Application of a Fuzzy Logic Controller for Hydropower Generator Speed Regulation

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***Abstract*—The hydroelectric plants flow rate always varies with time due to the speed rotation of turbines which affect the amplitude and frequency of electrical energy generated. Hydro plants are being utilized for the purpose of peaking as well as base load, pumped storage and spinning reserve power operation etc. Especially in a system consisting of large industries, where frequency and voltage fluctuations are required to be kept minimum, their stability determines the quality of power. For efficient use of plant, complex control techniques are employed in the station automation and these involve the turbine governor in control features for which a flexible governor design is essential. MATLAB 2007 Software was used to carry out simulations analysis to develop fuzzy logic controller for hydropower Generator speed regulation with aims of stabilizing output power supply in order to increase the water flows rate through the hydropower penstock. The result of the research shows the hydropower generator speed model which can be used to stabilized power output as a result of increase in turbine speed rotation when fuzzy logic controller is applied. The result showed that hydropower Generation speed regulation with and without fuzzy logic controller were 319.8m/s and 65m/s respectively. The speed increased by 254.8m/s. the result shows that application of fuzzy logic controller gives better result and increase the rotational speed of hydropower.**

***Index Terms*—Turbine Speed; Fuzzy Logic; Hydropower Plant; Electric Power Stability.**

I. INTRODUCTION

Presently, electricity mostly is generated by use of fossil fuels which involves coal, oil, and natural gas. The fossil fuels are always constrained and wear out in the future. Fossil fuels have a continuous environmental degraded condition and also they are nonrenewable energy source. Among electrical generation using the renewable sources, micro hydro generation systems are an attractive alternative for remote locations where a consider economical, robust and require minimal maintenance and are likely to be managed by un- skilled operators, because they are usually installed remote from any maintenance facilities. The squirrel cage induction machine with capacitive self-excitation, known as self-excited induction generators (SEIGs) are considered as an alternative to the well-developed synchronous generators. Induction generators are widely used for micro-hydro powered electric generation, especially in remote and isolated areas, because they do not need an external power supply to produce the excitation magnetic field. Furthermore, induction generators have more advantages such as low cost, reduced maintenance, rugged and simple construction, brushless rotor (squirrel cage), good over-speed capability, and inherent protraction against short circuit [5]. Keeping the voltage and frequency of SEIG constant in spite of the change in load, can be done by regulating the capacitance value or by controlling the speed of the prime movers. One alternative for supplying single phase loads widely used in remote and rural areas is using three-phase induction generator. It is used to supply the single phase loads by using the connection delta. If the induction generator is used to supply single phase with a constant load, the ELC could be applied to maintain constant power output SEIG, for this purpose the dump load must be connected in parallel with the consumer load so that the total power load is generated by the SEIG is constant. The amount of power that flowing into the dump load is controlled by the electronic load controller (ELC) [2],[6].

The duty of governor system is to provide control of the turbine speed and power by regulating the water amount access to turbine. If more power is required, more water is provided to the turbine inlet by the help of wicket gates. Likewise, if less power is required, wicket gates are closed at a certain degree and thus less amount of water is allowed to access the turbine. In this way, frequency is obtained in desired value [1].

Since the power drawn by the user from turbine plant varies at times, it leads to a change in turbine speed, thus in its output voltage and frequency. When the power drawn from the system increases, turbine speed decreases depending on the strain of the alternator, thus voltage and frequency falls under the desired value. In order to bring turbine to its normal speed, more water is required to be taken into system. Similarly, when the power drawn from the system diminishes, turbine speed goes up depending on discharge in the alternator, thus voltage and frequency rises above the desired value. In order to bring them to their normal values, the amount of water access into the system should be lowered. For that, automatic control system is utilized. This system consists of a sensor measuring the turbine speed and a mechanism which regulates the amount of accessed water into the system by opening-closing the wicket gate according to information from sensor, in order to keep the speed constant. Regulators are used to control the turbine speed. Until recent years, all regulators used in hydraulic systems were providing power change by

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regulating the water to the turbine. A regulator's duty is, whether it is mechanical or electrical, to regulate the speed on turbine shaft. If more power is required, more water is provided to the turbine inlet and likewise if less power is needed, turbine inlet is narrowed thus less amount of water can be taken into turbine [4].

The priority policy on energy field in our country is to project construction of large capacity dams and hydroelectric plants [5].

The aim of this study is to present a new model on speed regulators algorithm, which is one of the crucial elements in hydroelectric plants that have an important position among renewable energy resources.

II. Hydroelectric Plants Speed Regulation

Regulation and command are auxiliary actions which are used for automatizing a main operation. Duty of regulation technique is to control and regulate the physical magnitudes such as amount, pressure, number of revolutions or voltage on technical devices or of a material or energy in facilities, according to a plan given and designed in advance. In regulation operation, a previously given value of a magnitude is checked by a relevant unit of the regulator by being measured continuously. If any change occurs in the previously given value - the desired value, this change is automatically adjusted by the regulator [3].

For the regulation of the speed of water turbines which are used in hydroelectric plants, generally the number of revolutions of turbine-generator shaft or an electrical magnitude suitable for this number of revolutions, is considered to be the input magnitude signal of turbine speed regulator. But in some circumstances, frequency or voltage of synchronous generator which the water turbine drives, can be selected as the input magnitude signal of speed regulator. A speed regulator used in hydroelectric plants drives the control mechanism of the turbine via special servo motors, and leads to a change in turbine's wicket gates or in spacing of its deflector by the turbine's nozzle needle, and thus effects a change in power of the turbine. However, during the change in the power, turbine's revolutions per minute remain constant. No matter how much the power of turbine changes, it is the main duty of the speed regulator to keep the revolutions per minute constant in desired levels. The different effects of electrical network on turbine's speed regulation varies according to operating conditions of turbine generator unit, whether in an isolated network or in the national electricity system or with other energy production facilities. Another point which should not be out of consideration for speed regulation is the voltage regulation circuit of the generator driven by the turbine.

Particularly, adjustment issue of voltage regulation circuit of a hydroelectric plant generator operating in an ohmic charged isolated network is very important for speed regulation. Because any change to occur in number of revolutions for the turbine and generator also leads to a temporary change in generator’s voltage, and a change to occur in generator's active charge considerably affects the number of revolutions regulation circuit according to system status [7]. The regulation event performed by a regulator is generally caused by different events recorded below which occur automatically and in order.

III. Materials and Method

This research paper develops a fuzzy logic controller for hydropower generator speed regulation with aims of stabilizing output power supply in order to increase the water flows rate through the hydropower penstock. In this work automatic speed governor is develop to control the turbine output when a sudden load change occurs which helps the water flow control valves to control the rotation of the speed. This system designs a controller which monitors the power output of the hydropower speed. The speed of hydropower penstock is formulated and simulation was performed using MATLAB 2007 software.

A. Fuzzy Logic Controller

A fuzzy logic controller consists of four main components as fuzzification, rule base, inference mechanism and defuzzification. The fuzzification converts its inputs into fuzzy values with membership functions in the form of triangle, trapezoid, bell or other appropriate forms expressed by the fuzzy linguistic variables. The rule base contains the expert’s linguistic descriptions expressed in the form of logical implications such as IF x is positive THEN y is big. The inference mechanism evaluates fuzzy information to activate and apply control rules. The defuzzification that uses methods such as centre of gravity, maximum and weighted mean converts the inference mechanism into the crisp values applied to the actual system.

The first input is the error between reference value that is desired output value and generator output value. The second input is the derivative of the error.

B. Modeling of Hydropower Generator Speed Controller

The controller is corresponding to the error, and also proportional to the integral of the error, and the rate of change (derivative) of the error. This algorithm which is called a proportional – integral derivative controller PID controller. The general form of this controller is shown in (1).

$$M(t) = K_p E(t) + k_I \int_0^t E(t)dt + K_d \frac{dE}{dt} \quad (1)$$

Where:

K_p is proportional constant
K_i is integral constant
K_d is Derivative constant
E(t) is Error as function of time
M(t) is controller output derivative

Equation (1) gives proportional action. The second equation in the controller gives output which is constantly equal to the integral of the error. Which means, when the errors differ from zero, the controller output will continue to change. However, the physical limit of the algorithm potential should be noted when the controller output cannot change. The proportional constant is made unreasonable large without integral action; the process output never reaches the set point unless the condition changes. The last equation in the controller provides a component of the output when the rate of change of error is non-zero. The derivative mode hence previses the error at a faster response time when the process measurements are corrupted. The digital or discrete equivalent of (1) is given below:

$$M_i = K_p\left[E_i + TK_i\sum_{j=1}^{i} E_i + \frac{K_D}{T}\left(E_i - E_{i-1}\right)\right] \tag{2}$$

Where:

T is sampling interval
E_i is Error at i[th] sampling interval
E_{i-1} is Error at previous sampling interval

$$M_i = K_p\left(1+\frac{K_D}{T}\right)E_i - \left(\frac{K_pK_D}{T}\right)E_{i-1} + \left(TK_pK_i\right)S_i \tag{3}$$

and S_i is the sum of error

IV. Result and Discussion

The proposed fuzzy logic controller for hydropower speed regulator is formulated in Fig. 1 to Fig. 5. Fig. 1 Shows designed fuzzy rule that will generate constant power supply when the turbine rotates fast. This shows fuzzy rule that sticks strictly to the fast rotation of the turbine in order to enhanced stable power supply.

Fig. 2 Shows designed model for hydropower generator speed control using fuzzy software tool. The result obtained is an increased speed of the penstock rotation which enhanced stable power supply when fuzzy logic controller is used.

Fig. 3 shows hydropower turbine rotation speed without fuzzy vs time. The highest speed of hydropower turbine rotation verse time coordinate occurred at (65m/s,4s) while the least occurred at (50m/s,1s) respectively. This shows the positive difference between the speed of hydropower penstock(m/s) and time(s).

Fig. 4 Shows hydropower turbine rotation speed with fuzzy vs time. The result reveals the highest speed of hydropower turbine with fuzzy verse time occurred at (319.8m/s,4m) while the least occurred at (266.5m/s,1s). Therefore, the greater the speed of hydropower penstock, the greater the time required for the rotational speed of hydropower.

Fig. 5 shows comparing result of hydropower turbine rotation speed without and with fuzzy verse time. The result obtained shows that fuzzy gives higher speed rotation of the turbine than without fuzzy. The result also shows that fuzzy enhances stable power supply while without fuzzy causes intermittent power supply. This shows the stabilized power output as a result of increase in turbine speed rotation when fuzzy logic controller is applied. The result shows that application of fuzzy logic controller gives better result and increase the rotational speed of hydropower.

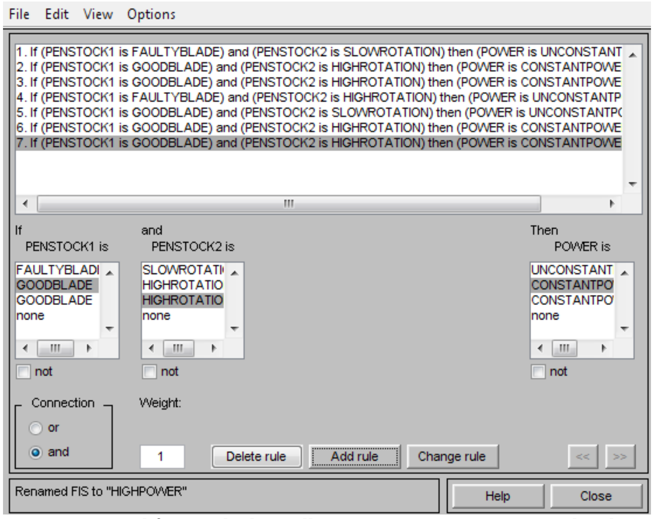

Fig.1. Designed fuzzy rule that will generate constant power supply when the turbine rotates fast.

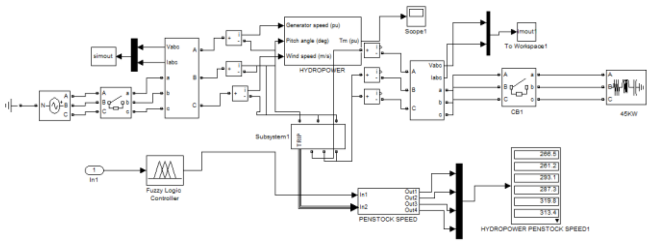

Fig. 2. Designed model for Hydropower generator speed control using fuzzy software tool.

TABLE I: Hydropower Turbine Rotation Speed Without Fuzzy Vs Time

HYDROPOWER TURBINE ROTATION SPEED WITHOUT FUZZY(m/s)	TIME(S)
50	1
55	2
60	3
65	4

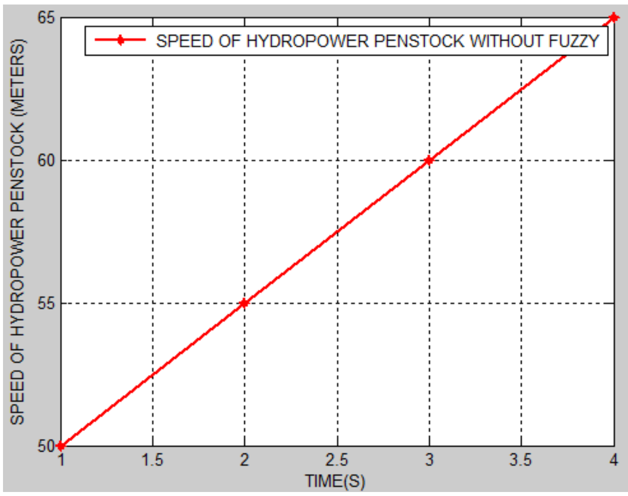

Fig. 3. Hydropower turbine rotation speed without fuzzy vs time

TABLE II: Hydropower Turbine Rotation Speed with Fuzzy vs Time

HYDROPOWER TURBINE ROTATION SPEED WITH FUZZY IN RPM(m/s)	TIME(S)
266.5	1
287.3	2
313.4	3
319.8	4

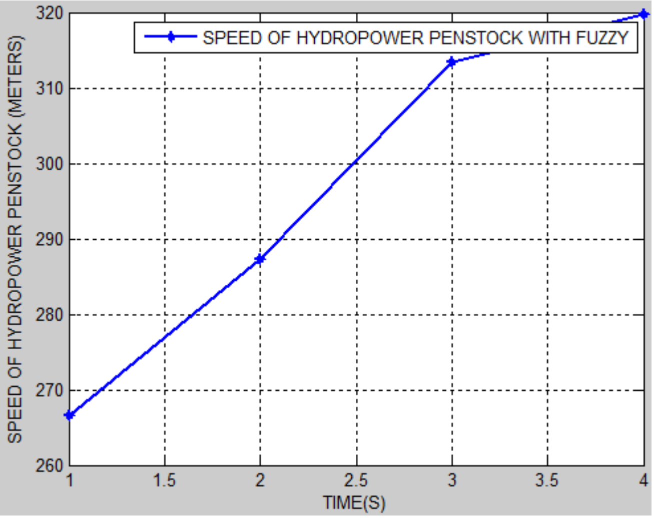

Fig.4. Hydropower turbine rotation speed with fuzzy vs time

TABLE III: COMPARING HYDROPOWER TURBINE ROTATION SPEED WITHOUT AND WITH FUZZY VS TIME

HYDROPOWER TURBINE ROTATION SPEED WITHOUT FUZZY	HYDROPOWER TURBINE ROTATION SPEED WITH FUZZY	TIME(S)
50	266.5	1
55	287.3	2
60	313.4	3
65	319.8	4

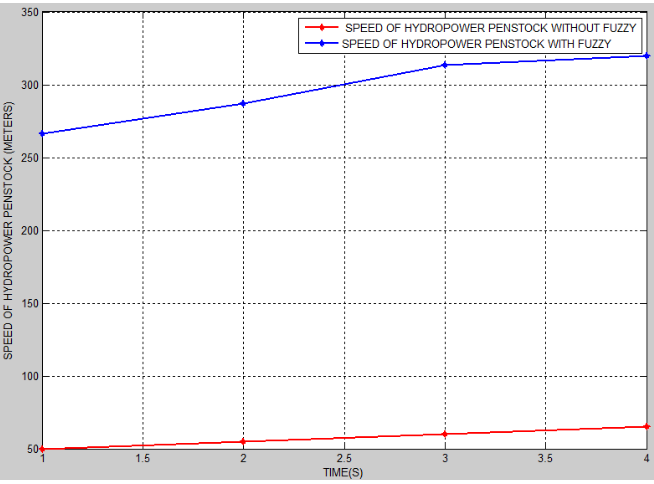

Fig. 5. Comparing result of hydropower turbine rotation speed without and with fuzzy vs time

V. CONCLUSION

A hydropower automatic speed governor is used to control the turbine output when a sudden load change occurs. This is to avoid the rotation speed of the turbine and generator to charge sharply due to load reduction or increase. Adjusting the water flow into the mini hydro turbine makes the turbine output meet the change of external load. Due to the swiftness or fastness of the load changes in the generator, artificial control method does not meet this requirement. This is why most hydropower stations are equipped with an automatic mechanical "governor" to regulate water flow through the penstock to the turbine blades. The simulation was performed using MATLAB 2007 Software in order to develop fuzzy logic controller for hydropower Generator speed regulation with aims of stabilizing output power supply hydropower penstock. The result of the research shows the hydropower generator speed model which can be used to stabilized power output as a result of increase in turbine speed rotation when fuzzy logic controller is applied. The result showed that hydropower Generation speed regulation with and without fuzzy logic controller were 319.8m/s and 65m/s respectively. The speed increased by 254.8m/s. the result shows that application of fuzzy logic controller gives better result and increase the rotational speed of hydropower.

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