Simulation of Combine Cycle Co-Generation Power Plant

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Abstract

Co-Generation Power Plant is used to produce power for electricity generation. At the same time, it may provide steam to be used for industrial process. Combine Cycle Co-Generation Power Plant is a power plant that uses natural gas as fuel for the combustion process in gas turbine engine. A part of electricity generation is coming out from turbine which is driven by hot combustion gas. The exhaust gas which has sufficient heat can be used as a heat source for a steam generator and produce another part of electricity generation and by-product steam using in process. The control of the operation of the Combine Cycle Co-Generation Power Plant as described above is a difficult and complex task for plant's operator. Consequently, the simulation of the Combine Cycle Co-Generation Power Plant can be used for training the plant's operator, so he can earn up more experience, knowledge and skill before going to operate the real plant. This can save time, money and reduce risk coming out from operator's error. The objective of this research is to create a simulator of the Combine Cycle Co-Generation Power Plant which is an existing plant in Thailand. The simulator is built by the MODELIX software, which is a software for power plant modeling. The simulator is divided in two parts, the first part is a simulation of fluid flow in the plant by using sub-program HYDRAULIX and the other part is a simulation of the control system of the plant by using sub-program CONTROLIX. The data for simulation is extracted from the operating condition of the real plant and used to validate the model, so the simulator can run the same way as the real plant. The condition of the simulator is done in various situations such as at full load, partial load, start-up or shutdown plant, etc. Benefit of this research can be used for training the plant's operator and the concept of the model simulation can be used to develop the simulator of the power plant that has a similar configuration.

Key Word : Simulation, Combine Cycle Co-Generation Power Plant, Electricity Generation, Steam Production, Training

1. Introduction

Cogeneration is considered to be a very cost-efficient means of generating both electricity and thermal energy from the same fuel source [1]. The cost efficiency comes not only from the generation of electricity, which can be used to reduce the expense of purchased utility power, but also from the fact that the generated steam is used twice [2-3]. The combined cycle cogeneration consists of gas turbine and steam turbine cycle, which can be controlled and adjusted the capacity of electricity and steam with wide range while maintaining the same efficiency. The control training of this system could not be taken by the plant's operators to

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practice directly at the real system because it could be loosed much more profits or to be dangerous for themselves when occurring the mistake of controlling. Moreover, this system have also complex controlling, therefore the new operators could be not succeeded for the controlling of real system. The combined cycle cogeneration simulator can be used to train the new operators to understand the control system until they become to be the expert operators and therefore shift to the real system [4]. This solution is the best procedure to improve the problems.

2. Modelix

Modelix [5] is an integrated modeling software development tool, featuring a common user interface and enabling modeling of fluid systems, electrical systems and I&C systems including logic diagram and control loop. This software is written in C language and use techniques of memory allocation, dynamic address calculation, and dynamic link to object libraries. Modelix is a CAD type Graphic Design Tool, component-oriented which enable model to be built, tuned and tested. The Modelix program has divided into three modules, Modelix-Hydraulix, Modelix-Controlix and Modelix-Electrix, which inside each module has contained standard objects which are minor parts used to create model circuits. Inside each object has also contained mathematics model equations. User can bring out these following objects to create the model circuits as user objective, furthermore, the user can also be created new objects (not standard objects) by used proceeding management in the Modelix program.

(1) Modelix-Controlix software has been specially designed for drawing the process interlockings, automatic sequences and control loops. The I&C part of each plant has many particular and specific features (special function, objects, etc). However, the basic principles of the I&C logic and analog operations vary little from plant to plant. Modelix-Controlix software relies on a sequential algorithm and processes three types of objects:

(1.1) Input objects: these are mainly sensors or operator actions, which model the information processing by instrumentation e.g. scaling, saturation, conversion etc.,

(1.2) Processing objects: these are the controllers (P, PI, PID, …), analog calculation or logic gates.

(1.3) Output objects: these are alarms, lamps for digital processing and actuators, set point for analog controllers.

(2) Modelix-Hydraulix module type objects are divided into four different types:

(2.1) Nodes are the “places” where the (mass and energy) balances, which are the main equations of the problem, are evaluated. They are also the “places” of the main variables of the circuit (pressure and enthalpy).

(2.2) Arcs are junctions for momentum balance yielding mass (for flow paths) and / or energy flow rate. The Arc links the two nodes or boundary conditions to one the other, it is the places of the fluxes used to compute the balances of the two adjacent nodes. These fluxes must be expressed in terms of the main variables of the two adjacent nodes.

(2.3) Boundary conditions are limited conditions, which are particular Nodes whose main variables are in fact parameters, assumed to be known at the time of solving. This only partially covers the notion of limit condition of the simulated system, for example, it uses to defined ambient temperature, which is all through constant during simulated.

(2.4) Sensors are the “passive” objects, which enable the model outputs to be calculated from status variables (or from intermediate variables): for the example calculating a temperature from the pressure and enthalpy of a Node or scaling of certain variables.

(3) Modelix-Electrix modules are used to create simulator for electrical systems but due to this research did not do in case of electrical systems, therefore these modules will not be explained in these documents.

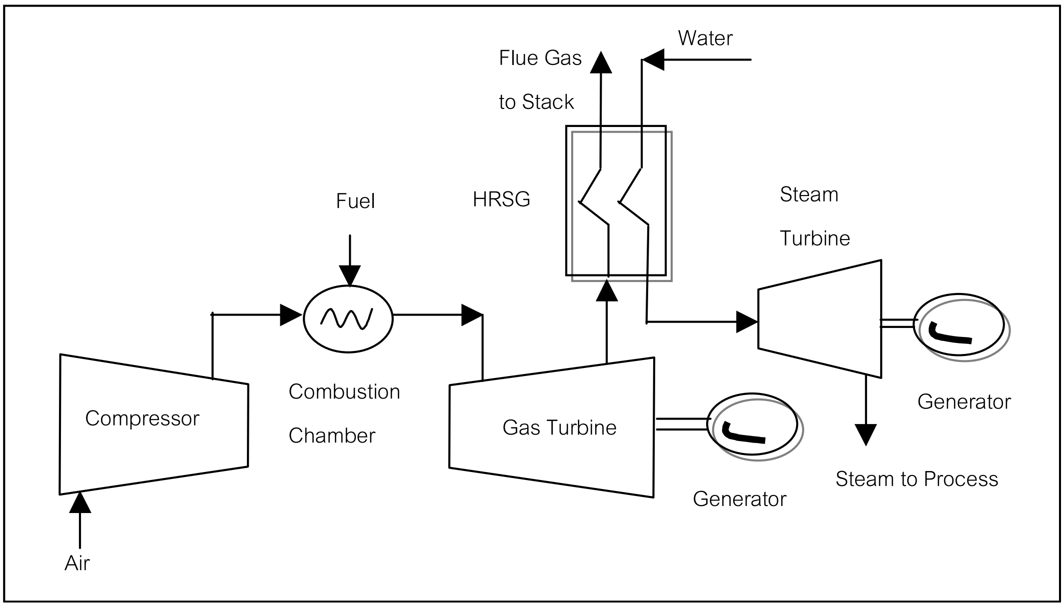

Figure 1 Combined cycle cogeneration system.

3. Combined Cycle Cogeneration System

Combined cycle cogeneration is a cycle that includes steam and gas cycle, which has a higher thermal efficiency than either of the cycles executed individually. Procedure criterion of general combined cycle can demonstrate as in figure 1; fresh air at ambient conditions is drawn into a compressor where its temperature and pressure are raised. The high-pressure air proceeds into a combustion chamber where fuel is burned at constant pressure. The result high-temperature gases then enter to gas turbine where its expand to the atmospheric pressure, thus producing electric power by generator. Exhaust gases leaving the turbine still have sufficient high-temperature for producing steam at Heat Recovery Steam Generator (HRSG). The exhaust gases flow into the HRSG and then transfer heat fluxes to water, thus creating high pressure steam. The result steam will flow into steam turbine, expanding, then flow to condenser, condensing at the low pressure. During the steam is expanded from high pressure to low pressure, this process can produce work to drive the generator and also creating electric power. The process of combined cycle cogeneration of electricity power plant for this research is shown in figure 2. The main accessories for one set of the plant consist of gas turbine, HRSG (Heat Recovery Steam Generator), HP (high-pressure) drum, steam turbine, condenser and deaerator & feed water tank. The sequence of procedure starts at the gas turbine system which is the same function as already mention above. The result exhaust gases leaving the gas turbine (average temperature around 550-560 °C) have flowed to the HRSG through large duct and then have been increased the temperature to about 600-700 °C by supplementary firing load which has obtained from another burner. After that the high-temperature exhaust gases have flowed continuously into HPS2 (High Pressure Superheater) and then transfered heat fluxes to superheated steam, which coming from RMC (Reducing Mixed Chamber) until its temperature is increased up to 430 °C. Then the hot exhaust gases have flowed continuously and also transferred heat fluxes to water in the several part of HRSG untill the temperature have been decreased to around 120 °C and then rejected to atmosphere. The steam conditions leaving the part of HPS1 have the average temperature around 365-370 °C, the condensate water conditions leaving part of HPEC2 and CSP have the average temperature around 255-265 °C and 100-110 °C, respectively.

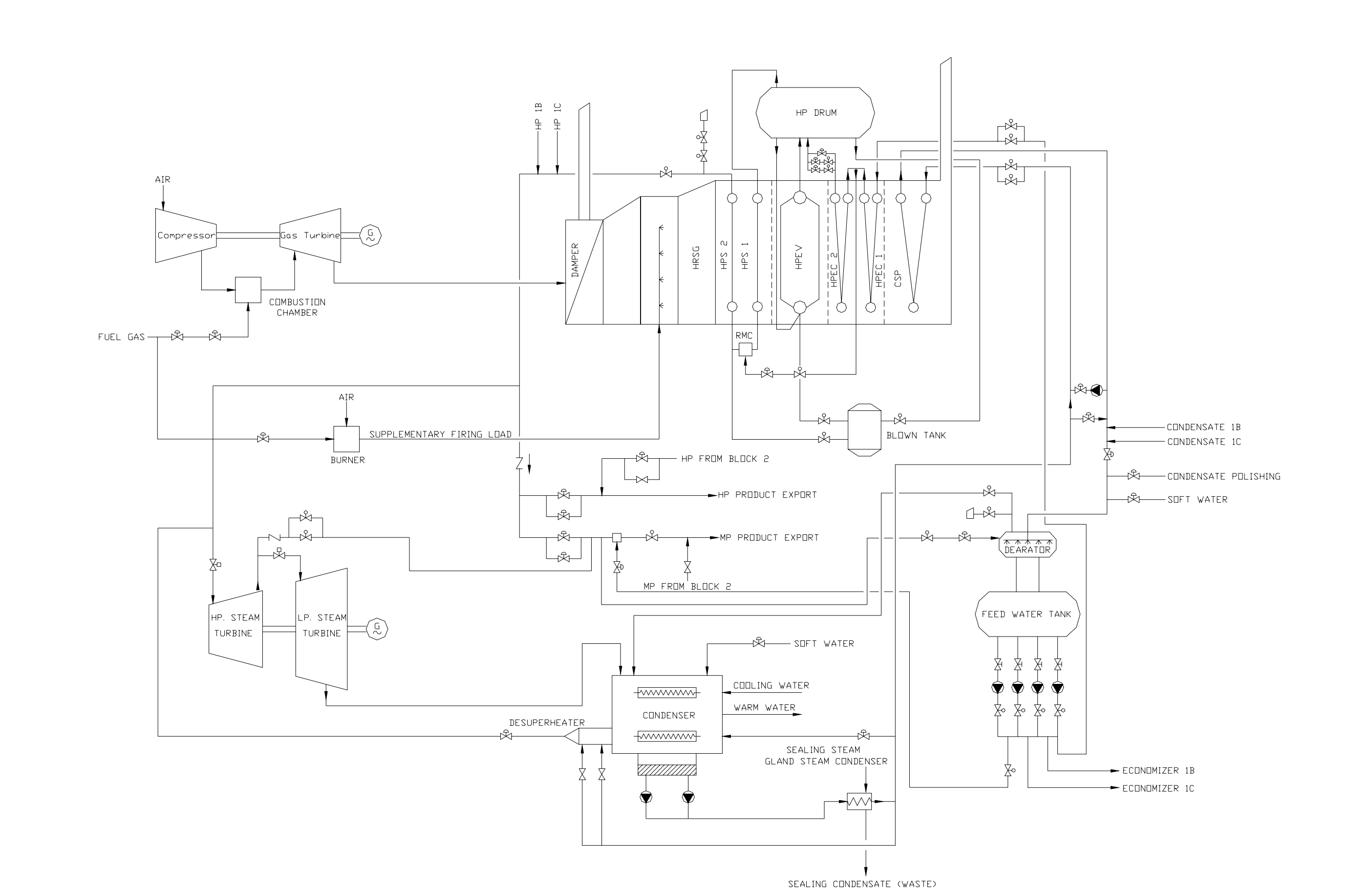

Figure 2 The combined cycle cogeneration system of electricity power plant

Some of HP superheated steam product is obtained from HRSG, flowing continuously to steam turbine when the remaining steam has flowed through expansion control valves, summing with the other unit (block #2) and then exported to consumers. Furthermore, these control systems can be changed direcly from the HP steam product to MP steam product by adjusting the other expansion control valves. Some of steam leaving the high pressure steam turbine has transferred to be the MP product after passed the process of decreasing in temperature at the mixing chamber before exporting to comsumers. The sum capacity of HP and MP steam products have produced around 200 tons/hour at 45 bar (g) and 20 bar (g), respectively. Some of steam passing the low pressure steam turbine has flowed into a condenser, condensing at vaccum pressure around 80-130 mbar and the steam then became to condensate water. The condensate water have been sent to HRSG in part of CSP for increasing its temperature by condensate pump. After that the condensate water flow back to the deaerator for eliminating oxygen which suspended in its. The pure condensate water has been filled in a feed water tank which has been sent back to the HRSG in part of HPEC1&2 and then flowed into the HP drum again by feed water pumps.

4. Creation of Simulator of Combined Gas and Steam Cogeneration by MODELIX

The cogeneration system consists of much more minor element accessories, e.g., valves, tanks, heat exchangers, pumps, etc., which procedure of creating the simulator must also be created from these minor element accessories and then connected by symbolic link again. Hereafter, we would like to explain some examples of creating the minor element accessories.

4.1 Valve and pipe

Model of valve and pipe is illustrated in figure 3. CLT (A1 and B1) are one type of object boundary condition which represents the pressure upstream and downstream and PCH (C1) is one type of Arc object which represent the valve or the pipe. Conditions, which have to be known for defining the several parameters, are shown below.

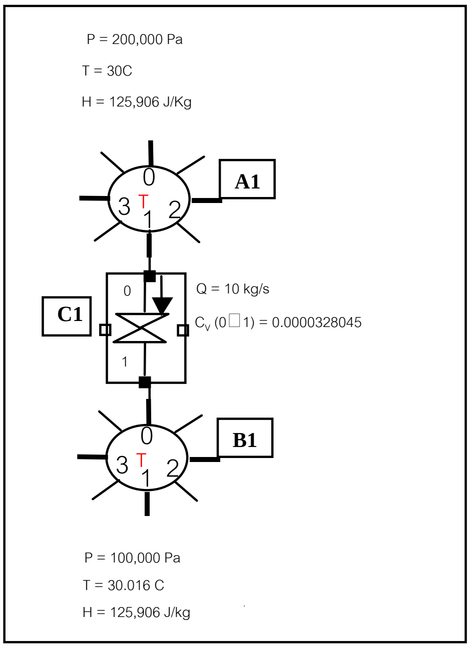

Figure 3 Valve and pipe model

(1.1) Pressure drop across valve (P_1 = 200,000 Pa and P_2 = 100,000 Pa)

(1.2) Temperature at the upstream and the downstream (App. 30 C)

(1.3) Flow rate passing valve (Q_1 = 10 kg/s)

The mathematical model of valve and pipe is in the following form :

$$Q = c_v \Delta P \quad (1)$$

By validating the parameters in this simple model, the coefficient c_v of 0.0000328045 can be obtained.

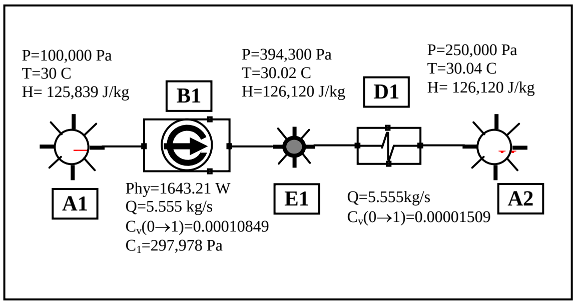

Figure 4 Pump model

4.2 Pump

The conditions which must be known for defining the model of pump are as follow;

(2.1) Flow rate of pump

(2.2) Total dynamic head of pump

(2.3) Efficiency of pump

(2.4) Speed of pump

For example, assume that we would like to create model of pump, which has flow rate of 5.555 kg/s, total dynamic head of 30 m., speed of 3,000 rpm. and efficiency of 60%.

Model of pump is illustrated in figure 4. E1 is one type of nodes, its name is standard homogenous node. B1 is one type of arcs, its name is pump for model of pump. A1, A2 and D1 are the same Boundary Conditions and Arc which described previously. Knowing pressures and temperatures of A1, A2 and E1, we can determine their physical conditions. After that, we define speed, efficiency and maximum total dynamic head at nil flow rate

(C_1) of B1 object and then running the program in order to obtain a suitable valve of conductivity (C_v $0 \rightarrow 1$) of B1 object. After we already get the several exact values, the procedure is completed. Performance curve of pump's characteristics is defined to be linear or quadratic for B1 object.

After several minor element accessories models were created and then moved or copied to create the combine-cycle cogeneration circuit, running again to looking for some fault values and improving until we can got the complete simulator of combined gas and steam cycle cogeneration system. Some circuits are shown as follow.

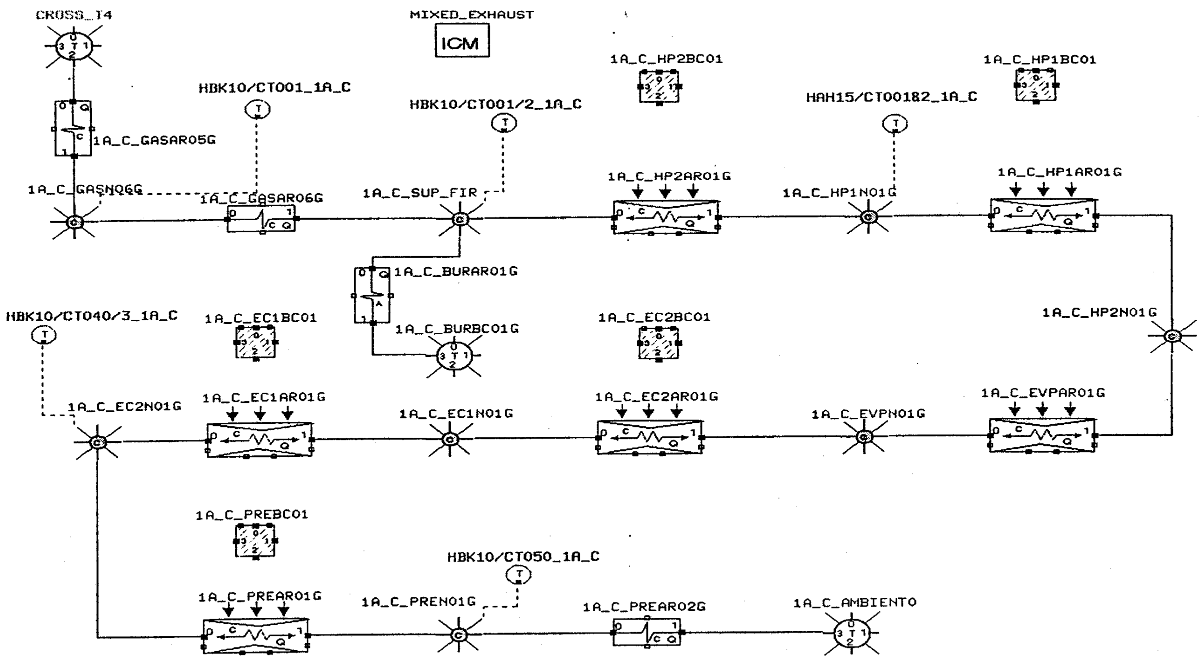

Figure 5 Exhaust gases model circuit of HRSG

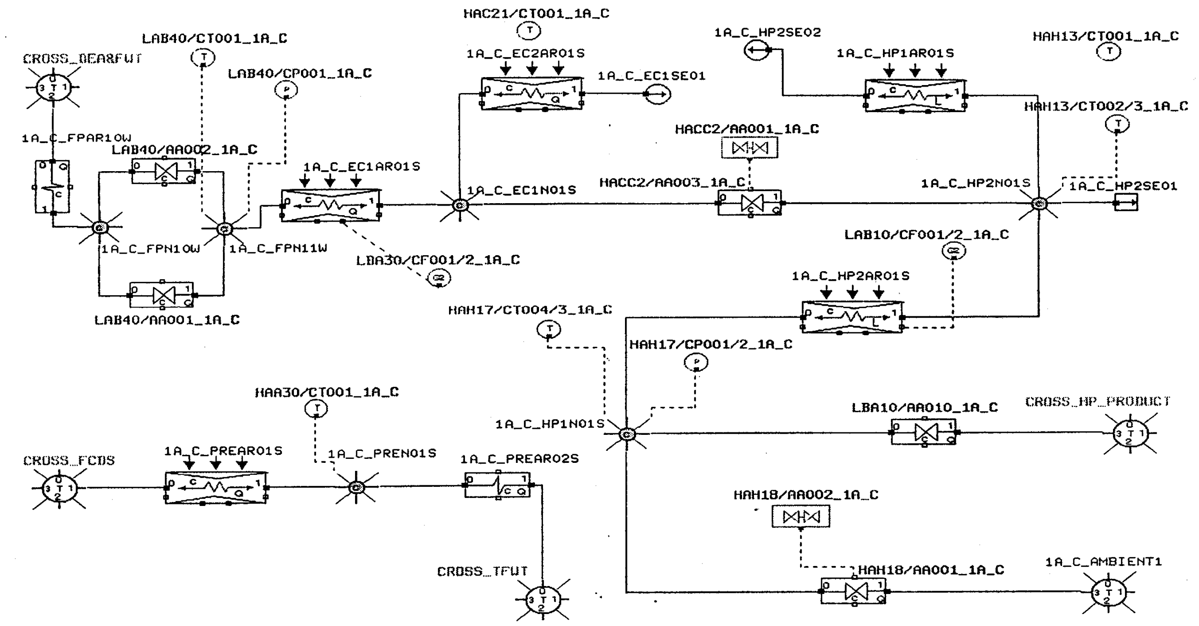

Figure 6 Steam model circuit of HRSG

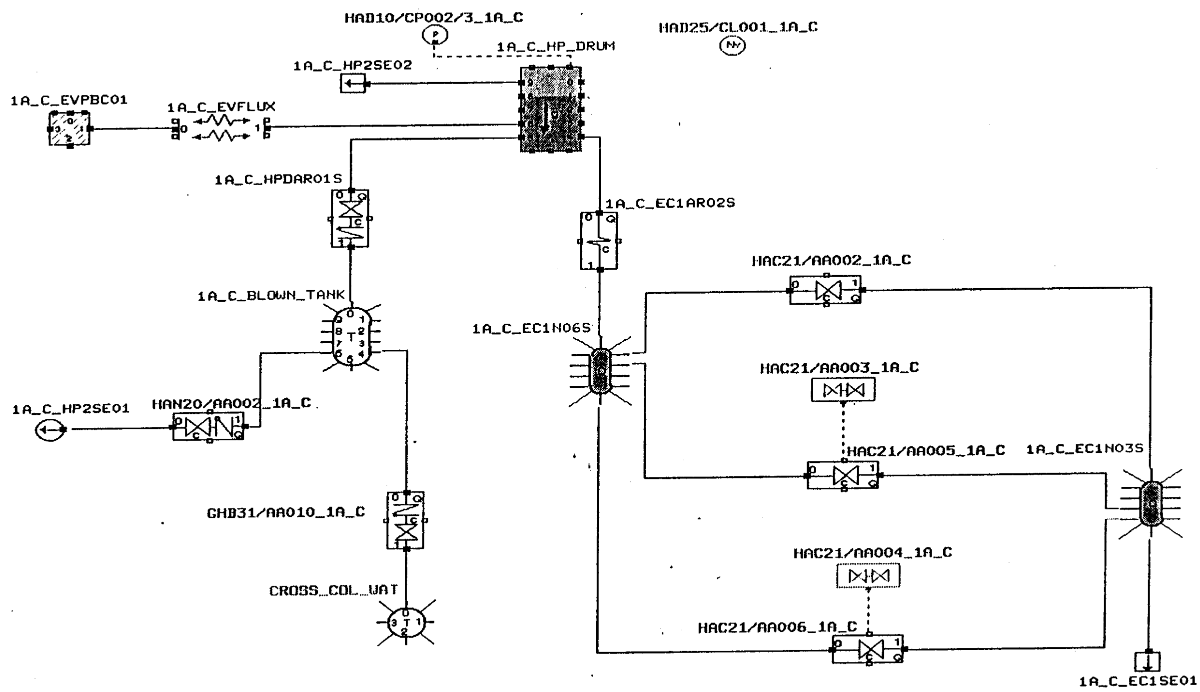

Figure 7 HP drum model circuit of HRSG

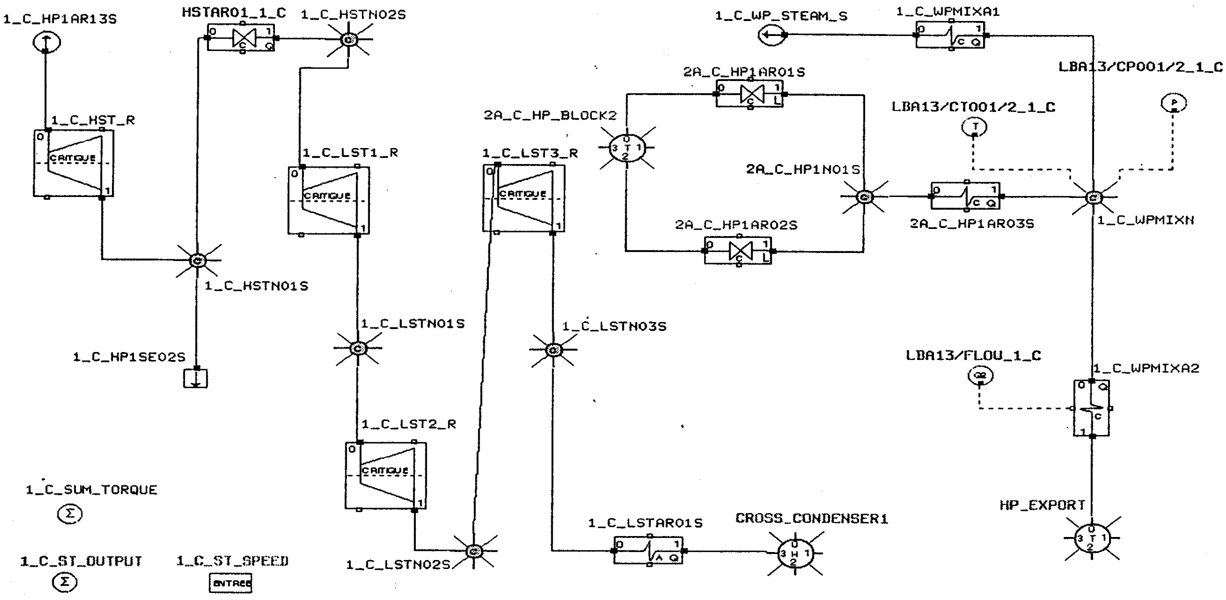

Figure 8 Steam turbine model circuit

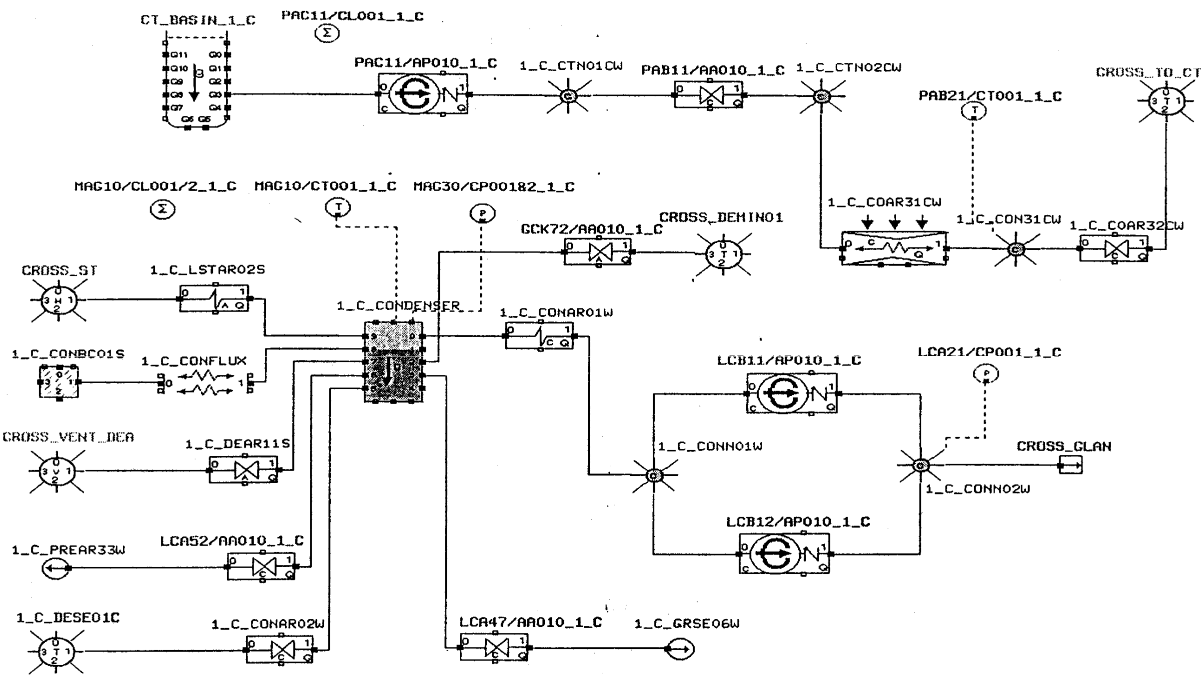

Figure 9 Condenser model circuit

Table 1 Running #1 : Values obtained from the model and the real plant

No	Description	Simulated Value	Real Value	Units
1.	Gas turbine power output	**34.18**	33.8	MW
2.	Fuel gas flow rate	**2.29**	2.3	kg/s
3.	Ambient temperature	29	29	^oC
4.	Compressor discharge pressure	**10.01**	10	Bar (g)
5.	Exhaust outlet temperature gas turbine	**556.29**	556	^oC
6.	Producing steam pressure HRSG	**52.71**	52.7	Bar (g)
7.	Producing steam flow rate HRSG	**108.48**	108	T/h
8.	Producing steam temperature HRSG	**429.01**	430	^oC
9.	Export MP steam pressure	**21.12**	21.0	Bar (g)
10.	Export MP steam temperature	**277.17**	277	^oC
11.	Export MP steam flow rate	**135.20**	135	T/h
12.	Export HP steam pressure	**47.61**	47.6	Bar (g)
13.	Export HP steam temperature	**420.04**	421	^oC
14.	Export HP steam flow rate	**129.08**	129	T/h
15.	Steam turbine power output	**50.30**	50.2	MW

Table 2 Running #2: Values obtained from the model and the real plant

No	Description	Simulated Value	Real Value	Units
1.	Gas turbine power output	**34.67**	34.8	MW
2.	Fuel gas flow rate	**2.54**	2.14	kg/s
3.	Ambient temperature	28.5	28.5	^oC
4.	Compressor discharge pressure	**10.15**	10.13	Bar (g)
5.	Exhaust outlet temperature gas turbine	**556.8**	556	^oC
6.	Producing steam pressure HRSG	**53.32**	53.31	Bar (g)
7.	Producing steam flow rate HRSG	**104.69**	105	T/h
8.	Producing steam temperature HRSG	**430.08**	430	^oC
9.	Export MP steam pressure	**20.03**	20.2	Bar (g)
10.	Export MP steam temperature	**267.1**	266	^oC
11.	Export MP steam flow rate	**84.95**	89.5	T/h
12.	Export HP steam pressure	**47.7**	47.6	Bar (g)
13.	Export HP steam temperature	**424.31**	421	^oC
14.	Export HP steam flow rate	**155.74**	154.2	T/h
15.	Steam turbine power output	**32.14**	31.7	MW

Table 3 Running #3 : Values obtained from the model and the real plant

No	Description	Simulated Value	Real Value	Units
1.	Gas turbine power output	**33.08**	33.5	MW
2.	Fuel gas flow rate	**2.48**	2.03	kg/s
3.	Ambient temperature	32	32	^oC
4.	Compressor discharge pressure	**9.9**	9.88	Bar (g)
5.	Exhaust outlet temperature gas turbine	**559.17**	559	^oC
6.	Producing steam pressure HRSG	**52.85**	53.18	Bar (g)
7.	Producing steam flow rate HRSG	**102.62**	103	T/h
8.	Producing steam temperature HRSG	**431**	431	^oC
9.	Export MP steam pressure	**19.89**	20.1	Bar (g)
10.	Export MP steam temperature	**259.8**	259	^oC
11.	Export MP steam flow rate	**64.37**	66.7	T/h
12.	Export HP steam pressure	**47.66**	47.5	Bar (g)
13.	Export HP steam temperature	**427.12**	420	^oC
14.	Export HP steam flow rate	**162.36**	164.7	T/h
15.	Steam turbine power output	**35.37**	35.4	MW

5. Summary and Suggestion

The results of this simulator have shown the good agreement between simulated and observed values (see table 1-3) and can also be used to simulate the manual control of the real cogeneration system. However, there are still some deviation values from the values obtained by the real instrument. For example, the flow meter of natural gases in the part of gas turbine has been set the density constantly but the real natural gases are not constant. When the density is not same, it can be effected the values of flow rate obtained by the model.

Finally the MODELIX program can be used to apply to build the simulator for every engineering projects especially the power plant or nuclear power plant industry systems.

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