Automation of Irrigation System Using ANN based Controller

[1]S.Muhammad Umair, [2]R. Usman
[1]umair_quaidian@yahoo.com, [2]usman_usman419@yhaoo.com
Research Centre for Modeling & Simulation, National University of Science and Technology, Pakistan

***Abstract*-- Irrigation systems are as old as man itself since agriculture is the foremost occupation of civilized humanity. To irrigate large areas of plants is an onerous job. In order to overcome this problem many irrigation scheduling techniques have been developed which are mainly based on monitoring the soil, crop and weather conditions. Irrigation scheduling engrosses when to irrigate and how much water to be applied. Currently most of the irrigation scheduling systems and their corresponding automated hardware are fixed rate. Variable rate irrigation is very essential not only for the improvement of irrigation system but also to reduce the irrigation cost and to increase crop yield. The heart of automatic irrigation system (fixed rate or variable rate) is its control unit: as it controls irrigation time and water flow. Intelligent control based irrigation is necessitated to maximize the efficiency and production. Existing technologies varies from water balance or check book method to sophisticated sensor-based systems [1].Most of the irrigation systems use ON/OFF controllers. These controllers can not give optimal results for varying time delays and varying system parameters. This paper presents Artificial Neural Network (ANN) based intelligent control system for effective irrigation scheduling. The proposed Artificial Neural Network (ANN) based controller is prototyped using MATLAB. The input parameters like air temperature, soil moisture, radiations and humidity are modeled. Then using appropriate method, ecological conditions, evapotranspiration and type of crop, the amount of water needed for irrigation is estimated and then associated results are simulated.**

***Index Term*-- Artificial Neural Network, Automated hardware, Irrigation scheduling, Evapotranspiration.**

1. INTRODUCTION

Agriculture has, throughout History, played a major role in human societies endeavors to be self sufficient in food[2].Irrigation is an essential component of crop production in many areas of the world. In cotton for example, recent studies have shown that proper timing of irrigation is an important production factor and that delaying irrigation can result in losses of between USD 62/ha and USD 300/ha [3]. Irrigation water use represents a substantial opportunity for residential water savings. Automation of irrigation system has the potential to provide maximum water use efficiency by monitoring soil moistures at optimum level[4].The control unit is the pivotal block of entire irrigation system. It controls the flow of water and therefore enables the grower to acquire optimized results.

1.1 Types of Controllers [5,6,7,8,10,15]

Irrigation process can be controlled by two types of controllers.

1.1.1Open loop controller:

This are also called non-feedback controllers. This type of controller is designed on following principles:

- It just takes input and computes output for the system accordingly.
- It does not have any feed-back to determine whether the desired output or goal is achieved or not.

This is most simple form of controller in which basic parameters and instructions are pre-defined such as:

- When to start watering/a task
- When to end watering /a task
- Time delay intervals

During execution of above set of instructions using open loop-controller no measures are taken to check whether right amount of water is supplied or not.

These controllers may have less cost, but they are not very good and they do not provide optimal (or a good) solution to irrigation problems.

1.1.2 Closed loop controller:

They are based on pre-defined control concept and utilizing feedback from controlled object/system in some manner. In this type of controller feedback of a necessary parameter is required to check right amount of water needed for irrigation.
There are several parameters which (play important role in order to make an optimal decision. Some of these parameters remains fix through out the process. Such as:

- Kind of soil
- Kind of plants
- Leaf coverage
- Stage of growth etc.

Whereas some of them varies with time and should be measured during irrigation process.
They are physical parameters such as:

- Soil humidity
- Air humidity
- Radiation in the ground
- Temperature

Whole irrigation process is mainly based upon above specified physical parameters. Since these parameters are physical and changes with time; consequently amount of water being used for irrigation also changes.

The irrigation system explicated in this paper exploit closed loop control. The control unit continuously receives feed back from different sensors placed in the field. It enables control unit to update its data about important system parameters. The control unit decides how much water tap to open, in accordance with the data collected from sensors and predefined parameters(depending upon the crop, weather conditions etc.)

The major parameters that determine the irrigation process are:

- type of growth;
- status of the growth (height, depth of roots);
- leaf coverage;
- kind of soil and saltiness;
- water budget (economy or normal irrigation).

Therefore, the input parameters that are used by the system are:

- soil (ground) humidity;
- temperature;
- radiation;
- wind speed;
- air humidity;
- salinity (amount of salt in the ground).

The output parameters are:

- opening/closing the valves for water and/or fertilizer, and adjusting their amounts in combination;
- Turning energy systems on/off (lights, heating, ventilation);
- Opening/closing walls and roofs of hothouses [9].

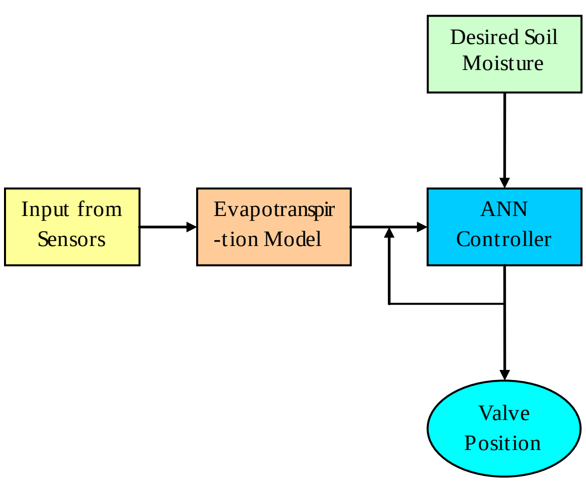

Fig. 1. Irrigation Control System block diagram

2. DESIGN OF ANN BASED IRRIGATION CONTROLLER

Figure 1 exhibits the block diagram of Complete Irrigation System ingrained with ANN Controller. It is seen that control system consists of four interconnected stages.

- Input from Sensors: In this stage different parameters like temperature, air humidity ,soil moisture, wind speed and radiation ,are collected. Then these parameters are passed to next stage as input.
- Evapotranspiration Model: This block converts four input parameters into actual soil moisture(details in next Section)
- Required Soil Moisture: This block provides information about the amount of water required for proper growth of plants.
- ANN Controller: This stage compares the required soil moisture with actual soil moisture and decision is made dynamically.

2.1.Modeling of System Parameters

We use the modeling of input parameters from [10];

2.1.1. Inputs Parameters: There are four factors (Temperature, air humidity, wind speed and radiation) by which evapotranspiration is influenced.

2.1.2 Temperature: This variable should be defined as a continuous signal (normally as a sine wave which simulated the day and night temperature changes), but may show sharp changes in special places like deserts
and so on therefore:

- A sine wave with amplitude of 5 ºC;
- A frequency of 0.2618 rad/h. This frequency is
- measured according to a time period of 24 h:
  0.2168 rad/h = 2pi/*T*=2pi/24.
- A constant bias(offset) of 30 ºC;

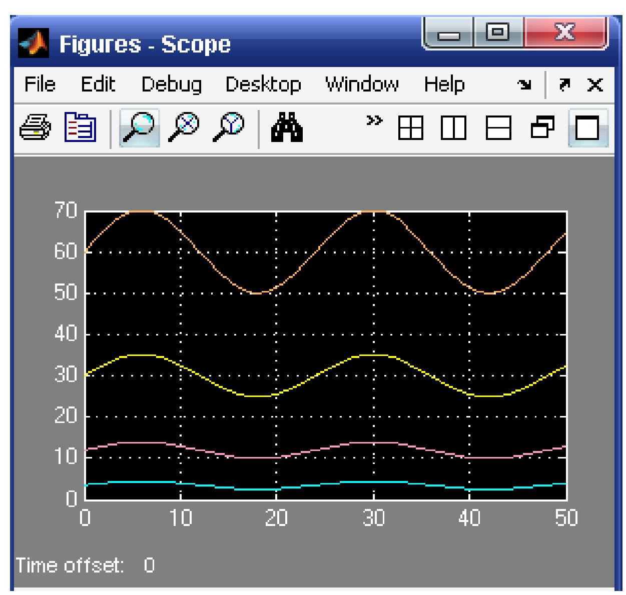

Fig. 2. Input Parameters of Evapotranspiration model-Graphical representation.

This stimulus generates a wave which at its maximum can reach 35°C (midday) and at its minimum can reach +25°C (midnight). In this way, the temperature on any given day can be simulated by changing the bias that is attached to the variable. This diversion is obtained by uniform number generation(Yellow graph in figure 2).

2.1.3 Air humidity: It is modeled as:

- A sine wave with amplitude of 10%;
- Bias of 60% (constant);
- A frequency of 0.2618 rad/h (Orange graph in Fig. 2).

2.1.4 Wind speed :

- A sine wave with amplitude of 1 Km/h;
- Bias of 3.5 Km/h (constant);
- A frequency of 0.2618 rad/h (Light Blue graph in Fig. 2) [10].

2.1.5 Radiation: It is modeled as maximum possible radiation at earth's surface (Rmax). (Light Pink graph in figure 2

- A sine wave with amplitude of $2MJ/m^2$
- Bias of 112MJ/m;
- A frequency of 0.2618 rad/h.

2.2 Required Soil Moisture: It is solely dependent on the kind of plant ,type of growth ,type of land and type of soil. The required soil moisture is calculated according to the above mentioned factors. An assumed graph is shown in figure3:

2.3.Evapotranpiration Model[10,11,12,13]:
Penman-Monteith equation is a combination equation that

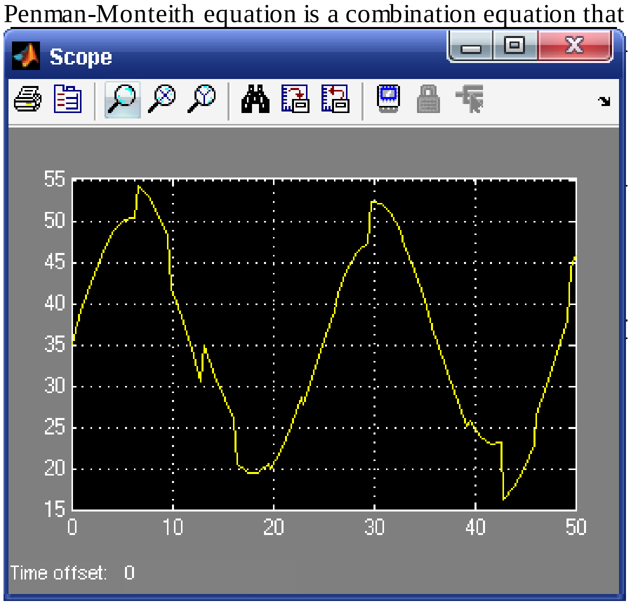

Fig. 3. Required Soil Moisture-graphical representation

has generally been accepted as a scientifically sound formulation for estimation of reference evapotranspiration (Eto). This equation is expressed as combined function of radiation, maximum and minimum temperature, vapor pressure, and wind speed.

After the Penman method is updated by FAO in May 1990, the Penman Monteith equation is written as the following:

$$Eto = \frac{0.408\Delta(R_n-G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u2)} \quad (a)$$

$$\Delta = \frac{4098eo(T)}{(T+273.3)^2} \quad (b)$$

$$e^o(T)=0.6108 \exp\left(\frac{17.27T}{T+273.3}\right) \quad (c)$$

$$\gamma = \frac{C_pP}{\varepsilon\lambda} \bullet 10^{-3} = 0.001628 \bullet P/\lambda \quad (d)$$

Where:

ET0 = Reference evapotranspiration [mm day-1],
Rn = Net radiation at the crop surface [MJ m-2 day1],
G = Soil heat flux density [MJ m-2 day-1],
T = Mean daily air temperature at 2 m height [°C],
U_2 = Wind speed at 2 m height [m s 1],
e_s = Saturation vapor pressure[kPa],
e_a = Actual vapor pressure [kPa],
e_s-e_a = e^o(T)= Saturation vapor pressure deficit [kPa],
D = Slope vapor pressure curve [kPa °C-1],
g = Psychrometric constant [kPa °C 1].
P = Atmospheric pressure [kPa],
z = Elevation above sea level [m],
e°(T) = Saturation vapour pressure at the air temperature T [kPa],
λ = Latent heat of vaporization, 2.45 [MJ kg-1],
Cp = Specific heat at constant pressure, 1.013 10-3 [MJ kg-1 °C-1],
ε = Ratio molecular weight of water vapour/dry air = 0.622.

2.4.Control Unit: The control unit consists of Artificial Neural Network based controller. This controller interfaces the required soil moisture and measured soil moisture. The main function of this stage is to keep the actual soil moisture close to the required soil moisture. As a result the output of this stage is control input for valve which supervises the amount of water which should be supplied in order to optimized the whole system. The block diagram of ANN based control system is shown in figure 4.

In the proposed method Dynamic Artificial Neural Network is used. Dynamic Networks are more powerful than static networks because dynamic networks have memory ,they can be trained to learn sequential and time varying patterns[14].

The controller has two inputs i.e. required soil moisture and calculated soil moisture from evapotranspiration model, and there is only one out put of controller also called control input for Valve position. It makes the system configuration very simple and straight forward.

3. ANN Controller Architecture

ANN Controller is implemented using the following;

- **Topology:** Distributed Time Delay Neural Network is used ;
- **Training Function:** Bayesian Regulation function is used for training.
- **Performance:** Sum squared error is taken as performance measure.
- **Goal:** The set goal is 0.0001.
- **Learning Rate:** The learning rate is set to 0.05.(Figure 6).

The block diagram of ON/OFF controller is shown in figure 5. In this configuration the valve is opened when the required soil moisture exceeds the measured soil moisture and it remains closed otherwise.

4. Simulation Results

(Performance Analysis)

Once the neural network is trained, it can be used as direct controller in cascade with the Evapotranspiration model. The control target is to bring the actual soil moisture as close as possible to required soil moisture and to optimize the resources like water and energy.

Keeping the aforementioned requirement in mind behavior of ANN controller is noted for reference (Required) Soil moisture. The Response of ANN controller is compared with ON/OFF controller implemented with the same evapotranspiration model. This is shown in figure 7-8.The important facts that can be extracted from the simulations are:

4.1 ON/OFF Controller

The legend of figure7 is:

- Yellow signal – Required Soil moisture
- Blue Signal-actual soil moisture.
- Light Red signal – valve out put.

1. In ON/OFF control based system ,the actual soil moisture tracks the required soil moisture but there are continuous oscillations around the required soil moisture.
2. The Continuous oscillation at the output shows that the ON/OFF control based system is not stable.

In ON/OFF controller the valve is opened and closed continuously at the extreme points(0 and 10).Due to this lot of energy and water is consumed which is undesirable.

4.2 ANN Controller:

The legend of figure 8 is:

- Yellow signal-Required Soil moisture
- Light Red signal-Actual Soil moisture
- Green-Valve output.

The actual soil moisture tracks the required soil moisture without any oscillations.

1. The error(difference between required and actual soil moisture)is steady and reasonable (less than 2%)
2. In ANN controller the ON/OFF of the valve and energy system is very low and hence lot of energy and water can be saved.

The main goal of designing the cost-effective and result oriented Irrigation Control System has been achieved by using ANN Controller.

5. Conclusions and Future Work

This paper has described a simple approach to Irrigation control problem using Artificial Neural Network Controller. The proposed system is compared with ON/OFF controller and it is shown that ON/OFF Controller based System fails miserably because of its limitations. On the other hand ANN based approach has resulted in possible implementation of better and more efficient control. These controllers do not require a prior knowledge of system and have inherent ability to adapt to the changing conditions unlike conventional methods. It is noteworthy that ANN based systems can save lot of resources(energy and water)and can provide optimized results to all type of agriculture areas.

In future we plan to remove some idealizations used in this paper (such as input parameters), and will make use of real data. We also plan for hardware implementation of current work.

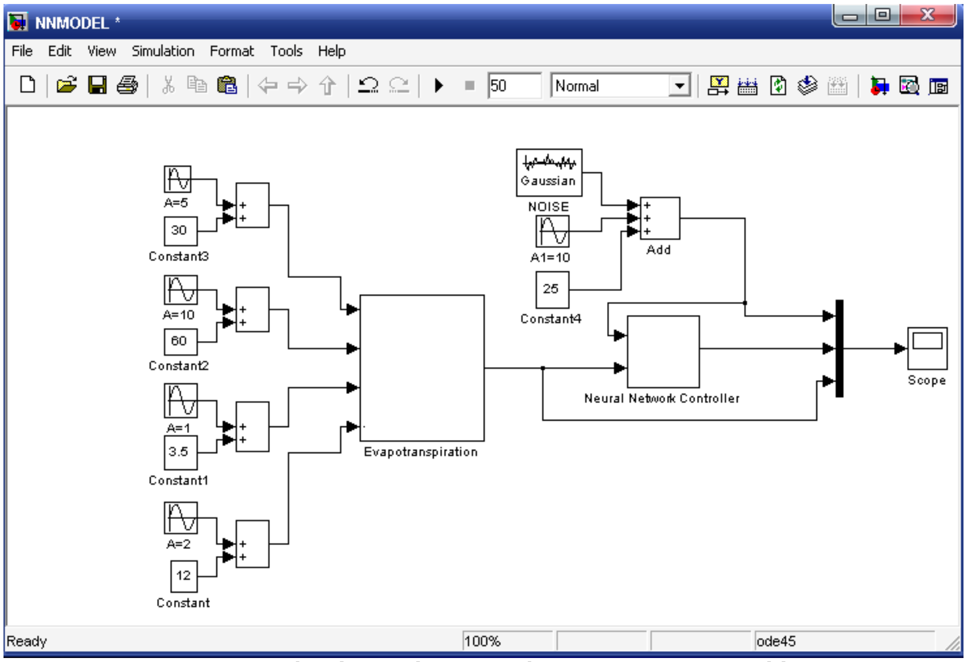

Fig. 4. ANN based Control System with Evapotranspiration model

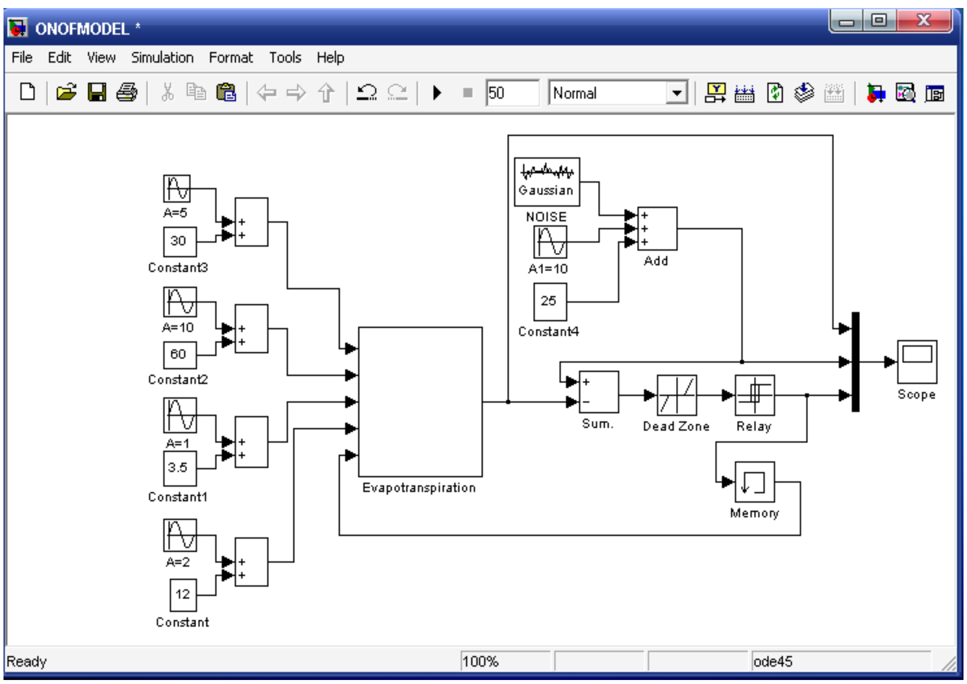

Fig. 5. ON/OFF based Control System with Evapotranspiration model

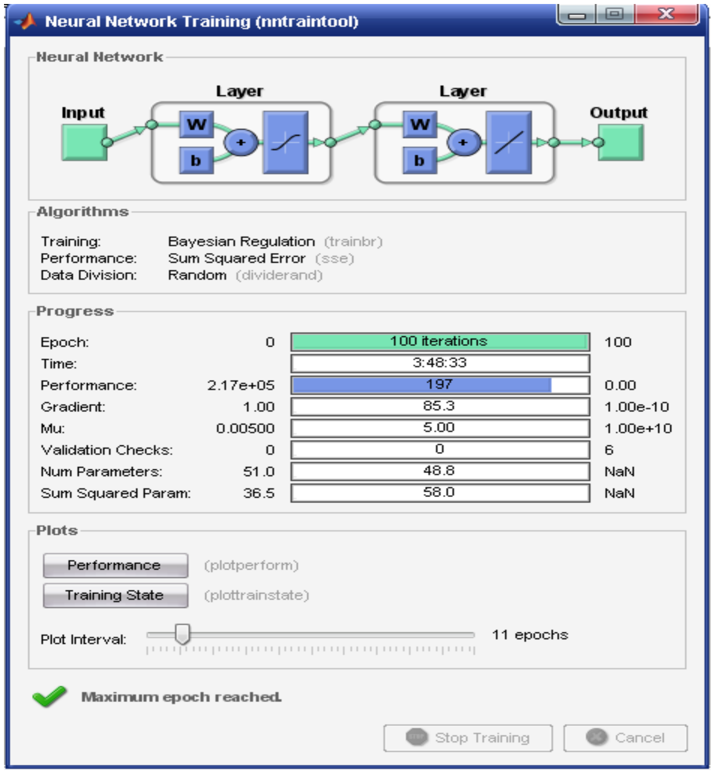

Fig. 6. Neural Network Training

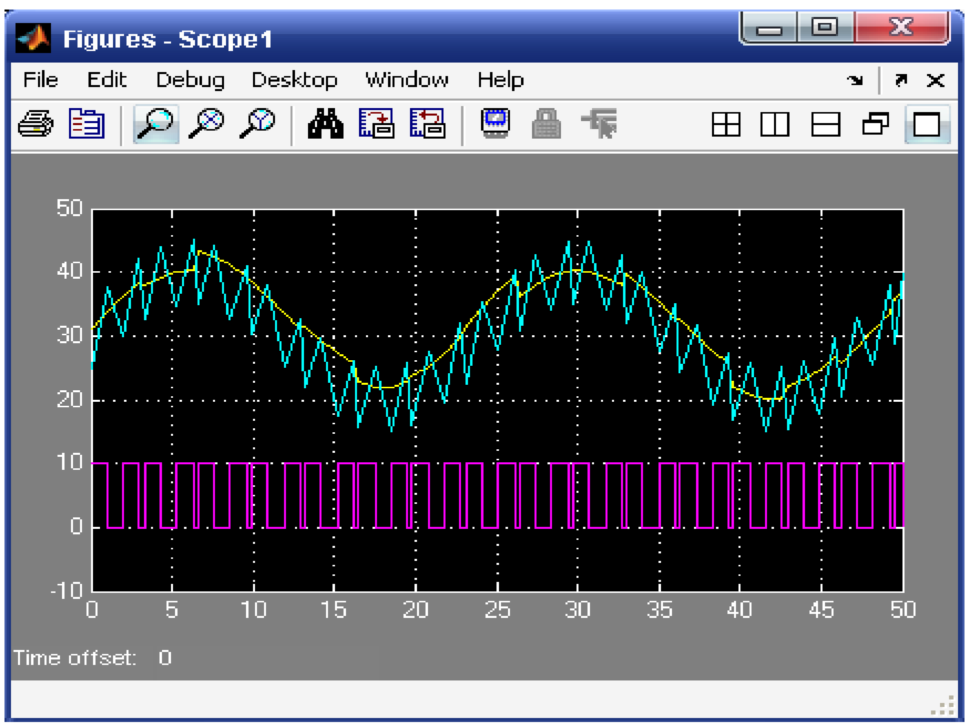

Fig. 7. Simulation Results of ON/OFF control based System

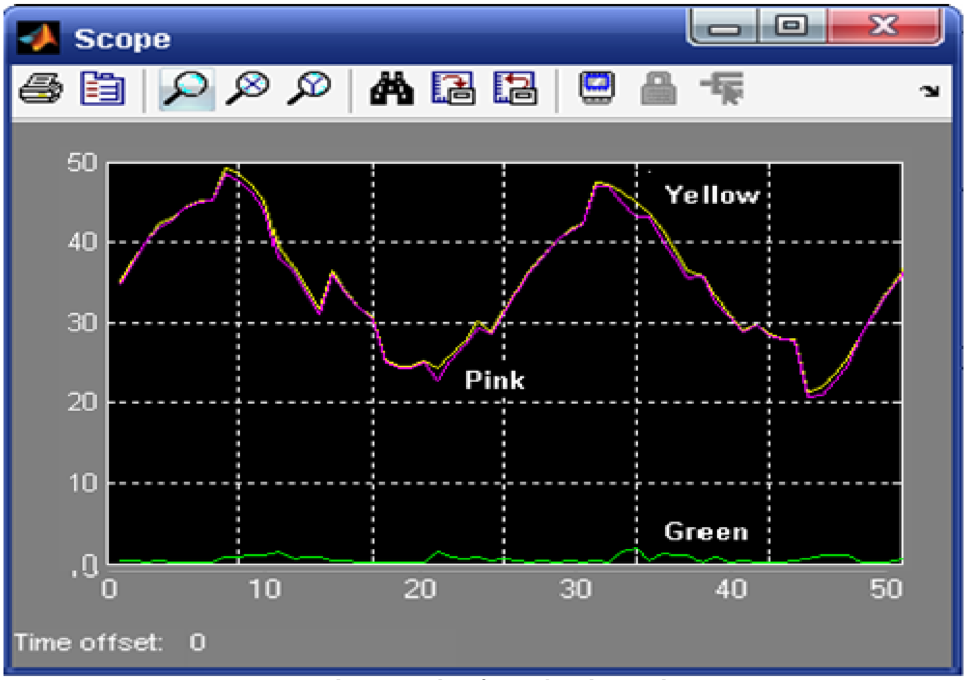

Fig. 8. Simulation Results of ANN based control System

REFERENCES

[1] G.Vellidis, M.Tucker,C.Perry, C.Kvien, C.Bednarz, Areal-time wireless smart sensor array for scheduling irrigation, computers and electronics in agriculture 61(2008)44–50.

[2] R. M. Faye, F. Mora-Camino ,S. Sawadogo, and A. Niang, 1998 IEEE. An Intelligent Decision Support System for Irrigation System Management

[3] Vories, E.D., Glover, R.E., Bryant, K.J., Tacker, P.L., 2003. Estimating the cost of delaying irrigation for mid-south cotton on clay soil. In: Proceedings of the 2003 Beltwide Cotton Conference National Cotton Council, Memphis, TN, USA, pp. 656–661.

[4] Bernard Cardenas-Lailhacar, Michael D. Dukes, Grady L. Miller, Sensor-Based Control of Irrigation in Bermudagrass.An ASAE Meeting Presentation Paper Number: 052180.

[5] Zazueta, F.S., A.G. Smajstrla and G.A. Clark,1994. Irrigation system controllers. Institute of Food and Agriculture Science, University of Florida (AGE-32).

[6] Burman, R. and L.O. Pochop, 2004. Evaporation evapotranspiration and climatic data. Elsevier, Amsterdam.

[7] Or, D., 2005. Soil water sensors placement and interpretation for drip irrigation management in heterogeneous soils. In: Proceeding of 5th International Microirrigation Congress, pp: 214-222.

[8] Ioslovich, I., P. Gutman and I. Seginer, 2006. A non linear optimal greenhouse control problem with heating and ventilation. Optimal Control Applications and Methods, 17: 157-169.

[9] Bahat, M., G. Inbar, O. Yaniv and M. Schneider,2000. A fuzzy irrigation controller system. Engineering Applications of Artificial Intelligence, 13: 137-145.

[10] P. Javadi Kia, A. Tabatabaee Far, M. Omid, R. Alimardani and L. Naderloo. Intelligent Control Based Fuzzy Logic for Automation of Greenhouse Irrigation System and Evaluation in Relation to Conventional Systems. World Applied Sciences Journal 6 (1): 16-23, 2009 ISSN 1818-4952.

[11] Hatfield, J. I. 1990. Methods of estimating evapotranspiration. In: Stewart, B. A., & Nielsen, D. R. (editors) Irrigation of Agricultural Crops: Agronomy 30. American Society of Agronomy. Madison.

[12] Richard, G.A., S.P. Luis, R. Dirk and S Martin, 2006. FAO Irrigation and Drainage Paper, No. 56: Crop Evapotranspiration.

[13] Alizadeh, A., 2006. Soil water-plant relation ship, Astane Ghodse Razavi.

[14] Howard Demuth,Mark Beale andMartin Hagan.Neural Network Toolbox™ User's Guide 2009.

[15] Kuo, Benjamin C. (1991).*Automatic Control Systems* (6th Ed.). New Jersey: Prentice Hall. ISBN 0-13-051046-7.

Mr.Muhammad Umair Siddique received his Msc degree in Electronics from Quaid-i-Azam University, Pakistanis. Currently he is pursuing MS in Computational Science & Engineering from Research Centre of Modeling & Simulation, NUST,Pakistan.His research interests include Formal Verification ,Embedded systems and Modeling &Simulation of Complex Systems.

Usman Rauf obtained his BS degree in Computational Physics from CHEP, Punjab University, Pakistan. Currently he is pursuing MS Computational Science & Engineering from RCMS, NUST,Pakistan.His research interests includes Model Checking, Artificial Intelligence and Modeling.