Intelligent Control for Emergency Unit of Sewerage Treatment Plant

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Abstract- **The Grand-Baie Sewerage Treatment Plant is the largest waste water treatment plant constructed in Mauritius. The aim of this construction is to treat waste water from the Northern coastal hotels and houses and to reuse this water and its substitute products instead of letting these flow into the sea and cause pollution. Presently, the level of water in the tanks of the emergency unit is controlled by overflows. This method is considered to be unsafe and inefficient since it is the only section on the site that is controlled manually, unlike others which are monitored by SCADA. Moreover, it will be difficult to open or close valves manually in this unit during bad climatic conditions. In this paper, a method of control for the level of water in the Emergency unit has been designed and this model has been successfully tested using Simulink and ANFIS in MATLAB. Finally, the Lagoon Controller is linked to the SCADA software by using any of the two above simulated algorithms.**

1. INTRODUCTION

The development of sewerage network in Mauritius took place early last century (Port Louis) and in the sixties (Plaines Wilhems). Thus presently only the predominantly urban areas of Port Louis and Plaines Wilhems have sewerage systems. The sanitation facilities have improved over the years. The shift to absorption pits and septic tanks over the years has led to an increase in the water usage and in the risk of groundwater pollution, especially in the Curepipe aquifer of the Plaines Wilhems area, which is extensively used for potable water. The outfalls that were designed and constructed discharged the wastewaters, after primary treatment, at shallow depths. There have been many reported points, overloading of the sewerage systems, illegal connections to the networks and broken pipelines.

In 1993, a National Sewerage Master Plan [1] described a complete scheme for the development of the wastewater sector in Mauritius. The Master Plan recommended institutional, legal and financial measures as well as the construction of new networks and treatment facilities. Reuse of treated wastewater has been investigated in detail by various consulting firms as one of the disposal options. Based on the technical feasibility and the financial viability, the new treatment plant at St. Martin and Grand Baie plans to use the treated wastewater for irrigation. These wastewater treatment plants would generate about 73 000 m^3 per day by the year 2004 for the irrigation of sugar cane crops in the western coast and the northern coast of Mauritius. Moreover, studies are also being carried out by local authorities for the use of treated sludge as fertilizer for the sugar cane crop and ultimately for other agricultural crops. The Grand Baie Sewerage Project aims at providing sewerage facilities in the Northern Tourist Zone (from Trou aux Biches to Cap Malheureux). The effluents after treatment will be used for irrigation purposes, mainly in sugar cane plantations. The project will cover an area of 575 hectares representing 74 km of sewer network.

The actual system basically consists of nine water treatment units namely: the Pretreatment Unit, Biological Unit, Blower Station, Deaeration Unit, Final Settling Tank and the Flowmeter Channel, Tertiary unit, Final Storage Tank, Sludge Treatment Unit and Polymerisation and finally the Emergency Tanks. After a survey on the Grand-Baie Sewerage Treatment plant, we have observed that the process of controlling water in the Emergency Tanks (Overflow) is inefficient, unsafe and inaccurate during bad climatic conditions. The aim of this project is to design an intelligent control for the Emergency Unit of Grand-Baie Sewerage Treatment Plant in Mauritius.

During heavy rainfalls or repairs in a particular section of the sewerage plant, the excess (unused) water is diverted to the Emergency unit to prevent overflows of water in the tanks of the processing units. The site is constructed with a small decent and valves have to be opened manually so as to allow the excess of water to flow gravitationally through the emergency tanks which is controlled by overflow. Storage of water can also be controlled that is different types of treated water can be stored separately in one of the five emergency tanks available.

The new proposed system for this particular unit is a Water Level Control System and the latter must be reliable when considering a cascade model. Since the manual control of the system may be dangerous and inaccurate during bad weather, we are proposing a system which can be implemented using a soft logic controller. The Water Level Controller System may be implemented using a PI controller but we must consider negligible disturbances (rain drops entering the tanks as the latter are open) in the system. However, although the system is subjected to heavy disturbances, its performance can be improved with the use of the fuzzy logic or both Fuzzy Logic and artificial neural network methodologies (ANFIS). The ANFIS, which is a Fuzzy Inference System implemented in the framework of adaptive networks, can be used as an observer. The observer design procedure can be replaced by the learning algorithm of the ANFIS.

Proportional-Integral and ANFIS controllers have been investigated and compared in terms of reliability and efficiency under MATLAB 6.1. Moreover, we have also identified a soft logic controller (Lagoon Controller) which is available in the market and which can be linked to the existing SCADA system, already present at the Sewerage Treatment Plant. This particular controller can use any of the algorithms of PI or ANFIS controller.

2. EXISTING SYSTEM

The inflow of the emergency storage tanks comes from a surplus flow of waste water from the pre-treatment unit and solid wastes from the Biological tank during bad climatic conditions. Actually there is a bypass pipe which diverts the flow of water from the biological unit to the emergency unit. The input flowrate of sludge water to the emergency unit is 143 to 230 m^3/h.

The total volume of the 5 tanks = 42 000 m^3.
Volume of tank ABE1 =10 500 m^3
Volume of tank ABE2 =10 500 m^3
Volume of tank AB1=7 000 m^3

Volume of tank AB2=7 000 m^3
Volume of tank AB3=7 000 m^3

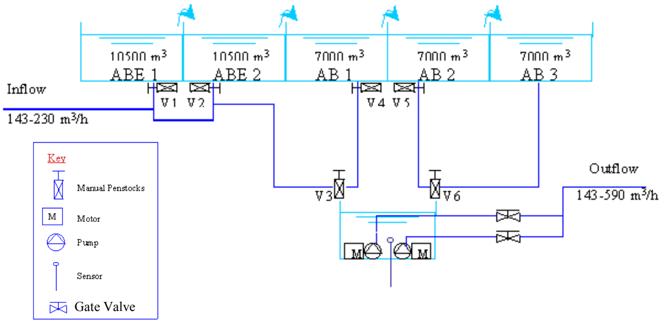

Figure 1: The Existing Emergency Tanks

Tanks ABE1 and ABE2 are fed with sludge water in a series process i.e. firstly the manual penstock V1 is opened and when the tank is filled the overflow enters the ABE2. Therefore, tank ABE2 rescues tank ABE1 in case of overflow. The manual penstock of tank AB1 is opened when tank ABE2 if filled. But if there is rapid flow of water and the penstock could not be opened on time, the water flows to the next tank by an overflow. The same method is used by tank AB2 to rescue AB1. Tank AB3 rescues AB2 only by overflow. It should also be noted that in the sewerage treatment plant, the flow of waste water is based on a gravitational flow and the ground level of the emergency tanks is inclined. (~10 degrees)

The output flowrate of sludge water from the emergency unit is 143 to 590 m^3/h. Two motors control the output flowrate of waste water. Therefore if a minimum flowrate is required at output only one motor is set on and if a high flowrate is required both motors are turned on. The gate valves are then opened to allow the output flow to the degreasing and degritting unit. Tanks ABE1 and ABE2 are fed with sludge water in a series process i.e. firstly the manual penstock V1 is opened and when the tank is filled the overflow enters the ABE2. Therefore, tank ABE2 rescues tank ABE1 in case of overflow. The manual penstock of tank AB1 is opened when tank ABE2 if filled. But if there is rapid flow of water and the penstock could not be opened on time, the water flows to the next tank by an overflow. The same method is used by tank AB2 to rescue AB1. Tank AB3 rescues AB2 only by overflow. It should also be noted that in the sewerage treatment plant, the flow of waste water is based on a gravitational flow and the ground level of the emergency tanks is inclined. (~10 degrees)

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3. MODEL DESIGN

The two tank model was used to build the new emergency unit. Basically, the simple level control model consists of two tanks connected in series. The system is assumed to be on a ground level which inclined by about 10^0 . Therefore, the flow of water in tank 1 will gravitationally flow in tank 2 and the two tanks will be filled in parallel.

Initially the penstock is assumed to be open when both tank are empty. A sensor is placed in the second tank in order to measure the level of water in the latter. Then water is allowed to flow in tank1. Obviously, the water will flow to tank2 gravitationally and the level of water in both tanks will rise at the same rate and simultaneously. This implies that at particular instant of time, the height of both tanks will be the same when they are measured.

So, as the liquid starts to flow in the second tank, the sensor reads the level of water in the tank feeds back a signal to the penstock to control its opening.

Considering the case when the height of liquid in the second tank (as well as the first tank) increases the penstock will close gradually and if the level of liquid in both tanks starts decreasing the penstock will open gradually. Therefore, the penstock remain open at different percentages until both tanks are filled up completely. Then, the penstock will automatically close itself to prevent overflow.

Figure 2 illustrates the final design of the emergency unit. The two tank model was considered as a reference model to build the cascade tank model. Clearly, each of the following group of two tanks (tanks 4 and 5, tanks 3 and 4 and tanks 2 and 3) will behave as the two tank model. Tank1 behaves independently from the others and it accepts flow of waste water at any time.

To understand better the whole system we assume that all the tanks are empty i.e. all the penstocks are opened and all valves are closed. Waste water then flows from the tank 1 to tank5, through tank 2,3 and 4, gravitationally due to inclination of ground level.

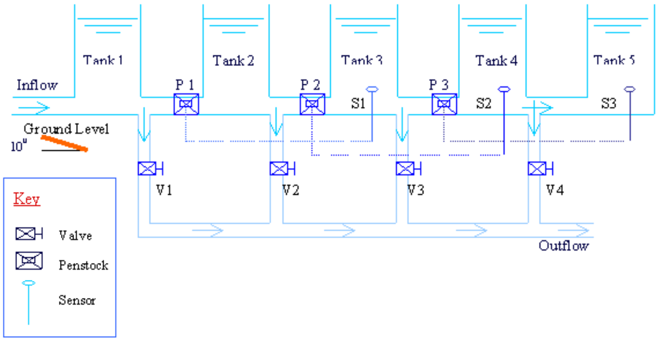

Figure 2: The Cascade Tank model.

Considering the flow of water in tank 4 and 5, we observe that the level of water will rise simultaneously in both tanks and as the level rises the penstock P3 will start to close. The same behaviour will be observed when considering tanks 3 and 4 and tanks 2 and 3. Therefore the level of water will rise equally in all tanks until all tanks attains its maximum level i.e. S1 commanding P1, S2 commanding P2 and S3 commanding P3 to close completely. From this experiment observation, we can deduce that in case of high flow rate entering the system the water will be distributed equally in all five tanks and there will not be any overflow in any of them.

But there may also be the case when all the five tanks are filled and there is still an inflow. In this particular situation, either V1 or V4 or both valves should be opened so that the flow of water is diverted to the output pipe.

If valve V1 is opened the water will be diverted directly to the output without causing any change in tanks 2,3,4 and 5. If V4 is opened the level of water in tank 4 and tank 5 will fall simultaneously thus due to the fall of level of water in tank 5 penstock P3 will start to open and decreasing height of water in tank 4 will cause penstock P2 to open gradually. Consequently if P3 starts to open, the level of water in tank 3 will decrease and this effect will cause P1 to open and water will continue to flow equally in all tanks.

In case where either V2 or V3 is opened, an overflow will be observed in tank1 (only V2 open) or in both tank1 and 2 (only V3 open) as P2 will remain closed even if P1 will open.

But if both V2 and V3 are opened simultaneously, a decrease in level of water in tank3 will cause P1 to open and even if P3 is closed water will flow to the output through V2.

It should also be noted that at the outflow we still have the two motors controlling two pumps (similar to the existing system) for giving the required output.

The system will be operating continuously, and our goal is to stabilize its operation near a given operating point while the system operates continuously [2].

The model of the system is constructed by measuring its dimensions and by calibrating its sensors and actuators. This construction will involve linearization, as the relationship between the amount of water in a tank and the flow out of the tank is nonlinear. An accurate system model is required so that the controllers used can be tested through simulation. This is important because a test on the actual system takes up to an hour or so, whereas a test of the simulated system takes only seconds.

IV. CONTROL SYSTEM

Figure 3 shows a block diagram of the control system of the two tank level control mode [3,4]. The control system runs as a program that takes measurements of the fluid level in the tank and compares it to the desired level R(s) to compute the error signal E(s). The control algorithm $G_c(s)$ computes an actuation signal which tells the valve how far to open. The valve transfer function is $G_a(s)$. The signal Y(s) tells the valve to open to a given percentage of its maximum opening, resulting in a flowrate $Q_i(s)$. The "plant" transfer function $G_p(s)$ represents the dynamics of the tanks themselves, with the flowrate into the tank1 as input and the height of the fluid in the tank2 as output. H(s) represents the sensor, which is the pressure (hence fluid level) sensor in tank2 (except for tank1 and cascade control models). The disturbance flow $Q_d(s)$ enters the loop between the actuator and the plant.

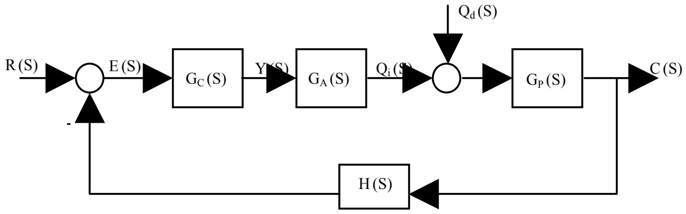

Figure 3: The Block Diagram Of The Two Tank Model with disturbance

Figure 4 shows The Two Tank Model structure used for building the simulation model. The size of the orifice corresponds to the maximum opening size (A m^2) of the penstock. The initial flow rate of sludge water is defined as Q_i and the flowrate at the orifice is defined as Q_0. At the output the flowrate is defined as Q_{out}. Note that the flowrate at the orifice is approximately equal for all tanks and since the flow of water is gravitational the height of tank 1(H_1) will be approximately equal to the height of tank 2 (H_2) i.e. the level of water will rise equally in both tanks considered in such a system.

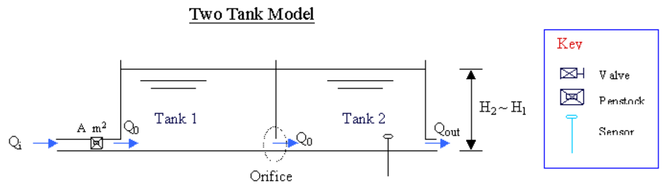

Figure 4: The Two Tank Model Structure

The Penstock Transfer Function is given by

$Q_{out}(s) = (H_R(s) - H_2(s)) / R$

where H_R is the reference height of tank 2
H_2 is the actual height of tank 2
R is the resistance of the penstock
Q_{out} is the output flowrate

The penstock was selected according to a standard size from Midland Valves' Company. The series WM - 30, 40 & 50 is a high duty range of Penstocks suitable for the control and isolation of water and sewage. The ranges of penstocks are provided with side, soffit and invert seals for 6 metre and off-seating heads [5].

Penstock Maximum Opening Length = 2m
Penstock Maximum Opening Width = 2m
Penstock Maximum Opening Cross sectional Area = 2 X 2 = 4 m^2

R is the resistance of the penstock and it characterises the percentage opening of the penstock. Letting A to be the maximum opening surface area of the penstock, the rate, per second, at which the penstock is opened is given by
$R = (1 / A)*t = (1 / 4)*1 = 0.25$ seconds / m^2 (since we are considering the rate (per second) of opening of the penstock, time,t=1). Therefore $1 / R = 1 / 0.25 = 4\ m^2$ / second.

Operating height, h, determines the operating height of water for the Two Tank Model system. Since the heights of the five tanks are the same (4 m) the operating height will also be same. For the safe operation of the simulation model, that is in order to avoid overflow, the value for operating height is chosen below half of the initial height of a tank.
Operating height, h = 1.75 m

$C_d = 1 / \sqrt{K_v}$ is the discharge coefficient of the penstock inserted in the pipe that is a function of the penstock type (i.e. local head loss coefficient Kv) and the opening percentage, being A_2 the reference area (e.g. penstock cross section). For the specifications of penstock used in the simulation of the Two Tank Model [6,7,8], $C_d = 0.61$

The discharge through the orifice or the flowrate of water entering the tank (due to Law of Conservation of Matter) [9], will be approximately equal to 21.62 m^3 / s ($q = 21.62\ m^3/s$).

A root-locus approach is also used in order to determine the value for the proportional and integral constants that will ensure the stability of the system. The method yields a clear indication of the effects of parameter adjustment [10]:
$K_p = 10$ and $K_i = 0.005$

V. SIMULATION RESULTS

The simulation was firstly performed for the Two Tank Level Control system and then for the Cascaded system and the responses are then observed.

A. Simulation of the Two-Tank Model

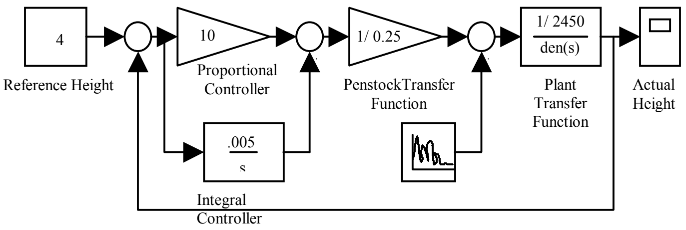

Figure 5: The Simulation Model for the Two Tank level Control

The simulation of the system is tested for 100 000 seconds in Simulink. The simulation output is observed from a scope. The response of the system has been satisfactory as we observe that the height in the tank 3 has a step rise from 0 to 3 m which is actually the maximum opening of the penstock. It is quite obvious to view this behavior since initially both, tank 2 and tank 3 are empty. Then for about 2 000 seconds the level of water gradually rises in both tanks to the required reference height which is 4 m. Then the level of water stays at this height and this shows that the penstock is closed when the actual height of the tanks attains the reference height. From the scope screen, the response also has small fluctuation which the level of water is raising, this is due to the disturbance added to the system.

B. Simulation of the Cascade Model

Figure 6 shows the cascade model of the Emergency Tanks at the Grand-Baie Sewerage Treatment Plant. As mentioned previously, in this unit the input is the flowrate of water from the other sections of the treatment plant which enters the tank ABE1. This flowrate of water is analysed and then processed to give the actual height of tank ABE1 which will serve as reference height to control the level of water of the other tanks.

Figure 7 show the simulation responses for each closed loop system simulated for 100 000 seconds. A step inflow of water of 230 m^3/s is fed into the control system of tank ABE1 and a step output of 3.5 m is observed. This is the reference height of water that all the three 'two-tank' loops use to control the level of water in each other. Eventually, we observe the level of water in each tank settles to 3.5m. For 'Tank 2 &3' we observe that the water level rises at a higher rate than 'Tank 3 &4' (Figure 7). We also observe that after 2000 seconds the level of in all tanks stabilizes, but with slight fluctuations, to the reference height i.e. 3.5m. Considering the results obtained from the Two Tank Level Control model we may conclude that the proportional and integral constants and all the other values calculated or estimated is correct as confirmed when the Cascaded model is simulated.

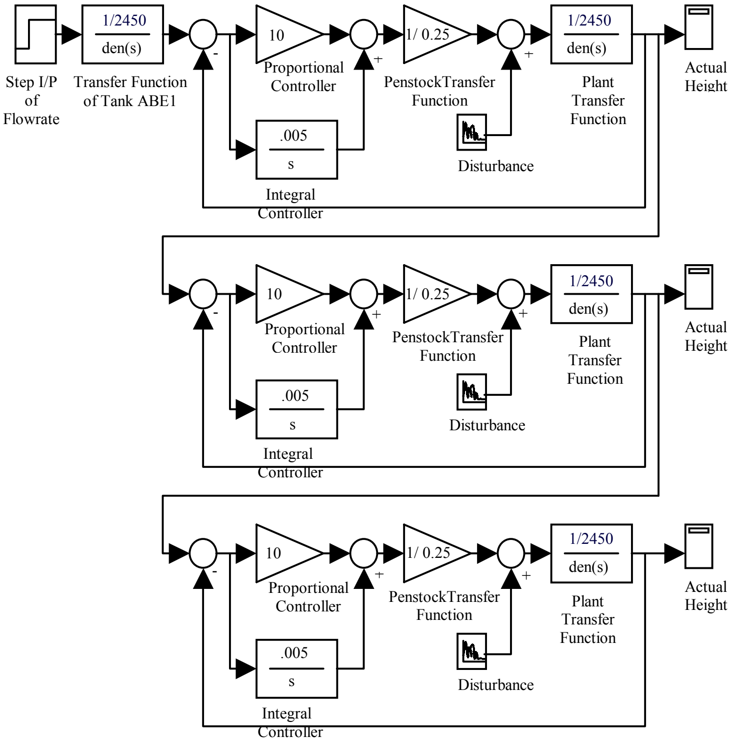

Figure 6: The Simulation Model for CascadeTanks

In the cascade model, there are actually three 'Two Tank' Level Control Model which are coupled to form the whole system. The first closed loop system describes the operation on tanks 2 and 3 (ABE2 and AB1 respectively) for the level control of water. The second closed system in turn controls the level of water in tanks 3 and 4 (AB1 and AB2 respectively) and finally the third closed loop system controls the level of water in tanks 4 and 5 (AB2 and AB3 respectively).

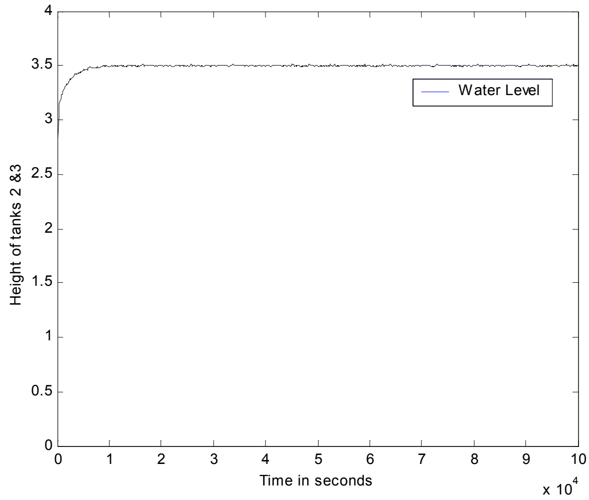

Figure 7: The Scope output for the level of water in tank 2&3, 3&4, 4&5

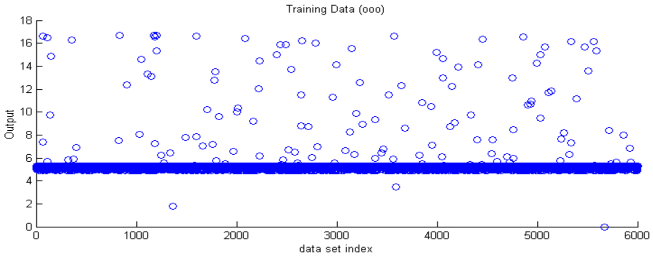

Figure 8: A set of 6 000 random training data

C. ANFIS Controller

The ANFIS [11] controller is then introduced into the system to replace the PI controller in Figure 6. This time the *ode45*, integration method is used as solver options for the simulation parameters. In the figure we observe three subsystems and they are quite similar. Each system is constructed from the same Anfis model except that the gains change.

Next, for more elaborate tests on the FIS we will consider random selection of data. From 10 000 values (corresponding to time during the simulation process) two sets of data are random chosen. A set, which contains 6 000 random values for each of the two inputs (Figure 8) and for the output of the FIS and in the other, we have taken only 4 000 random values (Figure 9).

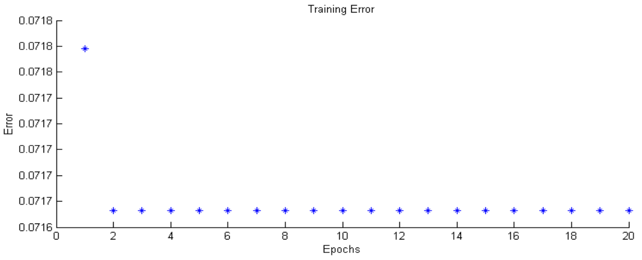

Figure 9: Training error plot for set of 6 000 random values

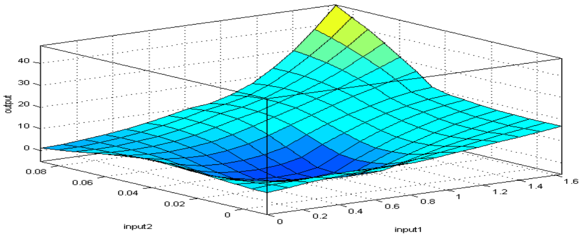

Figure 10: surface plot for set of 6 000 random values

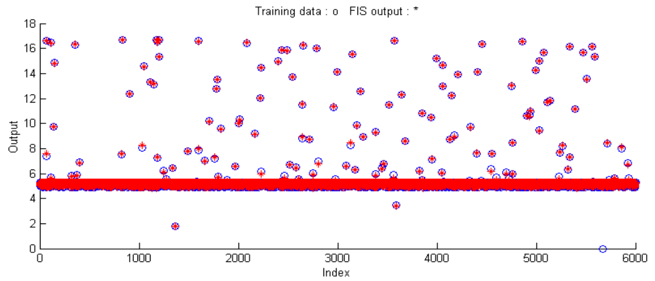

Figure 11: Testing the set of 6 000 random values as training data(‘o’ Training Data and ‘*’ FIS output)

The Anfis model has 9 if-then rules used and it was trained for 20 epochs. From Tables 1 and 2, it is observed that the training of the ANFIS is quite fast since the minimum training error could be observed only at the second epoch and then it stays constant. The response of the two inputs to the output could be observed through the surface plot in Figure 10. Obviously, we deduce the result will be satisfactory before even testing the FIS in the Simulink block since from the testing set of data we can observe that almost all the training data maps onto the FIS output values. Figure 11 shows the scattering of the random set of 4 000 values taken in the second case.

Table 1: Parameter before and after training of the Anfis (Random 6000 values) *Note: The training error is the Root-Mean Square Error (RMSE)*

TRAINING STATUS	**RMSE ERROR TOLERANCE**	**NUMBER OF EPOCHS**
PRE-DEFINED (BEFORE)	7.17729 E-2	20
REAL (AFTER)	7.16528 E-2	20

Table 2: Parameter before and after training of the Anfis (Random 4000 values)

TRAINING STATUS	**RMSE ERROR TOLERANCE**	**NUMBER OF EPOCHS**
PRE-DEFINED (BEFORE)	2.66965 E-2	20
REAL (AFTER)	2.60445 E-2	20

The responses of the water level of the tanks in the cascade control system with ANFIS controller are shown in Figure 12, with 6 000 values (graphs (a), (c), (e)) and 4 000 values (graphs (b), (d), (f)). The ANFIS controller trained on the set of 4 000 values give a faster response during the simulation.

Moreover to confirm the results for training values, tests are performed to compare the checking data and the FIS output. Firstly, the set of 6 000 random data is entered as training data and the remaining 4 000 random values are loaded as checking data then the values are tested for 20 epochs. Here also every checking data is matched with a FIS output. From these observations, we may conclude that the training of the FIS has been successful.

VI. CONCLUSIONS

Presently the flow of water is controlled gravitationally and by overflows where the water flows from one tank to another. In the system designed, we used the existing infrastructure and the actual environment to build a two tank level control system. The new system also functions gravitationally but three penstocks have been included to control the level of water that is flowing in the tanks.

Also, the usage of only *three* sensors linked with the penstocks proves to be economical since we may get a very good estimate of the levels of water in all *five* tanks in the system. Actually during rainfall or damages in a particular unit of the sewerage treatment plant, there exists only one bypass pipe the controls all the overflows and it is the pipe that serves as the only inlet to the emergency unit.

The new system has been tested for flow rates greater than the specified range because we did not want to limit ourselves to the initial inflow capacity and to allow more inlet flows in the emergency unit. So with this new cascaded model the government can allow pipes from each unit to enter the emergency tanks. This implementation can also be useful during cleaning and repairs of any unit at the sewerage plant and it ensures safety in all the parallel working units.

The performance of each of the two tanks level control with PI control has proved to be good since all water levels in the five tanks were responding perfectly to the required specifications. We also notice that the time for the water level each tank in the unit to attain reference is approximately the same (~650 seconds). The impact of disturbances (e.g. rainfall) on the system has also been considered, but their effects is negligible.

The response for the ANFIS showed that except for the first controller the other two loops have the same rate of rise and attains reference height quicker. Based on the second sample of 4 000 values, the controllers’ responses were faster than the ANFIS trained with 6 000 values. Moreover to confirm all results one set of the random values as training parameter and the other as checking parameter are used. The simulation proved to be successful since the errors obtain were minimum.

Considering the results from simulations, ANFIS has successfully been used to control the water level in the cascade system. The selection between the ANFIS and the PI controllers will depend whether a quick rate of rise of the level of water is needed or a similar response for all tanks present in the emergency unit.

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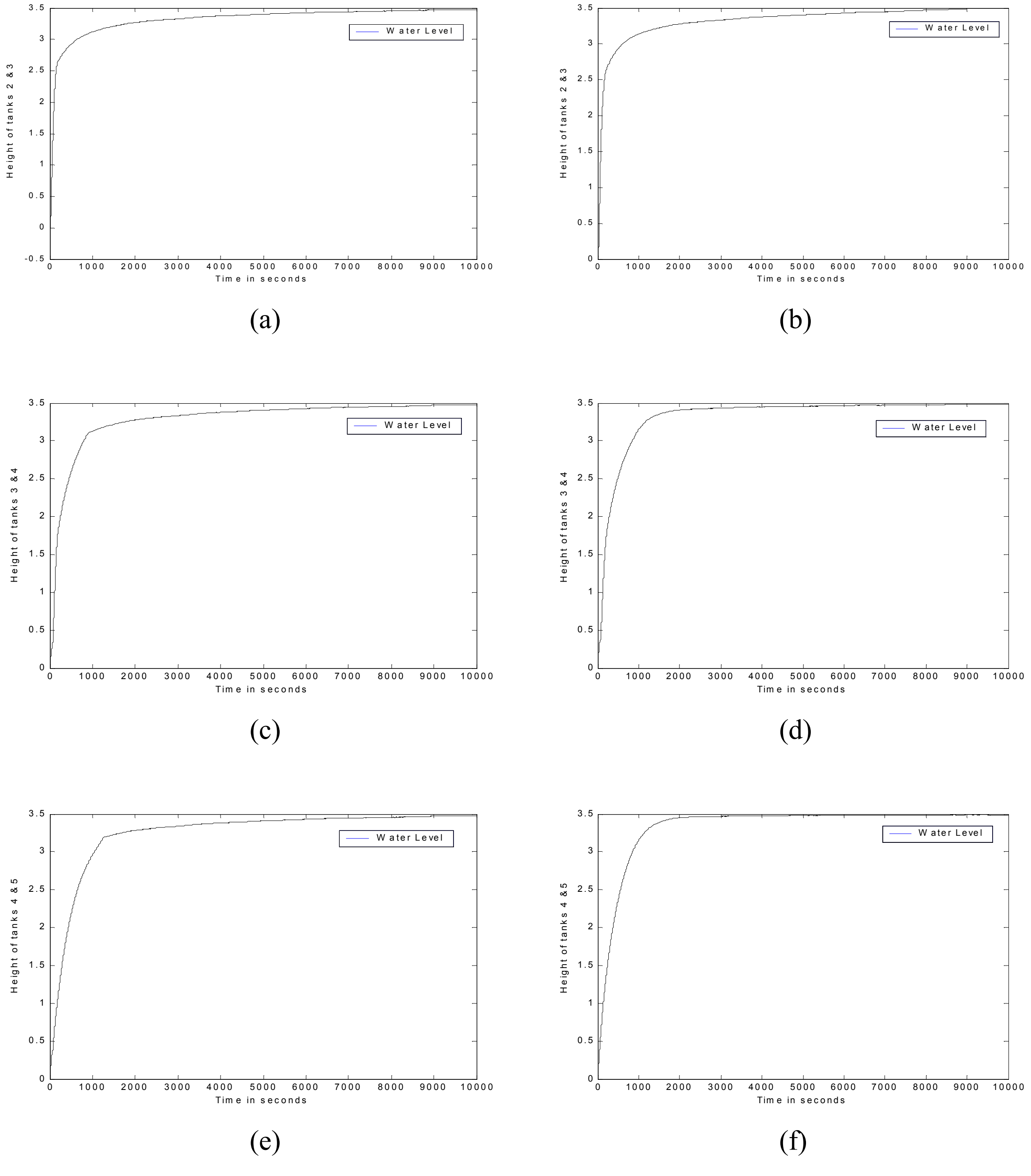

(a) (b)

(c) (d)

(e) (f)

Figure 12: Responses of three control loops for 2 sets of (random) data