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Fuzzy Logic Based Proportional Integral Control of Frequency for Small

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ABSTRACT

Tiny hydropower is one of the most competitive and reliable energy technologies for the renewable electricity supply. Some difference between production and requirement causes the device frequency to differ from its nominal value. As a consequence, high frequency variance can lead to collapse of the system. Mechanical governors control the frequencies of the current small hydro power plants. Those governors, however, are costive, complex and not quick to respond. In this paper simple, less cost and fast response fuzzy logic based proportional integral (PI) controller of frequency for small hydropower plant is modeled, designed and simulated by Matlab/Simulink. The frequency controller controls the flow rate of water by acting on stepper motor and keeps the frequency of the small hydropower system nearly constant. Eventually, the tests of the simulation of the standard PI controller are contrasted to fugitive PI controllers and have shown that Fuzzy PI has enhanced control efficiency..

Key words: Fuzzy logic controller, Hydraulic turbine model, PM Stepper motor, PI Controller.

1. INTRODUCTION

Nowadays renewable energy is becoming more and more popular as it is a sustainable and environment friendly source of energy. Clean energy sources are hydropower plants, which convert potential power from water into electricity and that are far more accurate and efficient energy sources than fossil fuel power plants. Energy is a fundamental thing for society and economic growth of any country. Houses, cottages, farmhouses, hutways, parks, factories, industries and small communities have been electrified using SHPP [1]. An increased access to electricity enhances opportunities form industrial development and improves health and education. A SHPP consists of the diverting dam, water system conveyor, pre-bay, penstock, wicket door, electric powerhouse, body structure and electrical and mechanical equipment. [2].
Generation capacity of small hydropower plants ranges from 1MW to 50MW [3]. The control system is one of the issues in the construction of a small power plant. Voltage and frequency are often regulated individually in a power system. The automated voltage regulators are built-in in most commercial synchronous generators. The frequency of a small hydroelectric system depends solely on the actual power balance. Thus, the objective of this paper is to model, design and simulate a less expensive, less complex and fast response frequency control system for small hydropower plants.

Load frequency control is necessary in the power system process to provide reliable and high-quality electricity. The power system frequency is based upon the active power balance of the power system and should stay almost constant under different conditions. Frequency is a standard network-wide parameter and an aggressive power or demand change in the single bus determines the overall system frequency. [4]. For this procedure multiple control techniques were used [5, 6]. But these conventional governors are not suited for frequency control of small hydropower systems, because of their cost, slow in response and complexity.

2. FREQUENCY CONTROLLERS SCHEME

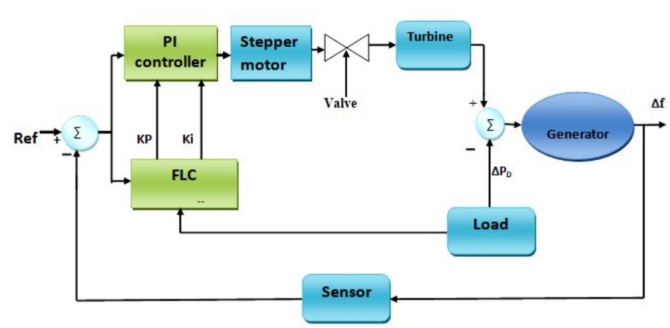

Figure 1: Frequency control scheme of small hydropower plant

3. DYNAMIC MODEL OF SMALL HYDROPOWER PLANT

Mathematical modeling is the process of representing the dynamic behavior of a physical system by set of mathematical equations. The most commonly used mathematical models in designing a control system are differential equation model, state space model and transfer function model. In this paper, to model the small hydropower system component transfer function model is used.

3.1 Hydraulic Turbine Modeling

Hydraulic turbine transforms the available water energy in the form of the spinning waft into mechanical energy. There are two types of turbine models from these linear turbine models is used in this paper which is expressed as [7].

$$\frac{\Delta \overline{p_m}}{\Delta \overline{G}} = \frac{1-0.5T_w s}{0.5T_w s+1} \quad (1)$$

Where, T_w water starting time and given by

$$T_w = \frac{LU_o}{a_g H_o}$$

3.2 Synchronous Generator and load Modeling

Generator is an electrical component which converts mechanical energy of the prime mover to electrical energy and it has different ratings. The synchronous generator model was taken from the swing equation [8].

$$\Delta\overline{\omega_r}(s) = \frac{\Delta\overline{p_m}(s) - \Delta\overline{p_e}(s)}{2Hs} \quad (2)$$

The overall frequency-dependent characteristics of a composite load can be expressed as [9].

$$\Delta\overline{p_e}(s) = \Delta\overline{p_D}(s) = \Delta\overline{p_l}(s) + D\Delta\overline{\omega_r}(s) \quad (3)$$

Where, $\Delta\overline{p_e}(s)$ is electrical power output, $\Delta\overline{p_D}(s)$ is power demanded; $\Delta\overline{p_l}(s)$ is non frequency sensitive consumer load changes; $D\Delta\overline{\omega_r}(s)$ is frequency sensitive load changes. Now, by substituting Equation (3) into Equation (2), we get load model which is given by

$$\Delta\overline{\omega_r}(s) = \frac{\Delta\overline{p_m}(s) - \Delta\overline{p_l}(s)}{2Hs+D} \quad (4)$$

3.3 Stepper Motor modeling

Stepper engine is used for small hydropower network spear valve control. The mathematical model of the PM stepping motor is developed from two main equations [10].

- Rotor dynamic equation (the motion of PM stepper motor)
- Voltage equation for stator winding

The transfer method is a second-order device for load-torque disturbances about the working point at the end of this stage and the initial load torque of 0. [10].

$$\Delta\theta(s) = -\frac{\Delta T_L(s) N_{RT}}{Js^2 + Ds + \sqrt{2}K_T I N_{RT}} \quad (5)$$

D is viscous damping coefficient, where J's the moment of inertia (kg.m2), K_T is constant, I is the currents in windings and N_{RT} is a number of rotor teeth and all parameters are given in Appendix.

4. DESIGN OF THE CONTROL SYSTEM OF SHPP

4.1 PI controller Design

Controller tuning is defined as the process of selecting controller parameters to meet a specific performance specification. In this paper the tuning method for Ziegler-Nichols is used and I set the parameter values of Kp and Ti for accordance with the table format1. Then, the PI controller parameters are determined from critical gain (Kcr) and critical period (Pcr) of the system transfer function and the initial gains k_{po} and k_{io} are found to be k_{po}=0.266 and k_{io}=0.823.

Table 1” Tuning of PI controller Parameter according to ZN Tuning (second method) [12]

Controller	K_p	T_i
P	0.5 k_{cr}	---
PI	0.45k_{cr}	$\frac{1}{1.2}$

4.2 Design of Fuzzy Logic Controller

Fuzzy logic is an artificial intelligence system that uses logical algorithms to make people think and determine. The following steps are applied to design the fuzzy logic controller.

- Fuzzification
- Rule base
- Inference Engine
- Defuzzification should be designed appropriately.

As Fig.1, Kp and Ki are tuned with two coefficients by a fugitive logic controller. Fuzzy inference system input variables are errors and fuzzy inference system load data as well as Kp and Ki output variables.

Input and output variable membership function is shown in Fig.2, Fig.3, Fig.4 and Fig.5. The linguistic variables are NL, NM, NS, NVS, ZR, PVS, PS, PM and PL, where ZR is zero; PS is positive small; PM is positive medium; NL is Negative large; PL is positive large; PVS is positive Very small; NM is

Negative medium; NS is Negative small and NVS is Negative Very small. The range of input variable for frequency error is taken to be [-0.05 0.05]. Hence the standard frequency deviation in any electric power system should not be greater than 5% of the nominal frequency [11].Kp and Ki parameters were taken as [-0.975, 0.975]. In this paper, the rules are presented to the controller in a format similar to the one below

Rule 1: IF X is A_1 and Y is B_1, THEN K_P is C_1 and K_i is D1.
Rule 2: IF X is A_2 and Y is B_2, THEN K_P is C_2 and K_i is D2.
Rule N: IF X is A_N and Y is B_N, THEN K_P is C_N and K_i is D_N.

The rule table is also established for Kp and Ki as shown in Table 2 and Table 3. In order to achieve optimum control performance, the furrowy logic control rule is calculated from practical expertise and simulars. Mamdani form and max-min deduction method is used to build Fuzzy logic controller. As the defluent method, the centroid method was chosen.

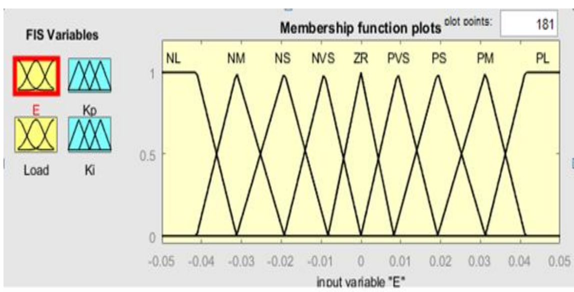

Figure 2: Input connection function for frequency error

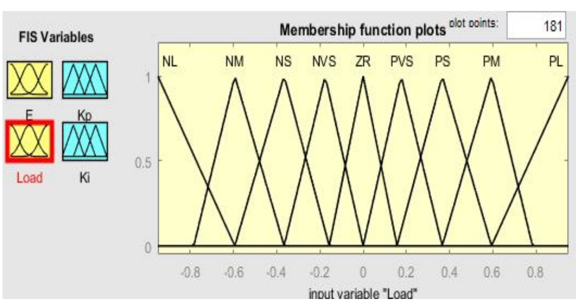

Figure 3: Input connection function for load

Table 2: Rule table for output Kp

Error	Load								
	NL	NM	NS	NVS	ZR	PVS	PS	PM	PL
NL	PL	PL	PM	PM	PL	PS	PS	ZR	ZR
NM	PL	PL	PM	PM	PM	PS	PS	ZR	PVS
NS	PL	PM	PM	PS	PS	PS	ZR	PS	PS
NVS	PS	PS	PS	PS	ZR	PVS	PS	PS	PM
ZR	PL	PM	PS	PVS	ZR	NVS	NS	NM	NL
PVS	PS	PS	PVS	ZR	NVS	NS	NS	NM	NM
PS	PM	PS	ZR	NS	NS	NS	NM	NM	NL
PM	PVS	ZR	NS	NS	NM	NM	NM	NL	NL
PL	ZR	ZR	NS	NS	NL	NM	NM	NL	NL

Table 3: Rule table for output Ki

Error	Load								
	NL	NM	NS	NVS	ZR	PVS	PS	PM	PL
NL	NL	NL	NM	NM	NL	NS	NS	ZR	ZR
NM	NL	NL	NM	NM	NM	NS	NS	ZR	NVS
NS	NL	NM	NM	NS	NS	NS	ZR	NS	NS
NVS	NS	NS	NS	NS	ZR	NVS	NS	NS	NM
ZR	NL	NM	NS	NVS	ZR	PVS	PS	PM	PL
PVS	NS	NS	NVS	ZR	NVS	PS	PS	PM	PM
PS	NM	NS	ZR	PS	PS	PS	PM	PM	PL
PM	NVS	ZR	PS	PS	PM	PM	PM	PL	PL
PL	ZR	ZR	PS	PS	PL	PM	PM	PL	PL

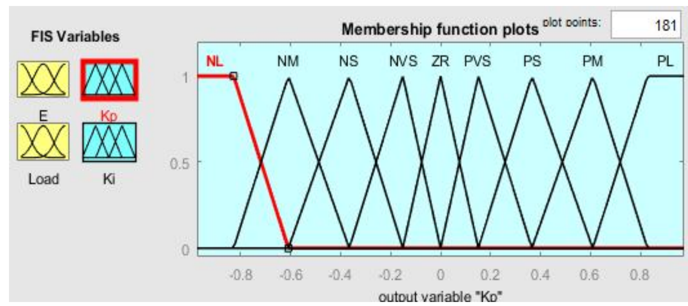

Figure 4: Output membership function for KP and Ki

5. SIMULATION RESULT

The SHPP mathematical model comprises of the phase pump, hydraulic turbine and parallel simulation of the generator. In compliance with the signal obtained from a foggy PI switch, the phase engine was used to change valve position. The simulation is carried out using the program Matlab / Simulink. The simulation findings for different load values and damping constants in the generator have been obtained after modeling the Matlab-Simulink model. This study uses four separate load value; 0.35, 0.55, 0.75 and 0.95 p.u and three different generator 1.3, 1.5 and 1.7 damping constant values were employed..

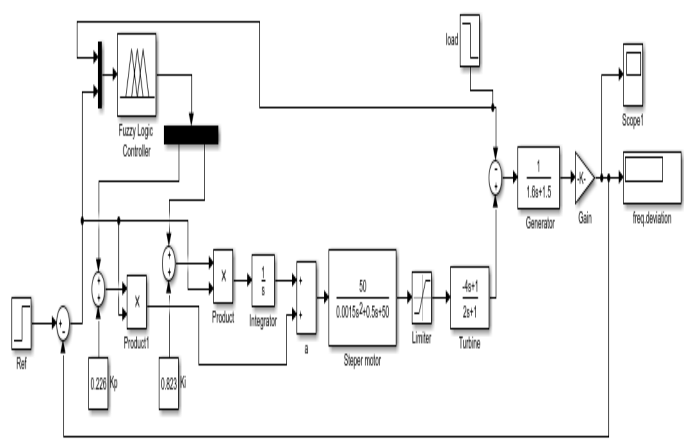

Figure 5: Overall Simulation Simulink Model with Fuzzy PI controller

Fig.6 And Fig.7 Presents the frequency deviations of the small hydropower system with fuzzy PI controller for a 0.35, 0.55, and 0.75 p.u load rejection and addition.

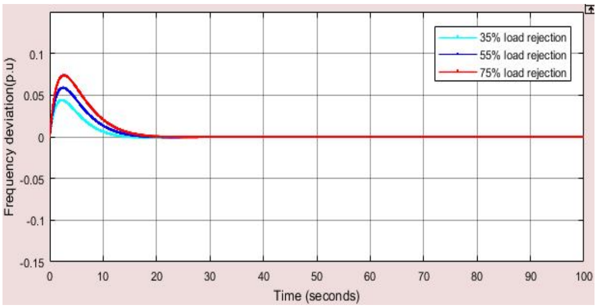

Figure 6: Frequency deviation of the system with fuzzy PI controller for different load rejection

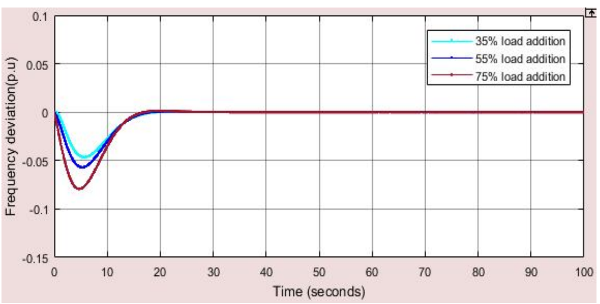

Figure 7: Frequency deviation of the system with fuzzy PI controller for different load addition

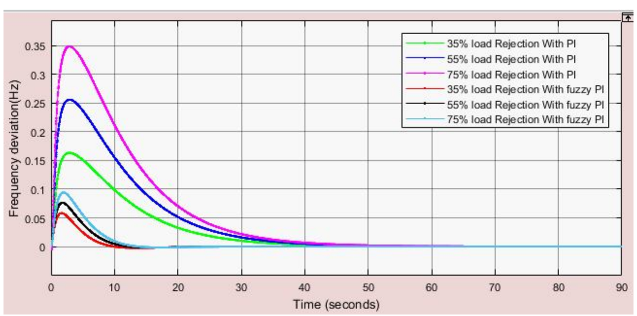

Figure 8: Frequency response of the system for 0.35, 0.55 & 0.75 P.U load rejection with PI and fuzzy PI controller

Table 4: Transient and steady state performance of PI and Fuzzy PI controller for sudden 35%,55% and 75% load Rejection.

Controller type	Overshoot (undershoot)	Settling time (seconds)	Steady state frequency Error in (p.u)
With PI (0.35 p.u)	15.33%	30	0
With PI (0.55 p.u)	24.81%	33	0
With PI (0.75 p.u)	34.89%	35	0
With fuzzy PI (0.35 p.u)	4.85%	9	0
With fuzzy PI (0.55 p.u)	6.02%	10	0
With fuzzy PI (0.75 p.u)	7.41%	11	0

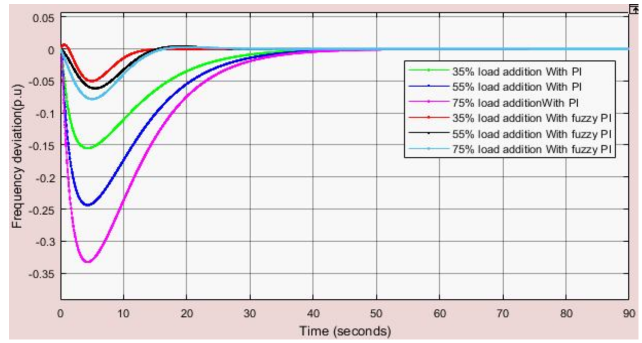

Figure 9: Frequency response of the system for 0.35, 0.55 & 0.75 P.U load addition with PI and fuzzy PI controller

Table 5 : Transient and steady state performance of PI and Fuzzy PI controller for sudden 35%,55% and 75% load addition.

Controller type	Overshoot (undershoot)	Settling time (seconds)	Steady state frequency Error in (p.u)
With PI (0.35 p.u)	15.48%	32	0
With PI (0.55 p.u)	24.35%	33	0
With PI (0.75 p.u)	33.23%	35	0
With fuzzy PI (0.35 p.u)	4.95%	11	0
With fuzzy PI (0.55 p.u)	5.89%	13	0
With fuzzy PI (0.75 p.u)	7.72%	14	0

Fig.10 shows that when we employee PI load controller for 0.3 p.u sudden load rejection it acts on gate position to close by 30%, after 33 seconds and when we employee fuzzy PI controller for 0.3 p.u sudden load rejection it acts on gate position to close by 30%, after 10 seconds. This result shows the capability of the fuzzy PI controller to supervise energy dissipated on ballast load.

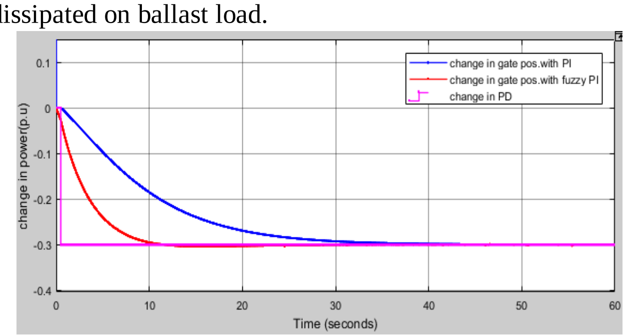

Figure 10: Change in gate position with fuzzy PI and PI controller for sudden 0.3 p.u load rejection

6. CONCLUSION

This paper aims to resolve the limitations of the traditional controller and analyze output such as the raises period, exceeds fired, set-up time, etc. Relative integrated frequency control system for small hydropower plants. It is checked and confirmed with simulation findings in Matlab / Simulink for its efficacy and practicability. The simulation results show a significant reduction in the device change time and implementation, with a significant improvement in control efficiency as soon as the fluid self-tuning algorithm is introduced to traditional PI systems. The proposed fluid-based logic PI controller provides benefits such as greater stability, adaptability of power,

APPENDIX A

TableA 1 : Specifications of SFW3150-8/1730 synchronous generator

Parameter	**Values**
Type	SFW3150-8/1730
Current rating	361 A
Power rating	3150kW/3938kVA
Power factor	0.8
Voltage rating	6.3kV
Rated speed	750 rpm
Rated frequency	50 Hz
Number of poles	3

TableA 2: Specifications of HLJ46-WJ-86 Hydraulic Turbine

Type	43HS2A200-654
Penstock length	95 m
Rated Head	95 m
Initial speed of water(Uo)	43.15 m/s
Acceleration due to gravity	9.8 m/s2
Rated speed	750 rpm
Rated power	3316 kW
Rated Discharge	3.9 m3/s

TableA 3 : Specifications of 43HS2A200-654 PM stepper motor

Parameter	**Values**
Type	43HS2A200-654
phase Current	6.5A
Phase resistance	1 ohm
Phase inductance	21mH
Lead wire	4
weight	15kg
Holding torque	30 Nm
Step angle	1.8^o
Moment of inertia	$0.0015 kg.m^2$
Torque constant	0.109
Viscous Damping constant	0.5Nm/rad/sec
Total number of rotor teeth	50

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