Design of a Control Panel for Drinking Water Treatment Plant

Eyman F. Ahmed, and Ali M. Abdelrahman

***Abstract*—**Due to the rapid growth of population and the necessity of providing adequate drinkable water supplies modern control techniques are applied for water treatment process to meet the hygiene conditions. In particular, this study introduces a flexible model for estimating volumes of water in distribution tanks through all phases of treatment process for a typical water treatment plant. The results obtained from the simulating model have been used in developing an interactive control panel for the plant. The main purpose of the control panel is to receive the meaningful signals from different sensors as inputs and transform these input signals into understandable visual codes that will assist the operators in monitoring and managing the overall plant performance.

***Keywords*—**Drinkable Water Treatment, Modeling and Simulation, Control Panel.

I. Introduction

TODAY, the automated control engineering becomes an integral part of industrial processes due to the current advanced in control systems and high speed of communication networks [1], [2], [3]. Implementation of modern control systems provides good quality with minimum efforts.

Recently, [4] has designed and implemented a robust control system for a drinkable water plant. His case study was a water treatment in a typical plant, called Bait Elmal plant, which is currently supplying a large part of Khartoum (Capital of Sudan). However, still there is an urgent need for fully automated monitoring system to manage and control processes in a modern water treatment plant.

This paper models and simulates a prototype for a typical water treatment plant, while maintaining the flexibility by allowing operators to set initial and critical values. Based on the simulation results an interactive control panel has been designed with a friendly graphical user interface. The control panel receives meaningful signals from different sensors as inputs and transforms these signals into understandable visual codes which assist the human operators in observing and managing the overall performance of the plant. Thus, the control panel receives the input signals from the model instead of the real plant and hence produces the corresponding control parameters as outputs without human intervention.

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The rest of the paper is organized as follows: the next section describes water treatment process in a typical water treatment plant. Section 3 provides a mathematical model for a typical water treatment plant. The simulation results of the model are presented in Section 4. Section 5 designs the control panel for a typical water treatment plant, followed by the conclusion in the last section.

II. Description of Water Treatment Process

This section provides a detailed description of the stages of a drinkable water treatment system under study, while discussing the operations contained in each stages.

Water treatment process of a typical plant in Sudan can be divided into two phases. The first phase consists of sucking water from the Nile via intake pumps, and keeping water in pre sedimentation tanks before switching to the next phase. The second phase of operations is composed of three operations. The first operation is mixing chamber, where coagulation materials (such as Polly Aluminum Chloride or Aluminum Sulphate) should be added. After mixing chamber the product passes to the sedimentation process, which aims to separate living organisms from water. After passing the sedimentation stage the product is known as clarified water. Finally the clarified water forced to pass through specific sand filter in order to insure retaining all parasites, algae, zoo and planktons and viruses [4].

Fig 1 shows the phases of water treatment process with the main operations in each phase. The mathematical model describing the overall treatment operations is derived in the next section and more details can be found in [5].

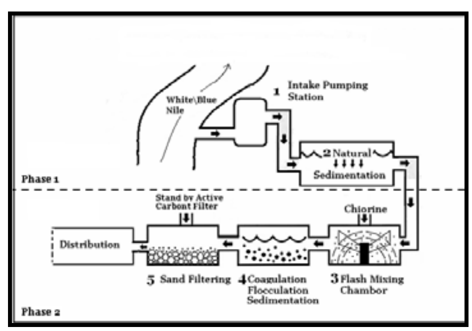

Fig 1: Water treatment process of a typical water plant.

III. Modeling of Water Treatment Process Control

In this study, a simple flexible model is proposed for the overall operations in a drinkable water treatment plant. The model relies on the general equation for calculating the volume of the liquids based on the flow rate of the pumping motors [6]:

$$V = \int_{t_\circ}^{t_n} R.dt \quad (1)$$

Where R refers to water flow rate, which is given by the following equation:

$$R = \frac{dv}{dt} \quad (2)$$

Where V represents the water volume, and t is the time.

By considering the initial volume of the water in the distribution tank (V_o), Equation (1) can be written as follows:

$$V = \int_{t_o}^{t} R.dt + V_0 \quad (3)$$

When a signal is received from the backwash filter sensor, determining the starting of the backwash process, an immediate action is needed to switch off the main intake pumps for enough amount of time to finish the backwashing operation. During this time there is no water flow in, therefore the expected amount of water should be subtracted from the total amount of water in "(3)" leading to " (4)" as shown below.

$$V = \int_{t_o}^{t} R.dt + V_0 - \int_{t_i}^{t_{i+n}} R.dt \quad (4)$$

Where $t_i - t_{i+n}$ represents the time required for finishing the backwashing process.

Finally, when a signal is received from an empty critical level sensor, no change in water volume, but if it is received from a full critical level sensor the intake pumps are switched off, and hence the expected amount of water flow during this time should be subtracted from the total volume of water as in the backwashing process. Thus "(5)" can be derived as follows:

$$V = \int_{t_o}^{t} R.dt + V_0 - \int_{t_1}^{t_{1+n}} R.dt - \alpha \int_{t_j}^{t_{j+m}} R.dt \quad (5)$$

Where α is a factor that determines the type of the critical level signal, which has two values 1 (for full level) and 0 (for empty level), and $t_j - t_{j+m}$ is a random time required to switch off the pumps and this time is based on the current distribution level.

Triggering full and empty sensors is totally based on the current distribution level. This process is simulated based on creating two sets: the first set containing possible distribution level values and the second set consists of distribution level indices for the values of the first set generated by a random number generator. These values are presented in "(6)" as shown below.

$$\left.\begin{aligned} D &= \{d_1, d_2, d_3, ..., d_N\} \\ S &= \{1, 2, 3, ..., N\} \\ D_i &= D(S(i)) \end{aligned}\right\} \quad (6)$$

Where D is the distribution set, S is the distribution indices set, and D_i is the current distribution value.

Equation (5) is considered as a primary equation in this study and it is implemented for simulating the process behavior of a water treatment plant. The simulation results are presented and discussed in the next section.

IV. Simulation of Water Treatment Process Control

This section presents the simulation results of the proposed model using Matlab; the results consider the status of the different sensors in the modeled plant. Initial simulation values are set as shown in Table i.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Simulation time per msec	1200
Initial volume of water per liter	500

Fig 2 describes the backwashing operation status where x axis stands for the time, the y axis stands for the ongoing operations and the vertical bars represent the condition of running backwashing operation:

The possible states for the backwashing are either 1 or 0. The 1 state refers to the backwashing operation on process and this case requires shutting down the entire intake pumps. The 0 state means that the system is working normally.

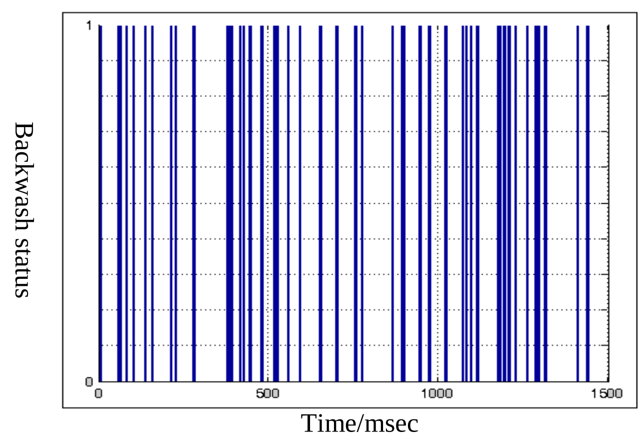

Fig 2: Backwashing operation status

Fig 3 illustrates the full tank sensor status, where the x axis stands for the time and the vertical bars stand for the full tank critical level sensor states.

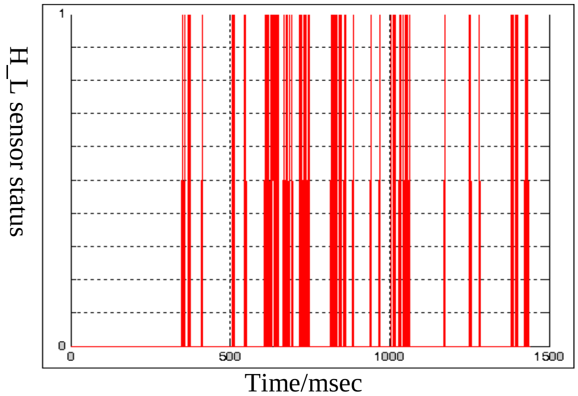

Fig 3: Full tank sensor status

The possible states for the full tank sensor are either 1 or 0. The first state refers to exceeding the full critical level, which requires switching off the intake pumps.

The empty tank sensor status results are presented in Fig 4, where the x axis stands for the time and the vertical bars stand for the empty tank critical level sensor state.

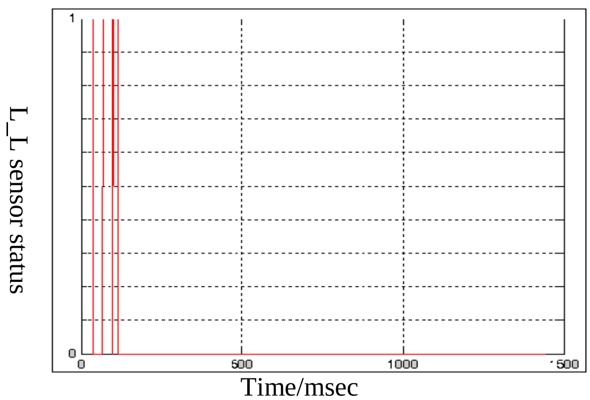

Fig 4: Empty tank sensor status

The possible states for the empty tank sensor are either 1 or 0. The 1 state refers to the volume is now less that the critical empty level and it requires switching on the intake pumps.

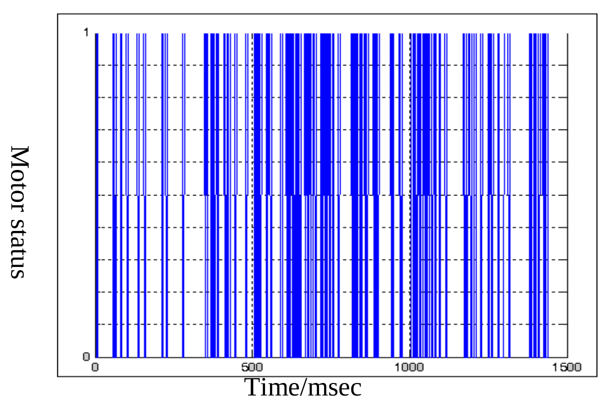

Fig 5: Intake pumps status

Fig 5 illustrates the intake pumps status, where the vertical bars stand for the current status of the intake pumps. The x axis refers to the simulation timing. The possible states are either 1, which refers to ON condition, or 0 which stands for OFF status. Each single bar represents an ON status which in turn means no current backwashing operation or the full tank critical level sensor is currently idle.

The toggling between 0 and 1 is due to the sensor states discussed in the previous sections.

Fig 6 presents the volume level of the water in the distribution tank. The x axis refers to the time while the y axis stands for the volume level. Each single circle represents a certain amount of water in the distribution tank at a particular instance of time during the simulation.

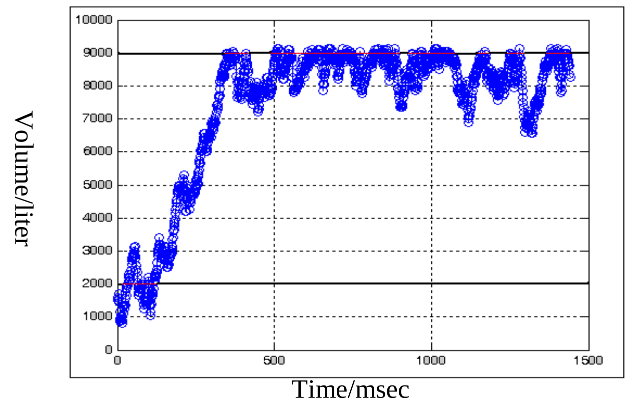

Fig 6: Water level in the distribution tank

The two horizontal bold lines in the Figure 6 represent the full critical level (upper line) and the empty critical level (lower line) in the distribution tank. The points fall above the upper bold line indicate that the water level exceeded the full critical level. The required action to meet this situation is shutting down the intake pumps so that the water level can decrease below the critical level due to the distribution system effects. The points fall below the lower line means that the water level is below the empty critical level. The required action to solve this problem is switching on the intake pumps so that the level of the water will increase to reach the normal state (between the two bold lines).

Next section constructs a control panel for displaying the values/status of the different sensors.

V. Construction of Water Treatment Process Control Panel

The main purpose of the control panel is to receive the meaningful signals from the different sensors as inputs and transform these input signals into understandable visual codes in order to assist the human operators observing the overall performance of the plant. In fact, the control panel receives the input signals from the model instead of the real plant; however, it operates like a real world monitoring port to allow observing the overall running operations from a single control room. Fig 7 shows the physical circuit that simulates the real system (control panel). The Matlab model generates the required signals and the physical circuit is added to the computer through the parallel port. The light emitting diodes are implemented in this work to serve the following functions:

- To show which sensor is ON.
- To show the status of the motor (ON/OFF).
- To determine the start of the backwashing process.

- To alarm the human operator if there is error and even the location of the error.

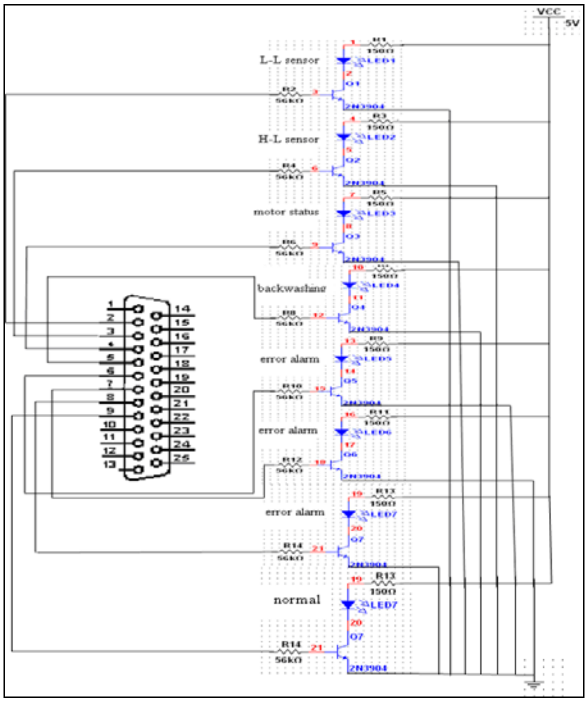

Fig 7: Control panel circuit

Fig 8 illustrates a picture for the actual control panel. The light emitting diodes are connected in the circuit through a set of transistors.

Fig 8: Control panel layout

The transistors are used as switches, if the output of LPT port is less than 2.5 volts the transistor will be in cut off region (no collector current) and the diode will not emit light, and if it is greater than 2.5 volts the transistor will be in saturation condition (collector is a few tenths of volts above emitter) and the diode will emit light. Fig 9 shows control panel user interface which displays real time information and alarms.

Fig 9: Control Panel GUI

VI. Conclusion

Due to the rapid growth of population and the necessity of providing adequate drinkable water supplies modern control techniques are applied for water treatment process to meet the hygiene conditions. In particular, this paper presents a flexible model for estimating the volume of the water through all phases of treatment process for a typical water treatment plant. The model of the system under study was simulated using Matlab. Moreover, the results obtained from the simulation are considered as a powerful tool for developing a complete control panel for the plant.

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