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PLC – HMI Automation based Cascaded Fuzzy PID for Efficient Energy Management and Storage in Real Time Performance of a Hydro Electric Pumped Storage Power Plant

A. Selwin Mich Priyadharson^{a*}, R. Ganesan^b, Prabhu Kumar Surarapu^c

^aAssociate Professor, ECE Dept, Vel Tech University, Avadi, Chennai – 600 062, India

^bAssistant Professor, IT Dept, Vel Tech University, Avadi, Chennai – 600 062, India

^cAssistant Professor, ECE Dept, Vel Tech University, Avadi, Chennai – 600 062, India

Abstract

Usually in order to balance the load demand at high peak hours, hydro electric pumped storage power plant is utilized. In this project a novel design, (CFPID) Cascaded Fuzzy PID (Proportional - Integral - Derivative) controller scheme using B&R (Bernecker & Rainer) Industrial Automation PLC - HMI (Programmable Logic Control - Human Machine Interface) for Efficient Energy management and storage in real time performance of a hydro electric pumped storage power plant is proposed. In this scheme, Fuzzy Level is cascaded with PID Flow for improvement in performance. A prototype model of a hydro electric pumped storage power plant with 22 digital inputs and 14 potential free outputs is fabricated with an objective of controlling the process variables, flow and level is done by using conventional PLC and the proposed CFPID control. There are two tanks in the prototype, lower tank with 2 stages of level and upper tank with 5 stages of level. HMI is used to monitor and operate the process in online - real time, for easy control of the operations. In this paper, the proposed PLC- HMI automation based CFPID control scheme is performed and finally compared with the conventional PLC by experimental results and validated by using real time statistics obtained from the hydro electric pumped storage power plant.

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* Corresponding author. Tel.: 919445785448

E-mail address: selwin_priyadharson@yahoo.co.in

1. Introduction

For generating power, hydro electric power is the most widely used renewable sources of energy. Hydro power generation depends on the available flow and altitude from which it falls. Rajeshwari et al [1] emphasize on controlling the process variable parameters such as level and flow with real time implementation of gate control of hydroelectric power plant using PLC. King et al [2] discusses the development of a fuzzy inference system (FIS) based governor control for a pumped storage hydroelectric plant. Kerning Xie et al [4] proposed a new fuzzy-immune PID cascade control system in superheated steam temperature control System. Tunyasirut [5] et al described the Fuzzy-PID cascade controller to control the level of horizontal tank. Gagan Singh et al [3] described that a suitable signal is necessary in hydro power plant to operate the gate, need to be identified which may satisfy the requirement of sudden large change in the loads, well as to maintain the constant speed.

To overcome the difficulties such as inherent time delay, nonlinearity due to uncertainty of the process and frequent load changes in the existing control schemes and thereby to enhance the performance of the hydroelectric power plant, the PLC-HMI based CFPID control scheme is developed. This paper is structured as follows: Section 2 deals with the hydro power plant and prototype model. Section 3 deals conventional scheme for hydroelectric power plant. Section 4 describes the proposed CFPID, fuzzy level cascaded with PID flow control scheme. Section 5 describes the PLC-HMI Visualization. Section 6 deals with Experimental results of the conventional and the proposed scheme. Section 7 gives the summary & conclusions.

2. Hydro Electric Pumped Storage Power Plant and Prototype Model

In Pumped storage power plant, Energy is stored by pumping water from lower reservoir to upper reservoir at the time of low power demand and at the time of peak load period's, stored water is utilized to generate and manage load demand. The sequences followed in Hydro electric pumped storage power plant that is put into operation in the prototype model are illustrated as follows: When the water level in the lower tank reaches the low level, the pump 1 is actuated and the water is taken to the upper tank from the lower tank. In upper tank, when the water level reaches the low level, pump 1 is, again switched on and water level raises upto average level. When water level exceeding average level, Gate1 is allowed to open.

Similarly when the level attains medium level, the pump 1 actuated and the water raises upto high level. When water is mounting beyond medium level, Gate 1 and Gate 2 is opened and when water level is reached the high level, Gate 1, Gate 2 and Gate 3 is opened. When the level increases beyond the high level, the pump2 is actuated and water is taken back to lower tank. If the water level reaches high level in lower tank and exceeding danger level in the upper tank, Gate 1, Gate 2 and Gate 3 will be closed and also the pumps 1 and 2 will be switched off.

The Lab scale Experimental Set up operation is shown in Fig.1. Prototype model is provided with lower tank of two levels and upper tank of five levels [1]. The upper five levels are Low level, Average level, Medium level, High level and Danger level. Whereas the two levels of the lower tank are Low level and High level. The Block diagram of Hardware set up is shown in Fig.2 which consists of the hardware components Programmable Logic Controller, FT - Flow transmitters, LT - Capacitive level transmitter, Pumps and Valves. Based on the level transmitter (LT) output, the ladder logic is programmed and as per the programmed ladder logic, the pumps and also the opening of gates of the dam are actuated at their respective levels. The Lab scale Experimental set up is operated based on the sequences demonstrated. The Lab scale Experimental set up is shown in Fig. 3.

3. Conventional Scheme for Hydro Electric Pumped Storage Power Plant

The Hardware components of B&R PLC system is shown in Fig. 4. It has Processor unit (CPU), Memory section, Input/output sections, Power supply unit, Programming device and System buses. The overall B&R Hardware with Power supply, PLC, Input/ Output modules is shown in the Fig. 5.

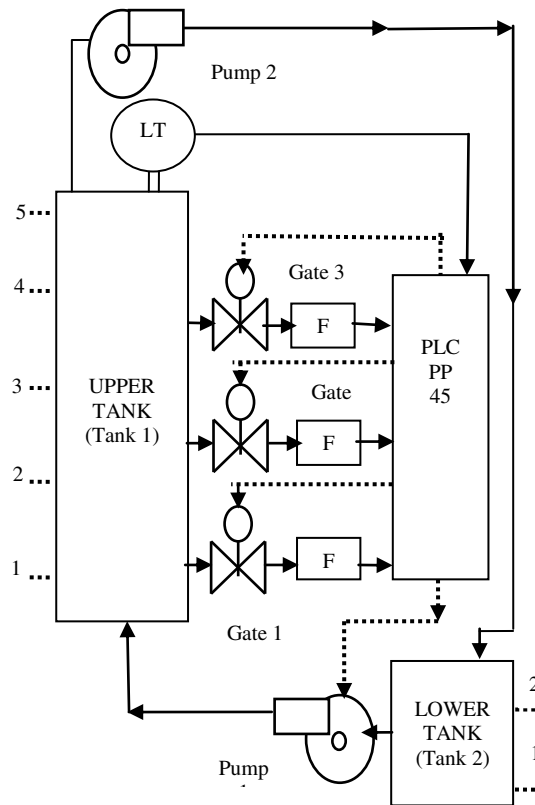


Fig. 1. Operation of Prototype Model

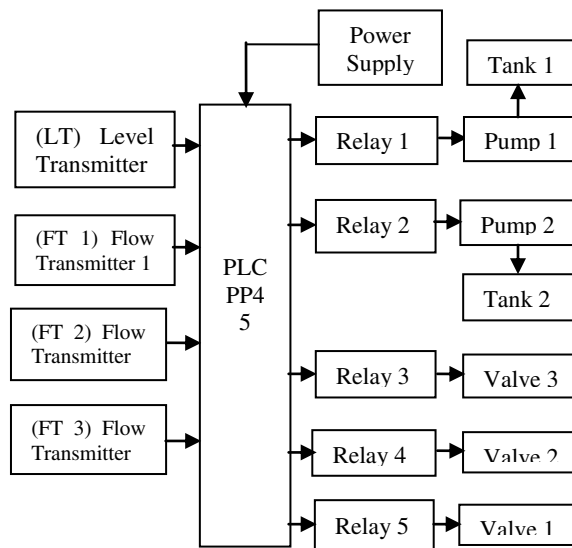


Fig. 2. Block diagram of Hardware Set up

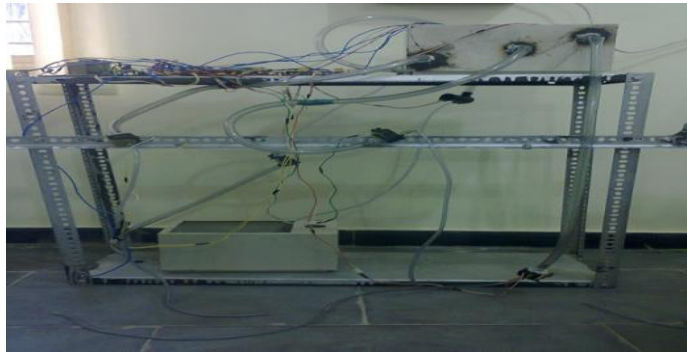


Fig. 3. Lab Scale Experimental Set Up

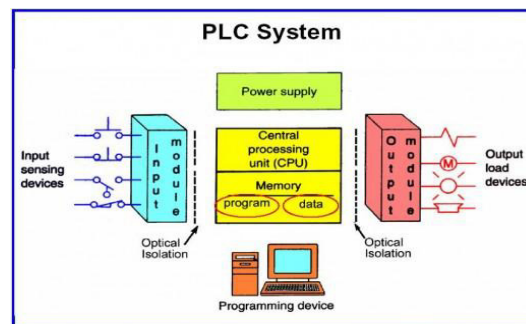


Fig. 4. PLC System



Fig.5. B&R PLC Hardware Set Up

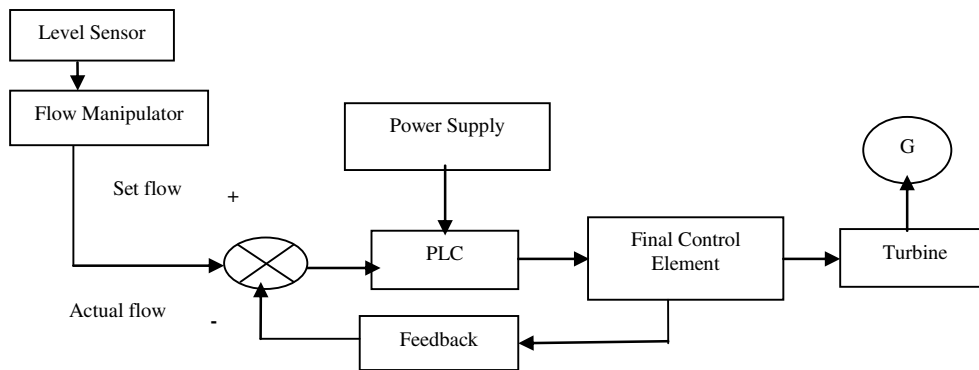


Fig. 6. Block diagram for flow control in Hydro Electric Pumped Storage Power Plant

In Fig. 6, Block diagram for flow control in Hydro Electric Pumped storage power plant is represented. Gates (Final Control Element) will open/close in the plant depending on the water level in the reservoir. The water level in the reservoir is measured by capacitive level sensor. The actual level value is manipulated to the flow set point by using flow manipulator. Comparison between water flow set point and actual flow is done and the error is controlled by PLC which gives manipulated variable to the Gate valves. The water outflow from the gate valve is taken to the turbine.

4. Proposed Cascaded Fuzzy PID Control Scheme

The proposed PLC based Cascaded Fuzzy PID control scheme for flow and level control is shown in the Fig .7.

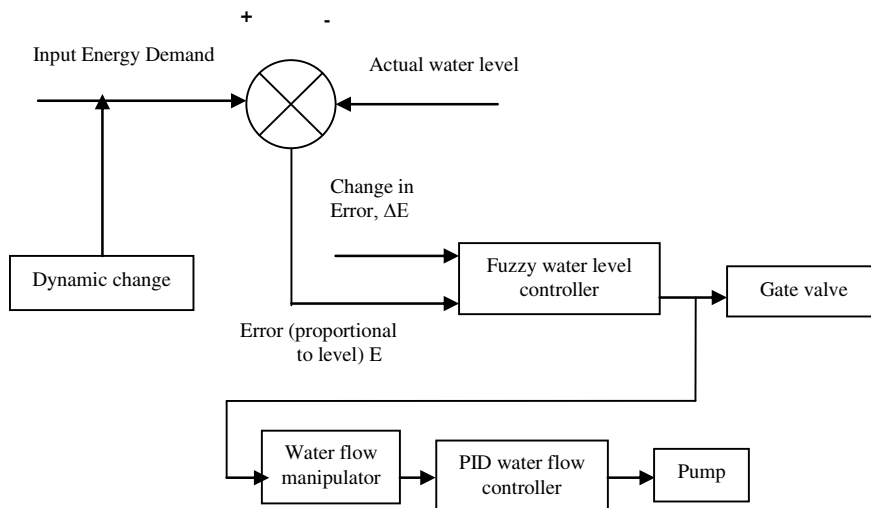


Fig. 7. PLC based Cascaded Fuzzy PID Scheme

During start up power obtained is opposite to the direction of change in gate position. When sudden open in gate is done because of water inertia the flow will not do immediate change instead of that the pressure across the turbine will reduce consistently making power to reduce. When sudden increase or decrease in load occurs the water

accelerates until the water flow reaches the new steady state value [3]. Because of the sudden increase and decrease in load the gate opening/closing operation may limit the speed deviation but it formulate damages to turbine/generator shaft. If slow and smooth operation of gate is preferred to prevent this type of damages that will leads to lagging in load due to low pick up of the turbine/generator and also the drop in frequency will occur. So it is necessary to get [3] a suitable signal so that to operate the gate which will satisfy the sudden load change and also to maintain the constant speed, the proposed PLC - HMI automation based CFPID scheme is done. Thereby the maximum sudden in and out of load change is estimated and corresponding change in gate position is identified using the proposed scheme. The opening and closing of the gate position is done in three types. It is step closing/opening for sudden change, ramp closing/ opening for velocity and exponential opening/closing for acceleration.

Fuzzy water level controller regulates water flow to the turbine through Gate valves. Input to the Fuzzy water level controller is Error (proportional to level), which is derived from the load demand. Whereas input to the PID water flow controller is cascaded with the output of the fuzzy water level controller. The fuzzy water level controller executed for hydroelectric pumped storage power plant has two inputs and one output. Error and Change in Error are the inputs and Valve position is the controlling output. The controller variables in the universes of discourse are represented as E, ΔE and U respectively. Linguistic terms (VS=Very small; S=small; M= medium; L= large; VL= Very large) are utilized and the triangular membership functions are employed to symbolize. Using Mamdani (min-max) method, Rule base is programmed and an inference mechanism is ordered that provides the output signal to the valve position as final control element. The FLC system proposed for the fuzzy water level controller is shown in Table 1.

Table 1.FLC parameters for flow controller

Parameters	Flow Control
Input variables	2
Fuzzy sets	5
Rules	17
Membership function	Triangular
Defuzzification method	Centroid

In PID water flow controller, the PID control signal,

$$U(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s\right) E(s) \quad (1)$$

Where K_p represents proportional gain, T_i represents integral time, T_d represents derivative time.

$E(s)$ represents error signal & $U(s)$ represents control signal. The PID controller parameters are obtained by Ziegler Nichol's method from offline tests performed in the prototype model for different increase and decrease in load conditions concerning real time data collected from hydro electric pumped storage plant are shown in Table 2.

Table 2. PID Parameters

Control loop	PID parameters		
	K_p	K_i	K_d
Flow Controller	1.89	1.0	0.01

5. PLC - HMI Visualization

In PLC – HMI, Visualization is done to design the process that will be user friendly and also useful to follow the ongoing process by monitoring in the screen. With the advancement in touch screen, the inputs can be fed in the PLC and if there any changes in the data can also be updated online. There are 3 valves and 2 pumps in the prototype model. Based on the operation, it will be indicated and displayed in the HMI.

6. Experimental Results

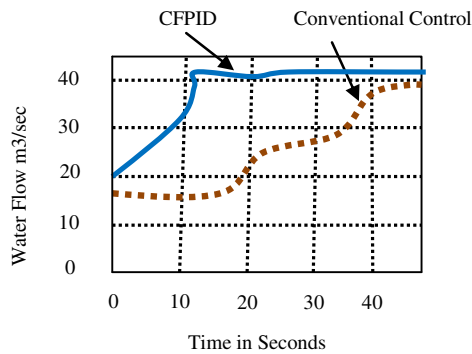


Fig. 8. Load 10 MW – 20 MW

Gate 1 Opening above average level
Set Point 20 – 40 m³/sec

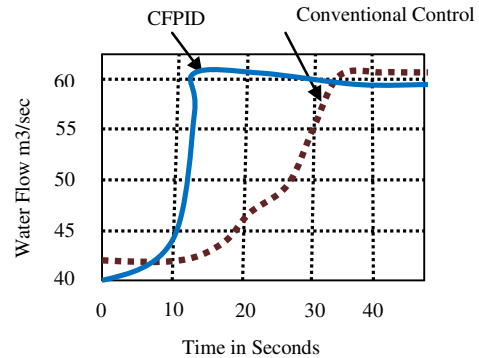


Fig. 9 Load 20 MW – 40 MW

Gate 2 Opening at medium level
Set Point 40 – 60 m³/sec

Table 3 Assessment of Performance Evaluation Criteria

Control scheme	Control loop	Load 10MW-20MW		Load 20MW-40MW	
		ISE	IAE	ISE	IAE
Traditional Method	Water flow	9698	8990	9742	8928
CFPID	Water flow	7292	7354	7450	7143

Table 4 Comparisons of Time Domain Specifications

Control scheme	Control loop	Load 10MW-20MW			Load 20MW-40MW		
		Rise time	Peak time	Setl time	Rise time	Peak time	Setl time
Traditional Method	Water flow	30	40	43	29	35	40
CFPID	Water flow	10	12	23	12	14	24

Fig. 8 and Fig. 9 represent the Experimental Results for conventional and the proposed CFPID control at the opening of Gates. Assessment based on Performance Evaluation Criteria such as Integral Square Error (ISE) and Integral Absolute Error (IAE) for various change in load was analysed. Also assessment based on the Rise time, peak time and settling time for traditional method and the proposed CFPID scheme was analysed for various change in load are shown in Table 3 and Table 4. Based on analysis it is clear that Rise time is more in Traditional method caused by the dead time and after dead time, gate valve will open suddenly that leads to water inertia and there was no immediate variation in flow. Whereas by applying this proposed CFPID scheme, gate position is determined quickly and a suitable signal from the controller is manipulated to operate the gate which balances the sudden load change and maintains constant speed with less settling time.

7. Conclusions

This work emphasizes the performance enhancement of the CFPID controller scheme using B&R PLC - HMI automation for various changes in loads. The conventional control system has 28% overshoot response for water flow and settles down after about 72 steps of increment. The PLC-HMI automation based CFPID water flow controller scheme shows satisfactory transient and dynamic response for Energy storage and management without much overshoot and settles down after about 46 steps of increment for water flow. Based on the assessment of Performance Evaluation Criteria it is found to be CFPID is 46% augmented over the traditional method in settling time for water flow. Consequently Proposed PLC – HMI automation based CFPID results in least ISE and IAE values for different change in load demand representing 22% augmentation for water flow when evaluating with traditional method. At last, concluding from the assessed statistics, PLC – HMI automation based CFPID control scheme exposes the supremacy over the Traditional method for efficient Energy management and storage in real time performance of a Hydro electric pumped storage power plant.

References

- [1] V. Rajeswari, Prof. Y. Rajeshwari and Dr. L. Padma Suresh, Real- Time Implementation of Hydroelectric Power Plant Using PLC and SCADA International Journal of Engineering Research and Applications (IJERA), 2012, Vol. 2, Issue 3, p.899-902.
- [2] King, D.J. ; Bradley, D.A. ; Mansoor, S.P. ; Jones, D.I. ; Aris, F.C. ; Jones, G.R., Using a fuzzy inference system to control a pumped storage hydro plant, The 10th IEEE International Conference on Fuzzy Systems, 2001, Vol 2, p 1008 – 1011.
- [3] Gagan Singh, and D.S. Chauhan, Simulation and Modeling of Hydro Power Plant to Study Time Response during Different Gate States, (IIAEST) International Journal of Advanced Engineering Sciences and Technologies, 2011, Vol. 10, Issue 1, p. 042 – 047.
- [4] Kerning Xie, Wei Hao, Jun Xie, Superheated Steam Temperature Cascade Control System Based on Fuzzy-Immune PID, Fourth International Conference on: Fuzzy Systems and Knowledge Discovery, IEEE, 2007, Vol 2, p. 642 – 628.
- [5] Tunyasrirot, Satean; Wangnipparnto, Santi, Level Control in Horizontal Tank by Fuzzy-PID Cascade Controller, Enformatika Academic Journal, Vol. 19, p78, 2007.
- [6] Gabriel Oltean, Mihaela Gordan, Emilia Sipos, Eugen Stancel, Ovidiu Dancea, Fuzzy Logic based Decision Making For Hydroelectric Energy Generation in a Cascaded Hydro power plants, Electronics and Telecommunications, ACTA Technica Napocensis, 2009, Vol 50, Issue 1, p. 42 – 48.
- [7] Selwin Mich Priyadharson. A., T. Ramesh Kumar, M. S. Saravanan, C. ThilipKumar and D.Dileepan, Neural Cascaded with fuzzy scheme for control of a hydro electric power plant, American Journal of Applied Sciences, 2014, Vol 11, Issue 9, p 1659 – 1670.
- [8] Selwin Mich Priyadharson A., Saravanan M.S., Gomathi N., Vinson Joshua and Mutharasan A., Energy Efficient Flow and Level Control in a Hydro Power Plant using Fuzzy Logic, Journal of Computer Science, Science Publications, USA, 2014, Vol 10, Issue 9, p. 1703-1711.
- [9] A. Selwin Mich Priyadharson, Vinson Joshua. S and Senthil Kumaran. B, PLC - HMI Based Pipeline Leakage Detection System in Petroleum Transfer Lines, Global Journal of Pure and Applied Mathematics, 2015, Vol 11, Number 3, p. 1699-1710.
- [10] Akitaka Hiratsuka, Takashi Arai and Tsukasa Yoshimura, Sea water Pumped Storage Power Plant in Okinawa Island, Japan, Elsevier, 1993, Vol 35, Issues 3–4, p 237–246.
- [11] Rabelo, R.A.L. ; Fernandes, R.A.S. ; Silva, I.N, Operational planning of hydrothermal system based on a fuzzy-PSO approach, IEEE Congress on Evolutionary Computation (CEC), IEEE, 2012, p 1 – 8.
- [12] Priyabrata Adhikary¹, Pankaj Kr Roy², Asis Mazum dar, Safe and Efficient Control of Hydro Power Plant by Fuzzy Logic, International Journal of Engineering Science & Advanced Technology, 2012, Vol 2, Issue-5, p. 1270 – 1277.
- [13] Omkar Yadav, Nand Kishor, Jesus Fraile-Ardanuy, Soumya R Mohanty, Juan I. Pérez, José I. Sarasúa, , Pond Head Level Control in a Run-of-River Hydro Power Plant using Fuzzy Controller, IEEE, 2011, p 1-5..
- [14] Luo Nanhua ; Yang Xiaojun, The adaptive fuzzy controller of hydroelectric units with hydraulic interconnection, Chinese Control and Decision Conference (CCDC), 2010, p 3998 – 4003.