A Hydroelectric Power Plant Brief: Classification and Application of Artifactual Intelligence

Ghazanfar Shahgholian, Majid Moazzami,
Sayed Mohammadali Zanjani, Amir Mosavi and
Arman Fathollahi

February 4, 2023

A Hydroelectric Power Plant Brief: Classification and Application of Artifactual Intelligence

Ghazanfar Shahgholian
Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
shahgholian@iaun.ac.ir

Majid Moazzami
Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
m_moazzami@pel.iaun.ac.ir

Sayed Mohammadali Zanjani
Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
sma_zanjani@pel.iaun.ac.ir

Amir Mosavi
John von Neumann Faculty of Informatics, Obuda University, Budapest, Hungary
amir.mosavi@nik.uni-obuda.hu

Arman Fathollahi
Department of Electrical and Computer Engineering, Aarhus University, Aarhus, Denmark
arman.f@ece.au.dk

***Abstract*— The energy generated using water force in hydropower plants can be a non-polluting, suitable, and stable alternative to traditional fossil fuels and various renewable electrical energy sources. Hydropower has one of the highest conversion efficiencies in comparison to other renewable energy sources. The main part of a hydropower plant is the hydro turbine, and the appropriate maintenance and operation of all the other components are crucial for producing electrical energy as efficiently as possible. The essential roles of the hydroelectric power plant are the generation of electric energy, the storage of irrigation water, the storage of drinking water supply, and the control of floods in the rivers. A brief overview of hydroelectric power plant classification is presented in this study. This classification is based on the output power generated by the peak water drop and storage. Based on the condition of water, there are several kinds of classification for hydroelectric energy plants, of which a pump storage water plant is more applicable. Impoundment, diversion, and pumped storage are the three varieties of hydroelectric power plants. Furthermore, the application of Artificial Intelligence (AI) in the various parts of a hydroelectric power plant is reviewed.**

Keywords*— *Artifactual Intelligence (AI) ; Power plant; hydroelectric; classification; generated power output.

I. Introduction

With population growth and the spread of new technologies, the demand for electricity has increased worldwide [1,2]. Power plants are industrial sites that are established to generate electricity and distribute power on a large scale [3]. Power plants use different renewable and non-renewable sources for their fuel [4,5]. Energy sources based on the consumed fuel are used to rotate the generator axes. This issue is the main difference in the performance of all types of energy plants [6]. Due to the limitations in the operation of power plants, power plants are usually built at a distance from the center of cities [7,8]. Energy for electricity production is divided into three main categories, which are fossil fuels, nuclear energy, and renewable energy sources [9]. Various kinds of power plants are employed to produce electricity, based on the energy source criteria for production, power plants can be generally divided into conventional power plants (use of conventional energy sources) and unconventional power plants (use of non-conventional energy sources) [10,11]. There are different types of power plants that can be mentioned as solar thermal power plant [12], fossil fuel energy plant [13], steam energy plant [14], nuclear power plant [15], hydroelectric power plant [16], geothermal power plant [17], biomass power plant [18], photovoltaic power plant [19], coal-fired thermal power plant, and wind power plant [20]. Compared to other large-scale generation options, hydropower has the lowest operating costs and the longest life of the power plant [21]. For many centuries, people have used water as a resource for a variety of things. More than 97% of the electricity generated by renewable sources is produced by hydropower, which is the primary source of renewable energy [22]. Hydroelectric power plants are primarily used to produce electricity, store irrigation water for later use, control river flooding, and store drinking water [23]. In this paper, a brief overview of the structure and types of hydropower plants is pro-vided. Hydro power plants have been checked in terms of output power, water height, electricity supply and water conditions. Also, the structure of the power plant is shown schematically. Moreover, we provided a brief overview of the utilization of AI in hydropower and attempted to predict where these plants will be most useful in the future.

The following is the outline for this paper: Section II presents the fundamental system Structure of a hydropower plant. In Section III, the classification of hydroelectric energy plant according to generated output power, water condition, availability of water head, and availability of loading type is summarized. Section IV structured the fundamental system Structure of a hydropower plant. Eventually, this paper is concluded in Section V.

II. PLANT STRUCURE

Hydropower is a dam-based system that operates by blocking the river's flow, thereby increasing, and storing water in the dams [24]. Hydroelectricity production is based on harnessing the gravitational force of flowing water [25]. In hydroelectric power plants, the kinetic power of the flowing water is utilized to rotate the blades in turbine, and then the kinetic energy is converted into electrical energy [26].

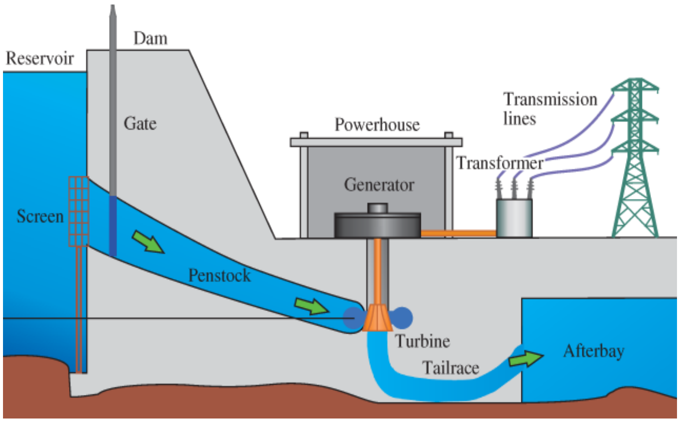

Fig. 1. Hydropower Plant Basic Parts

Fig. 1 shows the basic parts of a hydroelectric power generation system. The details of a hydroelectric energy plant include hydroelectric dam (helping to store water), water pipe (directing water to a turbine), turbine (connected to a generator by a shaft), generator, transformer (voltage conversion), power line (transmission power) and drainage mentioned [27,28]. The turbine provides mechanical energy, which is transferred to the generator, which then produces electricity. Simple surge tanks, restricted orifice surge tanks, and differential surge tanks are just a few of the many kinds of surge storage that can be set up.

III. HYDROPOWER PLANT CCLASSIFICATION

Hydropower plants are classified by different criteria, such as storage capacity, water flow and applied technologies. In this part, four various criteria are considered for the classification of hydroelectric power plants, which are briefly mentioned.

A. *Generated Output Power*

Traditional classifications of hydropower plants are based on their size, as shown in Table 1 [29,30]. Small hydropower plants typically range in size from 1 to 10 MW [31,32]. Large hydropower plants are defined as power plants with outputs greater than 10 MW [33,34].

TABLE I. CLASSIFICATION BASE ON GENERATED POWER OUT-PUT [42,43]

Classification	Rated power	Description
Pico Hydro	From a few hundred watt up to KW	-
Micro Hydro	From 5 KW up to 100 KW	Typically provided electricity for a small town or rural industry in a far-off location without access to the grid.
Mini Hydro	Above100 KW, but below 1 MW	Either independent schemes or, more frequently, grid-feeding.
Small Hydro	1-15 MW	Typically contributing to one grid
Medium Hydro	15-100 MW	Typically contributing to one grid
Large Hydro	More than 100MW	Typically contributing to a large electricity grid.

B. *Water condition*

Plants are divided into three categories, depending on their ability to either increase or decrease the rate of water flow, or to store or pump large quantities of water. Pumped storage water energy is a combination of two water reservoirs at different heights. By moving water from one to another (or in other words draining water) and passing through a turbine, power is generated. Also, this system requires energy as it pumps (or recharges) the water to the upper tank [35]. Hydropower provides pumped storage, energy balance, sustainability, storage capacity and ancillary network services [36].

C. *Availability of water head*

The head is a crucial metric in power plant engineering because it reveals the pressure of the water flowing through the turbines and the resulting power. The hydraulic head, which is equivalent to the water level in a still body of water,

represents the quantity of mechanical energy present in the water of a river, stream, or lake. Increases in hydraulic heads indicate that water energy is concentrated in a small area [37].
The hydroelectric energy plant is separated into three classes based on the head (depicted in Fig. 2), which are: high head plant (more than 300 meters), medium head plant (between 60 meters and 300 meters) and low head plant (less than 60 meters) [38].
The most common and largest hydroelectric power plants are of the type of high-head hydroelectric power plants and are used worldwide. This kind of hydroelectric energy plant usually uses a dam to store water at a high altitude [39].

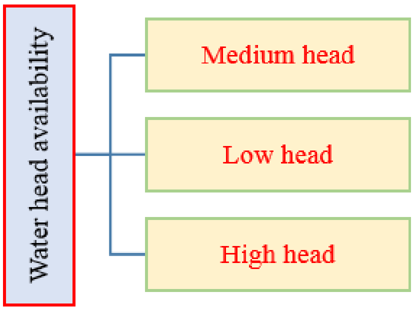

Fig. 2. Hydroelectric power plant classification according to the presence of a water head

D. Availability of loading type

There are three types of hydroelectric plants, all based on the types of loads they serve: base load, peak load, and pumped storage (Fig. 3). A large capacity plant with a wide supply, a base load power plant, is the type of power plant you'd find in a city. It can stand up to constant pressure. The peak load supply power plant requires a large water storage facility because it is optimized for the peak load curve. Pumped-storage power plants are used to meet the supply and demand for electricity. The turbines' storage pool up top is backed up by a supply of water for times of high demand [40].

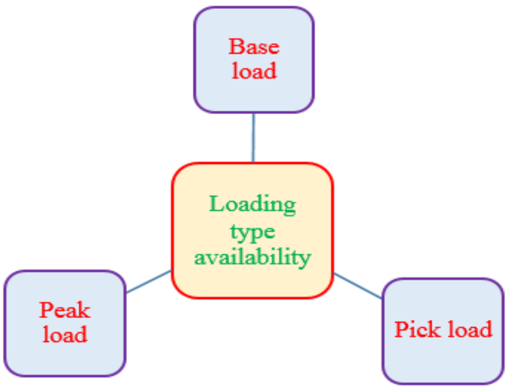

Fig. 3. categorization of hydroelectric power plants according to the availability of different loading types

IV. APLICATION OF ARTIFIUAL INTELIGENT IN HYDROPOWER PLANT

Hydropower plant parameters such as vibration, silt, discharge, and energy generation, must be controlled in real-time. Effective control can reduce system failures and enhance reliability. Using the IF-THEN rule, authors in [41] developed a Web-based hydro power plant fault detection approach. Heuristics diagnosed the hydro turbine fault. A real-time sediment load-controlling system is proposed in [42]. It is suggested in [43] to use an intelligent control system converter (ICSC) to transfer wake-induced vibration (WIV) into hydroelectric power. The system automatically and remotely maximizes cylinder oscillation according to free stream speed. Internet of Things technology made it possible to change the length and width of the downstream cylinder from afar. An online Kwater dam management approach to control 30 dams to protect them from extreme weather, aging, and earthquakes is materialized [44]. The authors demonstrate that by installing this system after the settling basins a primary alert system can be produced. In [45], an ADAM using assembly language is redesigned and installed in 16-channel data acquisition systems.

The forecasting of day plant load using machine learning, as accomplished in [46], aid in grid stabilization. A deep learning algorithm was used by [47] to forecast building energy usage in hydropower plants. An ANN-based algorithm is presented in [48] to predict the sediment loading of a watershed. The efficacy of five sequence classification methods for forecasting discharge flow in hydroelectric dams was evaluated in [49]. The outcomes demonstrated the neural network method's clear advantage over competing strategies. To forecast the pressure gradient, [50] employed an ANFIS and CFD approach. The findings of the investigation showed that the number of rules and the input parameters have a significant impact on the algorithm's accuracy.

In [51], the flow rate of hydroelectric plants is examined. This flow rate changes over time as a result of the turbine's rotation. Fuzzy logic and neural networks are combined to create an adaptive neuro-fuzzy inference system, which further improves the ability of load shedding for a variety of input data [52]. The output of the turbines was optimized using this algorithm to account for limitations on power demand and power capacity. The efficiency of the hydropower plant is currently being optimized in several procedures. An optimal load-shedding procedure with a backpropagation artificial neural network is created in [53]. This method can shed the critical load. By examining the economic, technical, and environmental criteria, Low-head (LH) hydropower method is thought to be the most environmentally friendly choice for generating electricity at wastewater treatment facility channels [54]. An outflow controller structure for hydropower plants is introduced in [55]. The outflow control is unique in that numerous actuators (weirs and turbines) were needed to regulate the reservoir's entire outflow. Neuro-fuzzy programming was compared using various options for generating electricity [56]. Researchers in [57] developed the application of the smart control approach in hydropower plants. Artificial intelligence-based procedures can create a low-cost power plant control and monitoring architecture, and these strategies can be utilized on historical information for computerized decision-making. Furthermore, there are a number of strong approaches, such as [58,59], that can be utilized in the field of planning the location of Hydropower plant parameters.

V. Conclusion

Energy is not only one of the most fundamental aspects of the electrical world, but it is also an extremely important contributor to the social and economic development of a nation. The criteria that are utilized for classification result in the categorization of hydropower plants into a variety of distinct groups. Hydroelectric power plants can be separated into a variety of categories according to the criteria that are used. There are three categories of hydropower plants that can be distinguished by the volume of water that they use: run of storage plants, river plants, and pumped storage power plants. There are three different sizes of hydropower plants that can be classified according to the amount of electricity they are able to generate: micro, small, and large hydropower plants. This work shows the outcomes of a short review of the literature on how AI is used in the hydropower industry. Load, head, silt, energy demand, discharge, and site choosing are just some of the forecasting areas where AI is currently being used. A large amount of investment is needed to begin building a hydropower plant. As a result, strategic planning is required to make the best use of available resources. Energy generation forecasting, demand prediction, and economic feasibility analysis are some of the primary applications of AI. On the other hand, it has found primary application in the areas of plant function optimization, energy price forecast, and reservoir management. In the future, AI could be utilized to optimize the function and control of hydroelectrical energy plants, allowing for a more precise and thorough analysis of their performance.

References

[1] A. Fathollahi, A. Kargar, S.Y. Derakhshandeh, "Enhancement of power system transient stability and voltage regulation performance with decentralized synergetic TCSC controller", Int. J. of Electrical Power and Energy Systems, Vol. 135,pp. 107533, Feb. 2022.

[2] G. Shahgholian, et al, “Impact of PSS and STATCOM devices to the dynamic performance of a multi-machine power system“, Engineering, Technology and Applied Science Research, vol. 7, no. 6, pp. 2113-2117, 2017.

[3] N. Hakimuddin, I. Nasiruddin. T.S. Bhatti, Y. Arya, “Optimal automatic generation control with hydro, thermal, gas, and wind power plants in 2-area interconnected power system”, Electric Power Components and Systems, vol. 48, no. 6-7, pp. 558-571, Aug 2020, doi: 10.1080/15325008.2020.1793829.

[4] A. Arastou, P. Ahmadi, M. Karrari, "Modeling and parameter estimation of a steam power plant including condenser back-pressure uncertainty using operational data", IEEE Systems Journal, vol. 16, no. 2, pp. 2979-2988, June 2022, doi: 10.1109/JSYST.20-21.3122228.

[5] P. Kolasiński, “Application of volumetric expanders in small vapour power plants used in distributed energy generation– Selected design and thermodynamic issues”, Energy Conversion and Management, vol. 231, Article Number: 113859, March 2021, doi: 10.1016/j.enconman.2021.113859.

[6] M. Mahdavian, et al., "Maximum power point tracking in wind energy conversion systems using tracking control system based on fuzzy controller", IEEE/ECTICON, Nakhon Ratch¬asima, Thailand, 2014, doi: 10.1109/E¬CTICo¬n.2014.6839750.

[7] L. Khalilzadeh-Ganjali-khani, F. Shei¬kho-leslam, F., H. Mahdavi-Nasab, “System identification of a nonlinear multivariable steam generator power plant using time delay and wavelet neural networks”, Journal of Intelligent Procedures in Electrical Technology, vol. 3, no. 12, pp. 67-73, Jan. 2013, dor: 20.1001.1.23223871.1391.3.12.8.3.

[8] A. Fattollahi, “Simultaneous design and simulation of synergetic power system stabilizers and a thyristor-controller series capacitor in multi-machine power systems”, Journal of Intelligent Procedures in Electrical Technology, vol. 8, no. 30, pp. 3-14, Sept. 2017.

[9] O.J. Khaleel, F.B. Ismail, T.K. Ibrahim, S.H.A. Hassan, “Energy and exergy analysis of the steam power plants: A comprehensive review on the classification, development, improvements, and configurations”, Ain Shams Engineering Journal, vol. 13, no. 3, Article Number: 101640, May 2022, doi: 10.1016/j.asej.2021.11.009.

[10] G. Putrus, E. Bentley, “20- Integration of distributed renewable energy systems into the smart grid”, Electric Renewable Energy Systems, Academic Press, pp. 487-518, 2016, doi: 10.1016/B978-0¬-1¬2-804448-3.00020-7.

[11] A. Fattollahi, et al., “Decentralized synergistic control of multi-machine power system using power system stabilizer“, Signal Processing and Renewable Energy, vol. 4, no. 4, pp. 1-21, Dec. 2020.

[12] S. Seme, K. Sredenšek, Z. Praunseis, B. Štumberger, M. Hadžiselimović, "Optimal price of electricity of solar power plants and small hydro power plants- Technical and economical part of investments", Energy, vol. 157, pp. 87-95, August 2018, doi: 10.1016/j.energy.2018.05.121.

[13] S. Kannaiyan, N.D. Bokde, Z.W. Geem, "Solar collectors modeling and controller design for solar thermal power plant", IEEE Access, vol. 8, pp. 81425-81446, 2020, doi: 10.1109/ACCESS.2020.29¬89003.

[14] A. Al Monsur, A. Rahman, F.M. Mohammedy, "Assessment of severity of impact on human within the proximity to a fossil fuel power plant", Proceeding of the IEEE/WIECON-ECE, pp. 247-250, Bhubaneswar, India, Dec. 2020, doi: 10.11-09/WIECON- ECE52¬138.20¬20.9¬3¬98-020.

[15] D. Lindenmeyer, A. Moshref, M.C. Schaeffer, A. Benge, "Simulation of the start-up of a Hydro Power plant for the emergency power supply of a nuclear power station", IEEE Trans. on Power Systems, vol. 16, no. 1, pp. 163-169, Feb 2001, doi: 10.1109/59.910793.

[16] Y. Si, L. Chen, X. Zhang, X. Chen, and S. Mei, "Capacity allocation of hybrid power system with hot dry rock geothermal energy, thermal storage, and PV based on game approaches," Journal of Modern Power Systems and Clean Energy, pp. 1-12, 2022, doi: 10.35833/MPCE.2021.000136.

[17] D. Moya, J. Paredes, P. Kaparaju, "Technical, financial, economic and environmental pre-feasibility study of geothermal power plants by RETScreen – Ecuador's case study", Renewable and Sustainable Energy Reviews, vol. 92, pp. 628-637, Sep. 2018, doi: 10.1-016/j.rser.2018.04.027.

[18] Z. Zhou, C. Wang, L. Ge, "Operation of stand-alone microgrids considering the load following of biomass power plants and the power curtailment control optimization of wind turbines", IEEE Access, vol. 7, pp. 186115-186125, Dec. 2019, doi: 10.1109/ACCESS.20-19.295¬86¬78.

[19] D. Wang, D. Liu, C. Wang, Y. Zhou, X. Li, M. Yang, “Flexibility improvement method of coal-fired thermal power plant based on the multi-scale utilization of steam turbine energy storage”, Energy, vol. 239, Article Number: 122301, Jan. 2022, doi: 10.1016/j.energy.2021.122301.

[20] M. Fooladgar, E. Rok-Rok, B. Fani, G. Shahgholian, "Evaluation of the trajectory sensitivity analysis of the DFIG control parameters in response to chan¬ges in wind speed and the line impedance connection to the grid DFIG", Journal of Intelligent Procedures in Ele¬ct¬rical Technology, vol. 5, no. 20, pp. 37-54, March 2015, dor: 20.1001.1.2¬322¬38-71.1393.5.20.4.9.

[21] T. Weldcherkos, A.O. Salau, A. Ashagrie, "Modeling and design of an automatic generation control for hydropower plants using neuro-fuzzy controller", Energy Reports, vol. 7, pp. 6626-6637, 2021, doi: 10.1016/j.egyr.202¬1.0¬9.143.

[22] Y. Damtew, G. Getenet, “Assessment of hydropower potential of selected rivers in north shoa zone, amhara regional state, ethiopia”, American Journal of Energy Research, vol. 7, pp. 15-18, no. 1, 2019, doi: 10.12691/ajer-7-1-2.

[23] X. Liu, C. Liu, "Eigenanalysis of oscillatory instability of a hydropower plant including water conduit dynamics", IEEE Trans. on Power Systems, vol. 22, no. 2, pp. 675-681, May 2007, doi: 10.1109/TPWRS.2007.8¬951¬56.

[24] G. Shahgholian, et al., “Improving Power System Stability Using Transfer Function: A Comparative Analysis“, Engineering, Technology and Applied Science Research, vol. 7, no. 5, pp. 1946-1952, 2017.

[25] N. Kishor, R.P. Saini, S.P. Singh, "A review on hydropower plant models and control", Renewable and Sustainable Energy Review, Vol. 11, No. 5, pp. 776-796, June 2007, doi: 10.1016/j.rser.2¬005.0¬6.003.

[26] F. Hedarpour, et al., "Design and simulation of sliding and fuzzy sliding mode controller in hydro-turbine governing system", Journal of Iranian Dam and Hedroelectric Powerplant, vol. 4, no. 12, pp. 10-20, Augest 2017.

[27] N. Kishor, R.P. Saini, S.P. Singh, "Optimal pole shift control in application to hydro power plant", Journal of Electrical Engineering, vol. 56, no. 11-12, pp. 290-297, 2005.

[28] G. Martínez-Lucas, J.I. Sarasúa, J.Á. Sánchez-Fernández, J.R. Wilhelmi, "Powe¬r-frequency control of hydropower plants with long penstocks in isolated systems with wind generation", Renewable Energy, vol. 83, pp. 245–255, Nov. 2015, doi: 10.1016/j.ren¬en¬e.20¬15.04.032.

[29] O.H. Souza, N. Barbieri, A.H. M. Santos, "Study of hydraulic transients in hydropower plants through simulation of nonlinear model of penstock and hydraulic turbine model", IEEE Trans. on Power Sys¬te¬m¬s, vol. 14, no. 4, pp. 1269-1272, Nov. 1999, doi: 10.110-9/59.¬80 1883.

[30] A. Tamrakar, et al., "Hydro power opportunity in the sewage waste water", American International Journal of Research in Science, Technology, Engineering and Mathematics, vol. 10, no. 2, pp. 179-183, March/May 2015.

[31] M. Hanmandlu, H. Goyal, "Proposing a new advanced control technique for micro hydro power plants", Electrical Power and Energy Systems, Vol. 30, pp. 272-282, 2008.

[32] D. Tiomo and R. Wamkeue, "Dynamic modeling and analysis of a micro-hydro power plant for microgrid applications", Proceeding of the IEEE/CCECE, Edmonton, AB, Canada, pp. 1-6, May 2019, doi: 10.1109/CCEC¬E.2019¬.88¬6¬18¬75.

[33] C. P. Ion and C. Marinescu, "Autonomous micro-grid based on micro hydro power plants", Proceeding of the IEEE/OPTIM, pp. 941-946, Brasov, Romania, May 2012, doi: 10.1109/OP-TIM.2¬012.6231918.

[34] J.H.I. Ferreira, J.R. Camacho, J.A. Malagoli, "A contribution to the study of the estimate hydroelectric potential for small hydropower plant", IEEE Latin America Transactions, vol. 14, no. 7, pp. 3215-3224, July 2016, doi: 10.1109/TLA.2016.7587623.

[35] D. Abdellatif, R. AbdelHady, A.M. Ibrahim, E.A. El-Zahab, "Conditions for economic competitiveness of pumped storage hydroelectric power plants in Egypt", Renewables: Wind, Water, and Solar, vol. 5, no. 2, 2018, doi: 10.118-6/s¬408¬07-01¬8-0048-1.

[36] J.I. Sarasúa, J.I. Pérez-Díaz, J.R. Wilhelmi, J.Á. Sánchez-Fernández, "Dynamic response and governor tuning of a long penstock pumped-storage hydropower plant equipped with a pump-turbine and a doubly fed induction generator", Energy Conversion and Management, vol. 106, pp. 151–164, Dec. 2015, doi: 10.1016/j.enc onman 2015.09.030.

[37] S. Zhang et al., "A regulating capacity determination method for pumped storage hydropower to restrain PV generation fluctuations", CSEE Journal of Power and Energy Systems, vol. 8, no. 1, pp. 304-316, Jan. 2022, doi: 10.17775/CSEEJP¬ES.2020.01930.

[38] F.J. Garcia, M.K.I. Uemori, J.J. Rocha Echeverria, E.d. Costa Bortoni, "Design requirements of generators applied to low-head hydro power plants", IEEE Trans. on Energy Conversion, vol. 30, no. 4, pp. 1630-1638, June 2015, doi: 10.1109/TEC.2015.2434617.

[39] M. Djukanovic, M. Novicevic, D. Dobrijevic, B. Babic, D.J. Sobajic, Y.H. Pao, "Neural-net based coordinated stabilizing control for the exciter and governor loops of low head hydropower plants", IEEE Trans. on Energy Conversion, vol. 10, no. 4, pp. 760-767, Dec. 1995, doi: 10.1109/60.475850.

[40] J.M. Pedraza, “Chapter 2- The use of hydropower for electricity generation”, Non-Conventional Energy in North America, pp. 89-135, 2022, doi: 10.1016/B978-0-12-823440-2.00010-X.

[41] G. Song, Y. He, F. Chu, Y. Gu, “A Web-based hydro turbine fault diagnosis system”, Expert Systems with Applications, vol. 34, no. 1, pp. 764-772, Jan 2008, doi.org/10.1016/j.eswa.2006.10.017.

[42] M.B. Bishwakarma, H. Stole, “Real-time sediment monitoring in hydropower plants”, *Journal of Hydraulic Research*, vol. 46, no. 2, pp. 282-288, Mar 2008, doi.org/10.1080/00221686.2008.9521862.

[43] J.F. Derakhshandeh, N. Gharib, M. Hadipour, “An intelligent IoT-based control system for harnessing hydropower energy from wake induced vibration”, J Ind Electron Appl, vol. 3, no. 1, pp. 2, 2019.

[44] J. Jeon, J. Lee, D. Shin, H. Park, “Development of dam safety management system”, Adv Eng Softw, vol. 40, no. 8, pp. 554-563, Aug 2009, doi.org/10.1016/j.advengsoft.

[45] W. Zhang, Z. Tongji, “Development and application of hydropower hydro monitoring system”, Procedia Engineering, vol. 15, no. 1, pp. 807-811, Jan 2011, doi.org/10.1016/j.proeng.2011.08.150.

[46] K. Kumar, R.P. Singh, P. Ranjan, N. Kumar, “Daily Plant Load Analysis of a Hydropower Plant Using Machine Learning”, *Applications of Artificial Intelligence in Engineering*, pp. 807-811, 2021.

[47] M. Fayaz, D. Kim, “A prediction methodology of energy consumption based on deep extreme learning machine and comparative analysis in residential buildings”, *Electronics*, vol. 7, no. 10,pp. 222, 2018.

[48] H. Lounis, M. Boukadoum, and V. Siveton, "Assessing hydro power system relevant variables: a comparison between a neural network and different machine learning approaches," in *Proc. International Conference on Neuro-Fuzzy Technology, Havana (Cuba)*, vol. 51, no. 28, Jan 2002.

[49] S. Shamshirband, A. Mosavi, and K.W. Chau, "Sensitivity study of ANFIS model parameters to predict the pressure gradient with combined input and outputs hydrodynamics parameters in the bubble column reactor," arXiv preprint arXiv:1907.09309, 2019.

[50] S. V. Egoigwe, C. Chukwudozie, C. Nwobi, T. O. Araoye, C. I. Arize, and E. C. Anoliefo, "Application of a Fuzzy Logic Controller for Hydropower Generator Speed Regulation," *European Journal of Engineering and Technology Research,* vol. 4, no. 3, pp. 132-135, 2019.

[51] P. Herath and G. K. Venayagamoorthy, "A service provider model for demand response management," in *2016 IEEE Symposium Series on Computational Intelligence (SSCI),* 2016: IEEE, pp. 1-8.

[52] F. Conteh, S. Tobaru, M. E. Lotfy, A. Yona, and T. Senjyu, "An effective Load shedding technique for micro-grids using artificial neural network and adaptive neuro-fuzzy inference system," *Aims Energy,* vol. 5, no. 5, pp. 814-837, 2017.

[53] M. Ak, E. Kentel, and S. Kucukali, "A fuzzy logic tool to evaluate low-head hydropower technologies at the outlet of wastewater treatment plants," *Renewable and Sustainable Energy Reviews,* vol. 68, pp. 727-737, 2017.

[54] J. Chapuis and F. Kraus, "Application of fuzzy logic for selection of turbines and weirs in hydro power plants," *IFAC Proceedings Volumes,* vol. 32, no. 2, pp. 7190-7195, 1999.

[55] R. Mamlook, B. A. Akash, and M. S. Mohsen, "A neuro-fuzzy program approach for evaluating electric power generation systems," Energy, vol. 26, no. 6, pp. 619-632, 2001.

[56] X. Haoming, W. Deyi, and L. Jiajun, "Process control optimization for hydroelectric power based on neural network algorithm," *AMSE Journals-AMSE IIETA*, vol. 72, no. 2, pp. 155-166, 2017.

[57] L. Horváth and I. J. Rudas, "Active knowledge for the situation-driven control of product definition," Acta Polytechnica Hungarica, vol. 10, no. 2, pp. 217-234, 2013.

[58] S. Mousavi, et al., "Dynamic resource allocation in cloud computing," *Acta Polytechnica Hungarica*, vol. 14, no. 4, pp. 83-104, 2017.