

CONTROL SYSTEM FOR REDUCING ELECTRICITY CONSUMPTION AND IMPROVEMENT OF THE OPERATING PARAMETERS OF COOLING TOWERS

Andrei Hudson Guedes Braga, andrei_projetos@yahoo.com.br

Cleonildo Soares Braga, cleonildoaires@ipojuca.ifpe.edu.br

Instituto Federal de Pernambuco

Jesus Marlinaldo de Medeiros, jesus_medeiros@yahoo.com.br

Instituto Federal da Paraíba

Abstract. The planet is experiencing major changes as a result of human interference in nature. The man changes his own behavior while it influences the nature, especially because of the new ecological requirements. The new consciousness established modifies the existing standards. The precept that we must preserve gains strength and increasingly reflects the need for change of habit. However, much depends on this new awareness of a new engineering model that should be reflected in standards and methods of manufacture and use, as well as the development of systems and equipment cleaner and with better yields. The problems related to the environment has been strongly debated a long time, but only in recent years came to be a major concern with the rational consumption of energy. Several alternative systems have been developed over the years in some areas of engineering. Thus, the research now being conducted to improve them. However, several other systems keep their operating characteristics and consumption. This paper presents a research carried out aimed at minimizing energy consumption in cooling towers. The goal is to reduce energy consumption in equipment and contribute to the positive impact on the environment. The mathematical modeling of a cooling tower will be done using the physical description of the phenomena involved through the white box technique. A control system that varies the flow of air as a function of engine will be designed, controlled from the request load at each instant. Therefore should be studied and compared the classic controller type Proportional - Integral - Derivative (PID) controllers and robust modern type that results in the desired operation. The completion of the design of controllers for use in the tower, requires the development of a mathematical model that is fully compatible with the theories of classical controllers. Thus, the mathematical model developed for the cooling tower should be focused on operating conditions of the controllers applied to thermal systems. The designed controllers, while minimizing the consumption of electricity, should act in order to respond quickly to any peaks, sudden increase or decrease the heat load and remove on-signals and reduce response time. Finally, analysis of different controllers for the reduction of energy consumption and peak thermal front of the lifetime and the cost of acquisition, installation and maintenance will be performed.

Keywords: *Cooling tower, increasing efficiency, classical and modern controllers*

1. INTRODUCTION

A major concern worldwide, which has been intensely debated in recent years is the environmental issue. It is closely related to serious problems like the energy crisis and environmental imbalance, leading to various phenomena such as El Nino and La Nina, which has altered the global climate. The planet has gone through major transformations in recent years and some comes from the strong human interference in nature. At the same time in which humanity influences the nature, their behavior has changed, especially due to new environmental requirements, arising from the need to make a positive impact and change the current situation. The precept that we must preserve gains strength and reflects the need for change in lifestyle, however, the challenge of preventing the degradation of the planet and the end of natural resources calls for a new global consciousness and a new engineering model, which should be reflected in standards and methods of manufacture and use, as well as the development of systems and equipment that pollute less and with better yields.

Currently, the rational consumption of energy is one of the issues that most concern scientists, governments and society, especially those who have suffered from the environmental imbalance. The consequences of environmental problems are known for some time, but only recently more objective measures were taken. A major problem is related to the known increased consumption of electricity and the adoption of effective strategies in trying to implement a culture aimed at the rational use of energy. Besides these measures, many efforts are made to develop more efficient systems. The energy crisis that occurred in the late 90th to the early years of the last decade, explained very clearly the need to invest in more efficient systems. Accordingly, researchers around the world have devoted much time and resources in trying to develop systems that are alternatives to existing ones. In some areas of engineering, several alternative systems have been developed over the years. Thus research now being conducted to improve them.

In the industrial sector, as well as residential, it is possible to observe processes and equipment that have a high energy consumption, mainly due to large power requirement and low efficiency. This has an impact on environmental degradation. Many systems have intakes incompatible with the current situation, however, none is cited as the equipment for air conditioning, refrigeration and cooling, especially today, where they are increasingly required. In modern society, many items previously considered luxury utility are considered basic today. Among them are air conditioners in rooms, refrigerators, humidifiers and dehumidifiers, both domestic and industrial use. According to Shelton (1982), about half of residential electricity consumed in the United States was destined for such purposes. However, air conditioning and refrigeration systems have especially strong growth in industrial demand resulting in an increased consumption of electricity. Modern industry has increasingly used the air-conditioning systems for rooms and refrigerating processes, and various activities to improve the quality of manufactured products. Whole sectors of the plant need controlled temperature, as the wire industry, where control of climatic conditions is required to ensure a quality standard.

The research developed in the areas of refrigeration and air conditioning have their focus turned to developing systems and increase yields of existing processes. Studies were conducted in this area since the society began to better understand the harm caused to the environment and its consequences, beginning with the use of refrigerants in compression refrigeration cycles, whose harmful effects have been established since the 60s (Sagan, 1998). Thus, the research resulted in the development of systems designed to eliminate or reduce harmful effects to the environment, many of which are already commercially available equipment such as evaporative cooling systems, designed for hot and dry places, desiccant systems for cooling and desiccant rotor for air conditioning. They deliver low-power consumption compared to conventional, does not contribute to environmental degradation, in addition, some models have a simple construction and fewer components. Despite the advantages, a critical look at the situation can throw new light on the matter, since the analysis of alternative systems, from the perspective of performance, demonstrates the fragility of them. The thermal coefficients of performance (COP) are substantially less than of the cycles of vapor compression refrigeration. Thus, for many years, conventional systems will continue to be widely used for air conditioning and refrigeration, which highlights a need for research aimed at reducing consumption of conventional equipment and to minimize the harm to the environment.

One of the industrial equipment that qualify as high-consumption and wasteful is the cooling tower. This type of system is very important and widely used in refrigeration and air conditioning of medium and large, as well as in various industrial processes cooling. According Kreith (1977), the cooling towers are devices used for cooling water in industrial processes. Due to new requirements, the systems of the type of liquid chillers with water condensation and self condensation water, using cooling towers, had its components were greatly modified, resulting in improved performance, including thermal COPs. However, the mass flow of air in the cooling towers as a parameter remains constant even when thermal loads are reduced, resulting in unnecessary energy consumption. A cooling tower is basically composed of a tank that collects water, filling, window shutters to sort incoming ambient air vent assembly mounted atop the tower and float to complete the water level in the tank. This equipment is used in general to cool fluids to be used in a process. Usually there cooled fluids have been used to remove heat from the process, being cooled in the tower and back to the process, performing cycles. Normal operation occurs with a hot fluid, which is already the case, entering the top of the tower and falling into the tank at the bottom. Meanwhile, the set of ventilation installed in the tower forces the air to enter through the shutters, installed above the tank, and move counter-current to the water that falls. The air that enters the ambient temperature when passes through the water ends up absorbing in the form of steam, a part of it. This phenomenon is called evaporation and requires a lot of energy for to be processed, which is greater the larger the amount of water transferred to the air stream. The volume of water absorbed depends directly on the absolute humidity of the air, so that the lower humidity, the greater the potential for absorption. The result of this evaporation is a cooling of the water circulating, thus resulting in the water tank can be reused to cool the process again. Considering that the towers are built indiscriminately, or for more or less dry climates, also receiving the maximum engine speed, and that furthermore, they lack means to control flow, we can see that this rotates at maximum rotation all the time. Consider the case of a tower supporting a climate control system. If the humidity is high, the tower will use its maximum speed, because in addition to high humidity, the system requires more power to be conditioned at the beginning. However, after air-conditioned, the system needs to remove less heat, but the tower still keeps spinning at full speed.

The need to ensure that systems operate within good ranges of performance and keep the operating points allowed us to use automatic controllers. The refrigeration systems by vapor compression always made use of these controllers. The first automatic controllers used in refrigeration by vapor compression were the on-off. This type of controller, applied to temperature control, operates according to the temperature of the air conditioner sucked by the (return air), which changes the resistance of the fluid contained in a bulb and this fluid acts on the relay, which turns on or off equipment. The simple construction and operational of this controller in addition to low cost, makes the majority of air conditioners of small and medium size use these controllers to maintain a constant average temperature, however, the need for better controllers, especially in systems large and the need to eliminate large variations in response, has caused other controllers to be developed on commercial scale equipment. One example is the cooling fluid of large size (chiller), or the systems developed for specific industries, which use classical control systems (Delgado, 2000).

The need for better control of thermal systems has become so evident that some researchers in various parts of the world are currently working in this area. For being two distinct areas of engineering, control of thermal systems or process control is endowed with some extra degree of difficulty, since each thermal system has its own dynamics, where his mathematical model, experimental or theoretical, can be difficult to determine. Thus, the success of this type of work can be in creating a model that can be integrated with control systems, which requires knowledge of both areas.

Although some studies are already being developed, many commercial thermal systems have had their income reduced by the lack of a more adequate control. Perhaps the difficulties that exist in uniting researchers, disciplines and knowledge, besides the difference in approach in addressing the problem, analysis and display of results, are decisive factors for the lack of further developing these two areas "(Braga, 2000)

Some relevant researches have been developed and attest to the efficiency of integration of thermal and control areas. Garcia et al (1999) studied a control strategy that enabled the optimization of temperature distribution inside a container volume. Spetios and Coonick (2000) used artificial intelligence techniques, neural networks and neuro fuzzy, to predict the hourly solar radiation on a horizontal surface. Already Alkham et al (2000) used a classic controller, PID, to control the temperature of a bioreactor is powered by a solar collector. This work stressed the importance of the PID controller and compared the result to a league off. Kalogirou et. al (1999) studied the use of artificial neural networks for modeling a system of domestic solar water heating.

In the area of cooling, some studies were also presented. Braga (2000) studied a classic control system applied to a heat exchanger played by evaporative cooling. The water coming out of the heat exchanger temperature control should have to serve any process. Mashuri et. al (1999) presents a study which shows the need for temperature control in the regeneration of the adsorbent and the process of evaporative cooling, in order to ensure a sensible heat ratio of around 75%, but also achieve acceptable performance levels. Braga et. al (2009) proposed a control system for cooling towers, where the temperature of the water tank is controlled as a function of air flow. The objective was to obtain desired values of temperature, even before the riots, always operating within the optimum range of income.

The great influence of the systems in electric energy consumption and environmental degradation suggests that other systems are created and upgraded. The development of systems that use other energy sources that do not pollute the planet's atmosphere and with a high coefficient of performance constitutes the great challenge of our times. However, the performance of any system must be evaluated not only as a mathematical relationship of input and output of energy, but also by reflex consequences.

The existing cooling towers, which are widely used in industry, have no control of air flow, resulting in a maximum power consumption during the entire running time. This paper presents a research carried out in order to minimize the energy consumption in cooling towers. The objective of this work is to study a control system that can be used in cooling towers, changing its dynamic characteristics and reducing the consumption of these devices, characterized by being an innovative solution. To this end, there will be a mathematical modeling of the cooling tower through the white box technique, using the description of physical phenomena involved, also designed an efficient system that can perform the change of air flow depending on engine speed, and controlled from the request load at every moment, therefore, should be studied like a classic controller Proportional - Integral - Derivative (PID) controller and a linear quadratic gauseano (LQG) that result in the desired operation. The completion of the design of controllers for use in tower, requires the development of a mathematical model that is fully compatible with the theories of classical controllers, so the mathematical model developed for the cooling tower should be focused on operating conditions of the controllers applied to thermal systems. The designed controllers, while minimizing the consumption of electricity, should act in order to respond quickly to any peaks, sudden increase or decrease the heat load, but also eliminate the overshoots and reduce the response time. In the end, analysis will be conducted and comparisons of different controllers with regard to reducing energy consumption and peak thermal front of the lifetime and cost of acquisition, installation and maintenance. Mathematical modeling and the approach and development of controllers are unprecedented for this equipment. Aimed at rationalizing the consumption of electricity, as well as the responses with lower peak temperatures, more stable and have lower steady-state errors.

2. MATHEMATICAL MODELING OF THE COOLING TOWER

In this section the following mathematical model of a cooling tower the designs and mathematical models of the controllers that will be used for the system. The mathematical model of the tower will be developed to make possible the implementation of the controllers of the types classic and modern, LQG. The mathematical models will be presented in the form of transfer functions and in state space. The controllers are designed to attend the performance specifications, so the variable should be controlled with a time error and maximum limits, as well as specific sign.

2.1. Mathematical Modeling of the Cooling Tower

The mathematical modeling of the cooling tower was done to allow the use of control strategies, given the incompatibility of strategies to control systems with multiple input, multiple output (MIMO), typical of more

conventional models. Thus, it was necessary to develop a mathematical model containing only one exit, even if you have multiple time-varying inputs.

The mathematical model of the system in question was done by global analysis, using mass balance and energy balance in a control volume. According to Felder and Rousseau (2008), the principle that underlies all the balance of energy is the law of conservation of energy, which establishes that the energy can not be created nor destroyed.

The energy balance for open systems at steady state is defined as the energy that enters in relation the energy coming out, (Felder and Rousseau, 2008). So that the energy balance to occur properly, the mathematical model can only be done after the definition of a control volume (Bejan, 1996). Figure 1 is a schematic representation of a cooling tower being used in conjunction with a process. In the case cited the heated water enters at the top and falls toward the bottom of the tower (tank) and, concomitantly, an air mass is forced to circular by the tower. A motor, installed on top of the tower, the air force to enter through the blinds, installed at the bottom and circular counter-current to the water, heading toward the top to be discharged into the atmosphere. These flows of water and air in direct contact inside the tower results in a decrease in water temperature, which can be used again to cool the process. The phenomenon that contributes most to the mass and heat transfer is evaporation. Evaporation is the result of the transfer of water in vapor form, to the air stream is not saturated, this transfer occurs naturally and requires a substantial amount of energy, according the amount of evaporated water, which in turn is function of the humidity and of the air flow circulating.

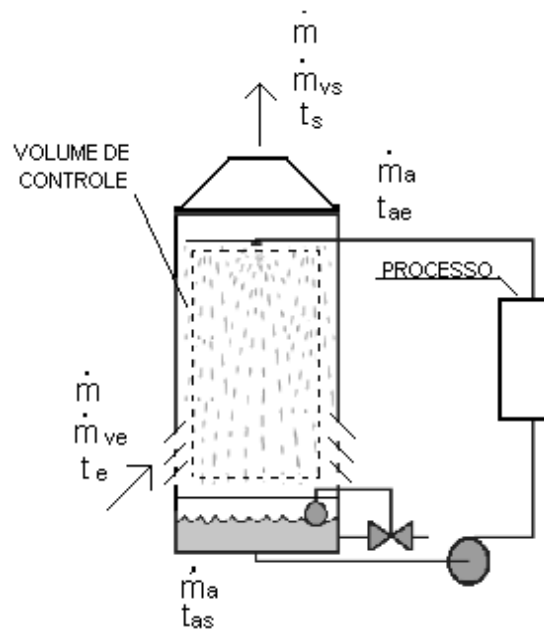


Figure 1. Scheme of a cooling tower

Defining the state of equilibrium, we have: $\left(\dot{m}_{vs} - \dot{m}_{ve} \right) h_e$

Energy input = energy output

Energy of the inlet air: $\left(\dot{m} + \dot{m}_{ve} \right) c_p t_e$

Energy of the air at the exit: $\left(\dot{m} + \dot{m}_{vs} \right) c_p t_s$

Energy of water in the input: $\left(\dot{m}_{ae} \right) c_{pa} t_{ae}$

Energy of water in the output: $\dot{m}_{as} c_{pa} t_{as}$

Energy of the evaporated water: $\left(\dot{m}_{vs} - \dot{m}_{ve}\right) h_e$

$$\left(\dot{m} + \dot{m}_{ve}\right) c_p t_e + \left(\dot{m}_{ae}\right) c_{pa} t_{ae} = \left(\dot{m} + \dot{m}_{vs}\right) c_p t_s + \dot{m}_{as} c_{pa} t_{as} + \left(\dot{m}_{vs} - \dot{m}_{ve}\right) h_e \quad (1)$$

Considering that the variation of mass flow of water is negligible in relation to total energy, we have that:

$$\dot{m}_{ae} = \dot{m}_{as} = \dot{m}_a \quad (2)$$

$$\dot{m} (c_p t_e - c_p t_s) + \dot{m}_{ve} c_p t_e + \dot{m}_{ae} c_{pa} t_{ae} = \left(\dot{m}_{vs}\right) c_p t_s + \dot{m}_{as} c_{pa} t_{as} + \left(\dot{m}_{vs} - \dot{m}_{ve}\right) h_e \quad (3)$$

Considering that the variation of the mass of water vapor is very small, we can say that the energy due to the heat sensitive portion is negligible, thus:

$$\dot{m} (c_p t_e - c_p t_s) + \left(\dot{m}_{ve} - \dot{m}_{vs}\right) h_e = \dot{m}_a c_{pa} t_{as} - \dot{m}_a c_{pa} t_{ae} \quad (4)$$

In transient regime, has:

$$Mc_p \frac{dt_{as}}{dt} = \dot{m}_a c_{pa} t_{as} - \dot{m}_a c_{pa} t_{ae} - \dot{m} (c_p t_e - c_p t_s) - \left(\dot{m}_{ve} - \dot{m}_{vs}\right) h_e \quad (5)$$

Applying Laplace transform to the equation:

$$Mc_p s t_{as}(s) = \dot{m}_a c_{pa} t_{as}(s) - \dot{m}_a c_{pa} t_{ae}(s) - m(s) (c_p t_e - c_p t_s) - \left(\dot{m}_{ve} - \dot{m}_{vs}\right) h_e(s) \quad (6)$$

$$\left(Mc_p s - \dot{m}_a c_{pa}\right) t_{as}(s) = -\dot{m}_a c_{pa} t_{ae}(s) - m(s) (c_p t_e - c_p t_s) - \left(\dot{m}_{ve} - \dot{m}_{vs}\right) h_e(s) \quad (7)$$

The variation of the mass of water vapor between the inlet and outlet of the tower, is a function of the mass of circulating air, also of the temperatures and humidities. It is can be defined as the variation:

$$\Delta \dot{m}_v = X \dot{m} \quad (8)$$

$$\left(Mc_p s - \dot{m}_a c_{pa}\right) t_{as}(s) = -\dot{m}_a c_{pa} t_{ae}(s) - m(s) (c_p t_e - c_p t_s) - X h_e \dot{m}(s) \quad (9)$$

To perform the simulation with real values, it is assumed that the humidity of air is 70% and that it leaves the tower saturated, will also be assumed that the dry bulb temperature of air is 30 ° C. With these values we have:

$$\left(Mc_{pa}s - \dot{m}_a c_{pa} \right) t_{as}(s) = -\dot{m}_a c_{pa} t_{ae}(s) - m(s)(c_p t_e - c_p t_s + 0,008h_e) \quad (10)$$

Another consideration is that made the air temperature in the output will be constant. Without this consideration the latest installment of the equation would be a function of two variants, disabling the control system. The simplifications made in the model have little influence on the response, especially since all are related to heat sensitive cargoes.

The mathematical model in transfer function is given in the equations below. Equation (11) represents the portion of the variation of the system due to variation of water temperature in the input while the equation (12) represents the variation of the system according of the control variable.

$$G_{1,1}(s) = \frac{t_{as}(s)}{t_{ae}(s)} = \frac{-\dot{m}_a c_{pa}}{Mc_{pa}s - \dot{m}_a c_{pa}} \quad (11)$$

$$G_{2,1}(s) = \frac{t_{as}(s)}{m(s)} = \frac{(-c_p t_e + c_p t_s - 0,008h_e)}{Mc_{pa}s - \dot{m}_a c_{pa}} \quad (12)$$

3. DESIGN OF CONTROLLERS

The following controllers will be designed type classic, proportional - integral - derivative (PID), and Type Fine, Linear Quadratic Gaussian (LQG). The design of both controllers result in a stable system that achieves the desired value in the shortest possible time, with error less than 2% and on minimum signal also should consume as little energy as possible, thus the variable control should be minimized.

3.1. PID controller design

The realization of the project a appropriate controller should consider the type of system that is being worked on, as well as the dynamic characteristics of the system. The following describes the actions of classical control, and characteristics proportional, integral and derivative, as described by Ogata (2003). There are several techniques for controller design classics, such as the Routh stability criterion, the methods of Ziegler and Nichols or the method of pole allocation. For the project it is necessary to allocate the values to the terms of the equations. The values of the terms of the the equations defining the dead time, time constant and the gain of the coupled system, which results in defining the dynamic behavior.

The values of the terms of the the equations are defined as follows:

$$\begin{aligned} M &= 2000kg & t_{as} &= 35^{\circ}C \\ c_p &= 0,24..cal/g^{\circ}C & t_e &= 30^{\circ}C \\ c_{pa} &= 1..cal/g^{\circ}C & t_{ae} &= \text{variable} \\ \\ \dot{m}_a &= 2kg/s & t_s &= 45^{\circ}C \\ \dot{m} &= \text{variable} & h_e &= 540..kcal/kg \end{aligned}$$

The first step to realize the design of controllers is to establish performance specifications you wish to achieve. The specifications for this project are: response time less than 100 seconds to sign up less than 10% of the disorder; response without many oscillations, which prevents premature wear of the final element of control.

To achieve the design of the controllers were the methods of Ziegler and Nichols. From the application of this methodology was possible to estimate the controllers and thus calculate the proportional gain, integral and derivative. After the calculation of earnings was necessary to perform an adjustment to find the gains that the system would lead to responses that meet the performance specifications

The controller design, performed by the method of Ziegler and Nichols, underwent final adjustments to fit the performance specifications. The controller gain obtained for each controller and containing the final adjustments will be presented in the results section.

3.2. LQG controller design

For the design of optimal controller, LQG, it took the mathematical model developed in section 2.1, the form of transfer function for the state space. The model below is a representation of the system in this format.

$$A = [-0,1]; B = [1]; C = [-0,3960]; D = [0]$$

The Plant presented above will be changed again. The mathematical model was generalized, resulting in another model, known as Plant generalized, this format was not included the dynamics of the disorder. For the controller design was necessary to generalize an integrator. Afterwards the plant's generalized association with generalized integrator. The matrices Q and R were defined as 1 and 0.25 xC'xC, respectively. Also included was a noise in the system. The method resulted in the LQG controller shown below. O controlador, em espaço de estados, é:

$$A1 = \begin{bmatrix} -1.0944 & 0.6293 & -1.5803 \\ -0.8584 & -0.5372 & -0.9997 \\ 0 & 0 & -0.0001 \end{bmatrix}$$

$$B1 = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$C1 = \begin{bmatrix} 1 \\ 0.2293 & 0.5371 & 0 \end{bmatrix}$$

$$D1 = 0$$

4. RESULTS

Below we present results of simulations for the system under the action of the PID controllers and LQG. The results will be analyzed and compared.

Figure 2 shows the system response under the action of the PID controller with proportional gain (kp) equal to 0.1, integral gain (Ki) equal to 0.01 and derivative gain (KD) equal to 1, as a result of the project. In this controller the integral action ensures the elimination of error in steady state, while the derivative action reduces the peak temperature due to disorder.

This is higher than the results presented in industrial towers without drivers. Here the peak is reduced and the temperature returns to baseline in less than 150 seconds. It is also possible to observe that the steady-state error is zero, unlike what happens with the equipment out of control. Controlled system in the control variable is also reduced proportionately, whereas in the uncontrolled system remains constant.

The system was subjected to a step input of 5°C. Note that the system response under the action of the controller was stable. The driver managed to bring the system to the desired value in a time less than 150 seconds, with minimal error. It is also possible to observe that the signal was less than about 3°C and had a short duration.

The controller gains can be adjusted to obtain further responses. Thus, the proportional gain, integral and derivative were adjusted to 0.1, 0.05 and 1, respectively. In Figure 3 we can observe that the signal was reduced about as well as response time, however, the system has become less stable. Note that this response exists over a signal and a second down on sign up.

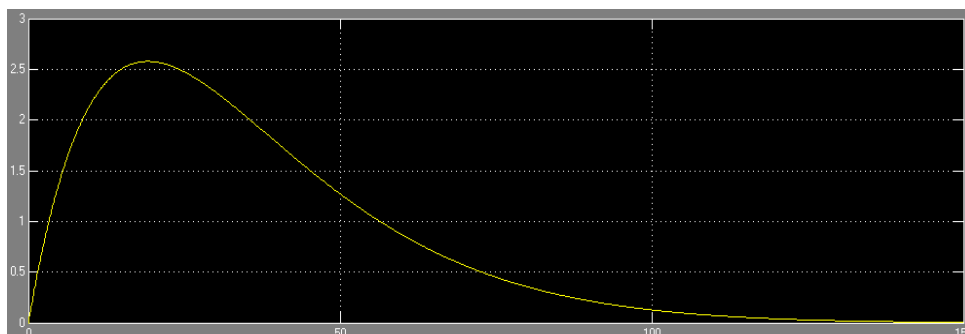


Figure 2. System response under the action of the PID controller, a step of 5 ° C. Kp = 0.1, Ki = 0.01, Kd = 1

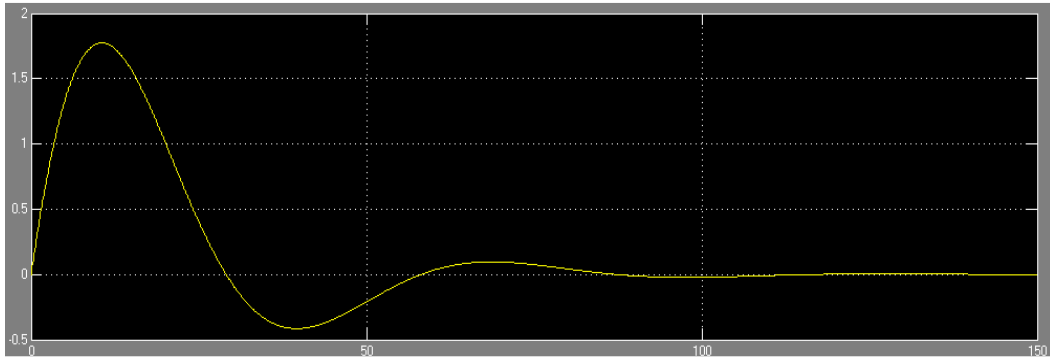


Figure 3. Response of system controlled by PID controller, a step of 5 ° C. $K_p = 0.1$, $K_i = 0.05$, $K_d = 1$

Figure 4 shows the system response under the action of the PID controller with proportional gain (k_p) equal to 0.1, integral gain (K_i) equal to 0.01 and derivative gain (KD) equal to 1, as a result of the project. The system was subjected to a step input of 10 ° C. Note that the system response under the action of the controller was stable. The driver managed to bring the system to the desired value in a time less than 150 seconds, with minimal error. It is also possible to observe that the sign was on at around 5 ° C and had a short duration.

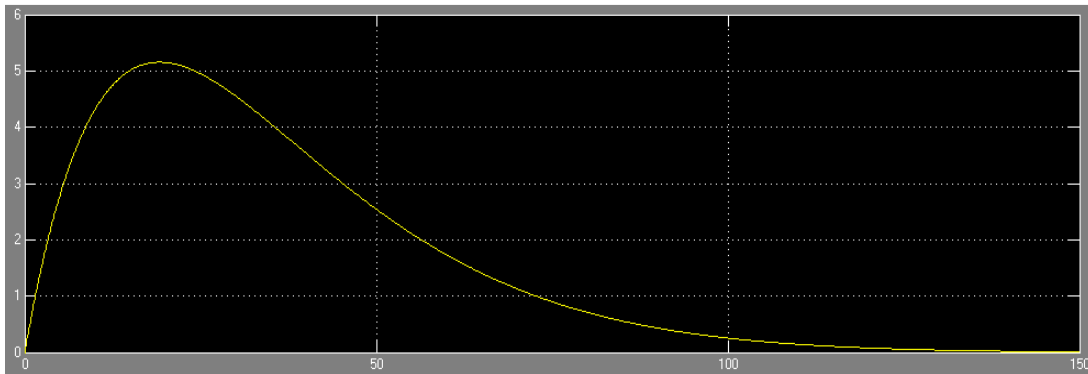


Figure 4. System response under the action of a PID controller to a step of 10 ° C. $K_p = 0.1$, $K_i = 0.01$, $K_d = 1$

The controller gains are adjusted to result in a faster response. Thus, the proportional gain, integral and derivative were adjusted to 0.1, 0.05 and 1, respectively. From figure 5 it can be seen on the signal was reduced and the response time, however, the system has become less stable. Note that this response exists over a signal and a second down on sign up.

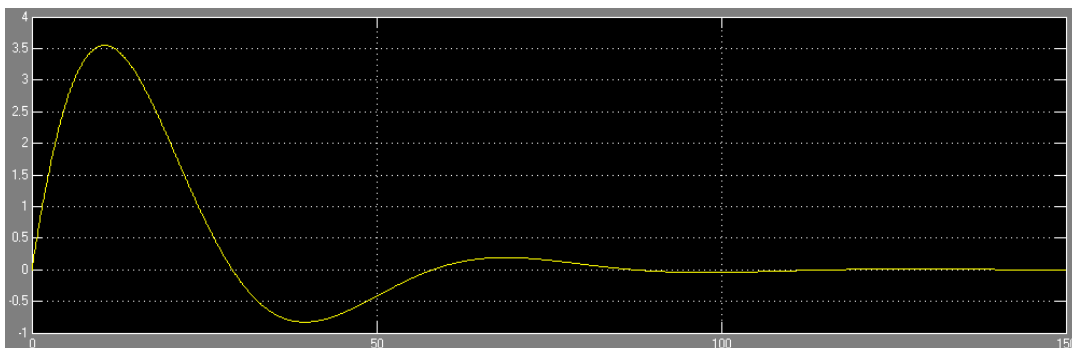


Figure 5. Response of system controlled by PID controller, a step of 10 ° C. $K_p = 0.1$, $K_i = 0.05$, $K_d = 1$

Figure 6 shows the system response under the action of the LQG controller as a result of the project. The system was subjected to a step input of 5 ° C. Note that the system response under the action of the controller was stable. The controller managed to bring the system to the desired value in a time less than 25 seconds, with minimal error. It is also possible to observe that the signal was less than about 1.2 ° C and had a short duration. Looking at

the chart and comparing it to earlier, it appears that the controller shows better results. Here the signal is about 50% less than the PID controller, the response time is only 1 / 5. The steady-state error is also null.

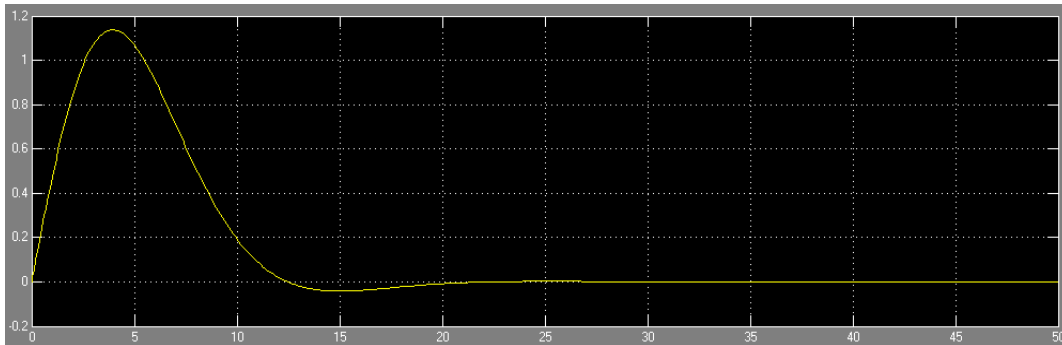


Figure 6. System response under the action of the LQG optimal controller, a step of 5 ° C

The following will be presented to the system response subjected to a step input of 10°C and LQG controller designed by the actuator. Figure 7 shows that, even under a step input of 10°C, the system remains stable and is controlled in a time less than 25 seconds. The resulting signal is about less than 2.5°C. The result presented by the LQG controller is superior to PID controller.

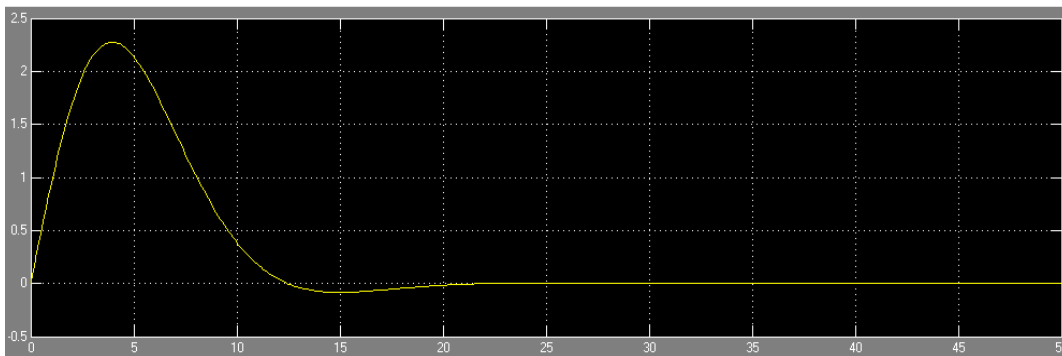


Figure 7. Response of system controlled by LQG optimal controller, a step at 10° C

5. CONCLUSION

The lack of control in the process variable of the cooling towers eventually results in higher and unnecessary energy consumption. The flow rate of air circulation, forced by the fan assembly, does not match the amount of heat to be changed every time. The controller on-off, acting on this system lacks the capacity to efficiently control, that because this action causes the controlled variable oscillate around the desired value, thus the use of other controllers is required. The results show that the PID and LQG controllers can keep the controlled variable on the desired value. Also that the LQG controller gives better results than the PID. Other important features are presented stability, maximum error and response time. These characteristics become important as the flow passes to vary with temperature.

The results presented by the system actuated controllers is superior to the results of the towers without industrial controllers. Here the peak is reduced and the temperature returns to its initial value in less time. It is also possible to observe that the steady-state error is zero, unlike what happens with the equipment out of control. Controlled system in the control variable is also reduced proportionally, while the system remains uncontrolled constante. Os results presented provide innovative features to the study.

The response time of the system served by the PID controller for a step input of 5 ° C is around 80 seconds, while the response to the LQG controller is less than 25 seconds. In relation the overshoot, it was observed that was approximately 1.8 ° C for the system actuated by PID and less than 1.2 ° C for the LQG-controlled system. The same is true for the system under a step input of 10 ° C. One can see that controlled by a PID, the response time is 80 seconds and the signal is about 3.5 ° C, while the response time the system worked for LQG controller is less than 25 seconds and the signal is about around 2.3 ° C.

The control system of water temperature of the output of a cooling tower, according the variations of air flow, presents better results when associated with type LQG optimal control, which presents sensible improvements in response time and overshoot, in relation to the PID controller, getting to be faster and better damping peaks. Both

controllers can be used, however, when he will need more accurate answers or lower power consumption due to the controller using linear quadratic Gaussian (LQG).

6. BIBLIOGRAPHY

- T. M., El-Khazali, R., Kablan, M. M., Alhusein, M. A. "Heating of a Biogas Reactor Using Energy System with Temperature Control Unit" *Solar Energy*, Vol. 69, No. 3, pp. 239 – 247, 2000.
- Braga, A. H. G., "Controle Aplicado a Sistemas Térmicos", Dissertação de Mestrado Apresentada à Universidade Federal da Paraíba para Obtenção do Grau de Mestre, João Pessoa, 2000.
- Braga, A. H. G., "Sistema de Controle de Temperatura para Climatização de Ambientes", Tese de Doutorado Apresentada à Universidade Federal da Paraíba para Obtenção do Grau de Doutor, João Pessoa, 2004.
- Bejan Adrian; *Transferência de Calor*; 4^o edição, Editora Edgard Blucher, 1996.
- Filippin, C., Beascochea, A., Esteves, A., De Rosa, C., Cortegoso, L., Estelrich, D. "A Passive Solar Building for Ecological Research in Argentina: The First Two Years Experience", *Solar Energy*, Vol. 63, No. 2, pp. 105 – 115, 1998.
- Kalogirou, S. A., Panteliou, S., Dentsoras, A. "Modeling of Solar Domestic Water Heating Systems Using Artificial Neural Networks", *Solar Energy*, Vol. 65, No. 6, pp. 335 – 342, 1999.
- Meunier, F., Kaushik, S. C., Neveu, P., and Poyelle, F. "A Comparativo Thermodynamic Study of Sorption Systems: Second Law Analysis". *International Journal Refrigeration*, Vol 19, N^o 6, pp. 414 – 421, 1996.
- Ogata, Katsuhiko; *Engenharia de Controle Moderno*; 4^o edição, editora Prentice Hall, 2003.
- Omtvedt, I. T., Nelson, R. E., Edwards, R. L., Stephens, D. F., Turman, E. J., "Influence of the Heat Stress During Early, Mid and Late Pregnancy of Gilts", *J. Animal Sci*, 32:312, 1971.
- Pons, M., Poyelle, F. "Adsorptive Machines with Advanced Cycles for Heat Pumping or Cooling Applications", *International Journal of Refrigeration*, 22, pp. 27 – 37, 1999.
- Rane, M. V., Pabla, S. S. And anand, G. "Activated Carbon/Ammonia Adsorption System for Bus Air Conditioning". *Proceedings of the of the sorption heat pump conference*, pp. 71 – 80, Munich – Germany, 1999.
- Sfetsos, A., Coonick, A. H. "Univariate and Multivariate Forecasting of Hourly Solar Radiation with Artificial Intelligence Techniques", *Solar Energy*, Vol. 68, No. 2, pp. 169 – 178, 2000.
- Shelton, Sam V., "Le Conditionnement D'Air Avec La Sorption Solide", *Applied Thermal Engineering*, pp 67 – 76, 1999.
- Wiersma, F. "Evaporative Cooling", *Transaction of the ASAE*.