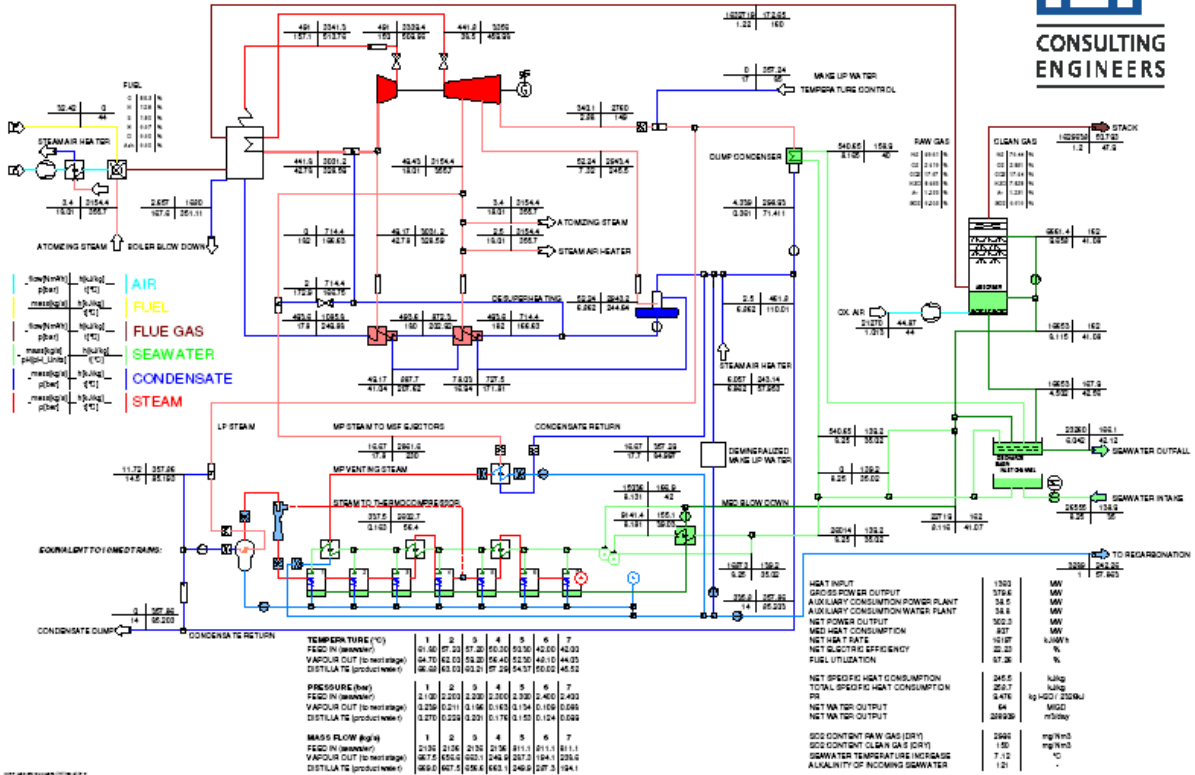


Figure 3: Steam Cycle Power Plant Combined with MED Distillation

IWPP WITH MSF DESALINATION

CROSS-CO-FIRED BOILER WITH HIGH-TEMP. BACK-PRESSURE STEAM TURBINE WITH MSF @ 3.0 bar(a) PSD (1) (R.01)

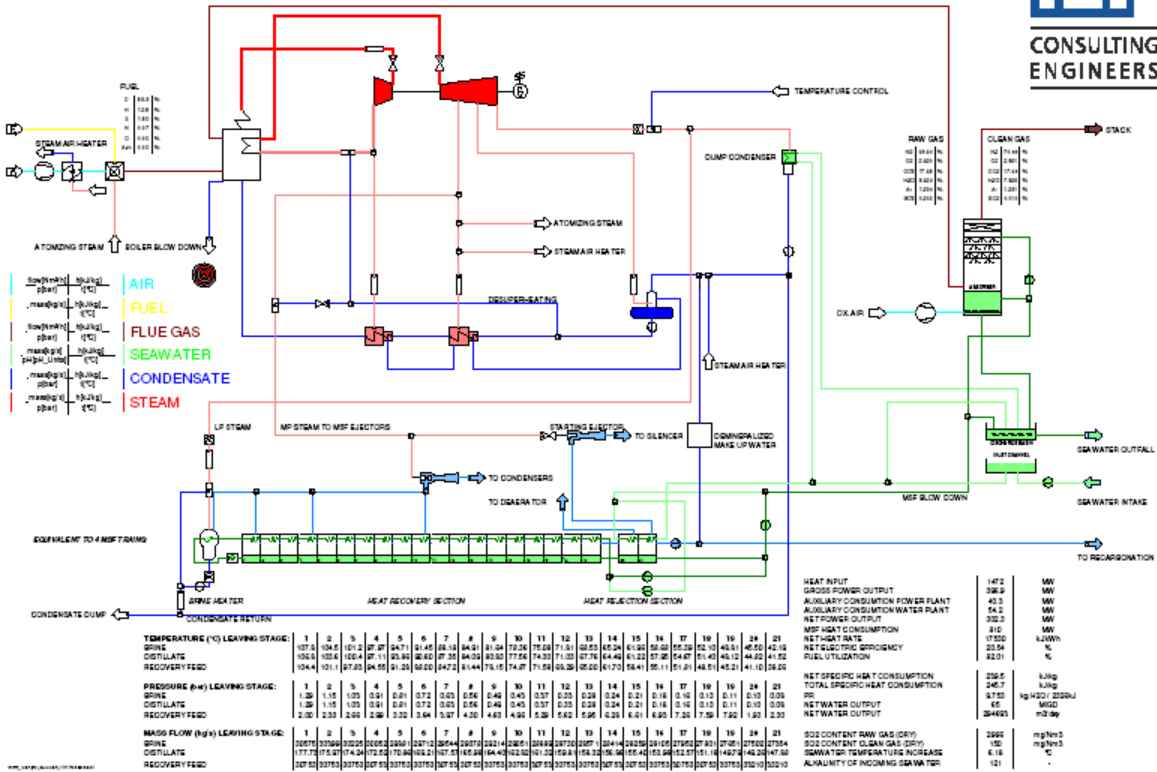


Figure 4: Steam Cycle Power Plant Combined with MSF Distillation

IWPP WITH RO DESALINATION

CRUDE OIL-FIRED BOILER WITH REHEATING, CONDENSING STEAM TURBINE WITH RO, 550 (1.0N, 0)

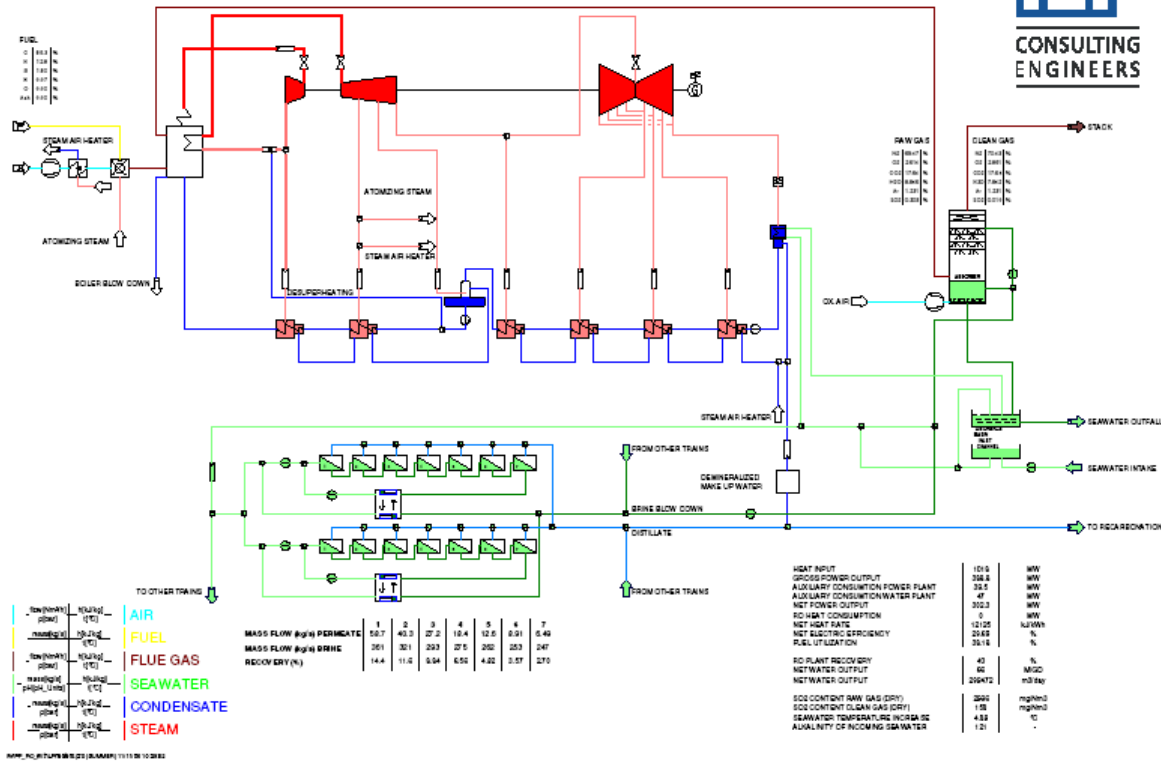


Figure 5: Steam Cycle Power Plant Combined with RO Desalination

III. COST ESTIMATION

The purpose of process simulation and modelling is to optimise the overall process design. Generally speaking, the parameter to be optimised is some form of cost, be that capital cost, operating cost, NPV or power/water tariff. The process design must be robust, constructable and in the case of IWPP's, financeable, and to this extent, it is the responsibility of the engineer to ensure that process parameters are defined appropriately within the models. The task of the simulation system is to generate the appropriate cost for each process configuration under consideration, thereby allowing different options to be evaluated on a level playing field.

Consequently to determine the most economic design, capital costs and operating costs have to be an integral part of the framework.

Capital costs

Major capital costs are generated from the unit process models. These unit process models have to be defined in sufficient detail to allow the link to cost estimation formulations. For example, the thermodynamic model of a heat exchanger will calculate the heat transfer area required for a given process duty. Additional parameters, such as tube material, tube diameter, length, wall thickness and

shell material as well as standard unit fabrication manhours need to be defined by the engineer so that a good estimate of equipment cost can be generated, taking into account aspects like local market situation and world market raw material prices.

The unit process models therefore generate the direct equipment costs for the overall project. An overall costing module then accounts for capital costs that are not directly linked to unit process model elements (e.g. fire fighting equipment). The overall costing module also accounts for equipment necessary for the completeness of a total plant but not relevant to the optimization process (e.g. housing compound, site access road).

Operating costs

Volumetric operating expenses are primarily defined by the main fuel, energy and chemical costs. Additional fixed operation and maintenance costs result from equipment replacement & refurbishment, consumables, local considerations and staff costs.

Fuel or primary energy demand is calculated by each unit process model, thereby allowing the overall energy requirement to be output. Chemical dosing unit processes allow chemical consumptions to be also output. Further related costs are calculated on an annual basis with annually changeable tariff from the market.

Maintenance costs are calculated by the unit process models, typically using a percentage of equipment cost per year (different percentages would normally be applied to the civil, mechanical, electrical and ICA components of the equipment cost). However, some maintenance costs are calculated in more detail where required (e.g. where a quote is available from the equipment supplier including an annual maintenance contract, which is typically the case for gas turbines, or in the case of reverse osmosis membranes, where there is an annual replacement rate required as a condition of the membrane guarantee).

IPSEpro „PSEconomy

PSEconomy is a software tool for analyzing and optimizing the economics of process systems. It implements a dynamic investment cost analysis and has comprehensive capabilities for analyzing the whole life economic performance. PSEconomy can be used as a stand-alone program or as an extension module for the IPSEpro-PSE software suite.

As a stand-alone program, the user enters cost and performance data as input directly in the program. As an extension module of IPSEpro-PSE, PSEconomy can also obtain cost and performance data from PSE models.

More specifically, PSEconomy allows the user to:

- Define cost structures for investment costs
- Estimate capital investment costs
- Define operating scenarios for the full operating life of a process system
- Estimate operation & maintenance costs throughout the operating life of a process System
- Optimize the costs of a process system

Like all other IPSEpro modules, PSEconomy is an open framework. Instead of being limited to a specific area of application or to a particular type of process system, PSEconomy can be adjusted for a specific application area by using an appropriate model library and suitable cost data.

The design of PSEconomy is based on the fact that the process equipment, taken into account during “standard” process analysis, significantly contributes both to the investment costs and to the operation and maintenance costs.

The accuracy of the estimates generated in OPUS™ depend on the level of detail available in the respective model library and in the cost data.

After an economic process analysis is started, PSEconomy also provides mechanisms to update it with more accurate available cost data (eg.: a firm quotation for a piece of equipment). This allows the user to increase the accuracy of the analysis during the course of a project.

With its capability to vary parameters very quickly, it can be used to analyze the sensitivity of process parameters. In this way, it is possible to provide working data until additional cost information is available in order to obtain sufficiently accurate results.

In profitability calculations, profits and costs that will occur in the future are considered. Associated risks and uncertainties, which can be significant, can also be taken into consideration.

PSEconomy implements a *deterministic investment analysis* for handling profitability calculations.

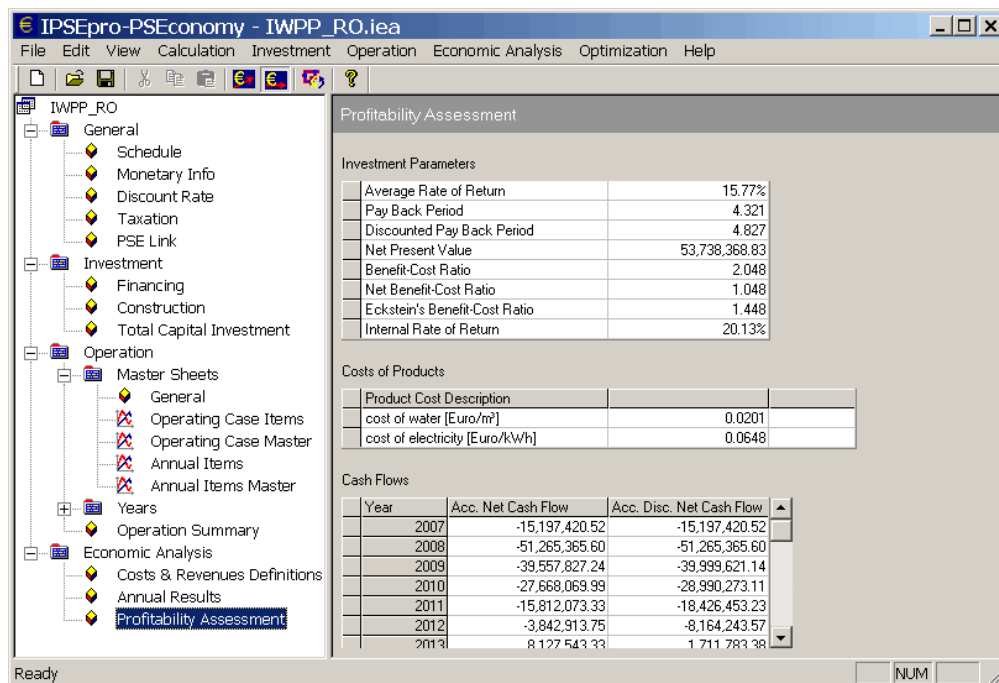


Figure 6: Typical PSEconomy screen

Financial model

In the financial model the following aspects are included:

- Expected demand and operating scenarios, taking into consideration downtime for maintenance as well as seasonal variation in power/water demand and long term demand growth.
- Changes in ambient conditions throughout the year
- Cost (S) curve during plant erection phase
- Inflation
- Taxes

IV. OPTIMIZATION

Overall optimization includes:

- Operating parameters in each evaluated operating case (eg. actual air cooled condenser fan speed)
- Design parameter for technical components (eg. design condenser pressure)
- Comparison of different technologies (eg. MED vs. MSF)
- Comparison of different financing models

IPSEpro „PSOptimize

IPSEpro-PSOptimize allows the user to calculate for selected model parameters those values that minimize or maximize a selected target function. PSOptimize is fully integrated into the IPSEpro framework and can be used for optimizing any existing process model in PSE.

Together with PSOptimize you can not only design a process, but also obtain optimal solutions according to your specifications. This requires a minimum of additional effort for your process model. A few considerations in advance and the specifications for the optimization problem are sufficient.