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Optimization of Hydropower Generator Performance using Neuro-Fuzzy Scheme.

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ABSTRACT

In this paper, Neuro-fuzzy software tool was used to ensure a design of an optimized hydropower plant model. It was used to estimate the size and technical data in a hydraulic turbine. The neural network software was imbibed into the fuzzy logic controller. Input data of this software are hydraulic site conditions, desired operating parameters namely, water level and flow rate, as well as the desired arrangement. The designed adaptive power stabilizers based on artificial neural networks (ANNs) and Fuzzy logic are meant to adapt themselves to the operating conditions based on input-output response of the system. Result analyses were carried out using Neuro-fuzzy software tool in MATLAB to ensure optimal turbine rotational speed is maintained at a desired real-time response. The real-time controller emphasizes the robustness of Neuro-fuzzy application of the scheme for steady-state rotational stability for turbine spinning in a hydropower system.

Keywords: *Hydropower System, Neural network, Fuzzy Toolbox, Neuro-Fuzzy, Fuzzy Inference System*

Introduction

In general terms, optimization is an act, process or methodology of making something or a process such as a design, system or decision as fully perfect, functional or effective as possible. It is the process employed in finding the greatest or least value of a given function for some constraints, which, regardless of the solution, must be true. Thus, it seeks to find the most suitable value of a function within a given domain. For the efficient operation of hydropower plants, hydropower production optimization, reservoir management and flood control are the key elements. Thus, efficient manipulations of the parametric variables in a control-driven environment results in a desired optimization of the output power generated by a hydropower plant.

When planning for hydropower generation, hydrological records of high quality water flow rate and sufficient water level are needed. Also, to ensure well-organized and safe operation, real-time observations are critical. In this presentation, Neuro-fuzzy scheme was used to achieve a high optimization level in the output of a hydropower system by using the Neuro-fuzzy software tool in MATLAB to estimate the size and technical data to ensure that optimal turbine rotational speed is maintained at a desired real-time response.

Review of Related Literature

In Optimization-Based Reliability of a Multipurpose Reservoir by Genetic Algorithm, by D. O. Olukanni, et al, (2018), the authors studied the application of Genetic Algorithm (GA) as an effective tool for modeling the operation of a multi-purpose reservoir with specific emphasis on Jebba Hydropower Dam, Nigeria. The operation rule which modeled the reservoir parameters such as inflow, elevation, turbine release, generating head, energy generation, tailrace water level and plant coefficient was specifically studied. A 27-year period (1984–2011) data was used for statistical analysis. Atotal annual energy generation of 42,105.63MWH, representing a 50% reservoir inflow reliability was recorded.However, GA for the total annual energy generation at operation performance of 95, 90 and 75% reservoir inflow reliability were 15,964.48 MWH, 21,009.53 MWH and 20,798.58 MWH, respectively. The GA application was to ensure a more realistic and reliable optimal value for the improvement of hydroelectric power generation and flood management, which would guide decision makers in the hydropower sector.

Also,Guilherme A. Caxaria, et al, (2011), in Small Scale Hydropower: Generator Analysis and Optimization for Supply Systems, focused on the analysis of the power operation feasibility when applied to water supply systems, of both the pump as a turbine (PAT) and an experimental propeller turbine. Using an electrical connection of the PAT's induction motor to the propeller turbine, an analysis was carried out. Computational modeling parameter optimization and adequate generator choice were allowed by the collected data. Multiple scenarios could be considered such as rescaling/resizing for larger turbines and systems and for further efficiency enhancement by the use of power electronics.

Aldo Cateni, et al, (2008), in Optimization of Hydropower Plant Performance of Rehabilitation and Maintenance in Particular for Runner Profilesshowed thata relevant role was played by hydraulic efficiency in the performance of Hydro Power Plants (HPP) as it constitutes one of the main elements for selecting the most appropriated interventionsthe objective of the article was to give an overview on the actual approach to the theme in Italy.The main methods of intervention for optimizing the HPP performance were discussed and they include partial renewal with complete replacement of obsolete active parts and rehabilitation of deteriorated profiles with different techniques, according to type and cause of deterioration.The paper concluded with reports of some economic considerations of the authors as well as their conclusions.It was pointed out that in the maintenance strategy of hydraulic machinery it should be taken into account a "Total Cost of Maintenance" which was the sum of: real maintenance cost, outage cost during maintenance and cost of performance decay.

The reviews presented here are meant to give an insight into the various aspects of hydropower optimization. The knowledge gained from them are expected to help this research in developing a new approach to the quest for the optimization of hydropower generator performance so as to improve the overall power generation.

Research Methodology

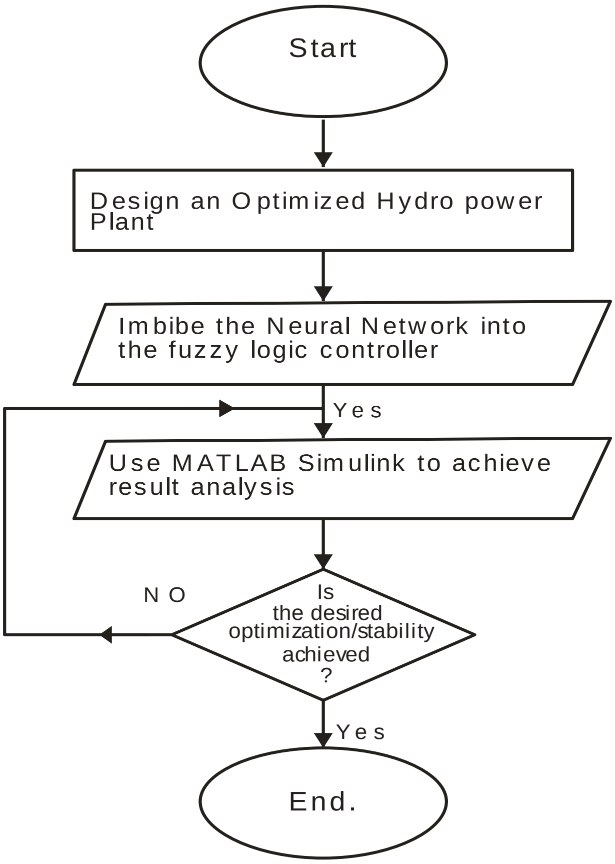

Figure 1: Flow chart for the research

Figure 1 shows the flow chart for the implementation of objective seven. In this objective, it was desired to design an optimized hydropower plant model using Neuro-fuzzy software tool. This flow chart describes the research methodology which is briefly described as follows.

The first step is to design an optimized hydropower plant model. After that, a trained Neuro-fuzzy which is an intelligent agent, which is a neural network, is imbibed into the fuzzy logic controller. In the fuzzy logic controller, a very flexible set of if-then rules are used to generate a solution that would be applied to the appropriate membership functions.

After a successful design as required, shown in Figure 2., neural network software was imbibed into the fuzzy logic controller. Result analyses were carried out using Neuro-fuzzy software tool in MATLAB to ensure optimal turbine rotational speed is maintained at a desired real-time response.

The designed model was excited and then simulated to produce relevant results. These are shown in Figures 5.0, 6.0 and 8.0, all graphs, as well as Figure 7.0, a source code.

Neuro-fuzzy software is developed for estimating size and technical data in hydraulic turbine. Input data of this software are: Hydroelectric site conditions of desired operating parameters and desired arrangement. As shown in Figure 2.0, the block diagram of a Neuro-fuzzy scheme for hydropower stability is presented in MATLAB/Simulink schematic. A combination of the parameters namely, the volumetric flow rate, velocity and penstock dimensions is needed for an optimized and stabilized output power as desired.

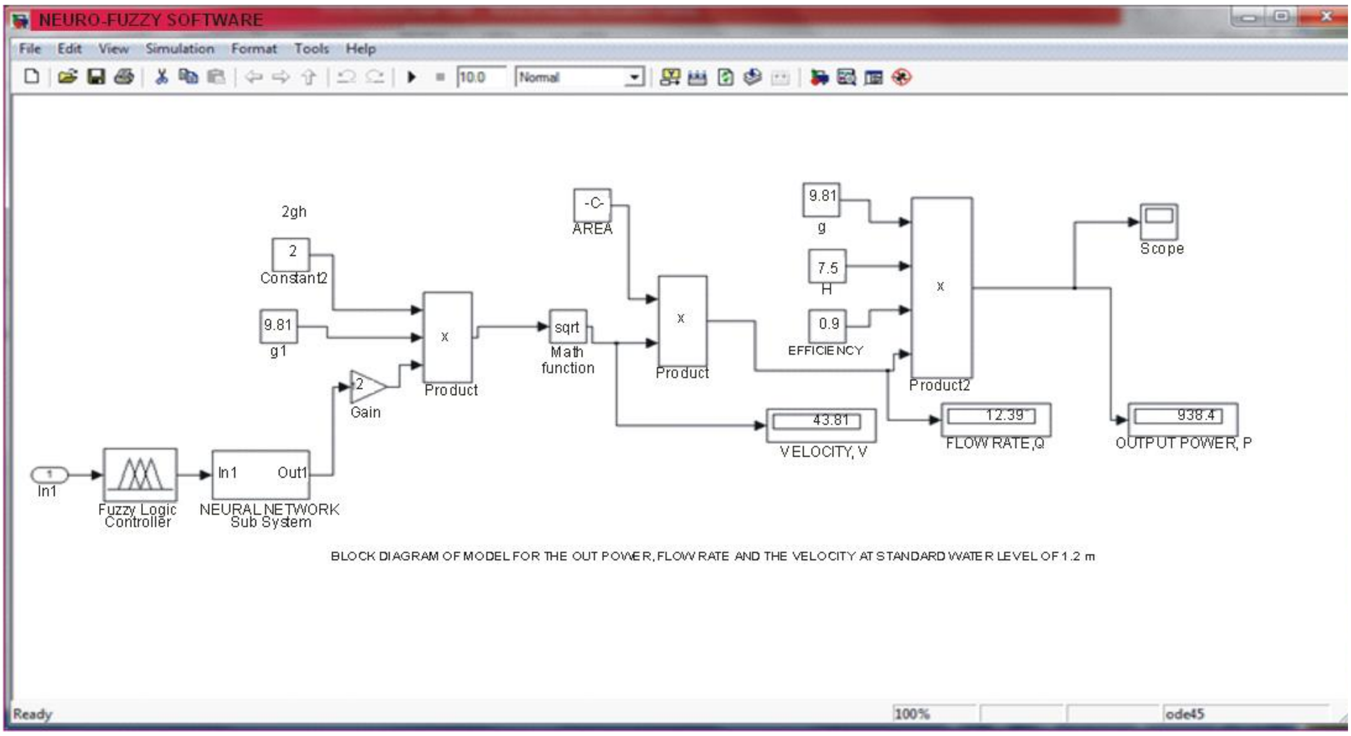

Figure 2. Block model of a Neuro-fuzzy scheme for a hydro power stability.

The designed adaptive power system stabilizers based on artificial neural networks (ANNs) and Fuzzy logic, are meant to adapt themselves to the operating conditions based on the input – output response of the system.

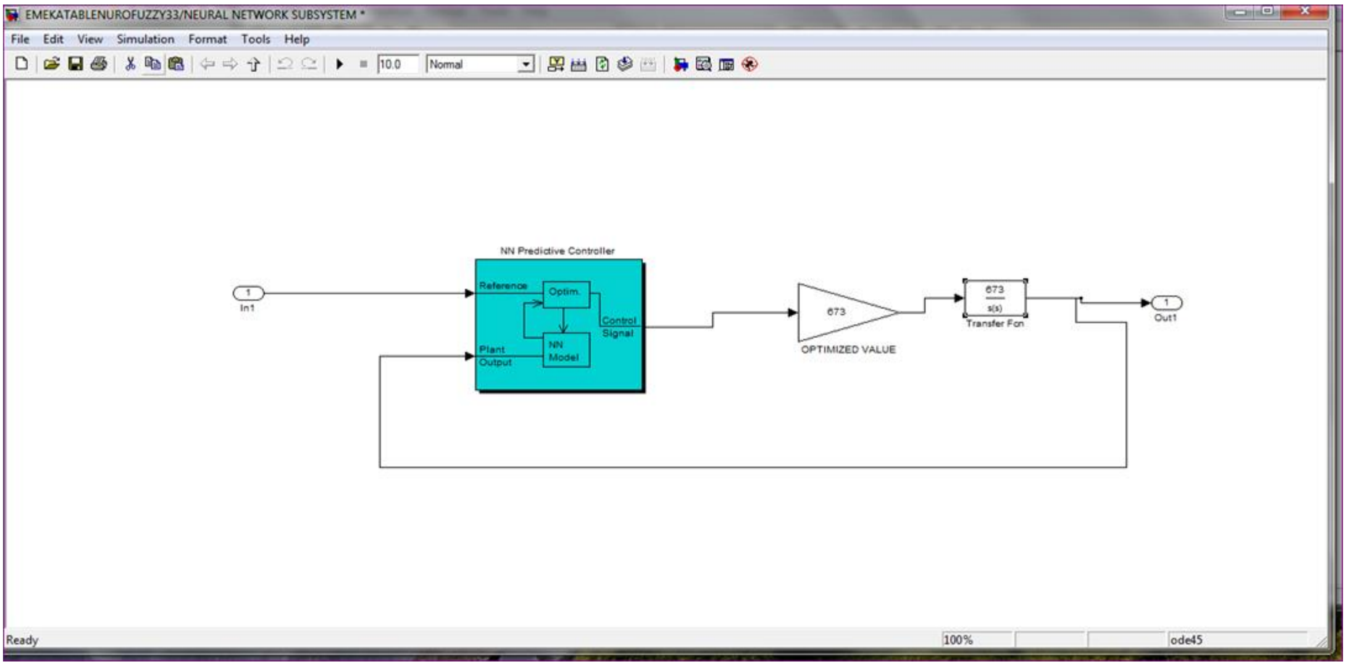

Figure 3. An internal structure of a trained ANN with the imbibed optimized parametric values.

To further analyze the model of the Neuro-fuzzy stability scheme, the structure in Figure 3. was also generated in MATLAB/Simulink showing the internal composition of a trained ANN the parametric values imbibed in the Neuro-fuzzy scheme to ensure an optimized output power. The internal structure comprises of a transfer function, optimized values, NBN predictive controller made up of NBN model, plant output and reference level. The two terminal points namely, output and input, are also distinct through which values are input and output to and from the model, respectively.

In order that the optimized output from the Neuro-fuzzy will be appreciated, a model of a stabilized output when only Fuzzy logic software was used is also presented. This is shown in Figure 4.0. The essence of this additional presentation was to present a dual analysis of output power values given Fuzzy and Neuro-fuzzy schemes. All these results are analyzed to show the level of output power optimization in both schemes so as to buttress the choice of the Neuro-fuzzy scheme in this research.

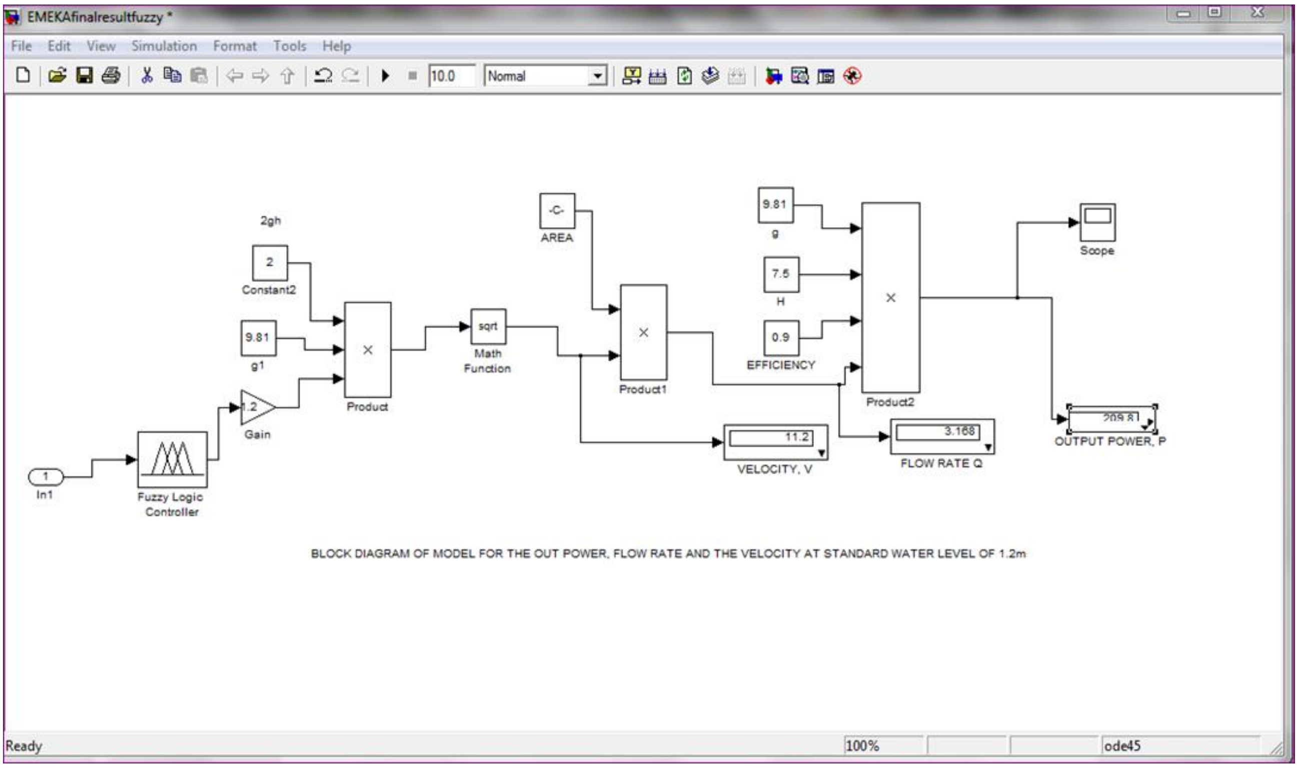

Figure 4. Block model of an optimal hydropower system stability using only Fuzzy logic software.

Presentation and Analysis

The results generated in the preceding section of this research are hereby presented for analysis. In order to properly analyze those results, suitable data and graphical representations are used. These data are shown in Tables 1 and 2 for optimized output power in kilowatts using Neuro-fuzzy and simulated data for hydropower turbine governor, respectively. Graphical representations of the realized values are also presented and shown in Figures 5, 6 and 8.

Table 1. Optimized Hydropower Output Power (Kw) using Neuro-fuzzy

Optimized output power (Kw) of Hydropower using Neuro fuzzy	Time
0	0
938.4	1
938.4	2
938.4	3
938.4	4
938.4	5
938.4	6
938.4	10

To generate the graph of Figure 5, the optimal output power was plotted against time. Observing the graph shows that one second after excitation, the speed of water flow through the penstock to the turbine stabilizes to generate constant output power of 938.4kw. This is the resultant optimized and stabilized output power.

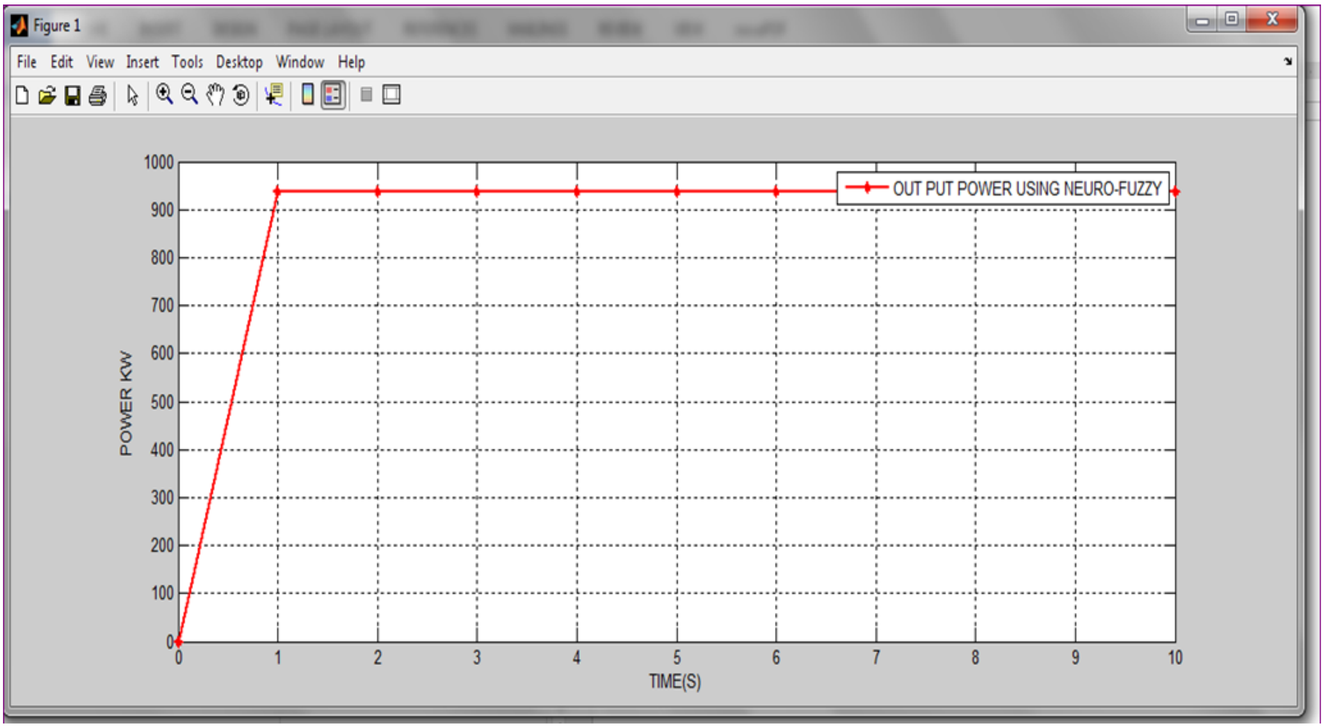

Figure 5. Graph of Output Power of the stabilized and optimized mini hydropower plant.

Having noted the output power, the researcher also considered the speed of the turbine against time. This is to determine how fast it takes the turbine to peak after initial excitation. From a speed of 0.5 m/s stability continues for the first 10s as shown in table 2. Graph of Figure 6 shows this relationship.

Table 2. Simulated data for Hydropower turbine governor

Speed (m/s)	*Time (s)*
0	0
0.5	1
0.5	2
0.5	3
0.5	4
0.5	5
0.5	6
0.5	7
0.5	8
0.5	9
0.5	10

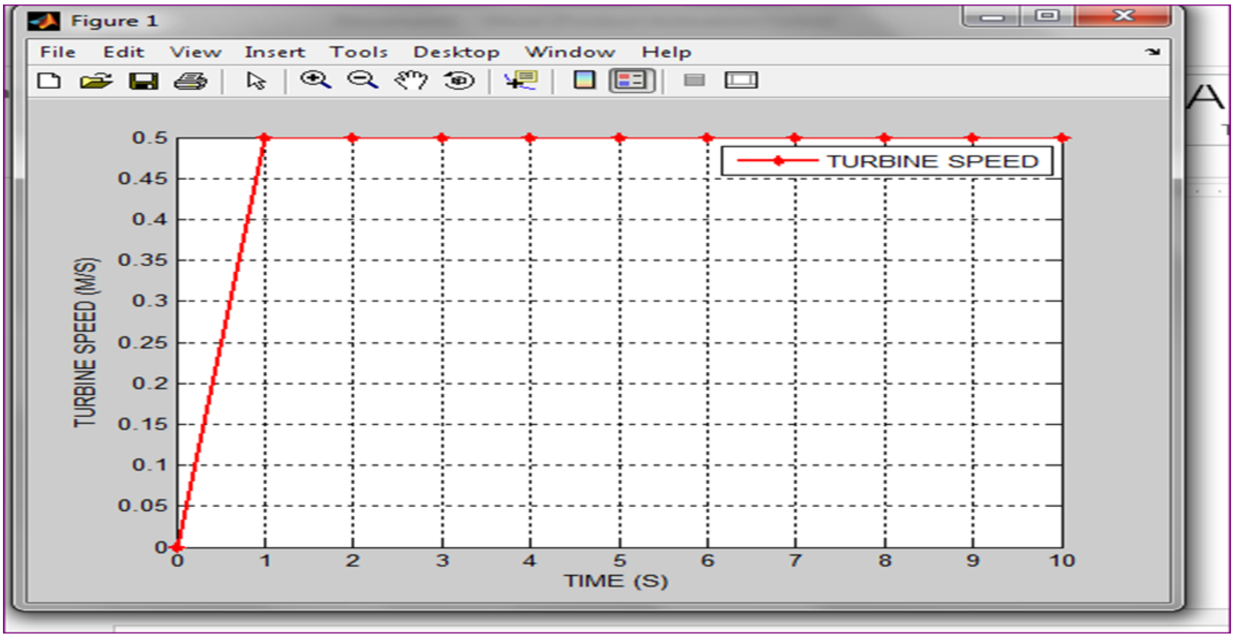

Figure 6. Optimized and stable Hydropower turbine generator speed.

The condition observed in the turbine speed is shown in the source code of Figure 7. In the sort code as presented, it is noticed that the time varies from 0 to 10s while the turbine speed remains constant after 0.5m/s. The reason is embedded in the fact that as soon as a turbine attains its maximum speed in revolution per second, it remains to ensure constant outpower generation.

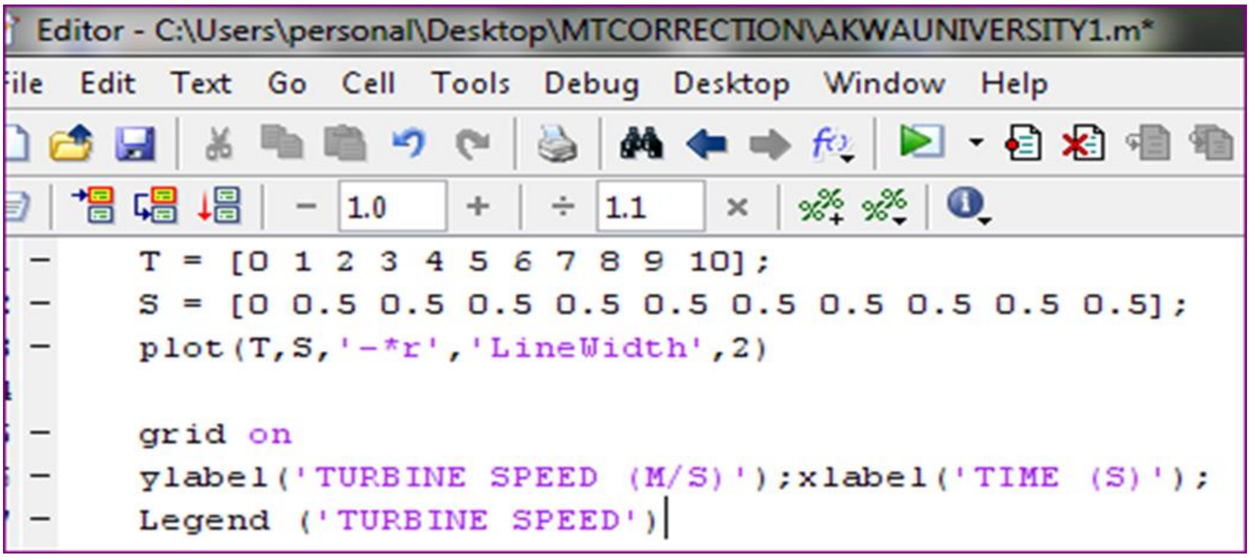

Figure 7. Source code of the simulated data for Hydropower turbine governor speed

Concluding these presentation and analysis, we can safely say that the ability of Neuro-fuzzy scheme to significantly reduce the time necessary for dynamic stability assessment is demonstrated. The real time controller emphasizes the robustness of Neuro-fuzzy application of scheme for steady state rotational stability for turbine spinning in a hydropower system.

As illustrated the study presents the design of Neuro-fuzzy to regulate water levels and control the flow through the gate valve in the penstock to the turbine.

When a Fuzzy logic controller with a cascade of PLC and HMI is used, the graph of Figure 8 shows the output power generated from the hydropower generator system. The magnitude of the power output shows that the output of the Neuro-fuzzy scheme provides the best optimized value in all. Thus, the primary objective of the research which is to show the efficiency of achieving the best optimization in output power using Neuro-fuzzy has been achieved.

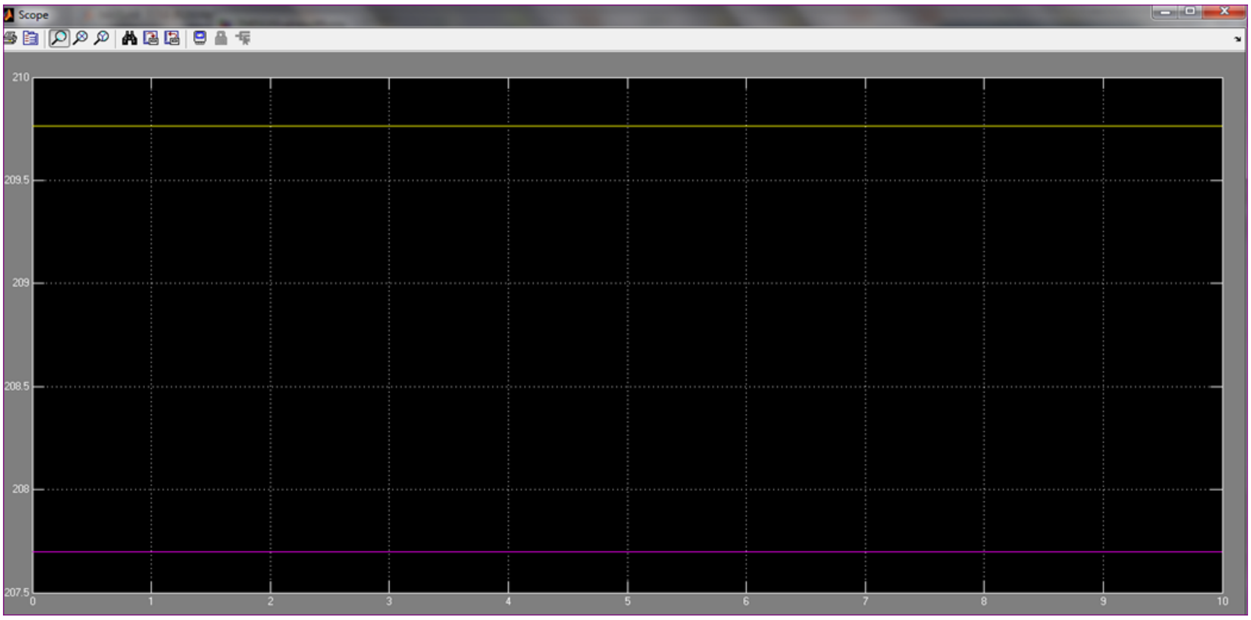

Figure 8. Graph showing the output result of the MATLAB Simulink data result forHydropower turbine speed using Fuzzy logic controller + PLC + HMI.

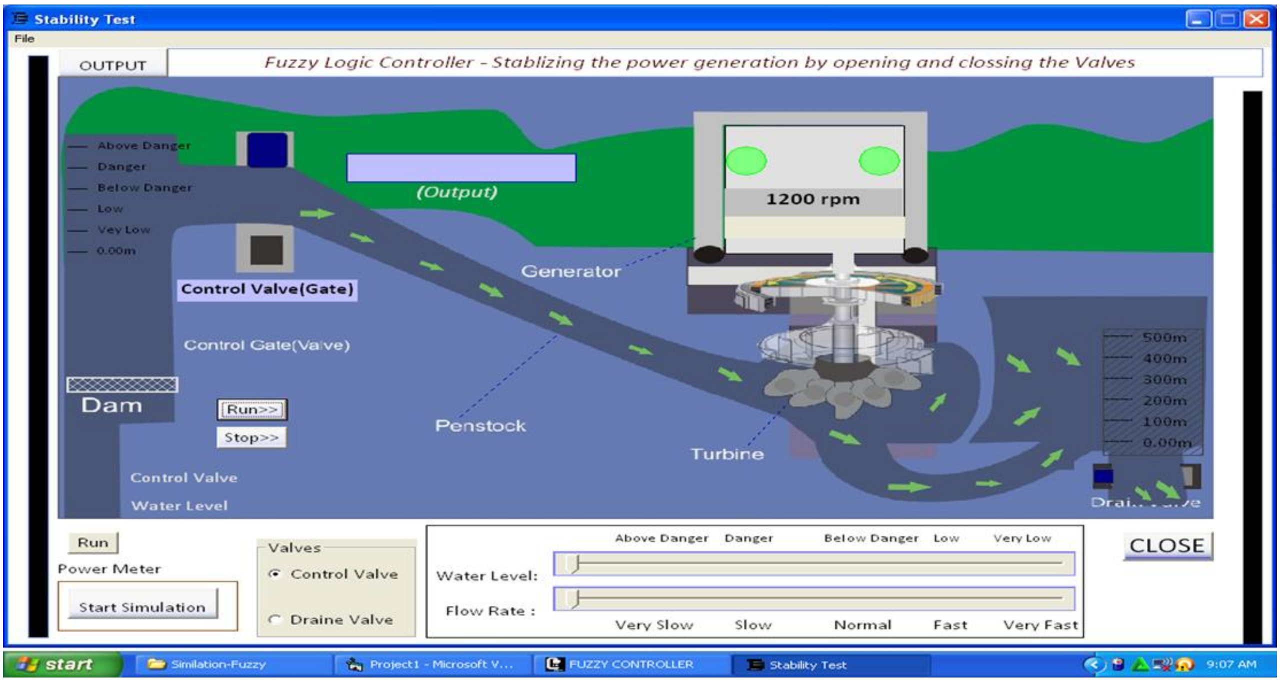

Figure 9. shows a visual demonstration of hydropower stability

In the figure, all the variables are depicted. These include the water level, flow rate, as well as control and drain valves. The flow sequences of very slow, slow, normal, fast and very fast are also shown. These are related to the volumetric flow rate. Conversely, considering the water level, the critical levels of above danger, danger, below danger, low and very low are also show in the visual representation. These combined conditions determine the gate valve control operations which are useful in the generation of the if-then rule treated by this researcher in a different journal paper.

Conclusion

It has been established that optimization in hydropower system involves combining parametric input values both in their proper magnitude and in the right timing. However, besides these, the application of a good means of stability is also key. This has been demonstrated in this paper by the use of Neuro-fuzzy scheme, a cascade of neural network and fuzzy software. Thus, after training the neural network so as to be able to stick to the rules generated from the parametric values, it functions as the human brains as the human brain by recognizing the rules whenever commands arising from them come. The timing in achieving stability was also shown to be relatively good. Thus, the use of Neuro-fuzzy scheme in the optimization of hydropower performance has been shown to be a better control option than ordinary fuzzy software or fuzzy PLC HMI. Results obtained in this research attest to this.

References

D. O. Olukanni, et al, Optimization-Based Reliability of a Multipurpose Reservoir by Genetic Algorithms; Jebba Hydropower Dam, Nigeria, Cogent Engineering, Volume 5, 2018 – Issue 1.

Guilherme A. Caxaria, et al, Small Scale Hydropower: Generator Analysis and Optimization for Supply Systems, World Renewable Energy Congress, Sweden, 8-13 May, 2011.

Aldo Cateni, et al, Optimization of Hydropower Plants Performance Importance of Rehabilitation and Maintenance in Particular for Runner Profiles, 7th International Conference on Hydraulic Efficuiency Measurements, September 3rd – 6th, 2008, Milan, Italy.

Enebechi T. C et, al, “Design and development of Neuro-Fuzzy controller for hydropower Generator Stability” IJSER, vol., 7, issue 6, June 2016.

Enebechi T.C et al., “ Improving the stability of Hydropower generator Using Neuro-fuzzy technique” IjoAT Volume 5, Issue 6, 2016.

N. Milivojevic, et al, Computet-Aided Optimization in Operation Planning of Hydropower Plants – Algorithms and Examples. Journal of the Serbian Society for Computational Mechanics / Vol. 3 / No. 1, 2009 / pp. 273-297.

Andrew Hamann, et al, Real-time Optimization of a Hydropower Cascade Using a Linear Modeling Approach, Power Systems Computation Conference, Wroclaw, Poland, August 18-22, 2014.

Aris P. Georgakakos, etg al, A Control Model for Dependable Hydropower Capacity Opitimization, Water Resources Research, Vol. 33, No. 10, pages 2349 – 2365, October, 1997.

Nattanin Ueasin, et al, Performance Assessment andOptimization of Biomass Steam Turbine Power Plants by Data Envelopment Analysis, International Journal of Energy Economics and Policy, 2015, 5(3), 668 – 672.

Fang-Fang Li and Jun Qiu, Multi-Objective Reservoir Optimization Balancing Energy Generation and Firm Power, Open Access Energies, 2015, 8, 6962-6976, ISSN 1996-1073.