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APPLICATION OF CLASSICAL CONVENTIONAL PI AND PID CONTROLLERS AND SMART FUZZY LOGIC CONTROLLER FOR LOAD FREQUENCY AND TIE-LINE POWER CONTROL IN MULTIGENERATION POWER SYSTEM

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Keywords:

Proportional Integral Derivative (PID); Fuzzy Logic Controller (FLC); Solar Thermal (ST); Membership Function (MF); Fuzzy Inference System (FIS).

ABSTRACT

With increasing demand for load, the generation of electrical power should also be increased and the interconnection of the network must be carried out in order to ensure the quality of the power generated and to feed the load. Load Frequency control (LFC) of three unrivalled interconnected thermal, hydro and solar thermal power plants has been designed with PI, PID and Fuzzy Logic controllers. AGC is used to stabilize disturbances in the power system with the use of different controllers. Classical conventional and Smart controllers are used as additional controllers independently to improve the performance of the Load Frequency Control (LFC) system by suppressing the oscillation of three uneven area systems, including Solar Thermal, Hydro and Nuclear Thermal, Systems in Area 1, 2 and 3 respectively.

The simulation result shows that Fuzzy controller gives excellent dynamic time-setting responses and effectively mitigates oscillations against both step load and random disturbances, PID controllers are simple and cost-effective. The system using three generation sources is used and simulated in MATLAB2015

1. INTRODUCTION

As “the word population increases day by day, there is also a growing need for power, which must be met by the power generation sector. Thermal power generation increases pollution and the reduction of fossil fuels. Increased renewable and nuclear power generation is needed to address the thermal problem. As a result, the size and complexity of the power network is increasing and must be managed through the interconnection process and better control techniques. AGC is an important function of the modern power system. As the load changes, so does the generated power, and therefore, there is a deviation in power and frequency in the system. AGC helps the system to make such deviations to zero or to reduce them to a specified value and to maintain the interchange power between the systems” (Singh & Sinha, 2016).

The "control area has thermal, hydro, nuclear and renewable systems. Many researchers have studied the AGC problem of hydro, thermal and solar thermal energy using PID controllers, Fuzzy controllers and other controllers. All of these controllers have their own advantages and disadvantages in their own operation. In this paper, a three-generation system consisting of solar thermal, hydro and nuclear power is used for simulation and AGC operation.

In the light of the foregoing, the main objective of this paper is
(a) Considering the combination of current generation systems, i.e. Solar Thermal, Hydro and Nuclear Power.
(b) Consideration and comparison of the results of different types of controllers.
(c) Examine the effect of droop value variation and load demand value" (Singh & Sinha, 2016).

Due "to various reasons, the demand for power is increasing. The generation should also increase according to demand. However, with the power generation stations available, it is very difficult to balance the demand for loads. As a result, there is a discrepancy between power generation and demand. This mismatch creates deviations in the frequency of the system (Δf) and the power of the tie line (ΔPtie). Schedule frequency and tie line power must be maintained within appropriate limits; otherwise the system may enter unstable conditions. Automatic Generation Control (AGC) or Load Frequency Control (LFC) maintains frequency and tie line power within a specific range by making zone control error (ACE) zero. Due to the pollution and depletion of fossil fuels (for thermal generation), researchers are looking forward to other sources of energy. Solar energy is abundant in nature free of charge, which is useful for the generation of clean energy. Solar radiation is intermittent in nature, however. Accordingly, this paper presented the three-area solar thermal (ST) system in AGC"(Raju et al. 2017)
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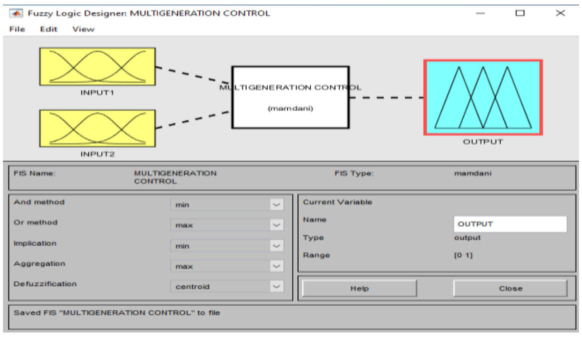
The "main task of the power generation system is to maintain the desired operating frequency, voltage profile and load flow conditions. A balance between power demand and power generation is needed to provide reliable, high-quality electrical power to users. Control of the actual and reactive power generated is performed by changing the parameters of the controllable source in the system. Whenever the load changes, the operating point of the power system can change a great deal during the duty cycle. Changes in power demand affect both the frequency of the power system and the tie-line power flow between the control areas. The prime purpose of the Frequency Regulation is to keep the system's frequency at the scheduled value by regulating generator units with an area control error (ACE) and making an area control error that tends to be zero under continuous active power adjustment" (Kumari & Jha, 2013).

2. CONTROLLER DESIGN

There "are two control methodologies that include fuzzy control and conventional control. The three-zone system with three power generation sources is controlled by controllers such as PI, PID and Fuzzy. In modern control theory, the use of fuzzy is increasing day by day due to its ease of use and improved output" (Singh & Sinha, 2016).

2.1 Controller with Fuzzy Logic

"A fuzzy control mechanism is a fuzzy logic-based control system, a computational structure that analyses analogue input values in comparison to classical or digital logic, working on binary values of either 1 or 0 (true or false) instead of logical variables with constant values between 0 and 1. Method used to define the characteristics of a system using a fuzzy inference rules is fuzzy modelling" (Kumar, 1998). Figure 1 below is the Fuzzy Logic designer



FIS Name: MULTIGENERATION CONTROL
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: OUTPUT
Type: output
Range: [0 1]
Saved FIS "MULTIGENERATION CONTROL" to file

Figure 1. Fuzzy Logic Designer

The "strategy has a distinctive feature in that it can convey non-linear processes that are linguistically complex. However, it is very difficult to define the rules and to adjust the functions of the fuzzy rationale of the membership functions. Customarily, fuzzy controllers are designed using fuzzy rules. These fuzzy rules are learned either from domain experts or by studying the individuals who are monitoring them at the moment. Membership functions for fuzzy sets are derived from the data available from domain experts and from the control actions observed. For the construction of such rules and membership functions, tuning is necessary. In other words, the output of the controller must be evaluated and the membership functions and rules modified on the basis of performance. This phase may take some time"(Kumar, 1998)."The reason for the use of a fuzzy logic controller is used to reduce the maximum overshoot and set time that is not easily attainable by the use of PI and PID controllers.
The simple configuration of the Fuzzy Logic Controller (FLC) as in Figure 2 consists of three phases.
(i) Fuzzification,
(ii) Knowledge base and Decision-making logic
(iii) Defuzzification" (Kumar, 1998).

The "Fuzzifier converts the input of real life data into appropriate linguistic values. During fuzzification, the Fuzzy Logic Controller's integral gain also recognized as the fuzzy parameter is obtained, and it is evaluated in the interface graphs identified as Membership Functions. The input values are always crisp numeric values. The input is first taken, and the sum of their membership Functions is calculated to relate with each suitable fuzzy set. The output of the fuzzification process shall be the degree of membership corresponding to its numerical value is described by the language set" (Bharadwaj, 2014).

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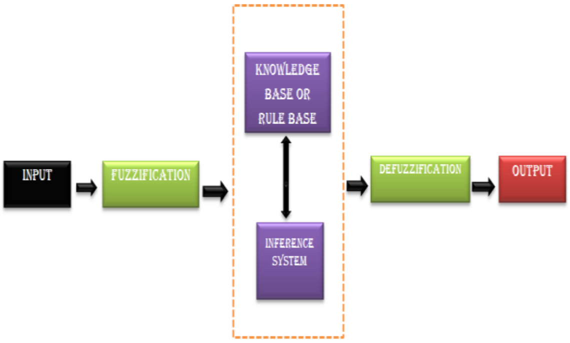
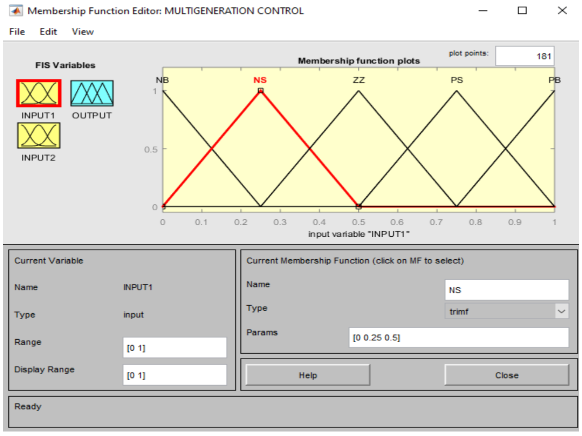


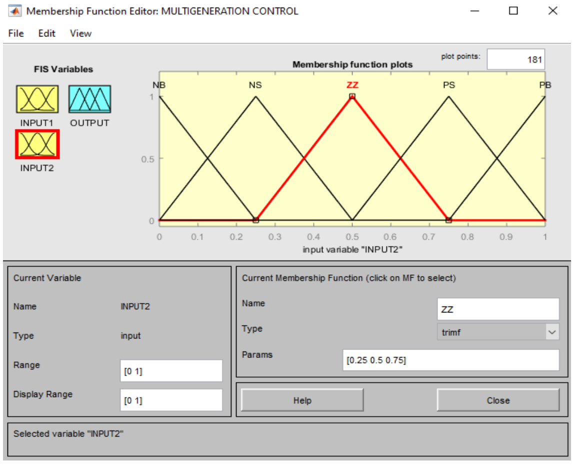
Figure 2. Structure of Fuzzy Logic Controller

In "this article, the controller has been established with two inputs, area control error and area control error. The result is a shift in the setting of the speed change. Then input data on the fuzzy logic controller are first transformed into fuzzy representatives by first transformed into fuzzy representatives by 5 member functions in the fuzzifier, as shown in Figure 3 and Figure 4, Negative Broad (NB), Slight negative (NS), Zero (ZZ), Slight positive (PS) and Positive Broad (PB). The input parameters differ between 0 and 1. There is triangular control parameters used since member levels from a line are easily intercepted. The performance variable membership features as shown in Figure 5 are: Slight (S), Middle (M), Broad (B) and Veritably Broad (VB) Veritably Veritably Broad (VVB). The performance variable was between 0 and 1" (Bharadwaj, 2014).



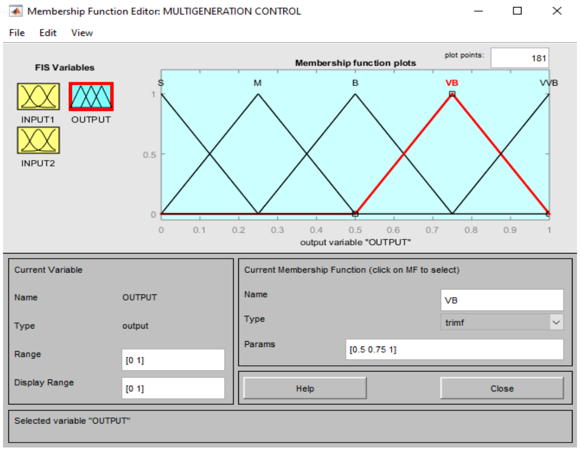
Current Variable
Name INPUT1
Type input
Range [0 1]
Display Range [0 1]
Current Membership Function (click on MF to select)
Name NS
Type trimf
Params [0 0.25 0.5]
Ready

Figure 3. MF for INPUT ONE parameter



Current Variable
Name INPUT2
Type input
Range [0 1]
Display Range [0 1]
Current Membership Function (click on MF to select)
Name zz
Type trimf
Params [0.25 0.5 0.75]
Selected variable "INPUT2"

Figure 4. Membership Function for INPUT2 variable



Current Variable
Name OUTPUT
Type output
Range [0 1]
Display Range [0 1]
Current Membership Function (click on MF to select)
Name VB
Type trimf
Params [0.5 0.75 1]
Selected variable "OUTPUT"

Figure 5. Membership Function for OUTPUT variable

The "second element of the Fuzzy Logic Controller is the rule base (Table 1) and the inference engine. The basic rule gives logic to taking decisions. We obtain target value for objective function for various given set of input objective function. The FLC is given up to 25 rules with five membership functions. The following table 1 shows the rules. For input as well as display, triangular membership features are used. The defuzzer is the third variable. The defuzzifier's final performance ought be in a narrow sum" (Bharadwaj, 2014).

Table 1. Table for Fuzzy Rule Base

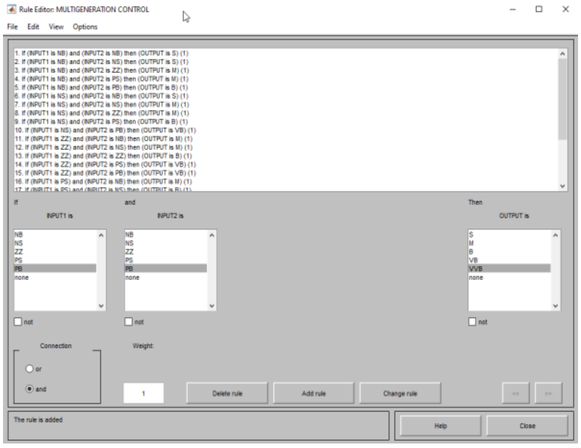
TWO INPUTS	Negative Broad	Slight Negative	Zero	Slight Positive	Positive Broad
Negative Broad	Slight	Slight	Middle	Middle	Broad
Slight Negative	Slight	Middle	Middle	Broad	Veritably Broad
Zero	Middle	Middle	Broad	Veritably Broad	Veritably Broad
Slight Positive	Middle	Broad	Veritably Broad	Veritably Broad	Veritably Veritably Broad
Positive Broad	Broad	Veritably Broad	Veritably Broad	Veritably Veritably Broad	Veritably Veritably Broad

Building of the Fuzzy Base Rules and Rule Viewer

The "rules are indeed the basic building blocks of the fuzzy logic controller, and twenty five rules are used for this construction. Figures 6 and 7 show the FIS editor and the rule viewer, respectively, which are actually used to represent the rules and their values. The rules are contained in the IF-THEN statements" (Sajad & Sharma, 2017).

Surface Viewer

This "symbolizes a three-dimensional graph between inputs and outputs; this has been shown to be helpful in designing a controller and shows how output control is changed by varying inputs. Figure 8 shows the surface viewer between the two inputs that is error and the output control error. This figure shows how the control signal is applied to the input error in sequence" (Sajad & Sharma, 2017).



1. If (INPUT1 is NB) and (INPUT2 is NB) then (OUTPUT is S) (1)
2. If (INPUT1 is NB) and (INPUT2 is NS) then (OUTPUT is S) (1)
3. If (INPUT1 is NB) and (INPUT2 is ZZ) then (OUTPUT is M) (1)
4. If (INPUT1 is NB) and (INPUT2 is PS) then (OUTPUT is M) (1)
5. If (INPUT1 is NB) and (INPUT2 is PB) then (OUTPUT is B) (1)
6. If (INPUT1 is NS) and (INPUT2 is NB) then (OUTPUT is S) (1)
7. If (INPUT1 is NS) and (INPUT2 is NS) then (OUTPUT is M) (1)
8. If (INPUT1 is NS) and (INPUT2 is ZZ) then (OUTPUT is M) (1)
9. If (INPUT1 is NS) and (INPUT2 is PS) then (OUTPUT is B) (1)
10. If (INPUT1 is NS) and (INPUT2 is PB) then (OUTPUT is VB) (1)
11. If (INPUT1 is ZZ) and (INPUT2 is NB) then (OUTPUT is M) (1)
12. If (INPUT1 is ZZ) and (INPUT2 is NS) then (OUTPUT is M) (1)
13. If (INPUT1 is ZZ) and (INPUT2 is ZZ) then (OUTPUT is B) (1)
14. If (INPUT1 is ZZ) and (INPUT2 is PS) then (OUTPUT is VB) (1)
15. If (INPUT1 is ZZ) and (INPUT2 is PB) then (OUTPUT is VB) (1)
16. If (INPUT1 is PS) and (INPUT2 is NB) then (OUTPUT is M) (1)

If INPUT1 is: PB
and INPUT2 is: PB
Then OUTPUT is: VVB

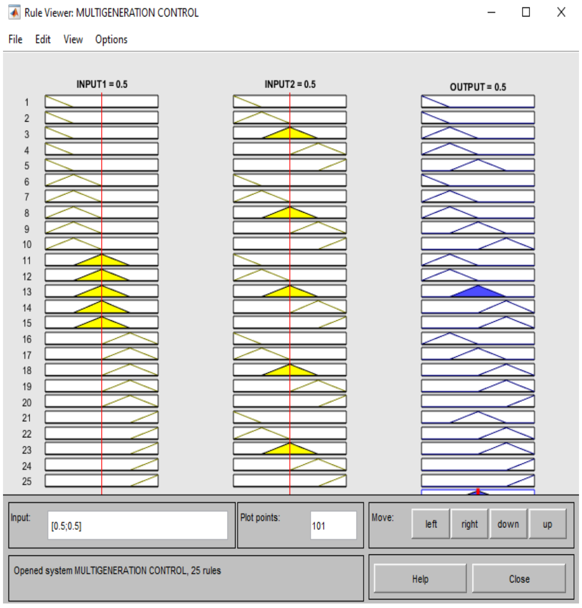
☐ not ☐ not ☐ not

Connection: ○ or ● and

Weight: 1

The rule is added

Figure 6. Rule FIS editor with IF-THEN statements

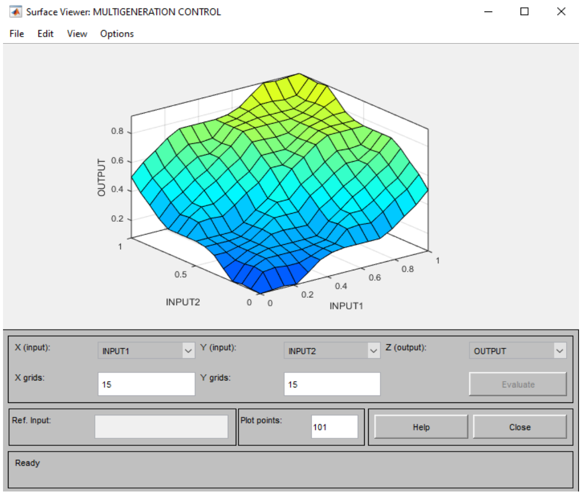


Input: [0.5;0.5]

Plot points: 101

Opened system MULTIGENERATION CONTROL, 25 rules

Figure 7. Rule Viewer



X (input): INPUT1

Y (input): INPUT2

Z (output): OUTPUT

X grids: 15

Y grids: 15

Ref. Input:

Plot points: 101

Ready

Figure 8. Surface Viewer

2.2 Classical Conventional Method (PID)

"Thermal and hydro power plant governors have an important role to play in bringing back the generation of load demand. This is called the primary control action. In addition to governing actions, to effectively suppress oscillations in frequency and tie-line powers, various secondary controllers are used which are referred to as secondary control actions. The PID controller as shown in Figure 9, is simple in structure, easy to handle and Tune" (Raju et al. 2017).

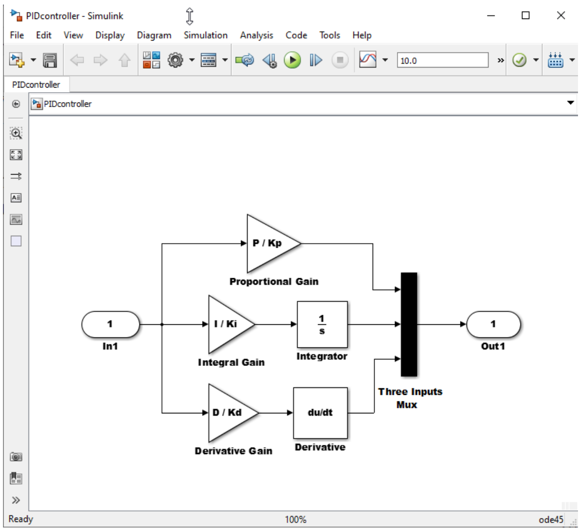


Figure 9. Simulink Model of PID Controller

At "the same time, the PI controller increases the steady state error while allowing a transient response with little or no overshoot. As long as the error persists, the integral output will increase, causing the velocity changer to reach a constant value only when the frequency error is reduced to zero. So it brings oscillations to the system. In order to reduce the error amplitude for each oscillation, the PID controller increases the transient response and the output is finally set to the final desired value. More stability margins are ensured with PID controllers. Restrictions on traditional Proportional Integral and Proportional Integral Derivative controllers are sluggish and incompetence in the handling of non-linear devices" (Kumar, 1998).

"Characteristics of P, I, and D Controllers

The proportional controller (Kp)-will reduce the increase time and reduce but never eliminate the steady state error.

Integral Control (Ki)-will have the effect of eliminating a steady state error for a constant or step input, but may slow down the transient response.

A derivative control (Kd) -The effect will be to increase the stability of the system, reduce the overshoot and improve the transient response" (Gaeid, 2018).

3. HIGH CONTROL SYSTEM SPECIFICATIONS

(1) "Exactitude: Exactitude must be very high as errors need to be corrected. The accuracy can be improved by using the feedback function.
(2) Sensitivity: environmental conditions, multivariate changes, internal and external disturbances, a good control system detects the necessary output adjustments.
(3) Noise: the noise is an undesirable signal and such noise types should be sensitive to a good control system.
(4) Stability: limited input and minimal output are available for stable systems. Adverse changes in stability should be addressed through a good control system.
(5) Bandwidth. In order to achieve a reasonable frequency response, a device bandwidth should be high.
6) Speed: the high speed of a good control system should be as fast as possible and the system should be as high as possible.
7) Oscillation: The output disturbance of the effective control system should be constant or have minimal oscillations, at least" (Gaeid, 2018).

A "strong and effective control system will have the effect of overvoltage and frequency deviations, and the failure of electrical circuits in a switchgear power system may result in abnormal over voltages with high inductances and capacitances. Over voltages can be as high as six times the voltage of the standard power frequency. Switching effect with a high voltage rate during circuit break operation may cause frequent re-striking of the arc between the circuit breaker contacts, resulting in a current leak that can energize the power transformer. Over voltages due to Switching High Natural Frequencies of the device and may be caused by sudden shut-off and unloaded shut-off of the transformer" (Budu & Bhagwan , 2020).

4. MATLAB MODEL SYSTEM CONSIDERED

The system considered is a three unequal area thermal and hydel system having a solar thermal power plant. Area 1 consists of a solar thermal power plant and a conventional thermal generation plant. Area 2 and Area 3 are Hydro and Nuclear Power Plants. And each area is connected through a tie-line with built-in secondary controllers such as a classical PID controller in area 1, a classical PI controller, and a smart area 3 fuzzy logic controller. Each of the three areas has its own turbines, turbines and generator-load models with thermal generators equipped with reheat turbines. The system transfer function model SIMULINK is shown below in figure 9.

5. SOURCES OF POWER GENERATION

5.1 Nuclear Power Generation

The "solution to the generation of bulk power is thought to be nuclear power plants. Today's nuclear power plants are working on the 235U principle of nuclear fission. In order to obtain enriched 235U, the concentration of 235U can be increased to 90% by the gas diffusion process. A lot of thermal energy and additional neutrons are generated when 235U is bombed by neutrons. These new neutrons are also bombarding 235U, generating more heat and more neutrons. Therefore, a chain reaction is set up. However, inside a closed chamber called a nuclear reactor, this reaction is allowed to take place in a controlled manner. Moderator and control rods shall be used to ensure a sustainable chain response. Moderators such as heavy water (deuterium) or very pure carbon 12C are used to reduce the speed of neutrons. Control rods made of cadmium or boron steel are implanted inside the reactor to control the number of neutrons. Neutrons may be absorbed by the control rods. Control rods are lowered much further down, and vice versa, if we want to reduce the number of neutrons. With the help of a coolant such as sodium liquid or some gaseous fluid, the heat generated inside the reactor is removed from the chamber. In order to convert it to steam, the coolant releases the heat to water through the heat exchanger. The steam then drives the turbo and, using the water supply pump, the exhaust steam from the turbine is cooled and recycled directly to the heat exchanger" (Nptel, 2018).

5.2 Hydel Plant

"In a hydel power station, the water head is used to drive a water turbine coupled to a generator. In the hilly region, the water head may naturally be available in the form of a water reservoir (lakes etc.) on the hilltops. The potential energy of water can be used to drive the turbo generator installed at the base of the hills through a pipe called a pen stock. The water head can also be artificially created by constructing dams on an appropriate river. The sites to be selected for such plants depend on the natural availability of water reservoirs on the hills or on the availability of suitable rivers for the construction of dams. Water turbines generally operate at low rpm, so the number of alternator poles is high. For example, the 20-pole and 10-pole turbine alternators are only 300 rpm and 600 rpm respectively" (Nptel, 2018).

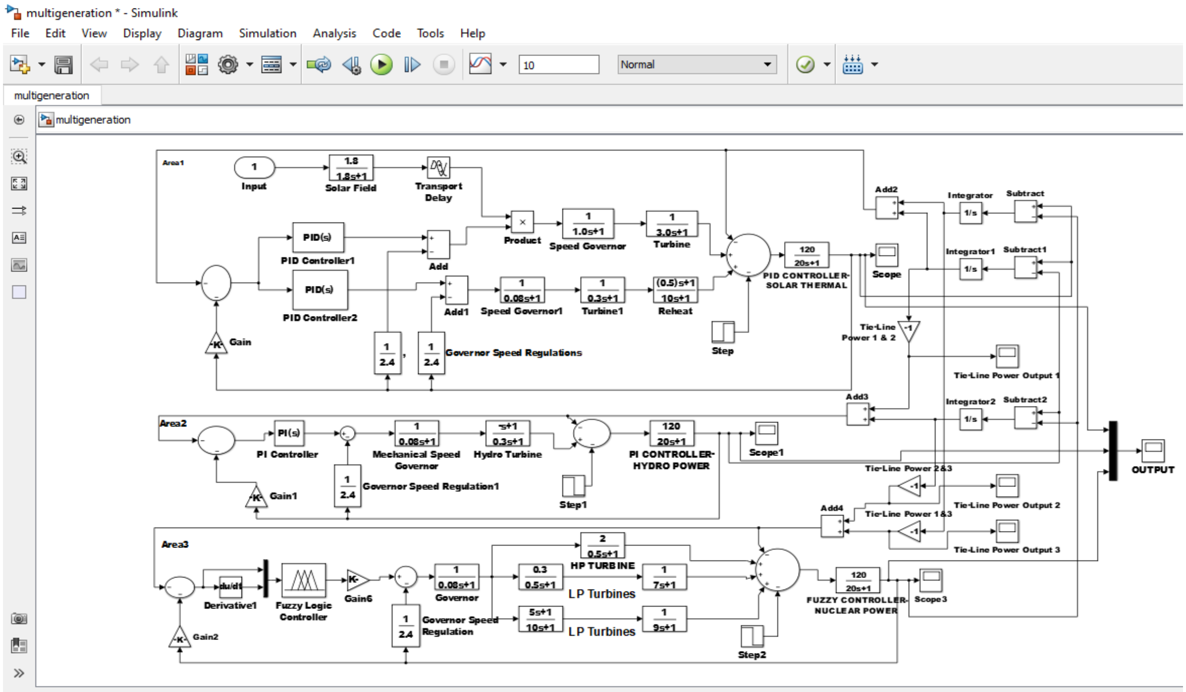


Figure 9. Transfer function model in MATLAB for three area interconnected solar thermal, hydro and nuclear power plants

5.3 Generation of Solar Thermal Power

"Electricity generation is performed in 2 phases in a solar energy plant. Next, the Sun captures and uses thermal energy to warm-up the working fluid. fluid, which is then used in the second stage of energy transformation to generate electricity. The actual operating temperature reached by the working fluid will depend on the rate at which the thermal energy is extracted by the working fluid (flow rate) and delivered to the generating system. Thermal energy from the Sun (Sun radiation) is intercepted by a concentrator which concentrates the energy on a heat absorber containing the working fluid, usually synthetic oil, which is heated by solar radiation at a high temperature typically of 400 degree Celsius. The machine is able to use the differential process via a steam generator to transmit the warmed oil, to increase the steam that is used to drive a heat engine or conventional turbine and generator in a separate circuit. Solar plants are therefore complemented by gas-fired boilers, which maintain the temperature overnight" (Solar Power, 2005).

6. OUTCOME AND ANALYSIS

The system is equipped with classic and smart controllers in all areas, i.e. PID, PI and Fuzzy Logic controllers with a load disturbance of 1% of the step load. The optimum values for PI and PID are shown in Table 2. With the optimum values, the corresponding dynamic reactions of the frequency and tie-line power are shown in Figures 10 and 11. The peak overshoot, undershoot and settlement time of the various responses in Figure 10 is shown in Table 3. From Figure 10 and Table 3, it can be seen that the Fuzzy logic controller achieves faster settling time than the PI and PID controllers, followed by the PID controller.

Frequency Deviations

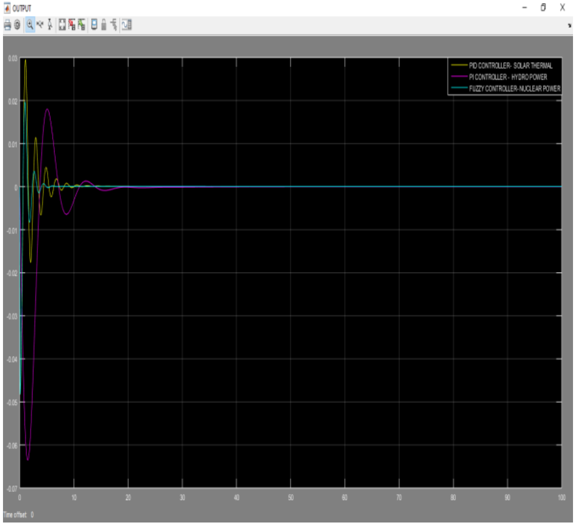


Figure 10. Comparison of dynamic frequency responses against time of three area system

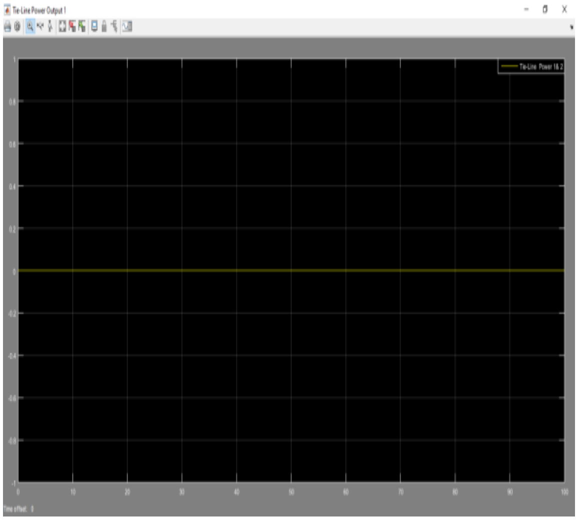


Fig.11(a) ΔPtie between Area 1&2

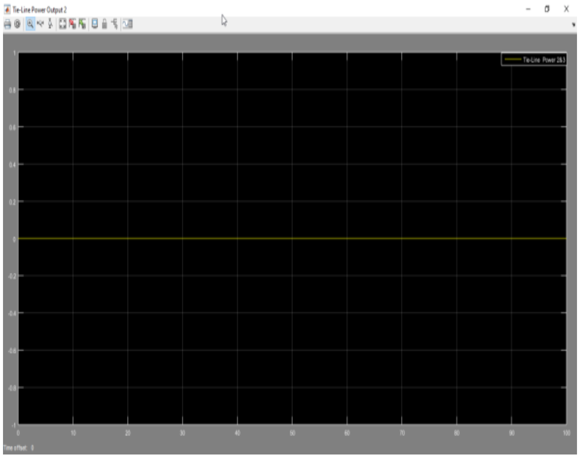


Fig.11(b) ΔPtie between area 2&3

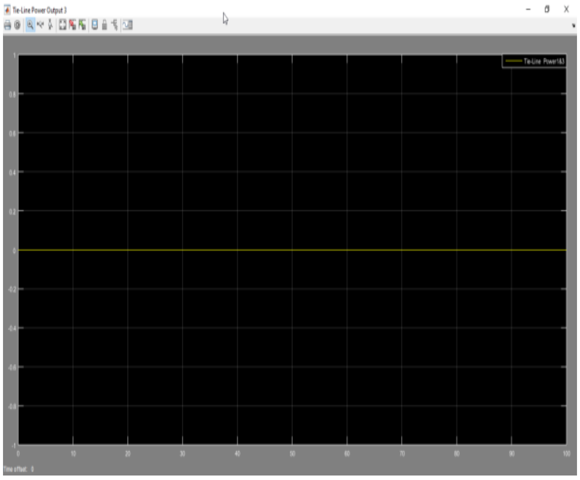


Fig.11(c) ΔPtie between area 1&3

Table 2. Optimum Values of PI and PID Controllers

	PI Controller	PID Controllers 1&2
P-Proportional	0.9	0.9
I- Integral	0.01	0.23
D-Derivative		1.99

The figures 12(a), 12(b) and 12(c) below shows the various individual dynamic responses of frequency deviations of three area multigeneration power systems.

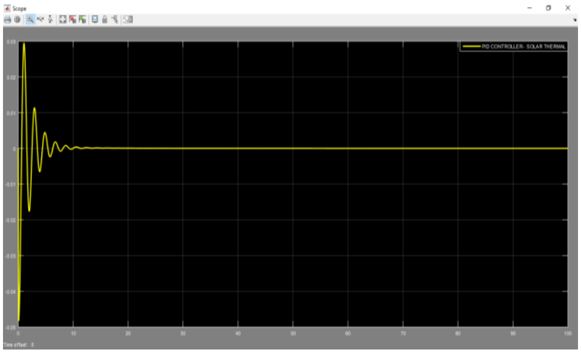


Fig.12(a) ΔF -- area 1

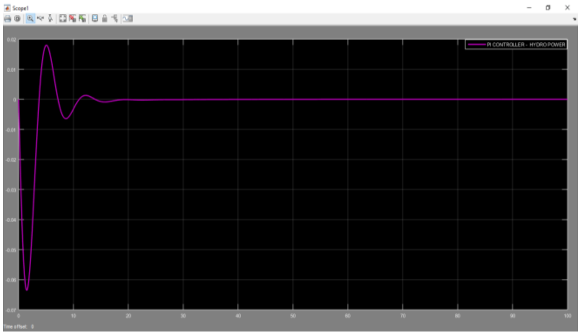


Fig.12(b) ΔF--area 2

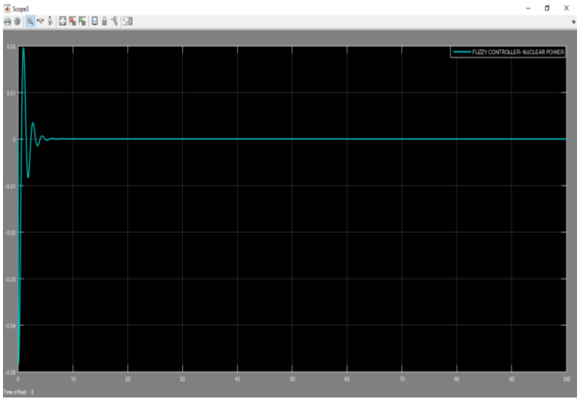


Fig.12(c) ΔF--Area 3

Table 3 . Values of Undershoot, Peak Overshoot and Settling Time of Figure 12

	Under-shoot	Peak Overshoot	Settling Time
PI Controller [Fig.12(a)]	-00635	0.018	25
PID Controller [Fig.12(b)]	-0.0483	0.0295	17
Fuzzy Controller [Fig.12(c)]	-0.0483	0.0197	7

7. CONCLUSION

The whole work finally provides a comparative analysis between the classical conventional PI and PID controllers and smart fuzzy logic controller for the three-zone solar thermal, hydraulic and nuclear thermal power systems. It strives at seeing how the load frequency system operates and enhances efficiency with both the three (3) control styles. The Answers of the different frequency deviations as well as from the comparison table for the three area power systems, it is clear in each case that the fuzzy controller system gives excellent dynamic output minimizes amplitude variance perturbation and energy distribution throughout the tie line. Frequency changes occur in all three areas due to load perturbations from one area at a time, but rather an artificial intelligence methodology using a fuzzy logic controller is more efficient and faster than classical conventional PI and PID controllers.

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APPENDIX

i = Subscript referred to area i (1,2,3),
Ks = gain of solar field (1.8),
Ts = time constant of solar field (= 1.8s),
Tgs = steam governor time constant of ST plant (= 1s),
Tts = steam turbine time constant of ST plant (= 3s),
Bi = Frequency Bias constant of ith area = 0.425 pu MW/Hz,
Ri = Governor Speed regulation values of ith area = 2.4 HZ/puMW
Tgi= Governor time constant for thermal power plant of ith area =0.08s,
Tt1 = Steam turbine time constant for thermal power plant of area 1=0.3s,
Tt2 = Hydro turbine time constant for Hydro power plant of area 2=0.3s,
Kr1= Steam turbine reheat coefficient in area one = 0.5,
Tr1= Time constant of Steam turbine reheat in area one =10sec,
Kpi = system of power gain constant in ith area =120Hz/puMW,
Tpi = system of power time constant in ith area =20s,
Kh1= Coefficient of High Pressure HP re-heat nuclear steam turbine = 2,
Kr1 = Coefficient of thermal re-heat steam turbine=0.3,
Trh1,2,3 = Low Pressure LP nuclear turbine time constant=7s, 5s, 10s,
T1 = Nuclear turbine time constant = 0.5s,
ΔF = Frequency deviation,
ΔPtie = Tie-Line Power deviation