MODELLING AND ANALYSIS WITH ECOSIMPRO OF A NUCLEAR POWER PLANT HEAT SINK BASED ON A COOLING POND

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Abstract

The heat sink of any Electrical Power Generating Plant is a fundamental element of the thermodynamic cycle from which part of the thermal energy produced can be recovered for export. The heat removal capacity of the heat sink has direct repercussions on cycle efficiency and consequently on the energy efficiency of the complete installation. One of the most typical heat sinks in large installations is the natural circulation heat sink. In this work we have used the capabilities of EcosimPro to model and analyse the heat sink of a nuclear power plant based on a cooling pond of large dimensions.

Key Words: Simulation, EcosimPro, heat sink, cooling pond.

1. INTRODUCTION

The heat sink is a fundamental element of any thermodynamic cycle in an electrical power generating plant, thanks to which the cycle can be put into effect to recover a significant part of the energy generated in a heat sink (heat recovery steam generator, nuclear reactor, etc) and converted into mechanical energy (turbines) and ultimately into electrical energy for export (generator). The main objective of a heat sink must be to cool the energy transmission medium of the cycle (typically water) to its minimum recoverable energy point. The point of interaction between the plant cycle and the heat sink is usually the main condenser. Under any operating conditions, the heat sink must guarantee sufficient heat removal to ensure that installation efficiency meets the design requirements.

Cooling towers (mechanical or natural draft), air-cooled condensers and natural resources such as the sea, fast flowing rivers or large natural and artificial reservoirs are some of the typical heat sinks in large electrical energy generating plants.

On sites where a constant supply of reasonably cold water can be ensured, it is common practice to use such low cost resources to cool the plant. In the particular case of nuclear power plants it is also typical to use water, thanks to the large masses available either from natural sources or artificial reservoirs.

Modelling the thermal efficiency of the heat sink is fundamental in the design of the installation. Analysis of an operating heat sink can help us to make changes or modifications in the operation of certain equipment in order to optimise overall performance of the installation. When the heat sink is a reservoir, it is not an easy task to determine its efficiency because of the different interactions between the elements involved -condenser, external environment, water feeds and discharges- each with a significant transient component.

2. OBJECTIVE

The purpose of this project is to model a heat sink which is already in operation, based on the cooling pond of a nuclear power plant. The model will also include the response of the plant cycle vis-à-vis the performance of the heat sink.

Once the validity of the model has been demonstrated, we will analyse possible technical solutions for improving heat sink efficiency from the point of view of performance of the complete installation.

3. THERMAL-BALANCE COMPONENT LIBRARY

Using the component library Thermal-Balance developed in EcosimPro, models can be built for carrying out thermodynamic analyses which include typical components that are representative of equipment which normally forms part of the cycles of hydroelectric and fossil-fired power plants, nuclear power plants and combined cycle gas turbine power plants. This library has been extensively used in studies directed towards the improvement of performance and the prediction of thermodynamic cycle behaviour in electrical power generating plants.

The library contains the following components:

Abstract Components

COMPONENT	FUNCTION
Channel	Component with a *water* IN port and OUT port
AdiabaticChannel	Channel with equal inlet-outlet enthalpies
Burner	Gas component in which combustion takes place

Figure 1 illustrates the components in this library. The library uses two types of ports, "water" and "gas", for the working fluids water-vapour and gases, respectively.

Operating Components

COMPONENT	FUNTION
AirInlet	Air supply
Alternator	Electric alternator
Aux_turbine	Auxiliary turbine
Boiler	Boiler
Chamber	Combustion chamber
Compressor	Compressor
Conden_SPE	Gland steam condenser
Condenser	Main condenser
Deaerator	Deaerator
Dereheat	Dereheater
Divider	Water divider
DrainCooler	Drain cooler
Drum	Boiler drum
Economizer	Economizer
Evaporator	Evaporator
FeedWaterHeater	Cycle feedwater heater
Flash_Tank	Flash tank
Fuel_room	Fuel storage pool
Gas_inlet	Gas inlet
Gas_Turbox	Gas turbine
Gpipe_nat	Gas pipe
Heater	Heat exchanger (i)
Hexu_mod	Heat exchanger (ii)
Mixer	Mixer
MoistSeparator	Moisture separator
Motor	Internal combustion motor
Orifice	Restriction orifice
Pipe	Pipe
Pump	Pump (I)
Pump_n	Pump (II)
Reheater	Steam reheater (with steam)
Reservoir	Reservoir (heat sink)
Split	Gas flow divider
Superheater	Superheater
Tower_m	Mechanical draft cooling tower
Tower_n	Natural draft cooling tower
Tower_tab	Cooling tower whose behaviour is defined by tables
Turbine	Steam turbine stage
Valve	Valve (I)
Valve_cv	Valve (II)
Valve_sb	Valve (III)

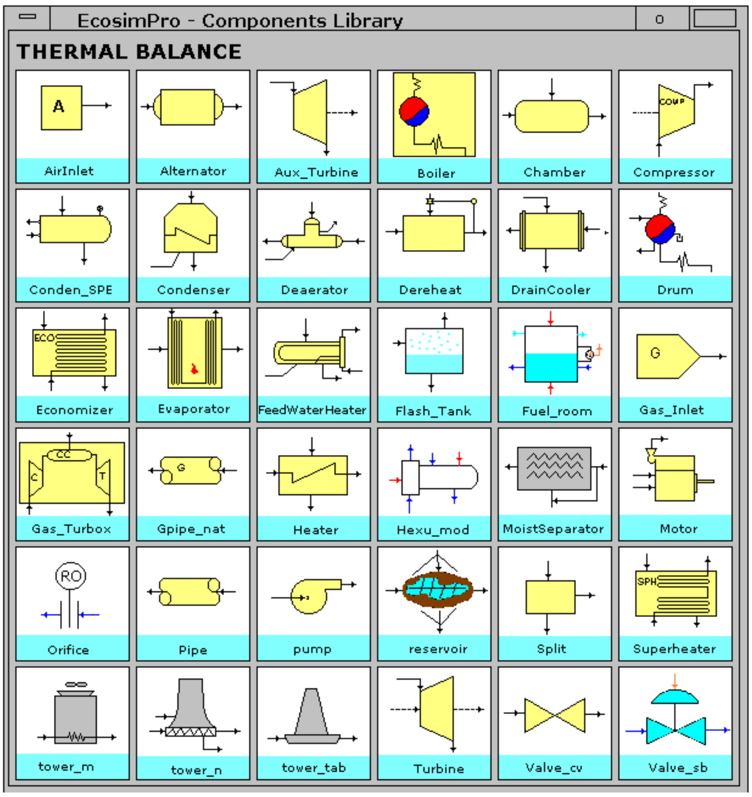

Figure 1

4. RESERVOIR COMPONENT

The reservoir component contains the physical-mathematical model which simulates the thermodynamic interaction of a large mass of water with the atmosphere and with other components with which it might be linked via ports of the "water" type. The main part of this component is formed by the equations that model the heat balance in the water-atmosphere heat exchanges, which are briefly and mainly as follows:

- Heat received by solar radiation: hr
- Heat received by long wave atmospheric radiation: *han*
- Heat exchanged by convection and conduction: *hc*
- Heat exchanged by radiation from water: hbr
- Heat exchanged by evaporation of water: hbr

The following is the program of the component part which models the above-mentioned energy exchanges.

```
--------------------------------------------------------------
CONTINUOUS

-- Determinacion de parametros ambientales

          TBH = t_b_humedo(Patm,HR,TBS,Ha,TD,EA,Ww)
          eammhg = EA * 750.0620188

--  Presion  de  saturacion  del  agua  a  la  temperatura  del
embalse

          EXPAND (k IN 1, nodos)
                    es[k] = H2O_Psat_vs_T (tembalse[k],IU())
          EXPAND (k IN 1, nodos)
                    esmmhg[k] = es[k] * 750.062188

-- Evaporacion (funcion de viento corregida para 18 ft segun
-- NUREG 0693, se aplica coeficiente 0.91814 según formula -
-- del HUTTE: Wx=Wy/(y/x)^(1/7))

          funcion_de_viento   =   a_viento   +   b_viento   *
          0.918**2*vel_viento * vel_viento
          EXPAND (k IN 1, nodos)
                    he[k] = (esmmhg[k] - eammhg) * Area[k] *
                    funcion_de_viento

--  Radiacion atmosferica de onda larga (1.2e-13 /3412.14 --
-- /24/.3048**2)
          EXPAND (k IN 1, nodos)
                    han[k] = 1.5773e-17 * ((TBS*1.8 + 32) +
                    459.57)**6 * Area[k]

--- Radiacion reflejada

          EXPAND (k IN 1, nodos)
                    hbr[k]    =    4.026e-8    *    (459.67    +
                    (tembalse[k] * 1.8 + 32.))**4 * Area[k]
                    / 3412.14/24/.3048**2

--- conveccion y conduccion

          EXPAND (k IN 1, nodos)
                    hc[k]   =   0.26   *   1.8   *   Area[k]   *
                    (tembalse[k] - TBS) * funcion_de_viento

--- Caudal de agua evaporado

          EXPAND (k IN 1, nodos)
          w_evap[k] = he[k] / H2OLV_H (tembalse[k])

--  Radiacion solar

          EXPAND (k IN 1, nodos)
                    hr[k] = rad_solar * Area[k]
```

The large dimensions of a cooling pond make it possible to simulate its behaviour in the form of different adjoining "nodes" in which –and within each of them- the complete mix hypothesis is sufficiently close to reality. Each of the nodes can be connected to other components which accept "water" ports, making it possible to add or remove water at different points of the reservoir. It should be noted that the existence of a thermal barrier across half the water surface is typical in this type of reservoir in order to obtain better flow times (water flow increases considerably) and in this way facilitate the exchange of heat with the atmosphere.

5. BUILDING THE HEAT SINK MODEL

The model which is going to simulate the behaviour of our heat sink will comprise the following elements:

- The cooling pond, with connecting ports at different points
- A simplified component, denominated "ciclo_condensador", which reproduces the behaviour of the plant cycle in response to temperature variations in the heat sink

The simplified component contains a set of curves which reproduce the response of the cycle to different inlet temperatures to the condenser (the inlet temperature relates to the vacuum which our condenser is capable of producing, and from this we can deduce the energy which our plant turbine is capable of generating).

The reservoir component is connected to the "ciclo_condensador" component at two points (condenser inlet-outlet). The reservoir component in turn has two ports where the water makeup (and corresponding temperature) or removal flows can be fixed at the temperature of the reservoir. The reservoir component will also be affected by the prevailing meteorological conditions (dry bulb temperature, relative humidity, solar radiation, atmospheric pressure and wind speed) which will affect the final capacity for plant heat removal.

Figure 2 below illustrates our system:

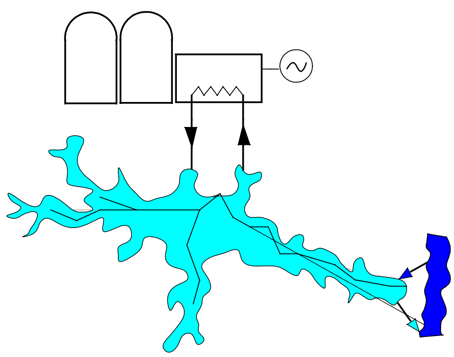

Figure 2

6. VALIDATING THE MODEL

The model built with EcosimPro was validated vis-à-vis real measurements. Reservoir behaviour was simulated for several years past, from which the following information was obtained:

- Averages of meteorological parameters with an hourly frequency
- Averages of plant operating modes
- Reservoir makeup water averages and the temperature
- Averages of reservoir water temperature in different areas of the water flow

The meteorological parameters, the annual operating mode and the makeup water flows with the temperature were used as input data. The results of temperatures throughout the reservoir were compared with real measurements taken in the water. The simulation was run for different years for which recorded measurements were available.

It can be seen that the simulation is correct for most of the year. The result is somewhat conservative during the hotter periods (summer). We can also clearly see two areas of relative minimum temperatures which coincide with two refuelling outages that took place during the year analysed.

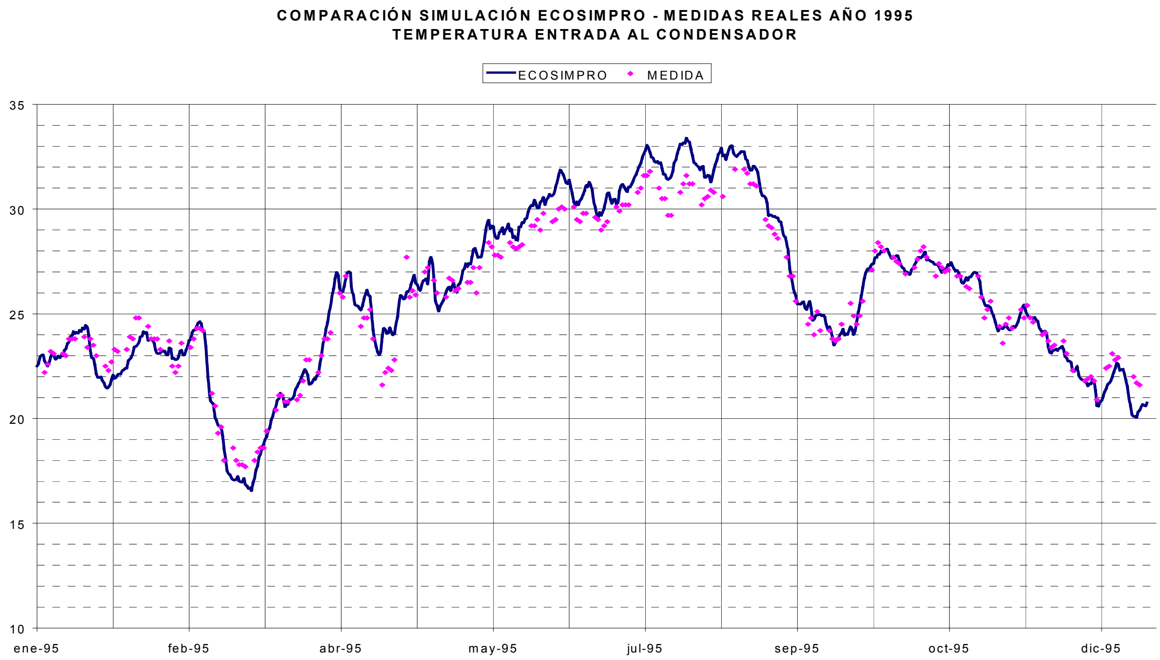

Figure 3

7. HEAT SINK OPTIMISATION ANALYSIS

The validated model of the plant heat sink makes it possible to analyse new operating modes or design changes with a view to improving plant output. Thanks to the versatility and the possibility of extended the range of EcosimPro components, it is relatively easy to carry out studied to assess design changes.

The analyses carried out were grouped into two parts:

- Analysis of operating modes
- Analysis of changes in the design of the heat sink

7.1 ANALYSIS OF OPERATING MODES

A study of was carried out of possible variant plant operating in order to obtain better heat sink temperature results. Changes in the circulating flows and in the flows added to the reservoir from the river were analysed.

7.2 ANALYSIS OF CHANGES IN THE HEAT SINK DESIGN

It was this activity which involved most work. Different modifications to heat sink operation were analyses, focusing on the incorporation of new equipment to remove a considerable part of the heat load to be dissipated: natural draft and mechanical draft cooling towers.

As an example, Figure 4 illustrates one of the configurations studied: incorporation of a natural draft cooling tower between the condenser outlet and the inlet to the reservoir.

Figure 4 (***)

To construct this model, use was made of one of the components included in the Thermal_Balance library, namely, the natural draft cooling tower ("tower_n"). With the available meteorological records and a forecast of the plant operating mode, we simulated the operation of the new configuration. Subsequently, a technical-economical analysis was made of the suitability of this type of improvement.

As an example, Figures 5 and 6 show the simulation result with regard to water temperature at the condenser inlet and the production of electrical energy operating under present conditions compared with those corresponding to the proposed new configuration. We can clearly see the drop in temperature at the condenser inlet during much of the year with the new configuration, and consequently the increase in electrical energy generated.

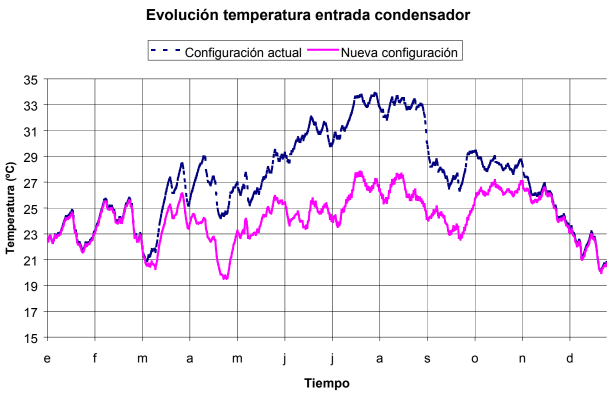

Figure 5

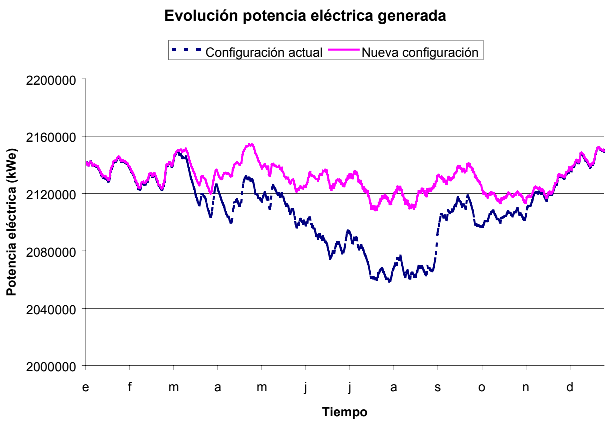

Figure 6

8. CONCLUSIONS

A heat sink has been successfully modelled based on a nuclear power plant cooling pond with natural draft circulation. The components we have used from the Thermal_Balance library of EcosimPro have demonstrated correct modelling of physical energy balance phenomena between the water and the atmosphere.

The model constructed will enable analyses to be carried out of the current plant configuration with a view to optimising power output.

Acknowledgements

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