Water management at CCGT unit

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Abstract: This paper discusses a water management optimization of cooling towers. Description of a problem solution as well as its industrial application is included. The used software belongs to Emerson's SmartProcess products. It has been applied to two power plants as a part of the Ovation DCS (distributed control system).

Keywords: optimization, Ovation, SmartProcess, power plant, cooling towers, Combined Cycle Gas Turbine

1. Object Description

New Combined Cycle Gas Turbine (CCGT) units located in West Burton in the UK and Blénod-lès-Pont-à-Mousson in France are cooled via wet cooling towers (hybrid cooling towers, for West Burton). Those towers are fed with clarified river water. A pump station is created on a river site. Pumps provide water to the pre-treatment units, which produce clarified water needed by cooling towers. Also this clarified water is used as demineralised water at the power plants. Those pre-treatment units are today the best available technology to produce clarified water from raw river water and to prevent bacteria (legionnel) growth in the tower basins. The pre-treatment unit works with very slow physicochemical reactions. Stabilization of the process is also slow. Any change in the flow rate upwards has to be slow (max. +10 % per hour) in order to have water quality at the output compliant with the tower specifications. Therefore, it is impossible to have the makeup water flow produced by the pre-treatment unit simply in-line with the tower needs. From that reason clarified water storage is put between the pre-treatment units and the towers.

2. Problem Description

Triple goal of the water optimization CCGT unit is the following:

- to produce enough water to satisfy exactly consumption needs for every forecasted hour in any case of unit operation,
- the pre-treatment unit should run as long as possible with lowest production rate. Water produced during a unit shutdown would be stored in the tank for next a unit startup – optimizer will take care of not overflowing it,
- to keep water volume in the storage close to minimum level defined by an operator and if necessary allow him lowering this minimum.

Water majority is consumed by the cooling tower due to evaporation. A part of water is used to compensate liquid having an excess concentration of minerals and apart is used by a demineralization unit. Total storage consists of a clarified water basin (1000 m^3) and a cooling tower basin (600 m^3). Process driven filling of make-up water basin for demineralisation (400 m^3) and cleaning of sand filters (200 m^3/h) are other water consumers and as unplanned are treated as upsets in optimization The optimization program considers storage as a common tank defined by two adjustable parameters for maximum and minimum capacity. The pre-treatment units have operational limitations like: a min/max flow from 155 m^3/h to 518 m^3/h and an hourly ramp rate (increasing: max 10 % in 30 min; decreasing: 100 % in 15 min) when changing its flow rate. They may produce "fresh" water, run in recirculation mode or go into shutdown. There are two pre-treatment units. Only one pre-treatment unit is running most of the time. The water production should be in line (with some tolerance satisfied by a water buffer) with the forecasted water consumption. The water consumption is a function of load and ambient conditions like temperature and humidity. Forecasted data should cover at least 24 hours to come.

3. Optimizer

3.1. Optimization approach

The proposed solution considers usage of general purpose solver for the mixed integer linear optimization problems. The software provides the user with abilities to find solution of x (a vector of independent decision variables) in the feasible regions (which are determined by a set of equality/inequality constrains), such that the local or global minimum or maximum) value of the objective function J, (which is a function of x), is obtained. The mathematical form of the optimization problem can be stated as follows:

$$\underset{x}{Min} \quad J = f(x)$$

$$s.t. \quad \begin{cases} g(x) \le 0 \\ h(x) = 0 \\ x_{i,\min} \le x_i \le x_{i,\max} \end{cases}$$

where x_i is either an integer or a real number.

To construct an optimization problem for the software to solve, all the coefficients in f(x), g(x), and h(x) need to be specified. Different values of those coefficients determine different „cases" or „scenarios" of the same optimization problem. For example, in the water production optimization problem when the forecasted water consumption or actual water buffer (most likely a coefficient in g(x) or h(x)) are changed, the optimal solution of x may be changed. As a result, the optimization problem needs to be solved again.

3.2. Objective function

Three conditions of the water optimization CCGT unit are defined by functions that calculate sum of different type of deviations. Sum of these three functions creates objective function. The goal for the optimizer is to find minimum of this objective function. The production is understood as water delivery for consumption - water for recycling is excluded from the process. The real variables x in the optimization problem are: setpoints for the pre-treatment units, Boolean variables to determine when to start/stop the pre-treatment units, another set of real variables that dynamically adjust the minimum storage volume. There are total 72 manipulated variables that are being changed between 155–518 m^3/h, 0–1 and 0–V_{min} accordingly. Constraints are: max/min flow limits, max flow rate ramp change, max/min storage capacity. Coefficients are: the number of pre-treatment units to run, the volume of water currently stored, the flow rate, consumptions from previous hour.

3.3. Optimizer implementation

The optimization program will search for a problem solution combined of 24 one-hourly problems. These 24 hours are hours to come from current hour. As result of the solution found are 24 setpoints for the pre-treatment units. Every hour the optimizer will search for a new solution since forecasted loads can change as well as ambient conditions. Also buffered water may increase or decrease from prediction volume so new initial conditions will be used for finding a new solution. The optimizer can be triggered by time (every hour) or any time on demand by operator. An operator is informed that the solution is found (or not). If the solution is found, setpoint for first hour is sent to the pre-treatment units where it becomes the current setpoint value. The change will be done with some ramp rate. A user can modify the previously entered values any time. Again, the optimizer always takes into computation first 24 hours.

4. Examples of Future Scenarios

The unit is operating in the cycling mode (1 start and 1 stop per day). It is required to keep the pre-treatment unit running continuously as long as possible from that reason the pump is started few hours ahead of unit startup and keep running at a minimum flow. Clarified water fills up the water storage close to the maximum value. At certain time pump increase the flow to cover consumption and leave storage at a minimum level (fig. 1).

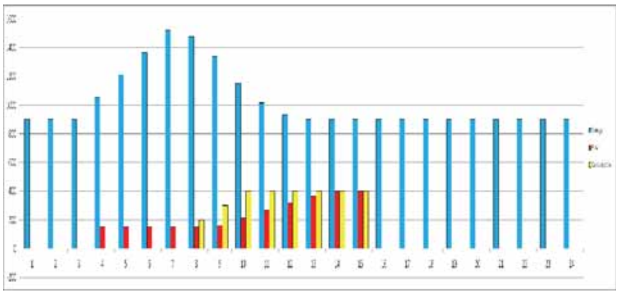

Fig. 1. Cycling work case 1 (colors: blue – storage, red – production, yellow – consumption)

Rys. 1. Praca cykliczna bloku – bilans wody typ 1 (kolory: niebieski – zasób, czerwony – produkcja, żółty – zużycie)

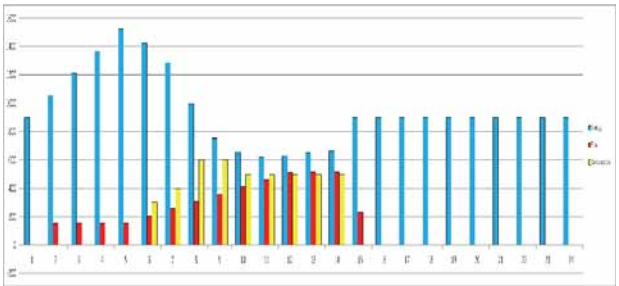

Fig. 2. Cycling work case 2 (colors: blue - storage, red – production, yellow – consumption)

Rys. 2. Praca cykliczna bloku – bilans wody typ 2 (kolory: niebieski – zasób, czerwony – produkcja, żółty – zużycie)

The unit is operating in the cycling mode (1 start and 1 stop per day), but the pump cannot keep up with the demand. It is need to use water stored temporarily and next restore the water buffer (fig. 2).

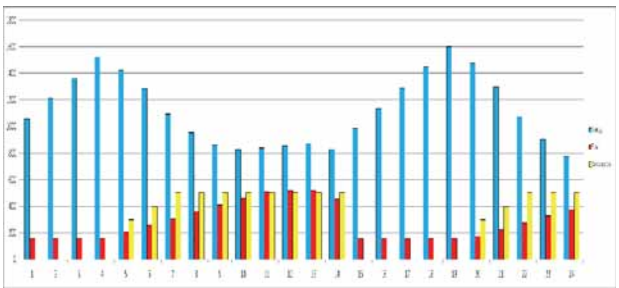

Fig. 3. One by one cycle (colors: blue – storage, red – production, yellow – consumption)

Rys. 3. Posobne cykle pracy bloku – bilans wody (kolory: niebieski – zasób, czerwony – produkcja, żółty – zużycie)

The unit is operating in consecutive cycles mode (more than 1 start and stop within 24 hours). The pump is working continuously (fig. 3).

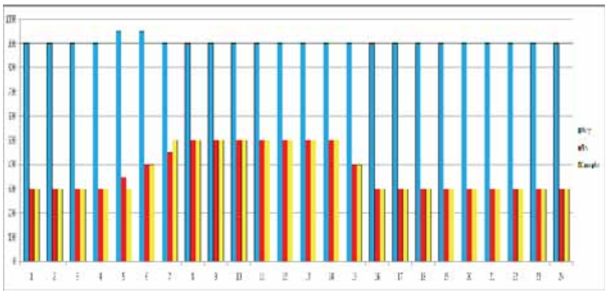

Fig. 4. Continuous work (colors: blue – storage, red – production, yellow – consumption)

Rys. 4. Praca ciągła bloku – bilans wody (kolory: niebieski – zasób, czerwony – produkcja, żółty – zużycie)

The unit is operating continuously. The pump is working continuously. Water production balances water consumption (fig. 4).

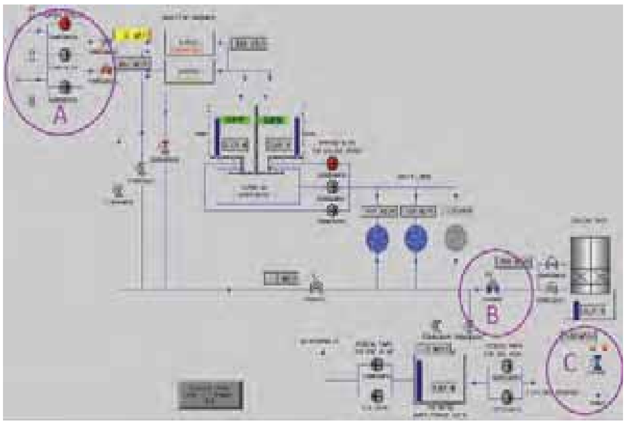

Fig. 5. Overview of the process at Blénod-lès-Pont-à-Moussonan power plant

Rys. 5. Ogólny schemat procesu przygotowania i obiegu wody chłodzącej w elektrowni w Blenod-lès-Pont-à-Moussonan

5. Ovation System Aplication

5.1. Hardware and software

Several control sheets with a set of algorithms are developed on a dedicated virtual controller to calculate the following values: actual and forecasted water flow consumption for the next 24 hours based on load (MW), ambient temperature and relative air humidity forecast which is received by OPC communication. Based on water consumption prediction and on water production forecast, volumes of stored water and of rejected water are calculated for the next 24 hours. The optimization package belongs to Emerson's SmartProcess products. The optimizer is a standalone linear solver of Frontline interfaced with the Ovation DCS by the OPC bidirectional communication. It comes with the MySQL database and runs on a separate Windows station. It runs fully integrated with the Ovation system. These values along with volume of currently stored water and water flow from the pretreatment units are sent to the optimizer. The optimizer, in turn, returns found solution as setpoints for the pretreatment units. The optimizer runs every one hour or on an operator request.

5.2. Equipments concerned

The water optimization solution has a direct connection to control of the following equipments: the river intake pumps (A), the control valve for water flow to cooling the tower basin (B), and the control valve for removal water having an excess concentration of minerals (C). The proper water flow setpoint of the river intake pumps is calculated with the help of the optimizer. The proper water flow setpoint of the control valve for water flow to the cooling tower basin is calculated in standard Ovation control sheets (normally the setpoint is equal to the water consumption). In the same way the proper valve position is calculated for the control valve for water removal having an excess concentration of minerals.

5.3. Operator Interface

Fig. 6. Ovation graphic with pop-up window of forecasted setpoints

Rys. 6. Grafika procesowa systemu Ovation z okienkiem prezentacji wartości zadanych

This is a process parameters graphic. It shows: water consumption forecast (m^3/h) for the next 24 hours, water production forecast (m^3/h) for the next 24 hours (this is what is calculated and updated by the optimizer in automatic mode or flow setpoints entered by operator in manual mode), stored water forecast for the next 24 hours, rejected water forecast for the next 24 hours, pop-up window from which optimizer parameters are entered, pop-up window from which water production setpoints are entered by operator (manual mode), buttons to start/stop pre-treatment units, button to validate scheduled water production setpoints in manual mode for the next 24 hours. It shows the forecast (MW, ambiant temperature, relatvie air humidity) coming from OPC communication or being entered manually by operator for today and tomorrow.

An optimizer input interface is developed in standard Ovation graphics. The solution can work in an automatic or manual mode. In the manual mode, the water production setpoints for the next 24 hours are entered manually by an operator (from pop-up "REMOTE SETPOINT MODE" on the graphic in fig. 6). In the automatic mode, they are calculated and updating by the optimizer every hour. If a solution is found, this new solution is taken into computation. If no solution is found, the solution of previous hour is kept. Results of the optimizer can be consulted even in the manual mode (from pop-up "REMOTE SETPOINT MODE" on the graphic in fig. 6). In the automatic mode, setpoints (coming from the optimizer) are automatically taken into computation. In the manual mode, an operator has to press the button "VALIDATION" to make his flow setpoints take into computation by the program. The four following parameters for the optimizer are entered by an operator (from pop-up "OPTIMIZER PARAMETERS" on the graphic in fig. 6.): max capacity (m^3), min capacity (m^3), number of the pre-treatment units (in automatic mode it is the current value of running pre-treatment units but in manual an operator can modify it for simulation), max flow rate (m^3/h).

6. Conclusion

An estimation of water consumption by the cooling towers is based on history of the weather conditions in past years. Some simulations confirmed the correct optimizer operation. It is expected that cost of water pre-treatment process will be reduced significantly after final implementation of the optimizer. Currently the unit is running with overproduction of clarified water. Water excess is turned back to the river. For a full practice test, it is need a few months of real operation.

Bibliography

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Optymalizacja gospodarki wodą w bloku gazowo-parowym

Streszczenie: W artykule omówiono optymalizację gospodarki wodnej w chłodni wentylatorowej. Podano opis rozwiązania problemu jak również jego zastosowania w przemyśle. Zastosowano część oprogramowania z pakietu SmartProcess dostarczanego przez Emersona. Pakiet użyto w dwóch elektrowniach, jako uzupełnienie rozproszonego systemu sterowania Ovation.

Słowa kluczowe: optymalizacja, Ovation, SmartProcess, chłodnia wentylatorowa, Cykl Kombinowany w Wysokosprawnej Kogeneracji

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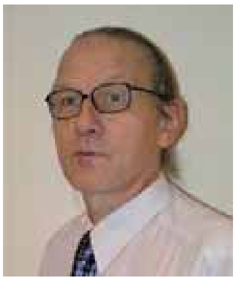

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