Bblocks Software for Thermoeconomic Analysis of Dual-purpose Power and Desalination Plants

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Abstract

This paper presents the main structure of the Bblocks (Building Blocks) software. Bblocks was a joint research project developed by the Research Centre for Energy Resources and Consumption, CIRCE, directed by A. Valero, and sponsored by The International Centre for Water and Energy Systems, ICWES, directed by Dr. D. Al Gobaisi. Bblocks was conceived for the thermodynamic and thermoeconomic analysis of dual-purpose power and desalination plants. Once a plant configuration was designed by means of its guided graphical interface, its steady-state performance could be easily calculated. Sensitivity analysis and thermoeconomic analysis of the configuration could be further performed, if desired. The end objective of Bblocks is then to search the optimum dual plant configuration in terms of energy efficiency, with the help of a user-friendly software tool.

Prof. Y. El-Sayed also actively collaborated in the design phase of Bblocks. His visionary research analysis of 27 feasible configurations to provide power (and water), including its own thermoeconomic optimization procedure, was a good start up to BBlocks. Moreover, some costing and modelling equations (including part load behaviour) developed in this analysis were included in Bblocks. He also visualized the need of a friendly-user interface that could allow a simple layout of any new configuration and its consequent analysis, taking into account the increasing capabilities of present computers.

Keywords: Desalination; thermoeconomics, simulation; optimization.

1. Introduction

Perhaps Prof. Y. M. El-Sayed was the first person who really dealt with the strong relationship between water and energy, especially when water is produced by energy intensive technologies. He was prolific in key scientific contributions: he was one that first used the term "Thermoeconomics" [1-2], or presented the first reference books on desalination [3-4], being also a pioneer in successfully linking both disciplines [5]. The design and optimization of complex energy systems [6-8], including the combined production of power plus water [9-10] was perhaps its best scientific challenge. All those issues were published in his latest book [11], in which 27 different energy configurations were thermoeconomically analyzed and optimized (6 of them related with power and water generation).

Prof. El-Sayed contacted another visionary person, Dr. Al-Gobaisi, who was the Director of the Water and Energy Department in the UAE in the 90s and promoted some universal projects like the EOLSS encyclopedia. By the year 1999, Dr. Al-Gobaisi proposed a research project to CIRCE Research Centre: to develop the Bblocks project.

The Building Blocks Software for Water and Energy Systems (Bblocks from now on) tried to tackle the complex solution of the synthesis and design of power and desalination facilities. In order to find the more sustainable solution to a combined power and water provider, it is highly desirable to let the choice of any system configuration entirely to the designer. Examples of

development in the same direction were yet given by Prof. El-Sayed in [6-11]. This, in turn, requires availability of software which should be totally modular in its conception: of course, computational facilities for modelling and simulation are then required. The thermo-economic analysis, environmental impact assessment and eco-efficiency evaluation, could be gradually included as further modular approaches. Anyway, computational tools incorporated in the software should go down to a device level: heat exchange devices, expanders, compressors, combustors, reactors, mixers, etc.

The present paper outlines an oriented object program which was developed in the said direction. Of course, Prof. El-Sayed ideas were immersed in the spirit of the program, which hopefully filled the gap in having user-friendly software in the form of Building Bblocks, as the appropriate framework to design either individual or integrated systems providing energy (and water). Such an approach transcends other traditional approaches for process integration and obviously it is a great help not only to designers but also to researchers, educators and students. New developments included in Bblocks are briefly explained here. They are related to include a new equations solver module, as well as to include a new module allowing thermoeconomic analysis of any configuration, once the thermal balance of the plant was successfully solved.

The subsequent sections outline the main features of the software program at its last version (v4.2, dated on

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December, 2006). Illustrations will correspond to a typical case study in Bblocks: the integrated analysis of a combined power (steam turbine) and a MSF desalination unit. Technical data correspond to Al-Taweelah B dual power and desalination plant (UAE) and MR case (Maximum continuous rating of power), which incorporates 6 twin units for providing 122 MW and 57.600 m³/d of distilled water, at their MCR operating mode (nominal production of both demands). Further details about the plant can be found in [12].

2. BBlocks Description

Bblocks is a stand-alone application for scientific and educational use. It is an object-oriented universal program developed in Java (thus compatible with Windows, Linux, Mac or any other operating system). The entire software code was specifically implemented here. Note that new software code is being created at the same time when the user introduces new information (piping, device attributes, connection, model options, etc.) about the configuration which is being analyzed. Consequently, it is not as fast as any other software based on an executable file.

Any selected energy and desalination plant may be studied in Bblocks by selecting some icons representing the various parts in the plant as building blocks. Bblocks will then automatically do mass and energy balances of the plant, thereby providing a powerful simulator for any given structure. Furthermore, Bblocks is able to perform a thermoeconomic analysis evaluating the exergy costs of the plant flowstreams. Thermoeconomic (causal) diagnosis of malfunctions in the plant devices can also be estimated, with respect to their design conditions or any other agreed reference. Next, a brief description of the three main programming modules of Bblocks is presented.

2.1 Graphic User Interface (GUI) to design a power + water plant

Bblocks structure is based on a powerful and easy to use Graphic User Interface (GUI). The GUI allows the user to build-up a plant layout by dragging and dropping elements onto a blank sheet from a collection database grouped by technology types. These elements represent processes or equipment (e.g. turbines, heat exchangers, boilers, desalination units, etc.), that are fully described by means of some properties and parameters, upon the request of Bblocks. Depending on the scope of analysis, simple but also complex models are available per each device. The GUI contains typical features in a 2-D design: elements include drag and drop, rotation, sizing, move, copy, automatic reposition or collating, double-click to modify properties, etc, Any flow sheet constructed in Bblocks would then be completed with the coherent interconnection of the elements: thus, non-viable configurations will be technically discarded. Figure 1 shows the use of Bblocks GUI in the case study. Al-Taweelah B (MR case, no distillate production) was modeled by a boiler, a 4-stages high-pressure steam turbine, 2-stages low-pressure steam turbine, 4 preheaters and their drainage valves, 2 pumps (condensate and feed), deaerator, condenser and cooling tower. If distillate is produced, the fourth extraction also provides the steam to the MSF unit, which can be designed in Bblocks by a specific window.

Below its standard windows appearance, it contains the typical ancillary functions of any commercial software:

- Assisted setup and uninstall; on-line help, customization and preferences.
- Menus, toolbars and shortcuts to access the most important and widely used commands
- New/open flow sheet and quit, with option to save the current work.
- Easy generation of new different plant states.
- Different calculation options (convergence criteria and solver methods).
- Direct access to diverse plan configurations.
- Printing the current depicted installation.
- Reporting the main results in a .txt file.
- Off-line help (User's manual in .pdf).

2.2 Simulator (calculation of heat and mass balances)

BBlocks is an open equations system, in the sense that the user is free to create a new installation, and therefore diverse systems of equations will be generated to solve the heat and mass balances (HMB) of that configuration. In order to solve the HMB, the same number of variables and equations is required. This was really the Bblocks bottle-neck: almost infinite power and water schemes could be tested, but enough information is required (design parameters of the devices, as well as plant set-points). Fortunately, in Bblocks the problem was solved by the use of the Tarjan's Algorithm [13], which is also used in the well-known software EES [14]. It is based on the Graphs Theory, and identifies, from the whole set of equations created by the GUI, the set of independent systems of equations (blocks of equations) that allow sequentially solving the entire system. If non-linear equations are involved in the system (real plant devices performance), adequate initial values for the variables are required, in order to help the user to find out the unique solution. In Bblocks v4.2, a set of initial values was automatically proposed, as a function of the plant set points and design parameters of the devices.

After a successful solution of the HMB of the depicted plant, numerical results from the heat and mass balances are presented in the thermodynamic table: mass flow, temperature, pressure, enthalpy, internal energy, entropy, specific volume, exergy, etc. Energy values involved in the different processes are also represented in a process table. Figure 2 shows the HMB results of the case study.

BBlocks was linked to Thermograph, which was also developed at Zaragoza University, and allows the use of thermodynamic charts. Once the installation has been depicted and solved, this facility represents the set of thermodynamic processes involved in the configuration, thereby improving its educational capabilities. In figure 3, T-s diagram of the case study is presented.

2.3 Thermoeconomic analysis tool

The thermoeconomic analysis is a powerful energy analysis tool combining Thermodynamics with economic aspects [15]. In the Bblocks environment, thermoeconomic costs and related calculations are based on the Structural Theory of Thermoeconomics [16-17]. Here exergy costs k* [15,18] are defined as the consumed amount of fuel exergy entering the plant for producing a given internal flow or a plant product. Bblocks proceeds with the Thermoeconomic analysis of the plant checking the Fuel, Product and Residues definition of any device composing the
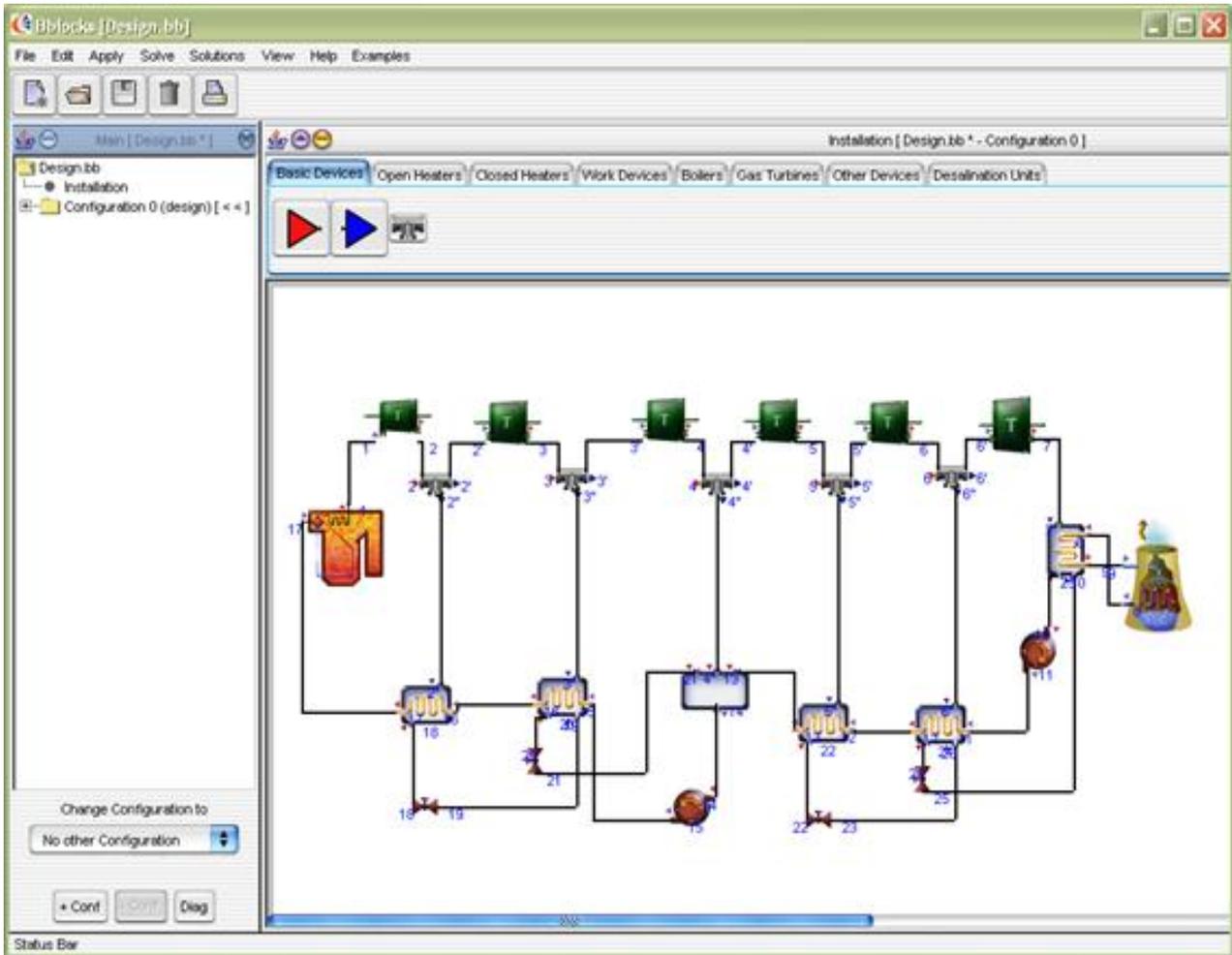
Figure 1. BBlocks GUI. Application to the MR case of Al-Taweelah B dual plant
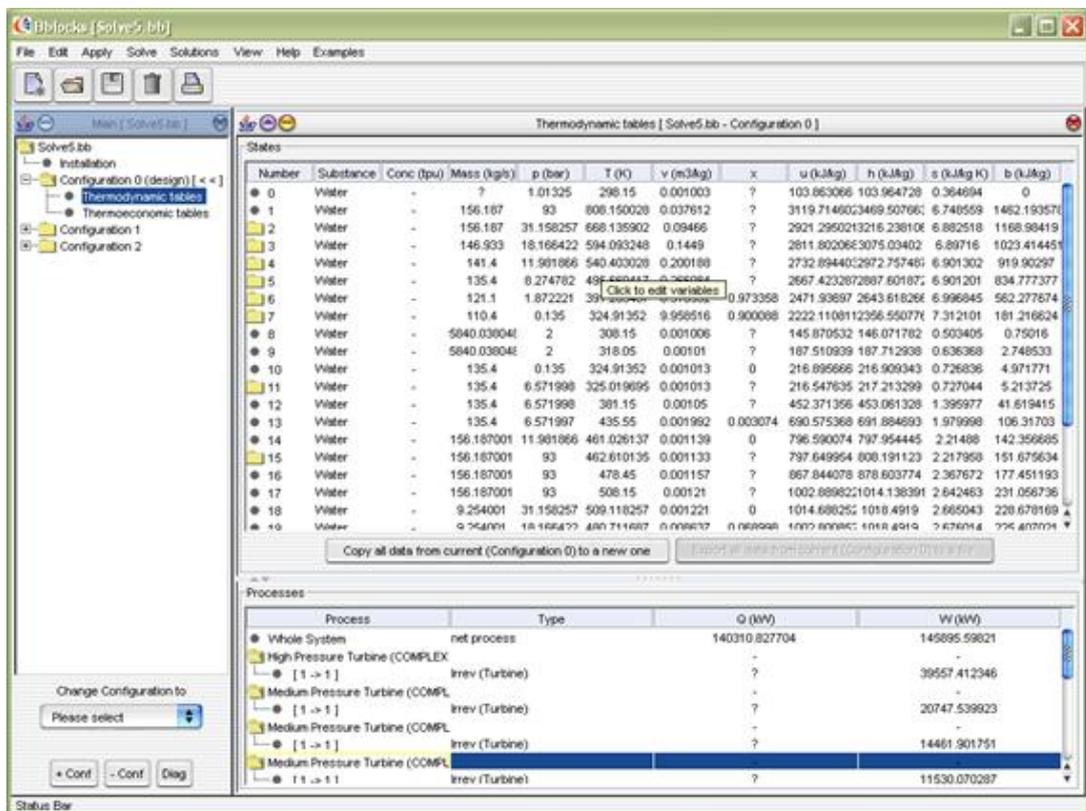
Figure 2. Successful solution of the HMB of Al-Taweelah B dual plant (MR case) in Bblocks: thermodynamic states and processes.
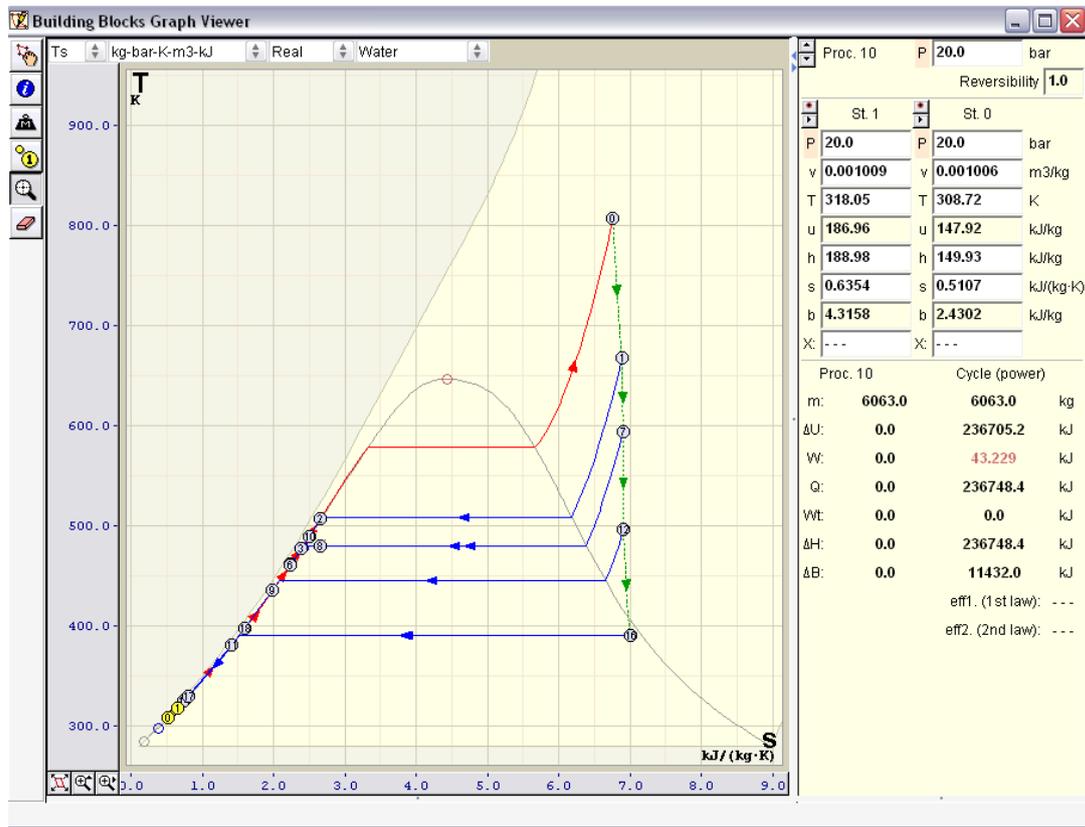
Figure 3. T-s diagram of the power cycle of Al-Taweelah B plant, MR case.

installation: it calculates the exergy costs of that main plant flowstreams. Once again, automatic calculation of exergy costs of every flowstream of the plant was not a simple task. It was solved in Bblocks by a specific algorithm that allows, from the Fuel-Product definition in each device, the cost calculation. Total costs C ($/kJ), that is, the addition of the exergy costs (in monetary terms) plus the amortization of the investment cost of any plant device Z ($) are also available. Costing equations provided by Prof. El-Sayed [9] were included in Bblocks, in order to help the user to find a realistic Z value for some devices.

The assessment of the fuel impact of malfunctions (operation diagnosis [15,19]) is also provided by Bblocks. The operation diagnosis informs about the cost of the inefficiencies occurring in the different plant units, and also how the inefficiency of a given unit affects the behaviour of the other devices, quantified in terms of additional fuel plant consumption. In order to apply the thermoeconomic diagnosis. For the latter, it is required to have two different operating conditions of the same plant. This second "picture" of the plant is very easy to create from a first one in Bblocks v4.2. Figure 4 shows the diagnosis of reducing the second stage of the low-pressure turbine efficiency (10%), in terms of an additional fuel consumption of the plant.

2.4 Software validation

The Bblocks v4.2 capabilities were validated with Al-Taweelah-B power and desalination plant at different operating modes. Additional 7 fully solved well-known examples can be found in [20].

3. Conclusions

Integrated analysis of combined power and water plants is really a complex issue. A systemic approach, as the one implemented in the Bblocks software, is required in order to detect the key aspects of the optimum operation of such complex systems. Otherwise, a properly and efficient synthesis and design needs to be found. Bblocks program fills the gap between water and energy issues research through a user-friendly software. The latter is available for students, researchers and technicians in the form of a building blocks approach, as it is the appropriate framework for the analysis, synthesis and design of either individual or integrated water and energy systems.

Unfortunately, optimization strategies developed by Prof. El-Sayed, including global but also a decomposition scheme of any configuration, were not finally implemented in BBlocks (v4.2). The main reason is its architecture and original conception: the open free-design environment does not allow selecting which are the free-design parameters to further optimize.

It is evident that some skills on thermodynamics, economics, power plant technology and desalination processes are required to make the most of Bblocks. Otherwise, the usefulness of Bblocks is really limited.

The Bblocks software is an example on how science works. Prof. El-Sayed visualised and put the conceptual foundations, Dr. Al-Gobaisi felt the industrial need for this tool and sponsored its development; and CIRCE generated it.
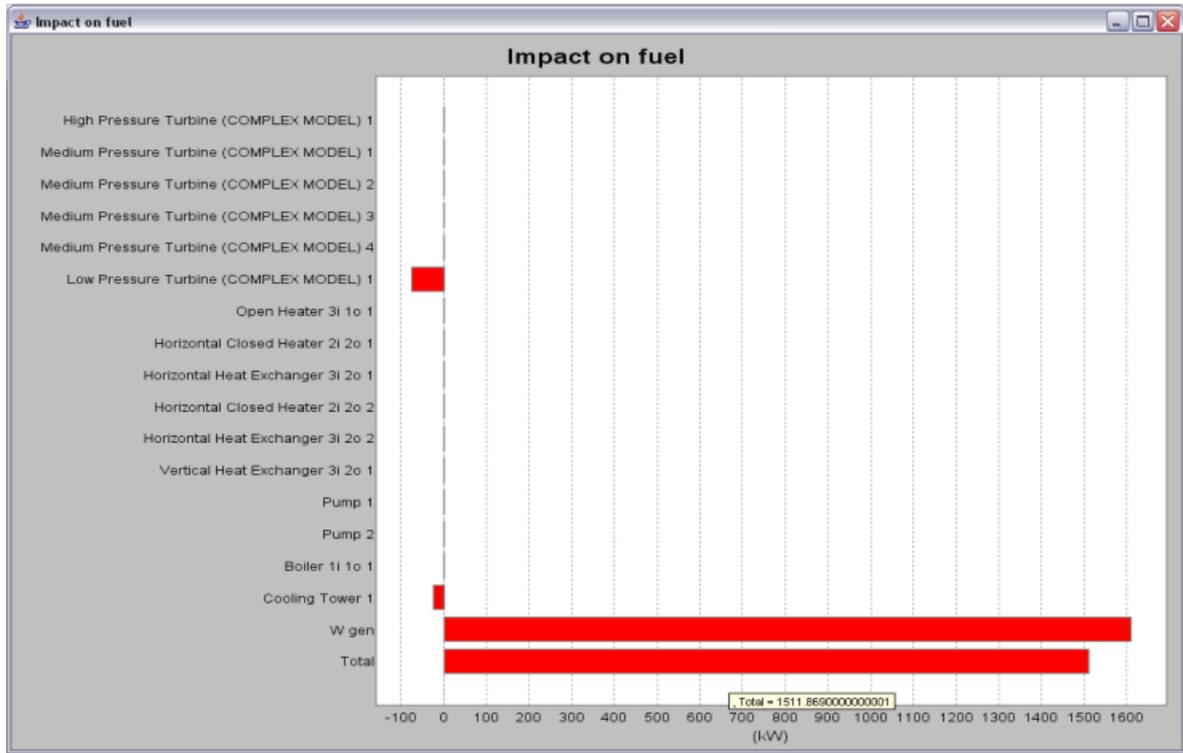
Figure 4. Fuel Impact graph of reducing the second stage of the low-pressure turbine efficiency.

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