A Modeling, Simulation, and Setting the Control Parameters for Automation of Irrigation System Using PID and ANN methods

Ravi Kant Jain

Senior Principal Scientist, Information Technology Group,
and Professor, AcSIR,
Head, Engineering Services Division (ESD-Institute)
CSIR-Central Mechanical Engineering Research Institute (CMERI)
Durgapur-713209, India
rkjain@cmeri.res.in; jainravikant@gmail.com
ORCID:0000-0002-8106-1256

Abstract— Irrigation systems have been demanding the automation of the system for getting faster and more precise manner of agriculture which will be enhanced the productivity rate and reduced the processing time and labor cost. During automation, irrigating the large areas of plants is a difficult job. To overcome such problems, irrigation scheduling techniques can be applied to monitor the soil and crop conditions. Irrigation scheduling plays a vital role when irrigating the land and how much water is to be applied. This improves the irrigation system as well as reduces the irrigation cost and increases crop yield. For this purpose, modeling, simulation, and setting of the control parameters for the automation of the irrigation system are carried out using Proportional-Integral-Derivative (PID). Further, to improve the performance of the control system, Artificial Neural Network (ANN) based intelligent control system is applied for effective irrigation scheduling where evapotranspiration, ecological conditions, type of crop, and the amount of water are estimated for irrigation The model is simulated using MATLAB software, and it is found that ANN-based intelligent control systems can provide a better solution for saving the resources and can also provide optimized results to different types of agriculture cultivation.

Keywords - ***Irrigation systems, PID control system, Artificial Neural Network (ANN), Irrigation Scheduling, Control system, etc.***

I. INTRODUCTION

The intelligent systems have been providing the solution for the environment to build the decisions making system for futuristic aspects and analysis of their surroundings which plays a vital role in human society's accomplishments to be self-sufficient in food and living of life requirements. Irrigation is the most important part of agriculture in many parts of the world where water is an inadequate resource and irrigation techniques must be automated with precision and accuracy so that limited resource can be utilized effectively and efficiently manner. During automation, the design of a control system for irrigation scheduling is the most essential aspect where irrigation scheduling is to attempt on when to irrigate and how much water will have to be supplied. This is focused on the fixed-rate or variable rate of its control system. For this different types of controllers are attempted such as ON-OFF controller, PD, PI, PID, etc. [1,2]. The major disadvantage of ON-OFF controllers cannot give optimal results for varying time delays phenomenon and varying system parameters of the controller whereas PD, PI, and PID give slightly better results than an ON-OFF controller. Artificial Neural Network (ANN) controllers have the potential whereby set up the input parameters like soil moisture, air temperature, humidity, radiations etc., the model of control system can be developed which provides the output information for evapotranspiration, type of crop, ecological conditions, the amount of water required for irrigation. Using proposed this method, effective irrigation scheduling can be achieved to the level of water, moisture in the soil, use of pesticides and fertilizers, etc.

The main objective of this paper is to develop a model for a control system where a PID system is applied and further improvement of the system, ANN control technique is applied for effective irrigation scheduling for agricultural land. The classifications of the crop into different types of areas can be set according to the requirement with different environmental conditions in similar resources so that these can be identified in a group in the same category. Therefore, irrigation needs can be identified with lesser water requirements.

This paper is presented as follows: a brief report of a literature survey for different controllers application towards irrigation applications is discussed in Section II. In section III, a novel concept on PID controller enabled in an irrigation system is proposed where the major focus is on minimizing the drawbacks of the ON-OFF control system. In section IV, a system architecture of ANN Controllers' application in the irrigation scheduling is discussed. The conclusion is written in Section V.

II. BRIEF LITERATURE SURVEY ABOUT MODELING, SIMULATION, AND APPLIED CONTROL SYSTEM ON THE IRRIGATION SYSTEM

In the past, some researchers have reported on automated irrigation systems where different types of control systems are identified. Ding et al. [3] have focused on the fuzzy self-adaptive PID controller which is applied to the automatic control system of canal operation. During operation, the controlled parameters are set based on fuzzy logic reasoning and the optimal best fine-tuning of PID controller parameters. Colaizzi et al. [4] have applied a plant canopy temperature for improving irrigation systems towards crop management where a remotely sensed plant canopy temperature theory has been applied. Shirazpasha et al. [5] have attempted automated irrigation for farms or nurseries which gives information to farmers about the exact amount of water requirement. This turns valves ON-OFF using a solenoid valve and microcontroller. Pavithra et al. [6] have developed an android phone-control irrigation system where Application Programmable Interface (API) is applied to develop Android applications platform using the Java programming language. Goyal et al. [7] have emphasized modeling of daily pan evaporation in subtropical climates using various controllers which increases the accuracy/precision of daily pan evaporation estimation during subtropical climates. Rodriguez et al. [8] have developed a control algorithm for automatic irrigation scheduling in a soilless culture where the control system is based on a PID algorithm and it provides the automatic operation with the minimum cost. Goodchild et al. [9] have attempted on a PID controller for providing the proper control of soil moisture conditions by supplying the exact amount of water according to the requirement of the plant. subsequently, the PID controller is modified by changing the environmental conditions such as different rainfall, high-temperature conditions, etc so that the controller can work under different conditions such as watering, windup, plant stress conditions, etc. Poyen et al. [10] have attempted an ANN controller which is applied for precise moisture control in smart irrigation. The controller interacts with the requisite soil moisture and calculated soil moisture conditions. Lozoya et al. [11] have presented a model of control strategy applied to an irrigation system for making efficient use of water for large crop fields, that is applying the correct amount of water at a suitable place at the exact time. Ghodake et al. [12] have focused on the design of an automated drip irrigation system where a feasibility study has been carried out regarding cost-effectiveness. Shitu et al. [13] have summarized the review on smart different control systems for water management applications whereas Guo et al. [14] have attempted the real-time control system for irrigation applications where a model for predictive control is applied for finding the plant's desired root-zone deficit level with specified variable rainfall parameters etc. Sheikh et al. [15] have emphasized the importance and significance of modernization of irrigation in the agriculture field by applying a PID controller where all-natural parameters including temperature, air humidity, wind speed, radiation, and soil moisture are taken into account. Munir et al. [16] have employed an IoT system for smart energy consumption and smart irrigation in tunnel farming where a set of sensors records the plant data efficiently and their water requirement. An application is also developed for monitoring and controlling the irrigation system. Sudharshan et al. [17] have attempted on renewable energy-based smart irrigation system where the fuzzy logic algorithm is used to control the solenoid valve and data from the sensors are sent to the adafruit.io cloud platform so that users can monitor the moisture and humidity level etc. Jacob et al. [18] have attempted on modeling the automatic sprinkler irrigation process using a PID controller and finite-state machine where automatic control logic is designed for automatic irrigation systems in real-time. Gonzalez-Briones et al. [19] have attempted an intelligent multi-agent system where the data are gathered from wireless sensor networks for potato crops. Further, the data have been uploaded to the cloud. EL-Zemity et al. [20] have developed a wastewater treatment model with smart irrigation utilizing a PID controller where the PID gain parameters are tuned using MATLAB and the correlation for the performance of the wastewater treatment processing is achieved. Abioye et al. [21] have attempted an IoT-based monitoring framework using ES Presso Lite and V2.0 module which interfaces the various soil moisture sensors to measure soil moisture contents for mustard leaf plants. Poyen et al. [22] have applied a fuzzy rule-based controller to control the check the water wastage by providing an optimal irrigating environment for farming where the necessary control action regulates the actuators by supplying the right amount of water to the farm. Further, Jain et al. [23,24] have demonstrated an IoT-enabled smart drip irrigation system using web/android applications for agricultural applications whereas in this paper, modeling, simulation, and setting of the control parameters for automation of irrigation system using PID and ANN methods are proposed which will help in an irrigation scheduling. This is a novel part of this paper.

III. DESIGN OF PID BASED AND ANN-BASED CONTROLLERS FOR AUTOMATED IRRIGATION SYSTEM

A. Modelling of system parameters for PID controller towards automated irrigation system

For designing the controller for an automated irrigation system, several parameters like the kind of soil, kind of plants, leaf coverage plays, etc play an essential role during the cultivation of crops where an optimal decision is required for providing the water requirement. For taking the optimal decision, the controller should be designed in such a way as to how much water (and/or fertilizer) will be used in respective irrigation sessions/areas and repeatability can be itself accordingly to the requirement. In the pre-defined control/direct control method, there is no feedback from the controlled object. For taking the account of a feedback system, the study on irrigation sessions is required where repeatability is a major concern according to irrigation session/area. Considering these aspects, a PID controller i.e. a close loop system is proposed for a feedback control system where the process variable may be fixed with a setpoint, and produced an error signal will be corrected as per requirement. This controls the output parameters of the system and this process may be continued up to the zero error signal or the process variable value will be equal to the set point. During operation, the input parameters are considered as soil humidity, air humidity, temperature, radiation, wind speed, and salinity and the output parameters are taken as opening and closing the operation of the valve for water requirement or fertilizer, and a combination of both, opening and closing walls, turning energy systems (like lights, ventilation, heating, etc), etc.

During the development of the controller, the following steps are attempted as given below;

i. **Input data from sensors**: In this step, various parameters like soil moisture, air humidity, temperature, radiation, and wind speed are collected. Then these parameters are needed for the next step as input.

ii. **Development of Evapotranspiration model**: During the development of the model, this block transforms the four input parameters for achieving the actual soil moisture.

iii. **Required soil moisture condition**: This block gives information about the amount of water required for the appropriate growth of plants.

iv. **Application of PID and ANN controller**: In this step, by applying the application of PID and ANN controller, the requisite soil moisture and actual soil moisture can be compared which helps in the decision-making process dynamically.

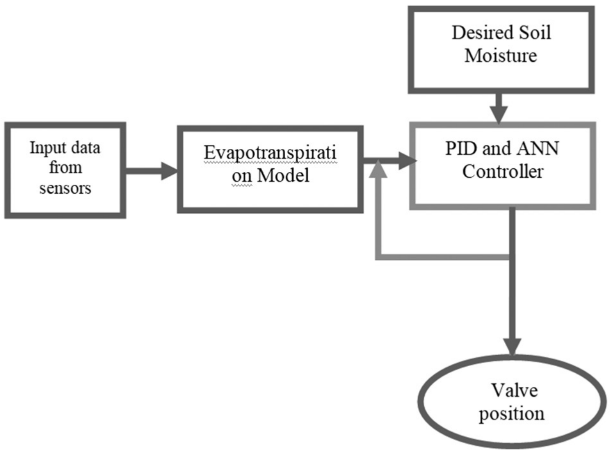


Fig. 1. Block diagram of basic irrigation control system

The input for the irrigation control system is simulated using SIMULINK in a MATLAB environment as shown in Fig. 1 where the following inputs are considered.

B. Modelling for input parameters from acquired sensors

For estimation of humidity from the environment, the four input parameters such as air humidity, temperature, radiation, and wind speed are considered which affects the evapotranspiration model.

i. **Temperature**: The temperature is the essential parameter for monitoring and control of the irrigation system which is illustrated as a continuous sine wave signal and simulated for the day and night temperature transformation. If any sharp changes occur in exceptional cases such as deserts etc. The following input variable parameters are considered as given below;

- A sine wave with an amplitude of 5 ºC is considered
- A frequency of 0.2618 rad/h for a time period of 24 h is measured (i.e. 0.2168 rad/h = 2pi/T=2pi/24).
- A constant bias (offset) at 30 ºC is taken

After simulation, it is found that the air humidity can reach the maximum temperature of 35°C (mid-day) and the minimum can reach +25°C (mid-night). In this manner, the temperature can be found on any particular day by setting the variable parameters as shown in Fig. 2.

ii. **Air humidity**: For considering the air humidity, the following parameters are taken.

- A sine wave is taken with an amplitude of 10%
- Bias of 60% (constant);
- A frequency of 0.2618 rad/h is measured for the period of 24 h.

iii. **Wind speed**: For considering the air humidity, the following parameters are taken.

- A sine wave with an amplitude of 1 km/h is taken
- Bias of 3.5 km/h (constant) is considered
- A frequency of 0.2618 rad/h is measured for the period of 24 h.

iv. **Radiation**: By considering the maximum possible radiation at the earth's surface (Rmax), the model is developed.

- A sine wave with an amplitude of 2MJ/m2 is taken
- The bias of 112MJ/m2
- A frequency ranging of 0.2618 rad/h is measured for the period of 24 h.

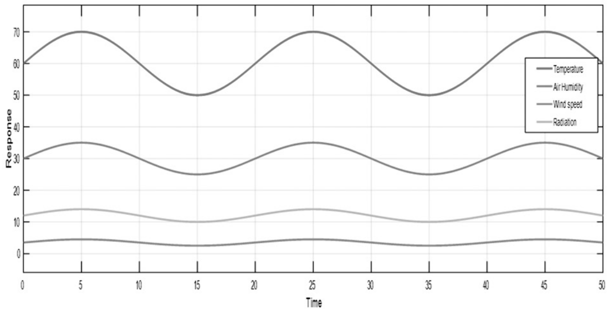


Fig 2. Input Parameters of Evapotranspiration model-Graphical representation

C.Required Soil Moisture Condition

It is dependent relative to the type of soil, kind of plant, type of growth parameters, type of land, etc. The required soil moisture is found as shown in Fig. 3.

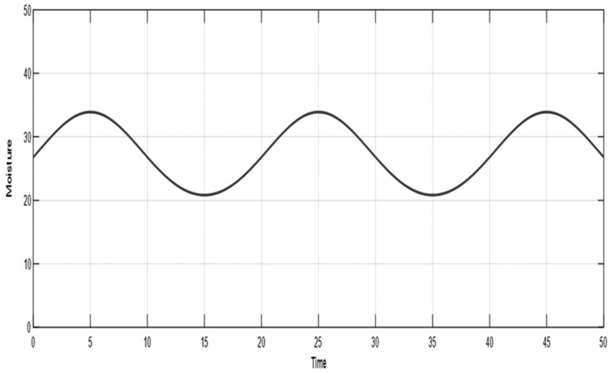


Fig. 3. Required soil moisture behavior

D. Evapotranspiration Model

A Penman-Monteith equation is considered based on an estimation of reference evapotranspiration eq. [25] where the equation can be presented by a combination function of maximum and minimum temperature, radiation, wind speed, and vapour pressure. The Penman-Monteith eq. [25] is written as given below;

$$Et_0 = \frac{0.408\,\Delta(R_n - G) + \frac{\gamma \times 900 \times u_2}{T+273}(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

$$\Delta = \frac{4098\ e^0(T)}{(T+273.3)^2} \quad (2)$$

$$e^0(T) = 0.6108\exp\frac{(17.27T)}{(T+273.3)} \quad (3)$$

$$\gamma = \frac{C_p}{\varepsilon\lambda} P \times 10^{-3} = 0.001628 \times \frac{P}{\lambda} \quad (4)$$

ET_0 = Reference evapotranspiration [mm day-1],

G = Soil heat flux density [MJ m-2 day-1],

R_n= Net radiation at the crop surface [MJ m-2 day1],

U_2= Wind speed at 2 m height [m s 1],

T = Mean daily air temperature at 2 m height [°C],

D = Slope vapour pressure curve [kPa °C-1],

e_s= Saturation vapour pressure[kPa],

e_a= Actual vapour pressure [kPa],

e_s-e_a= e^0(T) =Saturation vapour pressure deficit [kPa],

P = Atmospheric pressure [kPa],

g = Psychrometric constant [kPa °C1],

e^0(T) = Saturation vapour pressure at the air temperature T [kPa],

z = Elevation above sea level [m],

C_p= Specific heat at constant pressure, 1.013x10^{-3} [MJkg-1 °C-1],

ε = Ratio molecular weight of water vapour/dry air =0.622,

λ = Latent heat of vaporization, 2.45 [MJ kg-1].

E. Input and output of the controller

The controller has two inputs i.e. the required/desired soil moisture and calculated soil moisture from the evapotranspiration model. There is only one output of the controller, also called control input for the valve position. It builds the system configuration straightforwardly.

IV. RESULTS AND DISCUSSIONS

The above-mentioned requirement in mind behavior of the controller is simulated in SIMULINK-MATLAB software and the block diagram is shown in Fig. 4.

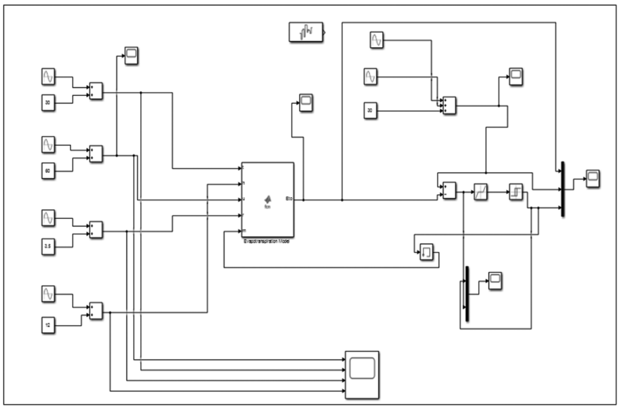


Fig. 4. ON-OFF based control system with Evapotranspiration model

At first, the ON-OFF controller is implemented along with the evapotranspiration model where reference (Required) Soil moisture is taken into account and simulated. It is found that the ON-OFF control-based system shows continuous oscillation at the output as shown in Fig. 5. This shows that the system is unstable and shows oscillating behavior. From input "Subsystem" to output "PID Controller", the output of step response before tuning is shown in Fig. 6. It is found that this ON-OFF control-based system is not stable.

For improving the control system and finding the stability of the control system, a PID control is applied using SIMULINK-MATLAB software as shown in Fig. 6. This helps in improving the real-time process parameters (such as moisture, humidity, temperature, sunlight intensity, etc.) of the control system.

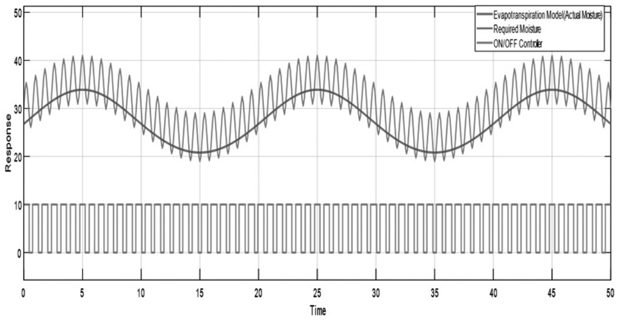


Fig. 5. Simulation results of ON-OFF control based system

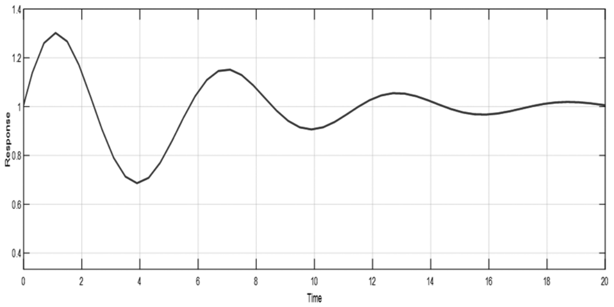


Fig. 6. The output of step response before tuning of PID control system

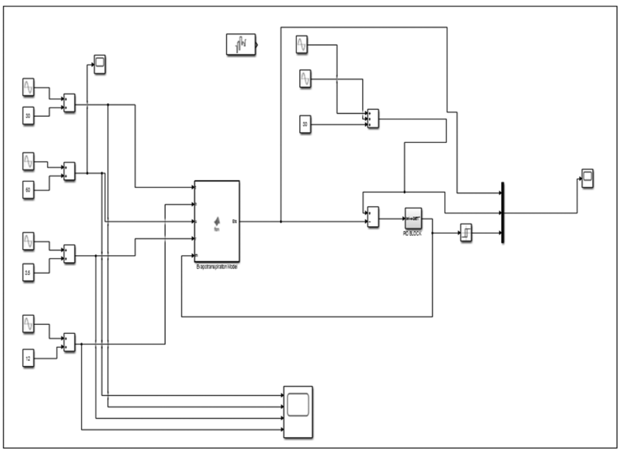


Fig. 7. PID based control system with Evapotranspiration model

By applying a PID control system, the closed-loop irrigation control improves crop yields condition and it also helps in effective resource utilization. By controlling the irrigation system, the changes in soil moisture meet the requirement of water for crop yielding. After applying a PID control system, the system reacts in a faster manner which provides precise manner change in environmental conditions like under-watering, rainfall, plant stress, and windup conditions. For obtaining PID gain parameters, the transfer function of the system is given below:

$$F(s) = \frac{-2s^2 - 2s - 1}{s^2 + s} \quad (5)$$

This shows that systems have two degrees of freedom and the system has oscillating behavior. During applying the PID tuner in the SIMULINK model, the value of kp, ki, and kd are given in Table 1. The obtained performance parameters of the PID control system are shown in Table 2.

Table 1. k_p, k, k_d values in PID Tuner

k_p	k_d	k_i	N
0.4755	0.4867	0.2722	1.7464

$$\frac{u(s)}{e(s)} = k_p + \frac{k_i}{s} + k_d\left[\frac{Ns}{s+N}\right] \quad (6)$$

k_p is the proportional gain, k_i is the integral gain, k_d is the derivative gain, and N is the filter coefficient respectively. After applying PID gain parameters, system response and Root Locus plot are shown in Fig. 8 and 9. These show the system is stable and the poles are negative and the Left side. The simulation results are shown in Fig. 10.

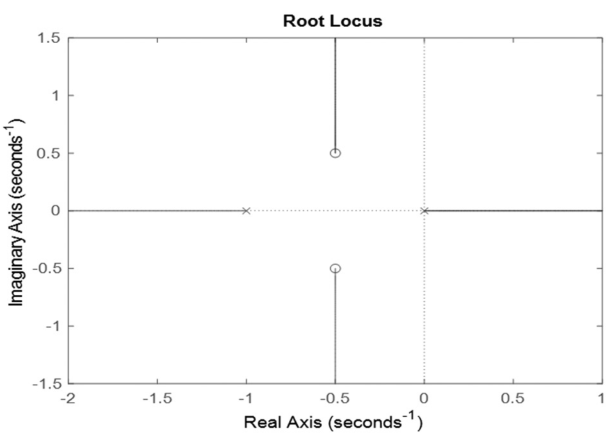
Table 2. Obtained performance parameters of PID control system

Controller Parameters

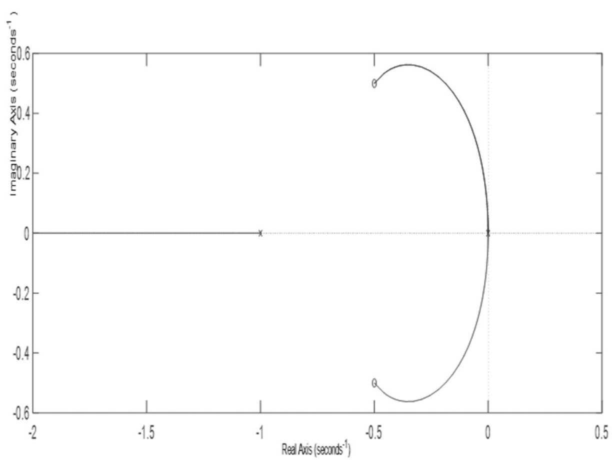
	Tuned	Block
P	-0.47141	-0.47556
I	-0.5052	-0.48672
D	0.25777	0.2723
N	1.8288	1.7465

Performance and Robustness

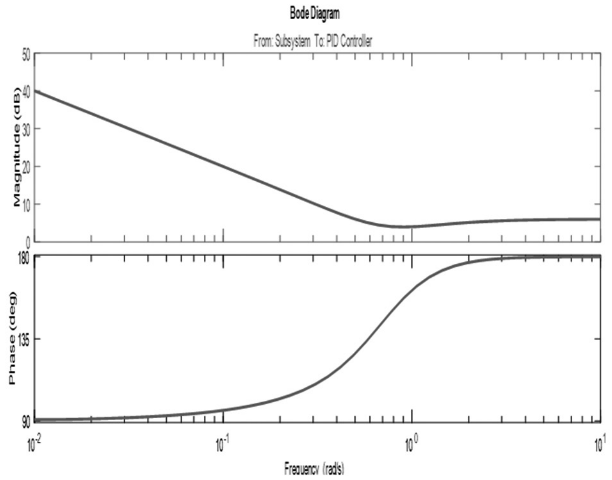
	Tuned	Block
Rise time	1.46 seconds	1.48 seconds
Settling time	12.3 seconds	12.4 seconds
Overshoot	14.7 %	14.8 %
Peak	1.15	1.15
Gain margin	-Inf dB @ 0 rad/s	-Inf dB @ 0 rad/s
Phase margin	111 deg @ 1.83 rad/s	110 deg @ 1.75 rad/s
Closed-loop stability	Stable	Stable



(a) Root Locus before tuning



(b) Root Locus after tuning



(c) Bode plot of PID controller

Fig. 9. Root locus and Bode plot of ON-OFF control based system

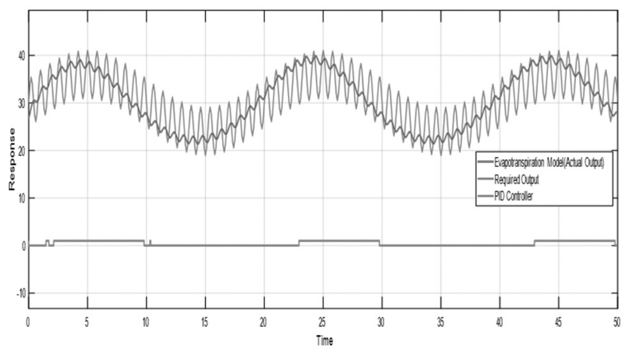


Fig. 10. Simulation results of PID based control system

Further, ANN method is applied in the control system for finding effective irrigation scheduling. This is modeled on the brain where neurons are connected in complex patterns to get the processed data by sensing through sensors and training the data and store in memories. This is a system based on the operation of biological neural networks or it is also defined as an emulation of a biological neural system.

During the implementation of the ANN Controller, the following parameters are considered in the design of control architecture in the SIMULINK model.

- Topology type: Distributed Time Delay Neural Network
- Name of training function: Bayesian Regulation function.
- Performance: Sum squared error is taken as a performance measure.
- Goal value: 0.0001.
- Learning rate: 0.05.

The SIMULINK model is shown in Fig. 11. During the training of the neural network model, the direct cascade controller along with the Evapotranspiration model is applied. The controller target is to achieve the actual soil moisture to the required soil moisture so that the resources like water and energy can be optimized. During analysis, the control valve is considered as an open condition and the required soil moisture limits go beyond the measured soil moisture and the control value should be considered a closed condition. The performance of the actual soil moisture shows without any oscillations as shown in Fig. 12.

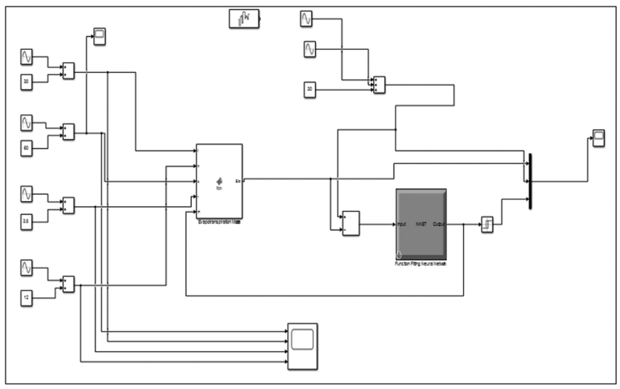


Fig. 11. Simulink Model of ANN Controller

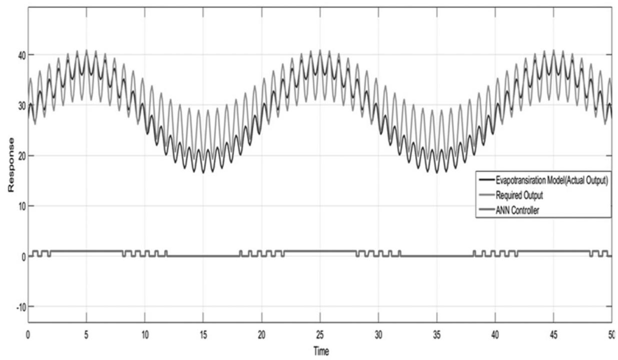


Fig. 12. The output of the Simulink Model of the ANN Controller

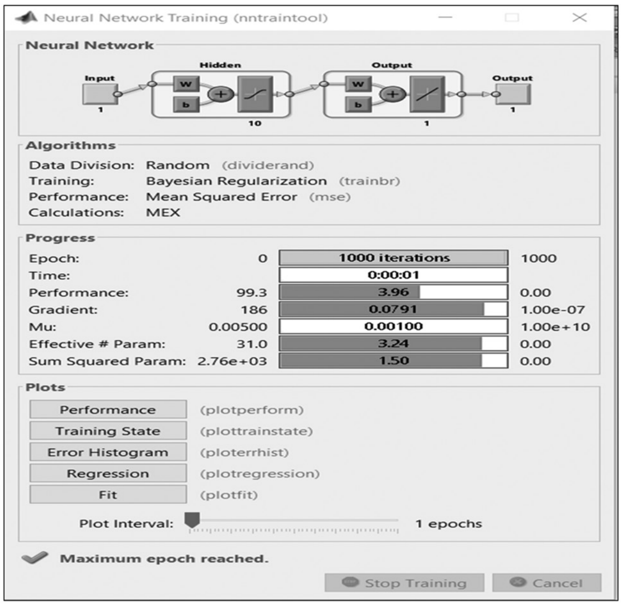


Fig. 13. Training the ANN Model

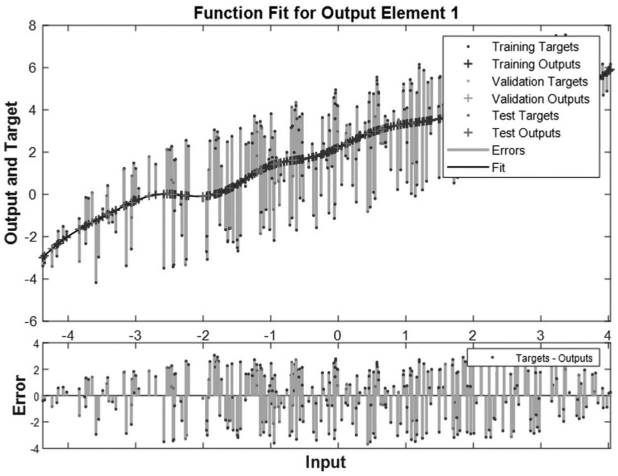


Fig. 14. Variations of the input-output model

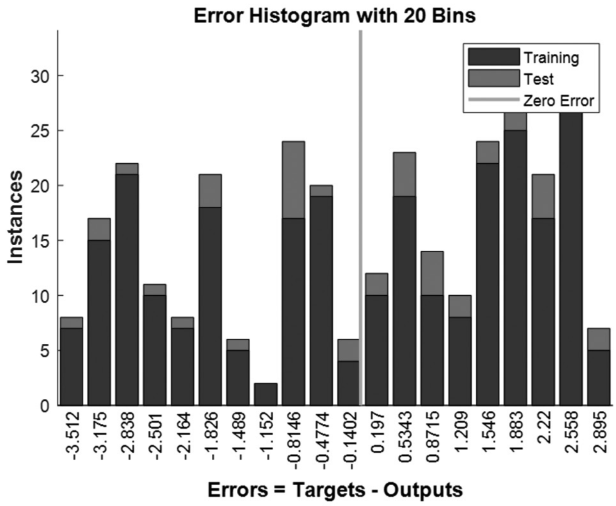


Fig. 15. Error histogram with 20 bins

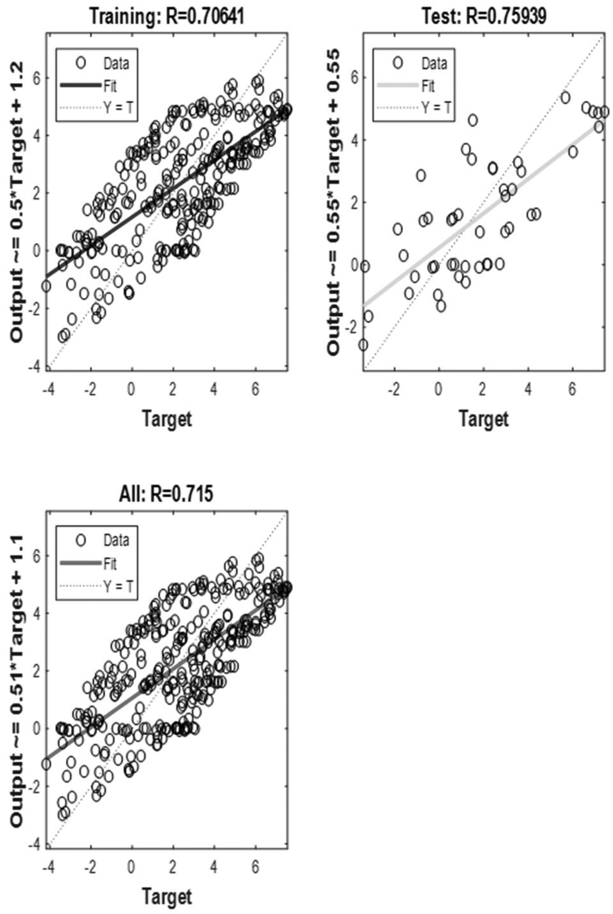


Fig. 16. Trained and tested output data of ANN model

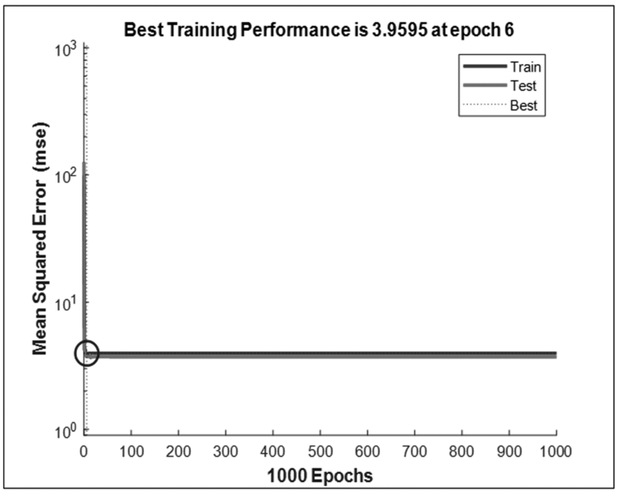


Fig. 17. Best training performance in terms of mean square error

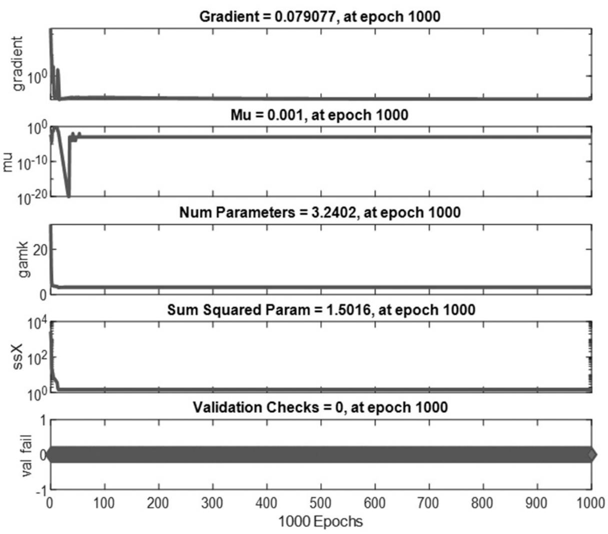


Fig. 18. Best performance of ANN controller

The following observations are envisaged as given in Table 3.

Table 3. Training and testing data

	SAMPLES	MSE	R
TRAINING	221	3.95948e-0	7.00783-1
TESTING	48	3.73856e-0	7.56047e-1

From Fig. 13 to Fig. 18, it is observed that:

1. The regression value of the model tested is 0.75 thus the model is 75 percent accurate in terms of predicting the optimal output.
2. The ANN controller controls the valve effectively where a low energy system is required for operating the system. Therefore, both energy and water can be saved in the environment.

Hence, by applying ANN controller, a cost-effective and result-oriented irrigation control system has been achieved which can be directly implemented for practical implementation.

V. CONCLUSION

In this paper, the control of drip irrigation systems is discussed by applying different types of control systems such as ON-OFF, PID, and ANN. The proposed ANN control method is also compared with PID and ON-OFF controller. It is found that the ON-OFF controller-based system fails suddenly due to its limitations where the PID controller is provided a solution for a stable control system by tuning the control gain parameters. The ANN-based approach has provided the trained data for drip irrigation scheduling and the results show a better implementation and more efficient control method. This ANN controller does not need the aforementioned knowledge of the system and has the intrinsic ability to self-adjust the changing conditions. It is important to note that ANN-based systems can provide a better solution for saving a lot of resources like energy and water and can also provide optimized results for different types of agriculture cultivations. In the future, this controller will be implemented with hardware in crop cultivation.

ACKNOWLEDGEMENT

The authors are grateful to the Director, CSIR-CMERI, and Durgapur India for providing the permission to publish this paper. Miss Khushali Bilare, from MANIT, Bhopal (Summer Intern at CSIR-CMERI) has carried out this work under my supervision during her summer internship at CSIR-CMERI, Durgapur.

REFERENCES

[1] E.T. Ososanya, S. Haghani, W.H. Mahmoud and S. Lakeou, "Design and Implementation of a Solar-Powered Smart Irrigation System", 122nd ASEE Annual Conference & Expositions, Seattle, WA, USA, 14-17 June 2015.

[2] J. Patel, E. Patel and P. Pati, "Sensor and Cloud Based Smart Irrigation System with Arduino: A Technical Review", International Journal of Engineering Applied Sciences and Technology, Vol. 3, No. 11, 2019, pp. 25-29.

[3] Z. Ding, C. Wang, G. Tan and G. Guan, "The Application of the Fuzzy Self-Adaptive PID Controller to the Automatic Operation Control of Water Transfer Canal System," Second International Conference on Intelligent Computation Technology and Automation, Changsha, Hunan, China, 10-11 October 2009, pp. 822-825, doi: 10.1109/ICICTA.2009.434.

[4] P.D. Colaizzi, S.A. O'Shaughnessy and T.A. Howell, "Using Plant Canopy Temperature To Improve Irrigated Crop Management", Proceedings of the 24th Annual Central Plains Irrigation Conference, Colby, Kansas, February 21-22, 2012 Available from CPIA, 760 N. Thompson, Colby, Kansas, pp. 203-223.

[5] B.R. Shirazpasha and B. Yogesha, "Microcontroller Based Automated Irrigation System", The International Journal of Engineering and Science (IJES), Vol. 3, No. 7, 2014, pp. 2319-1805.

[6] D.S. Pavithra and M.S. Srinath, "GSM based Automatic Irrigation Control System for Efficient Use of Resources and Crop Planning by Using an Android Mobile", Journal of Mechanical and Civil Engineering (IOSR-JMCE), Vol. 11, No. 4, Ver. I (Jul- Aug. 2014), pp. 49-55.

[7] M.K. Goyal, B. Bharti, J. Quilty, J. Adamowski and A. Pandey, "Modeling of daily pan evaporation in sub tropical climates using ANN, LS-SVR, Fuzzy Logic, and ANFIS", Expert Systems with Applications, Vol. 41, No. 11, 2014, 5267-5276, doi: 10.1016/j.eswa.2014.02.047.

[8] [8] D. Rodriguez, J. Reca, J. Martnez , R. Lopez-Luque and M. Urrestarazu, "Development of a New Control Algorithm for Automatic Irrigation Scheduling in Soilless Culture", Appl. Math. Inf. Sci. Vol. 9, No. 1, 2015, pp. 47-56.

[9] M.S. Goodchild, K.D. Kühn, M.D. Jenkins, K.J. Burek and A.J. Dutton, "A Method for Precision Closed-loop Irrigation Using a Modified PID Control Algorithm", Sensors and Transducers, Vol. 188, 2015, pp. 61-68.

[10] F.B. Poyen, S. Roy, A. Ghosh and R. Bandyopadhyay, "Automated Irrigation by an ANN Controller", Procedia Computer Science, Vol. 46, 2015, pp. 257-267.

[11] C. Lozoya, C. Mendoza, A. Aguilar, A. Roman, and R. Castello, "Sensor-Based Model Driven Control Strategy for Precision Irrigation", Journal of Sensors, Vol. 2016, Article ID 9784071, 2016, 12 pages, http://dx.doi.org/10.1155/2016/9784071.

[12] R.G. Ghodake and A.O. Mulani, "Microcontroller Based Automatic Drip Irrigation System", Techno-Societal 2016, International Conference on Advanced Technologies for Societal Applications, 14-15 December 2018, Pandharpur, India, doi:10.1007/978-3-319-53556-2_12.

[13] A. Shitu, M.A. Tadda and A.U. Danhassan, Irrigation Water Management Using Smart Control Systems: A Review", Bayero Journal Of Engineering And Technology (BJET), Vol.13, No.2, August, 2018, (12 Pages).

[14] C. Guo and F. You, "A Data-Driven Real-Time Irrigation Control Method Based on Model Predictive Control", IEEE Conference on Decision and Control (CDC), Miami Beach, Florida, USA, 17-19 December 2018, pp. 2599-2604, doi: 10.1109/CDC.2018.8619549.

[15] S.S. Sheikh, A. Javed, M. Anas and F. Ahmed, "Solar Based Smart Irrigation System Using PID Controller", IOP Conf. Series: Materials Science and Engineering, Vol. 414, 2018, p. 012040, doi:10.1088/1757-899X/414/1/012040.

[16] M.S. Munir, I. S. Bajwa, M. Asif Naeem and B. Ramzan, "Design and Implementation of an IoT System for Smart Energy Consumption and Smart Irrigation in Tunnel Farming", Energies, Vol. 11, 2018, 3427, doi:10.3390/en11123427.

[17] N. Sudharshan, A.V.S. Kasturi Karthik, J.S. Sandeep Kiran and S. Geetha, "Renewable Energy Based Smart Irrigation System", Procedia Computer Science, Vol. 165, 2019, pp. 615-623.

[18] A.I. Jacob, H.O. Edokpolor and E. H. Johnson, "Modeling of Automatic Sprinkler Irrigation Process Using Finite State Machine (FSM) and Proportional Integral Derivative (PID) Controller", Universal Journal of Engineering Science, Vol. 7, No. 4, 2019, pp. 75-81, doi: 10.13189/ujes.2019.070401.

[19] A. Gonzalez-Briones, Y. Mezquitaa, J.A. Castellanos-Garzon, J. Prieto and J.M. Corchado, "Intelligent multi-agent system for water reduction in automotive irrigation processes", Procedia Computer Science, Vol. 151, 2019, pp. 971-976.

[20] A.S. EL-Zemity et al., "Wastewater Treatment Model with Smart Irrigation Utilizing PID Control", 2nd Novel Intelligent and Leading Emerging Sciences Conference (NILES), 2020, pp. 374-379, doi: 10.1109/NILES50944.2020.9257882.

[21] E.A. Abioye, M.S.Z. Abidin and S. Mahmud et al., "IoT-based monitoring and data-driven modelling of drip irrigation system for mustard leaf cultivation experiment", Information Processing in Agriculture, 2020, https://doi.org/10.1016/j.inpa.2020.05.004.

[22] F.B. Poyen, A. Ghosh, P. Kundu, S. Hazra and N. Sengupta, "Prototype Model Design of Automatic Irrigation Controller", IEEE Transactions on Instrumentation and Measurement, Vol. 70, 2021, pp. 9502217 (17 pages), doi: 10.1109/TIM.2020.3031760.

[23] R.K. Jain, B. Gupta, M. Ansari and P.P. Ray, "IOT Enabled Smart Drip Irrigation System Using Web/Android Applications," 2020 11th International Conference on Computing, Communication and Networking Technologies (ICCCNT), Kharagpur, India, 1-3 July 2020, pp. 1-6, doi: 10.1109/ICCCNT49239.2020.9225345.

[24] R.K. Jain, "Design and Development of IoT Based Smart Irrigation Sensing, Control and Monitoring System for Agricultural Applications", 1st E-Business Technologies Conference Proceedings, University of Belgrade, Serbia, June 10-11, 2021, Vol. 1, No.1, 2021, pp. 162–166.

[25] S. Muhammad Umair and R. Usman, "Automation of Irrigation System Using ANN based Controller", International Journal of Electrical & Computer Sciences IJECS-IJENS, Vol. 10 No. 02, 2010, pp. 41-47.