Chapter One { TC "Chapter One " \l 1 }

Introduction

1.1 Brief system description - the steam cycle power plant{ TC "1.1 Brief system description - the steam cycle power plant" \l 2 }

Steam cycle power plants work on the principle of a Clausius-Rankine cycle. One characteristic of such a cycle is that not all the energy that is fed into the system can be converted into useful work. Common thermal efficiencies of modern steam cycle power plants are on the order of 39%. That means that 61% of the energy input has to be rejected as waste heat into the environment. For the purpose of heat rejection water is usually used as a coolant. There are in general two kinds of cooling systems, the once-through system and the closed-circuit system.

In a once-through system the cold water is taken from a natural source, which is a river or lake in most cases. The hot water is then discharged directly back into the water body downstream of the power plant. A once-through cooling system is the most efficient as it uses the lowest temperature of cooling water that is available. However, using a once through system can result in thermal pollution of the water body, into which the heat is discharged. The amount of heat that can be rejected may be limited by environmental regulations or by the amount of water that is available. Especially in summer months the availability of water can cause serious problems for plant operation.

In a closed-circuit cooling system the hot plant discharge water is cooled down by using cooling devices such as cooling towers or cooling ponds. The cold water is then again used for cooling purposes. The only water needed from outside the cycle is make-up water that compensates for losses. Although a closed-circuit system is less efficient than a once-through system, as the water inlet temperatures are usually higher than for a once through system, most steam cycle power plants use closed-circuit cooling. This is due to environmental regulations that in most cases do not allow once-through cooling.

This work focuses on the examination of the cooling system of the Columbia Generating Station near Portage, Wisconsin, which is operated by the Wisconsin Power&Light Company. The Columbia Station is a coal fired power plant with two units, each rated at 535MW electrical output. The condenser cooling system is of the closed-circuit type. It consists of a cooling pond and two cooling towers that are operated in parallel to the pond. Make-up water is drawn from the nearby Wisconsin River. A combination of cooling ponds and cooling towers is rather unique, as usually either cooling towers or a cooling pond is used, but not a combination of several devices.

The reason for this configuration is the way the Columbia power plant was originally designed. When the plant was laid out, first one unit was designed and the cooling pond was sized for the heat rejection of this unit. As the second unit was added environmental restrictions prohibited adjusting the pond size correspondingly because the Columbia station is located in a wetland area. Therefore the cooling towers had to be added to the cooling system to ensure appropriate capacity of the cooling cycle.

The need for the cooling towers becomes obvious when the average heat load on cooling ponds is reviewed. Jirka and Harleman [11] give ranges of heat loads for cooling ponds of 1.5 to 2.0 MW/acre for a number of operating plants. The heat load on the Columbia cooling pond is calculated to 4.2 MW/acre if the design plant load is assumed at a thermal efficiency of 33% when no cooling towers are operated. Thus the cooling towers ensure sufficient cooling capacity.

From an economical point of view cooling ponds are considered to be cheaper in operating costs than cooling towers, if the required land area is available at a reasonable price.

A cooling pond needs less auxiliary power to operate and the maintenance effort is less intensive. That is why a cooling pond was chosen as the primary heat sink of the Columbia plant.

1.2 Objective{ TC "1.2 Objective" \l 2 }

The efficiency of a steam cycle power plant, and thus its fuel economy, is to a large extent dependent on the cooling water temperature that is supplied by the cooling system for condenser cooling. The water temperature influences the plant performance in that the turbine back pressure developed in the steam condenser is dependent on cooling water temperature. Back pressure or turbine exhaust pressure is the primary variable that determines the steam cycle efficiency at otherwise constant conditions. A high back pressure not only reduces efficiency but can also limit the capacity of the power plant.

During summer months the cooling water temperature at the Columbia power plant becomes high, leading to a high back pressure and even to a cutback of produced power at certain times. Diurnal fluctuations are observed in the water temperature with the daily high in the early afternoon and the low in the night. The fluctuations in water temperature effect the plant performance, as the highest water temperature and therefore the lowest efficiency occurs when the electric demand is the highest. Lost power at high demand hours can be costly for the plant operators when electric power has to be purchased from other producers.

Considering the effect of the cooling cycle behavior on overall plant performance and the economical impact, there is a strong motivation to find a way of optimizing the cooling system and to achieve lower cooling water temperatures.

The general proposals of ways to optimize the cooling cycle performance were stated by the plant operators. These proposals include changing the water flow rate of the pond, dredging the pond or adding devices such as a cooling spray. Before this study was performed, the decisions would have probably been made by trial and error. For example, the decision to put sprays into the pond was almost made without examining the required spray system size to achieve a considerable effect. The same is true for the proposal to deepen the pond by dredging, which was also almost carried out without looking at the real effects. After a detailed analysis performed in this work, both ideas of dredging and of a cooling spray were rejected. Thus the need of a more reliable method to evaluate changes in the cooling system becomes obvious.

To optimize the cooling system of the Columbia station, first the single components have to be studied. The components of the cooling circuit are the cooling pond and cooling towers. In addition the possibility of adding devices to the cooling system is considered; for this purpose an atmospheric cooling spray is examined.

The closer examination of the single components is performed by building mathematical models of the components that are converted into computer programs. In this way the behavior of, for example, the cooling pond can be examined under different ambient and plant operation characteristics. The same is done for the cooling towers and a cooling spray.

There are previous studies found in the literature that can be used for building mathematical models of the components, namely cooling towers and cooling ponds. A pond flow model is developed in this work, that is suited to the actual cooling pond.

As the cooling cycle interacts with the power plant, links between water temperature and plant performance are needed. This is done by building computer models of the condenser and of the steam cycle to examine the influence of cooling cycle behavior on overall plant performance. The primary interest of the plant operators is to reduce the production costs. Therefore the plant efficiency has to be converted into operation fuel costs.

The present work takes a different approach from what is found in the literature. The power plant components of interest are not examined separately or only at design conditions. A transient system model is set up that allows a study of the behavior of the system under different ambient and load characteristics. Using the system model, it is possible to study diurnal water temperature fluctuations and the impact on performance on an hourly basis. In comparing the costs for different modifications of the system the best alternative can be found.

1.3 Software for simulation{ TC "1.3 Software for simulation" \l 2 }

As outlined in the previous section, computer models have to be built of the plant components. Following a short description is given of the software used for this task.

1.3.1 An Introduction to TRNSYS and a Description of its Components{ TC "1.3.1 An Introduction to TRNSYS and a Description of its Components" \l 3 }

TRNSYS is a transient system simulation program with a modular structure. The program is well suited to simulate the performance of systems, the behavior of which is a function of the passage of time. This is the case if outside conditions that influence the system behavior change, such as weather conditions, or if the system components themselves go through conditions that vary with time, such as storage, for example a cooling pond.

Modular simulation of a system requires the identification of components whose collective performance describes the performance of the system. Each component has to be formulated by mathematical equations that describe their physical behavior. The mathematical models for each component have to be formulated in FORTRAN code, so that they can be used within the TRNSYS program. Formulation of the components has to be in accordance with the required TRNSYS format. A basic principle in this format is the specification of PARAMETERS, INPUTS and OUTPUTS for each component. Parameters are constant values that are used to specify a certain component; this can be for example the geometry parameters of the cooling pond such as length, depth and width. Inputs are time-dependent variables that can come from a user supplied data source or from outputs of other components, for example weather data or plant discharge temperatures.

There can be several components of the same type specified in one simulation. The way this is accomplished is that a component is assigned an identifying type number that is component specific. A second number, the unit number, is unique and can only be used once in a simulation. Different unit numbers can be associated with the same type number, although there are limitations on how many types of one kind can be used in one simulation.

A system is set up in TRNSYS by means of an input file, called a TRNSYS deck. This deck contains all the information that specifies the components and how the components interact. The system is set up by connecting all inputs and outputs in an appropriate way to simulate the real system. For example, the output temperature of the power plant unit is the inflow temperature of the cooling pond. Once a system is set up in a TRNSYS deck, the program can be run for a user defined range of time that is specified by a certain number of time steps. At each time step the program calls each component and solves all the mathematical equations that specify the component performance. The program iterates by calling the system component subroutines until a stationary state is reached at each time step. The stationary state is reached when all calculated inputs to the components remain constant between two iterations. Naturally, in a numerical solution such as calculated by TRNSYS, there will always be a difference in results between two iterations, if the solution is not explicit. Therefore the user has to specify tolerances to define a criteria that defines a stationary state. If the change in value of a variable is below this tolerance between two iterations, a stationary state is assumed and the program moves to the next time step, when all variables have converged.

Aside from the components that simulate actual physical parts of the system, there are predefined utility components that can be used in the simulation. One of them is the data reader.

The data reader is able to read data from a user supplied data file that has to be assigned in the TRNSYS deck. Every time step of the simulation the data reader then reads the desired values from the file and makes them accessible to the components.

One other utility routine is a psychrometric routine that calculates psychrometric properties from two supplied air properties. In the simulation performed for this work this routine will be used to compute the humidity ratio from air dry and dew point temperature.

Another kind of utility component is used to produce an output that is accessible to the user. A printer is available that prints output data into a file. Several printers can be defined in one deck. These output files can be imported into a spreadsheet program and the results further examined. The on-line plotter can be used to make the progress of the simulation visible on the screen, so that the user can immediately decide, whether a run was useful or not. A quantity integrator is available to integrate values over time. In the present work this feature is used to calculate average values, e.g. for production costs. Another useful feature is the possibility to generate plots from the simulation results. That makes the results more evident and easier to evaluate.

A special feature of the TRNSYS program package is the possibility to create a more user-friendly input file called a TRNSED file. When the TRNSED program is started, the user only has to supply the important parameters and can change these easily for different simulations. In this way the program is accessible to users who are not experienced in using TRNSYS but are only interested in examining a particular system. A TRNSED file is one product of the present work and is designed to be used by the power plant operators.

1.3.2 Software selection{ TC "1.3.2 Software selection" \l 3 }

Based on the features mentioned in 4.1.1, TRNSYS was selected as the primary tool to perform the analysis of the cooling cycle. Its capability to simulate the system as a whole makes TRNSYS an especially appropriate tool for this task. The feature to create a TRNSED file for further use makes it even more appropriate for the present study as a program was to be developed that can be used by the plant operators.

Aside from TRNSYS another program was used for simulation of single components of the cooling cycle. EES, or Engineering Equation Solver, is a program that can solve linear or nonlinear equation systems. EES also contains built in functions to compute thermodynamic properties. As EES is easy to use and does not require substantial programming, it is used for preliminary parameter studies especially of cooling towers and sprays in this work. There is not a FORTRAN code available for a cooling spray and therefore the cooling spray examination relies on EES calculations alone.