GU J Sci, Part C, 10(4): 1083-1097 (2022)

Gazi University

Journal of Science

PART C: DESIGN AND TECHNOLOGY

http://dergipark.gov.tr/gujsc

Design, Control and Automation of MHPP - An Experimental Setup

Fatih Mehmet ULU[1], Hüseyin ALTINKAYA[2*]

[1]Karabük University, TOBB Vocational School, Department of Electrical, 78050, KARABÜK

[2]Karabük University, Faculty of Engineering, Department of Electrical-Electronics Engineering, 78050, KARABÜK

Article Info

Research article
Received: 24.07.2022
Revision: 26.10.2022
Accepted: 19.11.2022

Keywords

PID Controller
ANN
Frequency Control
Voltage Control
PLC

Abstract

In this paper the design, manufacturing and automation of a micro hydroelectric power plant (MHPP) prototype has been carried out. The experimental setup consists of three 1 kW synchronous generators (SGs) working in synchronization with each other and with the grid, three Pelton turbines with a single nozzle manufactured using a 3D printer, a water tank with a capacity of approximately one ton, a 5.5 kW centrifugal pump providing appropriate flow and head conditions and an 11 kW driver controlling the speed of this pump. The mechanical and electrical structure of the system and its working scenario are designed to be the closest to a real MHPP. S7-1200 PLC (Programmable Logic Controller) is used in order to control the voltage and frequency values of synchronous generators according to the load as well as for other control processes. It is possible to control and monitor the whole system through SCADA (Supervisory Control and Data Acquisition) screens. In this study, conventional PID control method and ANN (Artificial Neural Network) based PID are preferred for frequency and voltage control. The results have been evaluated by obtaining frequency-time, voltage-time, graphs of synchronous generators under different load conditions. Obtained results show that ANN-PID is faster than traditional PID and gives better results in terms of parameters such as settling time and overshoot.

1. INTRODUCTION

There are many equipment and intermediate stages in the production processes of HPPs. HPPs are complex and non-linear systems consisting of many mechanical and electrical-electronic equipment. There are many studies conducted on different aspects of HPPs. Since the aim of this study is to present the design and control of a prototype of a micro HPP, a summary of the work done especially on frequency and voltage control, has been given.

Micro Hydroelectric Power Plants with synchronous generators were stated to be advantageous in integration into the grid as compared to other renewable technologies. The PID-PI controllers were analyzed using the MATLAB / Simulink software package on the control of the speed regulator, which is one of the main components regulating the water flow of Micro Hydroelectric Power Plants. The synchronous generator voltage and rotor speed were compared using both control techniques under temporary and steady state conditions in their models, and they concluded that the PI control reached normal values faster than the PID control [1]. For a micro hydroelectric power plants, frequency control and voltage control were performed using Fuzzy Logic Controller and PI and PID controllers, respectively. The system was tested with active and reactive loads at different stages. As a result, the study also revealed the problems experienced in the correlation of experimental work with reality [2]. A model was created by predicting that using small powerful turbines with different powers instead of one large powerful turbine in MHPP would provide the highest benefit in variable water potential as a result of seasonal effects. In this model, the integration of the turbines into the grid was designed with a PLC using Fuzzy Logic algorithm. SCADA

*Corresponding author, e-mail: haltinkaya@karabuk.edu.tr DOI: 10.29109/gujsc.1148045

system was also used for remote monitoring and data recording of the system. In this model design, the system installed with three turbines of different powers were calculated to provide an increase in efficiency enough to compensate for the investment cost of the system with a single turbine that would occur in 5-5.5 years [3].

Although the parameter selection of PID controller remains challenging, it plays an important role in regulating quality and ensuring system stability. Using system decoupling in Jordan normal form with a state matrix, a state space model of hydraulic turbine regulating system (HTRS) with a surge tank was presented along with a formula derived for dimensionless rotating speed of turbine. The PID controller parameters were selected based on regulating quality parameters (RQP). Time-domain simulations as well as a comparative analysis of direct solving method (DSM) were performed based on a practical HPP. Same results were yielded by both methods; in providing a full RQP domain, DSM was found to be considerably efficient. The proposed DSM suggested the use of only state parameters in the selection of PID controller parameters. Considering varying conditions in the operation of hydro power plants, DSM was found to be effective in tuning purposes [4]. Another study presented a proportional integral derivative (PID) design for a hydro dominating energy system model, which was based on load frequency control (LFC) scheme. The designed controller was implemented in area-1 for at least 1% load disturbance and the values were compared with the values of classical PID. The performance of the controller was evaluated under various system conditions, thus, considering the non-linearity as well as the application results [5]. Based on fuzzy proportional derivative (PD) method, a new method was presented for LFC. The PD gains were tuned automatically using fuzzy rules to keep frequency at some nominal value under frequency variations. In order to control the frequency of mini hydropower system, the proposed controller was used. The performance of the system using the control scheme was evaluated by simulation performed under frequency variations. The results showed high performance frequency control when compared with conventional PD controller having fixed-gain [6]. In a paper, the design, modeling and experimental analysis of a hydropower plant with Automatic Generation Control (AGC) was presented. Adaptive Neuro Fuzzy Inference system (ANFIS) was used in the model. The aim was to reduce the frequency deviations occurring during power generation and to control the parameter selection for effective control of power in the HPP. Matlab was used in order to investigate the FLC, conventional PID and ANFIS controllers. The results showed that the ANFIS controller has a better performance rate as compared to conventional PID and FLC [7]. The study was conducted on non-linear model predictive controller (MPC) in order to control the variable speed hydropower (VSHP) plants. According to the simulation results, the proposed MPC was able to reduce water hammering experienced in the penstock pipes, damp the power oscillations found in the grid and improve turbine flow, power and head estimation. Therefore, VSHP may provide some considerable amount of FFR (fast frequency reserves) to the grid [8].

Many studies have been conducted on AVRs, which control the output voltage of synchronous generators. These are control methods performed together with various algorithms such as traditional PID implementations [9-12], cuckoo search algorithm [13], particle swarm optimization [14], coyote optimization algorithm [15], whale optimization algorithm [16,17], nonlinear robust coordinated [18], PSS and $H\infty$ optimization [19] and kidney-inspired algorithm [20].
In addition to traditional PI and PID applications for the control of load frequencies of synchronous generators and power systems, control methods used with different algorithms, artificial intelligence and optimization techniques are also seen. Full order sliding mode [21], fuzzy proportional–integral [22, 23], passivity-based control [24], stability boundary locus approach [25], ant colony optimization [26], bat algorithm [27] and fuzzy sliding mode controller [28] are also among the techniques used. There are such studies [29, 30] in which traditional PID applications are performed and frequency control of other studies is reviewed [31,32].

In this study, micro HPP prototype experimental setup was designed and manufactured. Traditional PID and ANN based PID were used for voltage and frequency control. Voltage and frequency control was carried out simultaneously in the experimental environment.

2. GENERAL STRUCTURE OF THE MHPP PROTOTYPE

In this section, the general working principle of the closed-loop MHPP prototype, which can be operated in a laboratory environment with the working principle as close as possible to the working conditions and scenario of a real micro/mini/small HPP, and the equipment and their functions used for the manufacturing will be focused on.

In the prototype, the water absorbed from the water tank with a capacity of approximately one ton is brought to the proportional valves by using a horizontal shaft, four-stage pump driven by an asynchronous motor and a piping system.

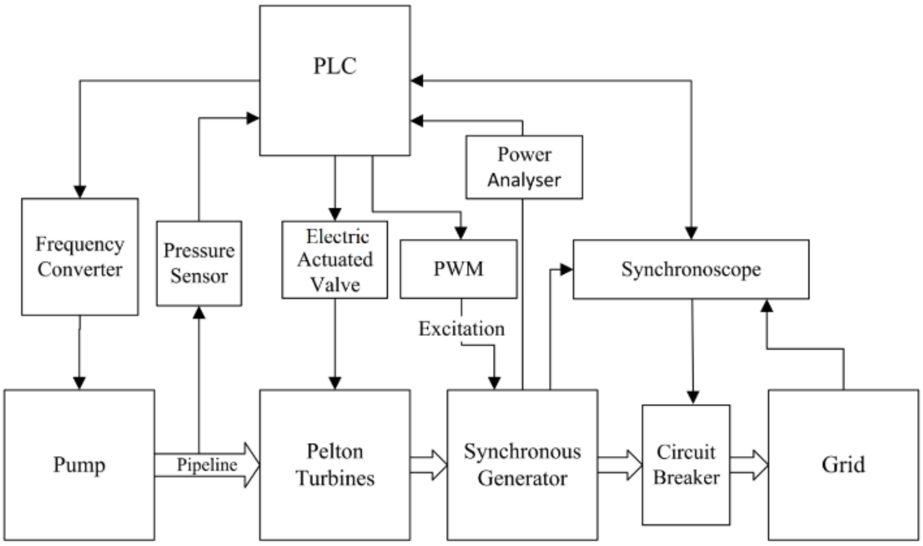

Figure 1. *Block diagram of prototype.*

Figure 2. *General view of the experimental setup.*

The water pressure in the piping system is measured with an analog sensor. Centrifugal pump motor provides stabilization of water pressure in the system by means of frequency converter (driver) controlled by PLC. With proportional valves, the adjusted amount of water from the nozzle is hit to the Pelton turbines with an increased speed. The water loses its energy in the turbine and returns to the tank by free fall. The energy converted into rotational motion in the turbine generates electrical energy by being proportionally excited with the DC PWM clipper coupled to the turbine shaft with the SGs (Synchronous Generators). Frequency control of SGs is performed by controlling proportional valves with PLC. Integration of the electrical energy with the grid is performed with synchroscope devices. During all these processes, PLC monitors and controls the system with sensors and network analyzers. In addition, events can be monitored instantly with PLC-SCADA software. The block diagram of the system and general view of the experimental setup are given in Figures 1 and 2.

3. CONTROL SYSTEM

3.1. Frequency Control

The frequency control in the experimental setup is based on the control of the proportional valve connected to the analog outputs of the PLC, which processes the 0-10V signal received at the analog input comprising the analog frequency data from the network analyzers. Before synchronization, the frequency value of the generator is equalized to the network frequency value, i.e. 50 Hz. The flow chart of this cycle is given in Figure 3.

It is important to make the above-mentioned fine adjustment until the synchronization occurs and this loop is terminated once the synchronization process ends. Adjusting the proportional valve is essential for active power supply to the network.

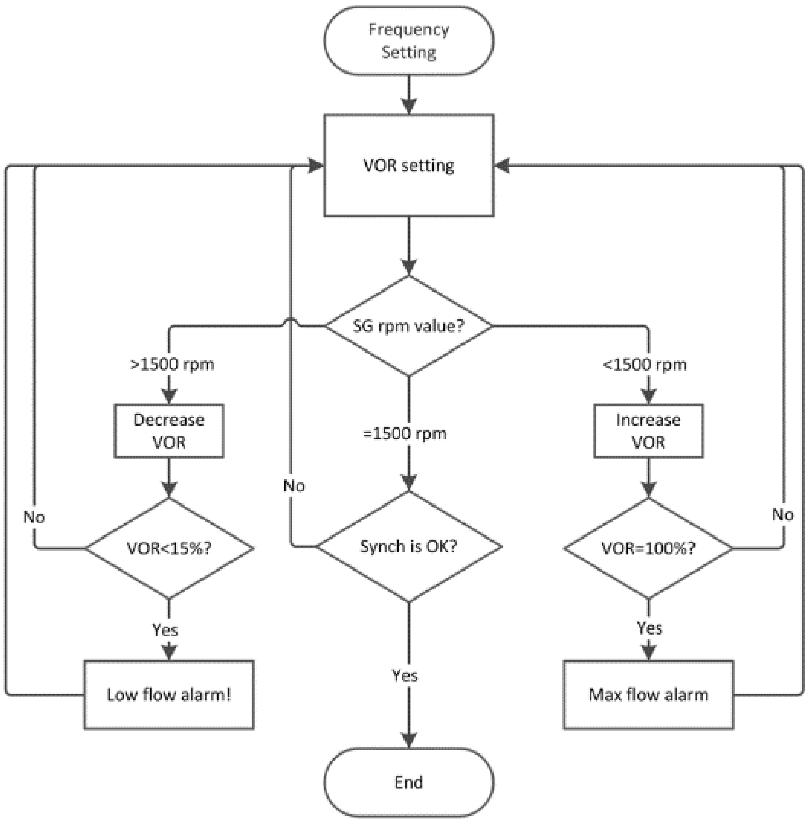

Figure 3. *Frequency control flow chart.*

3.2. Voltage Control

Adjustment of the voltage produced by the generator is performed by connecting a 0-5 V DC analog control input of the DC voltage clipper circuit placed for each generator at the power supply output, to the analog outputs of the PLC, and changing the excitation voltage. Before synchronization, the voltage value produced by the generator is equalized to the mains voltage.

In order to equalize the voltage generated before synchronization, processes shown in the flow diagram in Figure 4 are performed. It is important to make this fine adjustment until the synchronization occurs. This loop is terminated after the synchronization process.

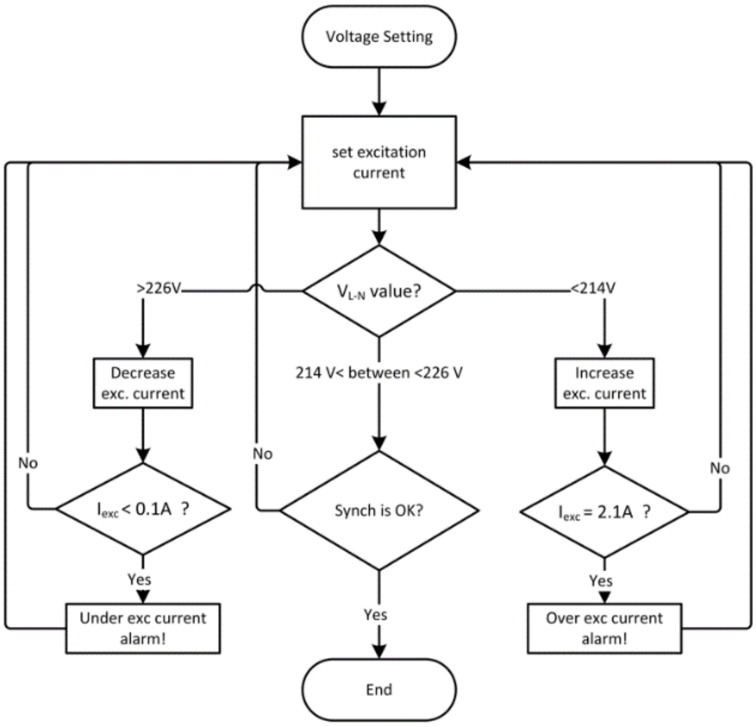

Figure 4. *Voltage control flowchart.*

3.3. PID Function

Adjustment of the frequency and voltage values of the SGs according to the load is provided by using the PID_Compact function in the PLC software. The PID algorithm works according to the equation given below:

$$y = K_p \left[(b.w - x) + \frac{1}{T_I.s}(w - x) + \frac{T_D.s}{a.T_D.s + 1}(c.w - x) \right] \quad (1)$$

Where y is output value of the PID algorithm, K_p is proportional gain, s is Laplace operator, b is proportional action weighting, w is set point, x is process value, T_I is integral action time, T_D is derivative action time, a is derivative delay coefficient, c is derivative action weighting [33].

PID block diagrams related to frequency (rpm) and voltage set points in the system are shown in Figure 5 and Figure 6, respectively.

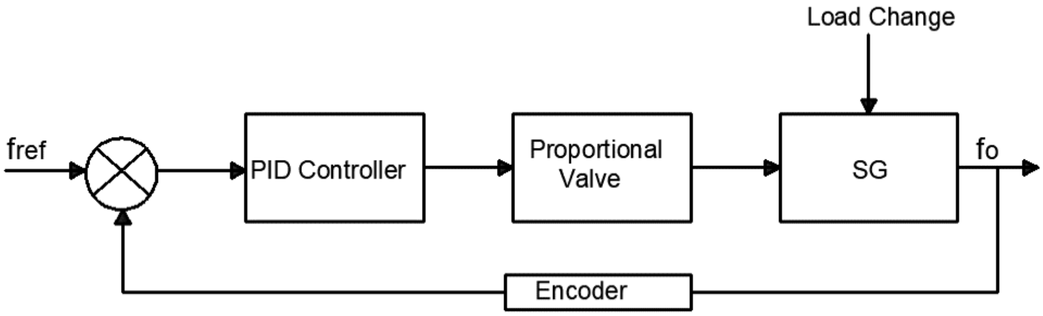

Figure 5. *PID block diagram of frequency control.*

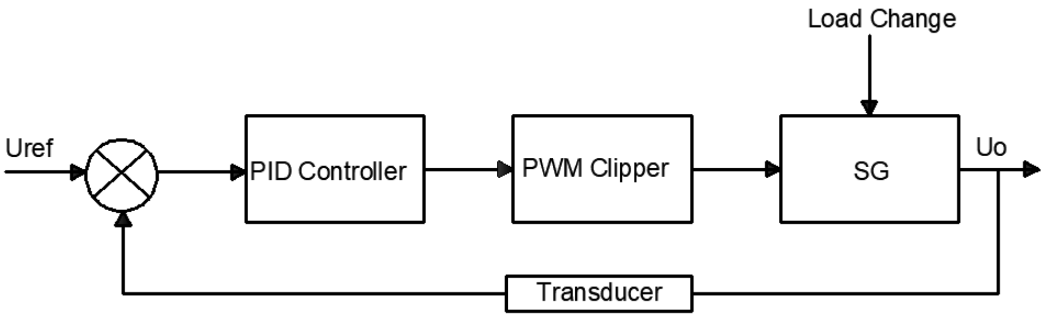

Figure 6. *PID block diagram of voltage control.*

The values of the PID parameters obtained after the Pre-tuning and Fine-tuning processes of the PID_Compact function run in automatic mode in the experiments are shown in Figure 7 and Figure 8 for frequency and voltage, respectively.

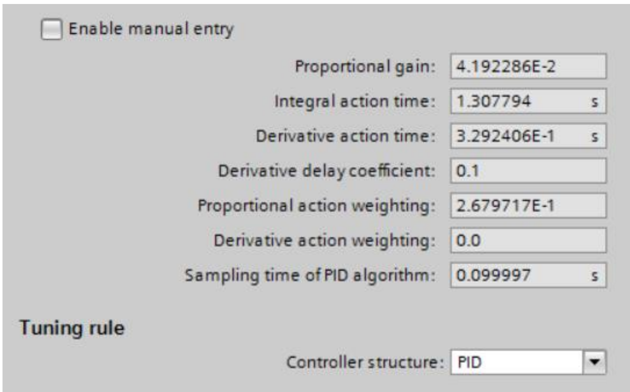

Figure 7. *Frequency PID_compact values.*

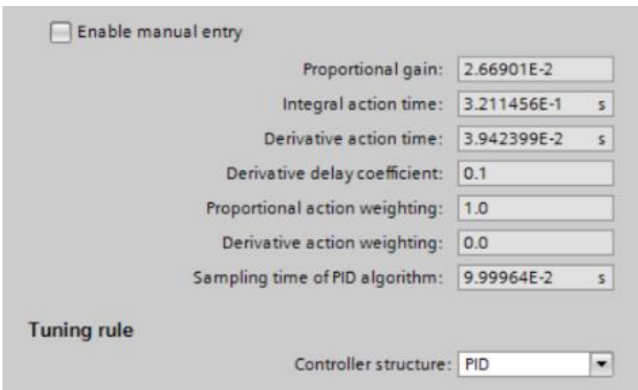

Figure 8. *Voltage PID_compact values.*

4. ANN-PID CONTROLLER

In this chapter, an ANN-based self-tuning (adaptive) PID controller is presented for frequency and voltage control. PID gains are tuned online using NN based algorithm. The robustness of control system is carried out by continuously tuning of PID parameters (Kp, Ki and Kd). PID controller tuning depends on the adjustment of its gains. As well known, PID controller equation in time domain can be expressed in equation 2.

$$e(t)= r(t)-y(t) \quad (2)$$

where e(t) is error value, r(t) is set point, y(t) is output value, u(t) is control variable.

A block diagram of self-tuned PID control with artificial neural network is shown in Fig. 9. Error, reference and output are fed into PID controller. ANN-based self-tuning algorithm adjust Kp, Ki and Kd values as system parameters change using ANN based PID, the PID gains are constantly updated.

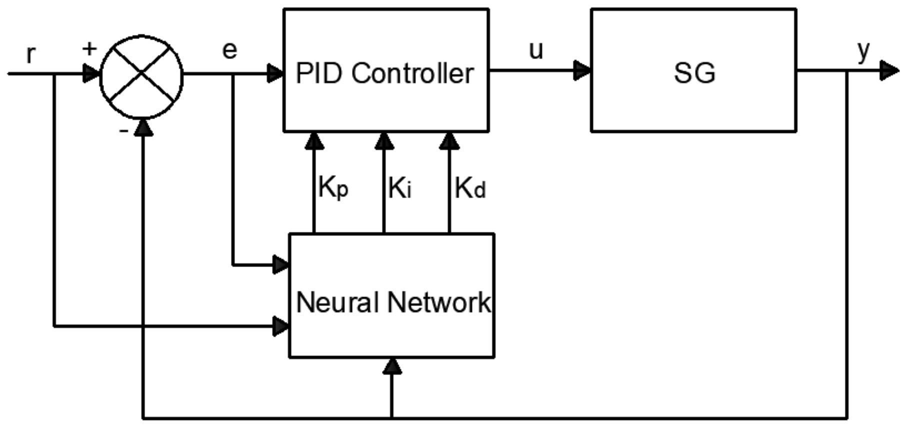

***Figure 9**. ANN-PID controller.*

Data obtained from multiple experiments with various load changes were recorded in PLC/SCDA software (TIA portal interface). These data were used for training and testing of ANN. ANN was created in Matlab interface. Load variation (ΔP), error (eu/ef), reference value (ref) and settling time (ts) input parameters; Kp, Ki and Kd were chosen as output parameters. For learning rule, the feed-forward back-propagation method; as transfer function, tansig; for training fuction, LM were selected. Number of iterations was determined to be optimum 100.

From the ANNs established with varying architectures, the artificial neural network architecture that provided the best results and that had two hidden layers with 8 neurons in the first layer and 4 neurons in the second layer was used. In total, 1325 data were used for training and 255 data for the test. In Figures 10 and 11, architecture of the designed ANN and view in Matlab, respectively, are given.

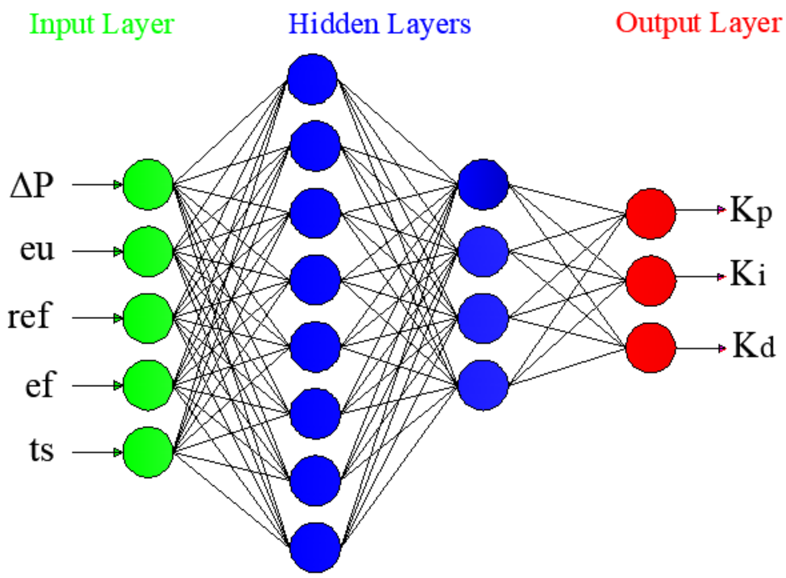

Figure 10. *Architecture of the ANN.*

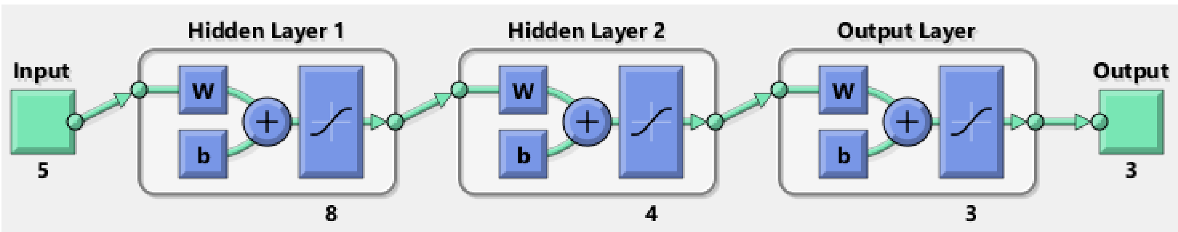

Figure 11. *View of the ANN in Matlab.*

In Section 5, characteristic graphs of SGs drawn with data from the field have been given.

5. EXPERIMENT RESULTS

The data obtained in the experiments performed with the established experimental setup are graphed. As a result of the experiments, the highest active power produced by the generators is measured to be 400 W. Although the line voltage value between phase-neutral is shown as 220 V in flow diagrams, ladder and SCADA screen displays, the set value of the voltage (L-N) is determined according to the network values at that instant since the network voltage value changes (by taking into account the synchronization with the grid) at the time of the experiments. Therefore, the test results and graphics were calculated and drawn accordingly.

The results of the transition from no load to 180 W load (0-45%) are given in Figures 12 and 13. In the experiment using conventional PID, the lowest voltage value was 228 V (overshoot is 7 V) and the lowest frequency value at the rate of 48.3 Hz (overshoot is 1.7 Hz). Voltage and frequency values were made to reach the set values in 18 seconds by the PID controller. In the experiment with ANN-PID, the lowest voltage value was 232 V (overshoot is 3 V), and the lowest frequency value at the rate of 49.6 Hz (overshoot is 0.4 Hz). Voltage value was made to reach the set values in 9 seconds, while frequency value in 6 seconds with the ANN-PID controller.

The test loads are switched on at t=0 point and in the pulse transition form (not linear increase).

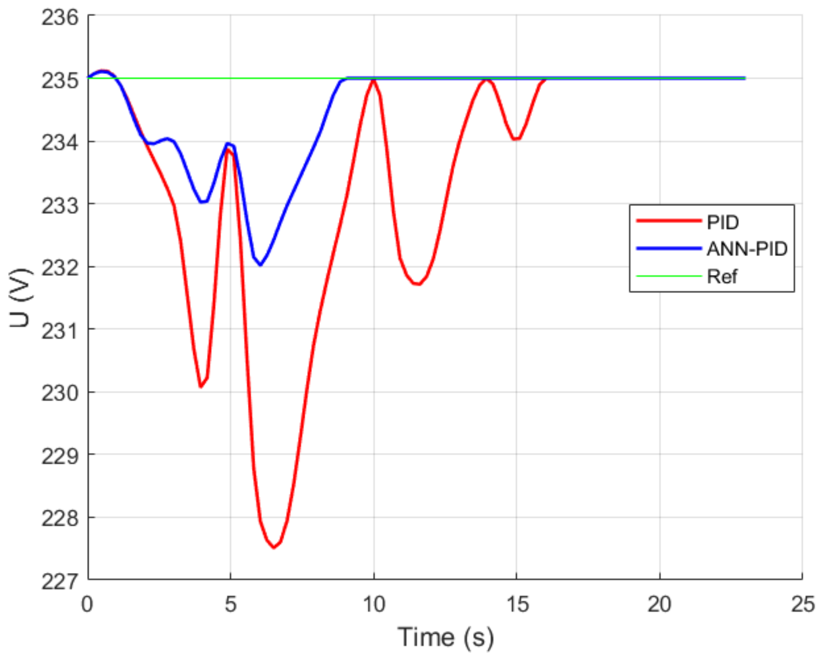

Figure 12. *0-180W U-t graph.*

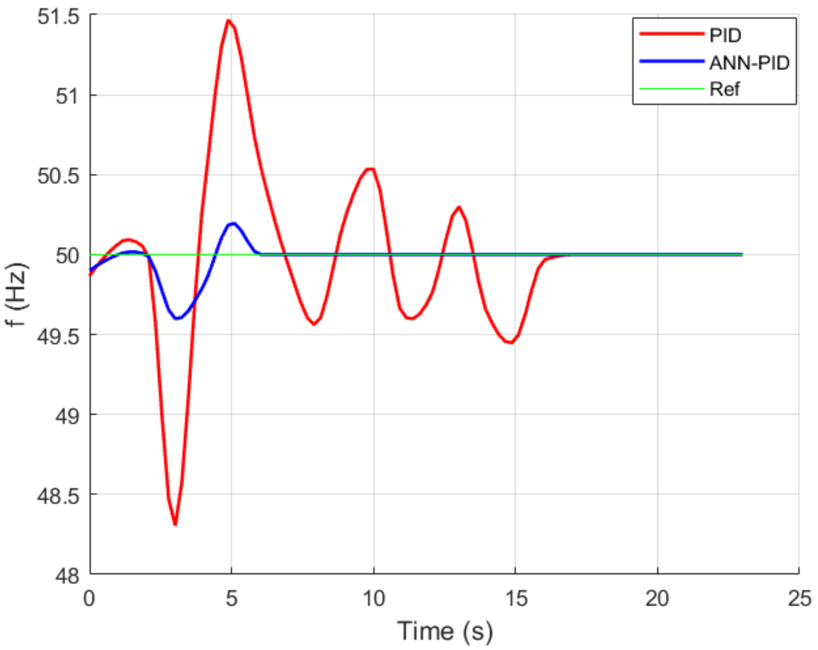

Figure 13. *0-180W f-t graph.*

The graphs showing the transition of a single generator operating in local mode at a constant pressure of 8.6 bar from no load to 340 W (0-85%) load are given in Figures 14 and 15. The lowest voltage value in the experiment with conventional PID was observed to be 171 V (overshoot is 64V) and the frequency value was 38.9 Hz (overshoot is 11.1 Hz). Voltage and frequency values reached their set values in 18 and 22 seconds. In the experiment using ANN-PID, the lowest voltage value was 213 V (overshoot is 22 V), and the lowest frequency value at the rate of 48.2 Hz (overshoot is 1.8 Hz). Voltage and frequency values reached their set values in 14 seconds and 7 second respectively.

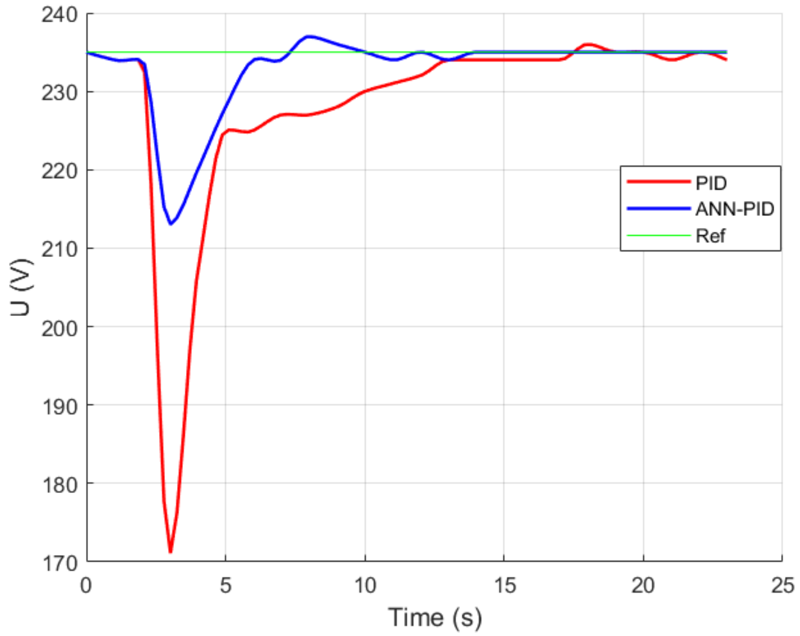

Figure 14. *0-340 W U-t graph*

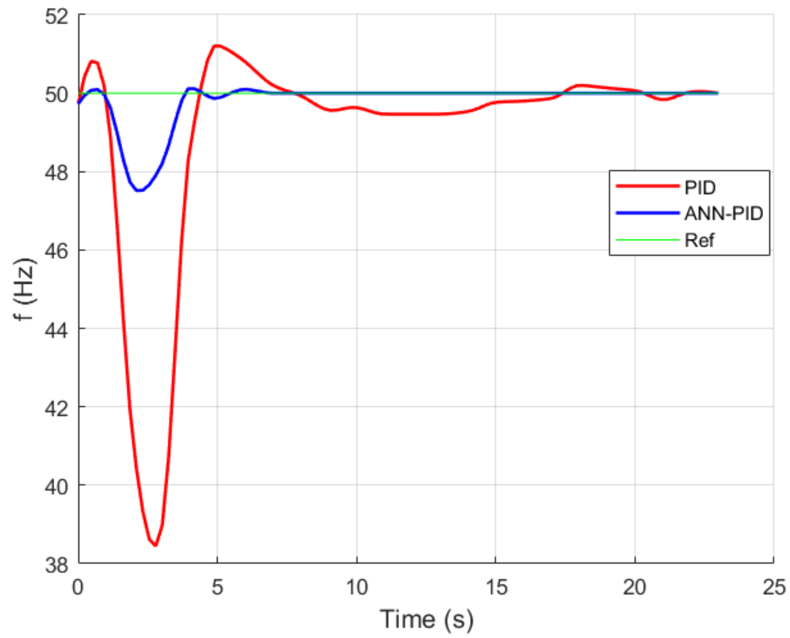

Figure 15. *0-340 W f-t graph*

The graphs showing the transition of synchronized SGs at 8.6 bar constant pressure from 860 W load to 200 W load (72%-16%) are given in Figures 16 and 17. Using traditional PID, the highest and the lowest voltage values obtained in this experiment were 240 V and 224V (overshoots are 5V and 11V), thus, exceeded the frequency value at the rate of 72 Hz (overshoot is 22 Hz). The voltage value reached the set value in 21 seconds, whereas the frequency value reached the set value in 14 seconds. With ANN-PID, the highest and the lowest voltage values obtained in this experiment were 238V and 232V (overshoots are 3V and 3V), thus, exceeded the frequency value at the rate of 56.5 Hz (overshoot is 6.5 Hz). The voltage and frequency values reached the set value in 9 seconds.

The test loads are switched off at t=0 point and in the pulse transition form (not linear decrease).

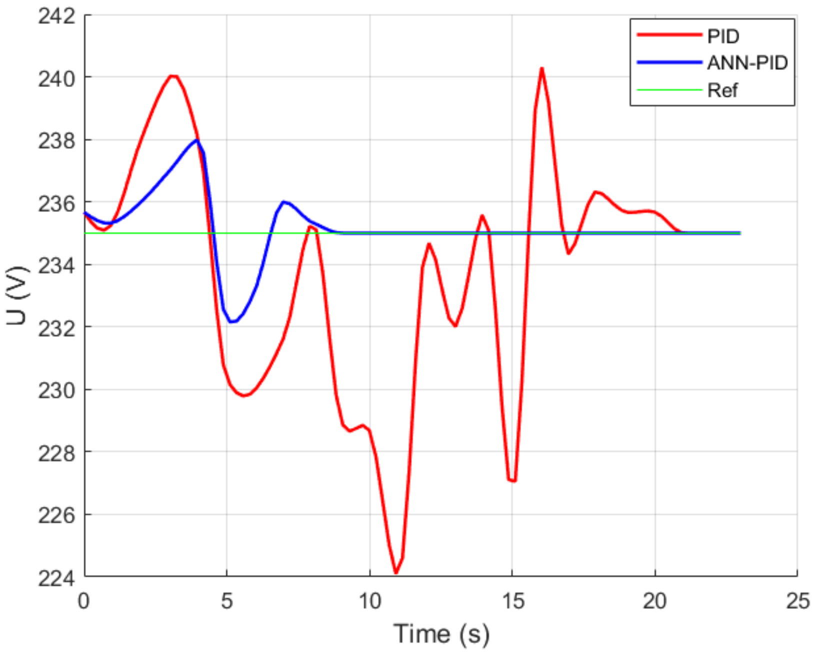

***Figure 16**. 860-200 W U-f graph.*

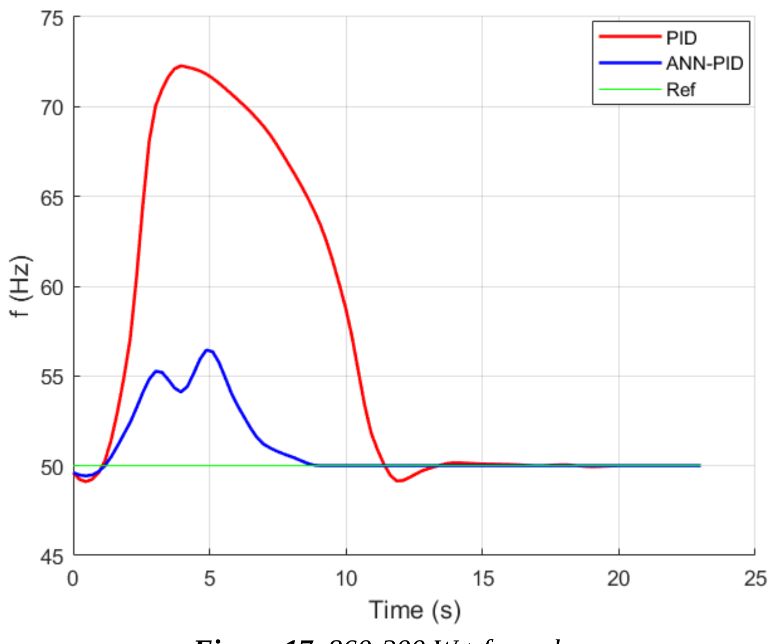

***Figure 17**. 860-200 W t-f graph.*

The results obtained from traditional PID and ANN-PID in the experiments are given in Tables 1 and 2 for voltage and frequency control respectively.

Table 1. *PID and ANN-PID comparison for voltage control*

Experiment	**Settling Time (s)**		**Overshoot (V)**	
	PID	ANN-PID	PID	ANN-PID
0-180W	18	9	7 (3%)	3 (1.3%)
0-340W	18	14	64 (27%)	22 (9%)
860-200W	21	9	11 (4.7%)	3 (1.3%)

Table 2. *PID and ANN-PID comparison for frequency control*

Experiment	**Settling Time (s)**		**Overshoot (Hz)**	
	PID	ANN-PID	PID	ANN-PID
0-180W	18	6	1.7 (3.4%)	0.4 (0.8%)
0-340W	22	7	11.1 (22.2%)	1.8 (3.6%)
860-200W	14	9	22 (44%)	6.5 (13%)

6. CONCLUSIONS

In this article, a micro-level prototype of a HPP with three SG and Pelton turbines was established. The design, installation, control and automation of a non-linear system consisting of many mechanical and electrical equipment and subsystems were performed. Since three turbines could be operated at the same time with the experimental setup, different control modes were created for SGs such as synchronization of more than one SG among themselves and with the interconnected grid, as in a real MHPP. Automation of the system was also conducted with PLC and SCADA software. The voltage and frequency control of the system was performed under different loads. Conventional PID and ANN-PID control mode were selected for control. In normal operation, while the voltage and frequency are made to reach the set value simultaneously by the PIDs, the indirect or direct effect of these two parameters causes the voltage to reach the set value later than in the individual operation. Generally, only the frequency or voltage of the SGs is controlled in the papers. Theoretically, it is assumed that frequency and voltage do not affect each other, but in practice, when evaluated together with other parameters, they do. In this study, the voltage and frequency of a real system (MHPP) built as a prototype were controlled simultaneously under changing loads. It has been observed that ANN-PID gives much better results than traditional PID in terms of parameters such as settling time and overshoot. The results of the present study showed that ANN is an effective and reliable method for voltage and frequency control of SGs, which is a nonlinear and complex system. Although the settling time seems to be long in the experiments, it can be understood that these times are considerably shorter when the acceptable tolerances for voltage and frequency are taken into account.

In future studies, the results can be compared using different artificial intelligence techniques and algorithms for voltage and frequency control. The ANN algorithm can be further improved.

ACKNOWLEDGEMENTS

This work was supported by Coordinatorship of Research Projects of the Karabuk University. Project Number: KBÜ-BAP-16/1-YL-142.

REFERENCES

[1] Waqas A, Waseem, A. (2017). PID vs PI Control of speed governor for synchronous generator based grid. J. Fac. Eng. Technol, 24(1), 53–62.

[2] Özdemir MT. (2012). Active and reactive power control based on intelligent controller at micro hydro power plant. PhD. thesis, Fırat University.

[3] Kurt H. (2013). Small-scale hydroelectric power plant turbine control using PLC with fuzzy logic algorotihm. MSc thesis, Fırat University.

[4] Yu X, Yang X, Yu C, Zhang J, Tian Y. (2017). Direct approach to optimize PID controller parameters of hydropower plants. Renew Energ 2021;173, 342-350.

[5] Panwar A, Sharma G, Nasiruddin I, Bansal RC. (2018). Frequency stabilization of hydro– power system using hybridbacteria foraging PSO with UPFC and HAE. Electr Pow Syst Res 2018;161, 74–85.

[6] Khana MRB, Pasupuletia J, Jidina R. (2018). Load frequency control for mini hydropower system: A new approach based on self-tuning fuzzy proportional-derivative scheme. Sustain Energy Techn., (30) 253–262.

[7] Weldcherkos T., Salau AO, Ashagrie A. (2021). Modeling and design of an automatic generation control for hydropower plants using neuro-fuzzy controller. Energy Rep, (7), 6626–6637.

[8] Reigstad TI, Uhlen K. (2021). Nonlinear model predictive control of variable speed hydropower for provision of fast frequency reserves. Electr Pow Syst Res., (194), 107067.

[9] Jarman R, Bryce P. (2007). Experimental investigation and modelling of the interaction between an AVR and ballast load frequency controller in a stand-alone micro-hydroelectric system. Renew Energ, (32) 1525–1543.

[10] Sahib MA. (2015). A novel optimal PID plus second order derivative controller for AVR system. Eng Sci Technol, (18) 194-206.

[11] Sreedivya KM, Jeyanthy PA, Devaraj D. (2019). An effective AVR-PSS design for electromechanical oscillations damping in power system. In: 2019 IEEE International Conference on Clean Energy and Energy Efficient Electronics Circuit for Sustainable Development (INCCES) doi:10.1109/INCCES47820.2019.9167703..

[12] Nirgudkar SS, Sarode UB. (2015). Implementation of digital automatic voltage regulator (AVR) for small laboratory alternator. In: 2015 International Conference on Energy Systems and Applications (ICESA 2015) 338-341.

[13] Sikander A, Thakur P. (2020). A new control design strategy for automatic voltage regulator in power system. Isa T, (100) 235–243.

[14] Zamani M, Ghartemani, MK, Sadati N, Parniani M. (2015). Design of a fractional order PID controller for an AVR using particle swarm optimization. Control Eng Pract 2009;(17) 1380–1387.Sahib MA. A novel optimal PID plus second order derivative controller for AVR system. Eng Sci Technol, (18) 194-206.

[15] Moschos I, Parisses C. (2015). A novel optimal $PI^{\lambda}DND^{2}N^{2}$ controller using coyote optimization algorithm for an AVR system. Eng Sci Technol 2022; Article in press Sahib MA. A novel optimal PID plus second order derivative controller for AVR system. Eng Sci Technol, (18) 194-206.

[16] Mosaad AA, Attia MA, Abdelaziz AY. (2019). Whale optimization algorithm to tune PID and PIDA controllers on AVR system" Ain Shams Eng J, (10) 755–767.

[17] Ozgenc B, Ayas MS, Altas İH. (2020). A hybrid optimization approach to design optimally tuned PID controller foran AVR System. In: 2020 International Congress on Human Computer Interaction, Optimization and Robotic Applications (HORA) doi:10.1109/HORA49412.2020.9152898

[18] Verrelli CM, Marino R, Tomei P, Damm G. (2021). Nonlinear robust coordinated PSS-AVR control for a synchronous generator connected to an infinite bus. IEEE Transactions on Automatic Control, doi:10.1109/TAC.2021.3062174.

[19] Mešanović, A, Münz U, Szabo A, Mangold M, Bamberger J, Metzger M, Heyde C, Krebs R, Findeisen R. (2020). Structured controller parameter tuning for power systems. Control Eng Pract, (101) 104490.

[20] Ekinci S.. Demirören A., Zeynelgil H.L., Kaya S. (2019). Design of PID Controller for Automatic Voltage Regulator System through Kidney-inspired Algorithm. GU J Sci, Part C, 7(2): 383-398.

[21] Guo J. (2019). Application of full order sliding mode control based on different areas power system with load frequency control. Isa T, (92) 23–34.

[22] Salhi I, Doubabi S, Essounbouli N, Hamzaoui A. (2014). Frequency regulation for large load variations on micro hydro power plants with real-time implementation. Electrical Power and Energy Systems, (60) 6–13.

[23] Kamble, SV, Akolkar SM. (2017). Load frequency control of micro hydro power plant using fuzzy logic controller. In: 2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI) doi: 10.1109/ICPCSI.2017.8392021.

[24] González WG, Montoya OD, Garces A. (2020). Modeling and control of a small hydro-power plant for a DC microgrid. Electr Pow Syst Res, (180) 106104.

[25] Sharma J, Hote YV, Prasad R. (2019). PID controller design for interval load frequency control system with communication time delay. Control Eng Pract, (89) 154–168.

[26] Singh O, Verma A. (2020). Frequency Control for stand-alone hydro power plants using antcolony optimization. In: 2020 IEEE International Conference on Advent Trends in Multidisciplinary Research and Innovation (ICATMRI) doi: 10.1109/ICATMRI51801.2020.9398417.

[27] Yuniahastuti IT, Anshori I, Robandi I. (2026). Load frequency control (LFC) of micro-hydro power plant with capacitive energy storage (CES) using bat algorithm (BA). In: 2016 International Seminar on Application for Technology of Information and Communication (ISemantic) doi: 10.1109/ISEMANTIC.2016.7873828.

[28] Kardile AH, Mule SM, Nagarale RM, Shiurkar UD. (2026). Small Hydro Power Plant control based on Fuzzy Sliding Mode Controller using Particle Swarm Optimization algorithm. In: 2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT) doi: 10.1109/ICEEOT.2016.7754888.

[29] Oliveira EJ, Honório LM, Anzai AH, Oliveira LW, Costa EB.(2015). Optimal transient droop compensator and PID tuning for load frequency control in hydro power systems. Electrical Power and Energy Systems, (68) 345–355.

[30] Guo W, Yang J. (2018). Stability performance for primary frequency regulation of hydro- turbine governing system with surge tank”. Appl Math Model, (54) 446–466

[31] Singh RJ, Kumar BA, Shruthi D, Panda R, Raj CT. (2018). Review and experimental illustrationsof electronic load controller used in standalone micro-hydro generating plants. Eng Sci Technol, (21), 886–900.

[32] Sami I, Ullah N., Muyeen SM, Techato K, Chowdhury S, Ro AJS. (2020). Control methods for standalone and grid connected micro-hydro power plants with synthetic inertia frequency support: A comprehensive review. IEEE Access 2020; Volume:8 doi: 10.1109/ACCESS.2020.3026492.

[33] https://support.industry.siemens.com/cs/document/100746401/pid-control-with-pid_compact-for-simatic- s7-1200-s7-1500?dti=0&lc=en-WW