Performance Assessment of Fuzzy Logic Controller for Load Frequency Control in Multi Source Multi Area System

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Abstract- This article confers the performance of Fuzzy logic controller for Load Frequency Control (LFC) in multi-source multi area power system. The distinct energy sources include hydro, thermal, wind and diesel power plants. The suggested multi area systems for various operating load conditions are studied to realize the deviations found in system frequency and the interchange power through tie-line. Primarily, two source single area system for a step load variation is considered and the results for PI and fuzzy logic controller are compared. The proposed system model is extended to two source two area and three source two area power system model. To observe the superiority of the proposed controller the system models are run with a 24 hour MW load variation and the results found are compared with that of PI controller. From the simulation results it is remarked that the proposed fuzzy logic controller contributes superior dynamic response over conventional PI controller.

Keywords: Multi-source multi area system; Two source two area system, Load Frequency Control, PI controller, Fuzzy Logic Controller.

Nomenclature
ACE – Area control error
LFC – Load Frequency Control
MSMA – Multi source multi area system
TSTA – Two source two area system
PI – Proportional integral controller
FLC – Fuzzy Logic Controller

1. Introduction

The comfort of human being lies on consumption of electrical power which increases the load demand. The power system operations are vastly influenced by load change in the existing system. Progressively, due to dynamic load change in the interconnected system, the control area frequency and power flow through tie line, deviate from their nominal values. This ultimately makes the power system vulnerable [1]. Load frequency control performs an indispensable place in the power system operation to get over the complexities found due to load variation [2]. The load frequency control includes a speed governing system as primary controller to match the power generation with the load demand. The estimable tuning of the system frequency is done with a secondary control loop [3-6].

A lot of analysis have been carried out for several possible combinations of single source multi area system. Many researchers have studied the LFC problem comparing the conventional control with different control approaches in the system [7,8]. Rout et al. [9] have considered a two area non-reheat thermal system and Differential Evolution (DE) optimization technique is used to optimize the parameter gain. Single source multi area power systems are taken in to account and a newly designed Integral Double Derivative (IDD) controller is implemented by Saikia and Nanda in their work [10]. A lot of analysis have been analyzed for LFC in multi area system, assuming single source in each control area. But in actual practice, both the hydro and thermal power generating sources take part in power generation for individual control area. These control areas when connected through tie-lines, configure a multi-source multi area (MSMA) system. Parmar et.al [11] suggested an optimal output feedback controller to investigate LFC of a realistic multi source power system and the result was compared with full state feedback controller. Ali et.al[12] proposed and confirmed the superiority of a model predictive control(MPC) technique for load frequency control of a power system containing thermal ,uncontrolled variable solar and variable wind power. Mohanty et. al,[13] observed the Differential Evolution (DE) optimization technique to optimize gain parameters of PI controller for LFC in a multi-source power system containing hydro, thermal and gas power plants. The results derived, were compared with the results obtained for similar system, with output feedback controller. Chandrakala et. al,[14] made a comparison of the results found with ZN tuned PI controller and variable fuzzy gain scheduling in a multi-source system. The authors have considered the speed governor together with the secondary controller to reduce the frequency deviations and interchange power through tie-lines. With implementation of FACT devices in MSMA system, the offsets found in the responses are improved [15].

The differences attained in frequency and tie-line power due to dynamic load variation can be controlled through different intelligent controllers [16]. Along with this, various optimization techniques can be applied to optimize control parameters[17,18]. Ramakrishna et. al[19] have executed the Genetic Algorithm for optimizing the gain parameters of a PI controller in a multi-source two area system with different loading conditions. Sahu et. al,[20] employed teaching learning Based optimization algorithm to optimize the PIDD controller parameters and the superiority of the method is compared with others approaches. With addition to different optimization approaches of PID controller, the load frequency control problem is also examined with some intelligent controllers in the system. The load frequency control in a two area power system is considered and the controller gains are optimizied with a newly introduced Jaya Algorithm by Bhongade and Parmar in their work[21]. But a few research is undergone for load frequency control considering fuzzy logic controller in the system [22-25]. However less work has been carried out for load frequency control in multi source multi area system taking FLC in to consideration.

With reference to all, it is intended to study and compare the robustness of the proposed fuzzy logic controller with conventional PI controller for the load frequency control of a multi-source multi area system. Primarily the two source single area hydro thermal system is studied with the proposed fuzzy logic controller. To look at the benefits of using FLC, the study is put through two source two area system and the simulation results obtained, are compared with PI controller. Moreover a two area power system containing three generating sources including renewable energy, is considered. The superiority of the FLC approach is proved by considering a load variation of 24 hour duration.

2. Power system model and description

In a realistic power system model, each control area has diverse energy sources for generating power. The MSMA system used for the study is the combination of sources like hydro, thermal, wind in first area where the second area includes hydro, thermal and diesel power units. The block diagram of MSMA system is shown in Fig. 1, and different plants are represented with equations which are suggested by reference [11, 16].

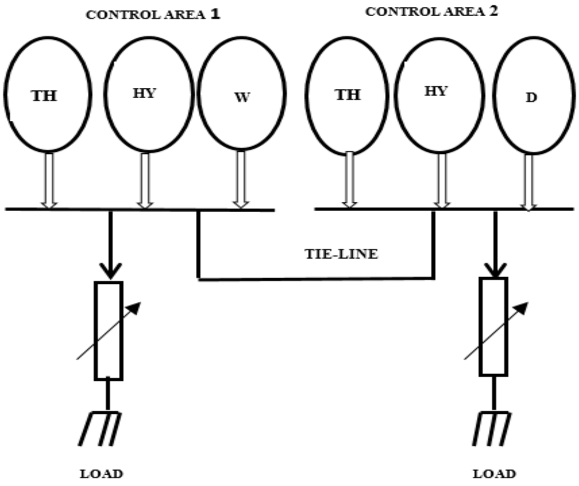


Fig. 1. Block diagram of proposed MSMA system

2.1. Thermal power system modeling

In a thermal power plant, the variance in generation and demand in the system is identified by the speed governor and the governor controlled the steam input to the turbine. The governor action of the plant depends on the change in control area frequency (ΔF) and the reference power setting (ΔP_{ref}).

The transfer function equation for speed governing system can be furnished as equation (1)

$$\Delta P_g = \Delta P_{ref} - \left(\frac{1}{R_1}\right)\Delta F \tag{1}$$

Where, ΔP_g is the speed governor output power and R_1 represents the governor speed regulation.

The output power of governor (ΔP_{gov}) can be given as equation (2)

$$\Delta P_{gov} = \frac{1}{1+sT_g}\ \Delta P_g \tag{2}$$

Where T_g is the governor time constant.

In large capacity steam turbines, the expansion of high pressure steam, results in increase of moisture content in the turbine. Hence to avoid excess moisture in steam and to increase the quality, the steam is to be reheated. The reheated steam in the turbine occurs to be more efficient for the system. The performance of the turbine is governed by the turbine time constant (T_t) and reheat time constant (T_{rt}). The value of reheat steam turbine constant (K_{rt}) is calculated considering the fraction of total steam is being reheated.

The incremental turbine output power (ΔP_{tg}) of the reheat steam turbine is represented by the equation (3)

$$\Delta P_{tg} = \left(\frac{1}{1+sT_t}\right)\left(\frac{1+sK_{rt}T_{rt}}{1+sT_{rt}}\right)\Delta P_{gov} \tag{3}$$

The generator load model can be expressed as equation (4),

$$\Delta F = \frac{K_{ps}}{1+sT_{ps}}(\ \Delta P_{tg} - \Delta P_d\ ) \tag{4}$$

Where ΔP_{tg} is the change in turbine power output which drives the generator and ΔP_d represents the incremental load in the control area. The power system gain constant K_{ps} and time constant T_{ps} are considered for corresponding control areas.

2.2. Hydro power system modeling

In a hydropower system, the turbine is driven by the mechanical force supplied, due to the kinetic energy of water.

The power output of a hydro governor (ΔP_{gh}) can be represented in equation (5) as

$$\Delta P_{gh} = \left(\frac{K_{gh}}{1+sT_{gh}}\right)\left(\Delta P_{ref} - \frac{1}{R_2}\Delta F\right) \qquad (5)$$

Where K_{gh} represents the parameter gain and T_{gh} denotes the time constant of the hydro governor.

The hydraulic valve output (ΔP_{Hgov}) can be stated using the relation between reset time of the speed governor (T_r) and transient droop time constant (T_2) by the transfer function as in equation (6)

$$\frac{\Delta P_{Hgov}}{\Delta P_{gh}} = \frac{1+sT_r}{1+sT_2} \qquad (6)$$

The output power equation for hydro turbine (ΔP_{Ht}) can be furnished in equation (7) as

$$\frac{\Delta P_{Ht}}{\Delta P_{Hgov}} = \frac{1-sT_{wh}}{1+0.5sT_{wh}} \qquad (7)$$

Where T_{wh} is the water starting time and its values varies according to the load conditions.

The transfer function equation of generator load model can be expressed in equation (8) as

$$\Delta F = \frac{K_{ps}}{1+sT_{ps}}(\Delta P_{Ht} - \Delta P_d) \qquad (8)$$

2.3. Wind power system modeling

Recent utility- scale renewable power generating units such as wind power plants have efficiently reduced the dependency on imported fuels. The wind turbine system converts the wind kinetic energy to electrical energy. Considering turbine safety during power capturing of wind power plant, different power control methods are used. Appreciating the benefits, the hydraulic pitch control method is considered for the wind power plant . A simple lag, the data fit pitch response is needed to complement the phase and gain characteristics of the system model.

The power output equation of a wind turbine generator (ΔP_{wtg}) can be furnished using gain constant (K_{p1}) and time constant (ΔT_{p1}) of hydraulic pitch actuator, time constant of data fit actuator (T_{p2}) as equation (9)

$$\Delta P_{wtg} = \left(\frac{1}{1+sT_{p2}}\right)\left(\frac{K_{p1}(1+sT_{p1})}{1+s}\right)\Delta P_{wg} \qquad (9)$$

2.4. Diesel power plant modeling

The dynamics model of a diesel power plant entails a diesel engine to drive the synchronous generator. A speed governor in the plant, controls the speed of the diesel engine irrespective of load variation.

The feedback mechanism of the governor in the plant changes the speed as required and maintains a constant speed for this. The transfer function representation of diesel output power (ΔP_{dtg}) can be stated using the diesel turbine gain constant (K_{dis}) and diesel time constant (T_{dis}) can be given as equation (10)

$$\Delta P_{dtg} = \frac{K_{dis}(1+s)}{s(1+sT_{dis})}\Delta P_{dg} \qquad (10)$$

2.5. Tie-line modeling

A tie-line connects the control areas in a power system to make the system more stable and reliable. The load difference in any control area can be expiated by all control areas. The change in tie line power flow (ΔP_{tie}) between the areas can be furnished in equation (11) as

$$\Delta P_{tie} = \frac{2\pi T}{s}(\Delta F_1 - \Delta F_2) \qquad (11)$$

Where ΔF_1 and ΔF_2 are the incremental changes in control area frequency.

3. Control technique

The power system performance can be enhanced with proper implementation of control techniques to design LFC controller.

3.1. PI controlling technique

Conventional PI controllers are widely used in industry applications due to their simpler and robust design compared to other controllers. The proportional controller improves the transient response but it results the response with an uncompensated stability error. The steady state error can be compensated with integral controller, but with this, the transient response goes worse. The block diagram of PI controller used in the study is shown in Fig.2.

The mathematical equation for controlled output (*u(t)*) of a PI controller can be represented as equation (12)

$$u(t) = K_p\, e(t) + K_i \int_0^t e(t) \qquad (12)$$

Where K_p and K_i represents proportional and integral gain of PI controller.

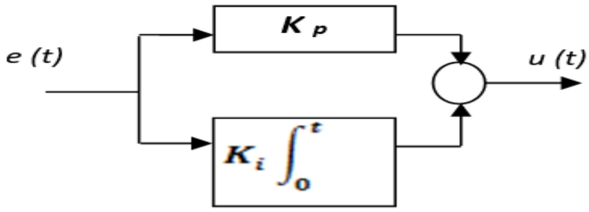


Fig 2. Block Diagram of PI controller

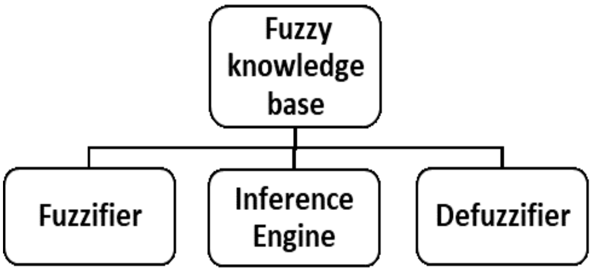


Fig 3. Block Diagram representation of FLC

3.2. Fuzzy controlling approach

To attain less oscillation and relatively smooth operation of the proposed system with a variable load, a fuzzy logic based intelligent controller is realized. The elementary block diagram of a fuzzy logic controller is represented in Fig 3.The FLC uses the logical system containing multi valued logics, which is a representation of human reasoning in the form of fuzzy logic language.

The rule base for the fuzzy logic controller can be framed by taking possible combinations of the input variables as presented in Table 1. With the increasing number of fuzzy logic membership functions, the output response attains to be more accurate. Based on this, 7 membership function is considered for this study. The area control error and change in area control error of the system are the two inputs to fuzzy logic controller.

The input variables are presented by 7 membership functions like Negative Large(NL), Negative Medium(NM), Negative Small(NS), Zero(ZE), Positive Large(PL), Positive Medium(PM), Positive Small(PS) respectively.

Table 1. Fuzzy rule viewer

Error	d(error)						
	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	N M	NM	NS	ZE	PS
NS	NL	NM	NM	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PM	PL
PM	NS	ZE	PS	PM	PM	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

4. Multi source multi area power system

In this study, different possible combinations of power generating sources are designed for the control areas. The proposed transfer function model of a three source two area power system is presented in Fig 4.

Initially, the proposed system model is observed for two source single area hydro thermal system, considering governor controller alone. The speed governor discerns the deviation in the system frequency and later change the position of the valve to match the power generation with the demand. Several control areas can be connected through tie lines for an uninterrupted and reliable power supply. Each control area could contain more than one generating sources to increase the power generation and to meet the randomly changing load. So the system model is investigated for a two source two area (TSTA) system with 10% step load change in both control areas.

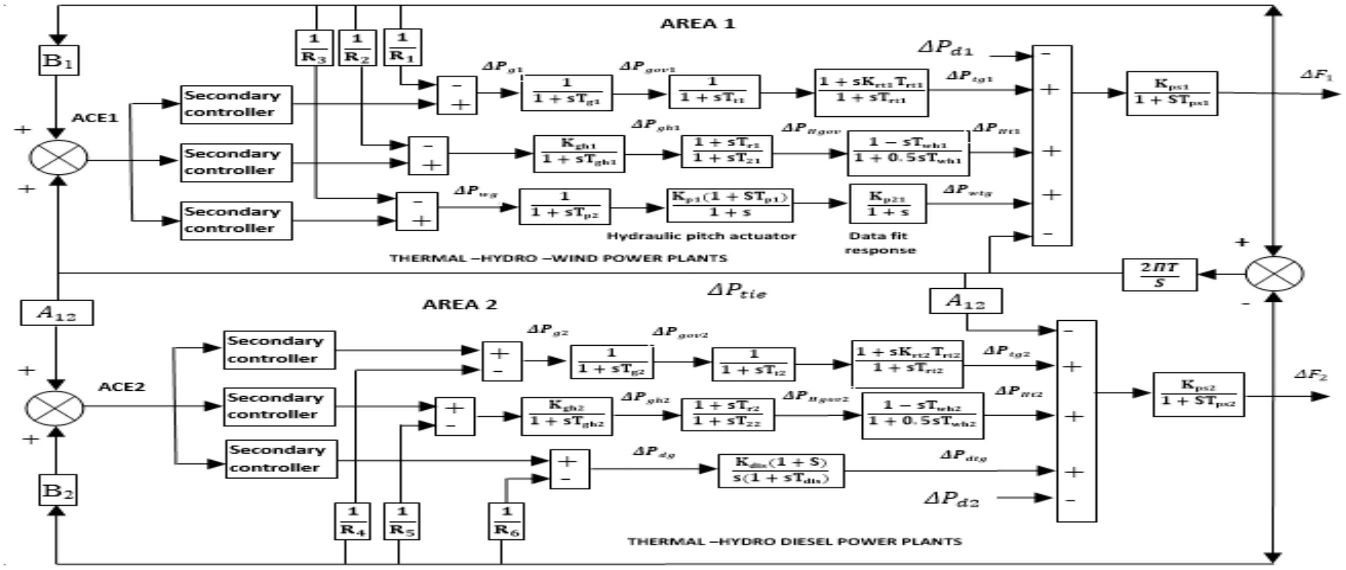


Fig. 4. The three source two area power generating system

The LFC in the interconnected power system regulate the generation in the areas to retain the change in frequency and the power exchange through tie line at a low value.

To an extension, the hydro thermal power plants are synthesized with the wind and diesel power plants to structure as a three source two system. First control area includes thermal and hydro power plants with a wind power plant as the renewable source. Whereas the second area includes comprise thermal, hydro along with a diesel power plant. In order to maintain the scheduled values of the power system frequency and tie line power flow at various loading conditions, secondary controller is incorporated in the system. Due to its reliability, simplicity and robustness, the PI controller is given preference to act as a secondary controller for the power system operation and control. In view of the offsets found in control area frequency and power flow through tie line in the interconnected system and to meet a fairly stable system, the PI controller can be replaced by fuzzy logic intelligent controller.

5. Simulation result and discussion

The MSMA system for study as represented in Fig. 4 is verified in MATLAB/Simulink and the values of different variables used are provided in Appendix.

5.1. Analysis of Single area power system

To realize the performance of frequency deviation for a two source single area system with 10% step load change, MATLAB/Simulation of system is done. The output of simulation results for PI and Fuzzy logic controllers are compared and the comparison of frequency deviation graph is presented in Fig. 5.

It can be seen from the Fig.5 that the two source single area hydro thermal system run with PI controller, when subjected to 10% step load variation exhibits an overshoot of 0.556 with more oscillation and the system took 24.2 sec to settle down. Moreover the proposed fuzzy logic controller outperforms the PI controller in damping oscillation efficiently and the system attains stability in a reduced time of 6.2 sec.

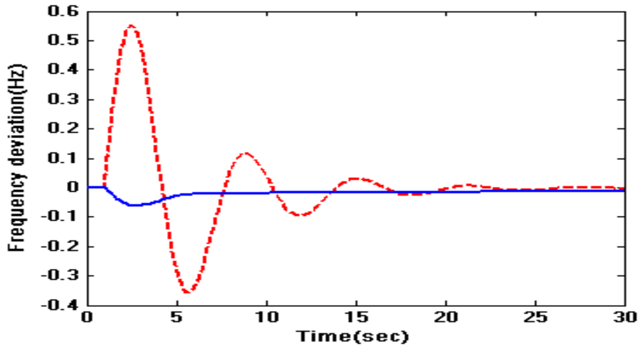
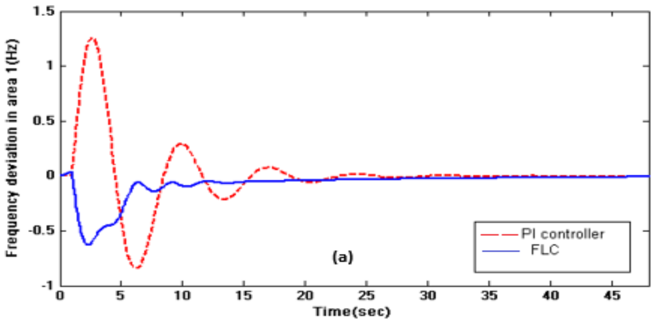


Fig. 5. Frequency deviation in single area for 10% step load variation

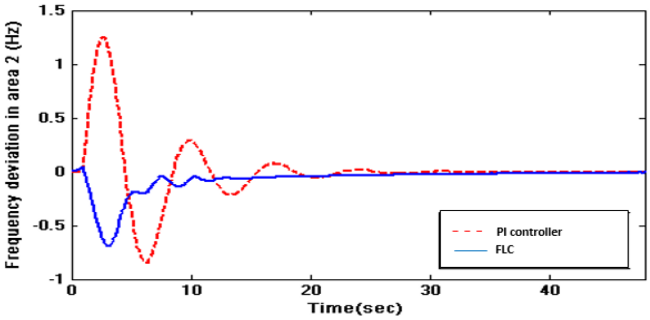
5.2. Analysis of two source two area power system

To comprehend the effectiveness of FLC, a two source two area hydro thermal system is exposed to 10% step load increase both the two control areas. A comparative analysis of frequency responses ΔF_1 in control area 1, ΔF_2 in control area 2 and interchange tie line power ΔP_{tie} with PI and FLC are presented in Fig.6. (a),(b),(c) .

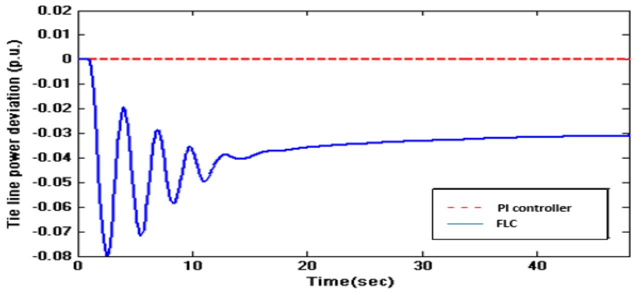
The frequency alteration in area 1 (ΔF_1) shows in Fig.6 (a) exhibits that the proposed system with PI controller results the response more oscillatory with a peak overshoot of 0.553 appeared with a large settling time of 20.56 sec. Whereas the damping oscillation can be found as effectively reduced peak overshoot with a faster settling time of 12.17 sec through fuzzy logic controller .



(a) Deviation in frequency F_1 in area 1



(b) Deviation in frequency F_2 in area 2



(c) Deviation in tie line power P_{tie}

Fig. 6. Dynamic response the two source two area hydro thermal system

The frequency deviation in the second control area(ΔF_2) as shown in Fig.6 (b) presents the superiority of FLC on PI controller, showing improved damping characteristics of the TSTA system. The peak overshoot with PI controller is completely suppressed with fuzzy logic controller. The settling time of 20.43sec with PI controller is decreased to 12.22 sec with FLC and adds to system stability.

The change in tie line power (ΔP_{tie}), as shown in Fig.6 (c) demonstrated that PI controller cannot monitor the power flow in the tie-line whereas FLC can effectively monitor it with minimum oscillation to settle the frequency variation in the control areas.

5.3. Analysis of three source two area power system

5.3.1. With 10% step load variation

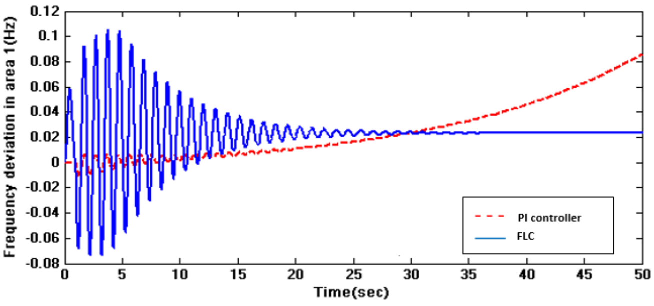
To figure out the effectiveness of the suggested fuzzy logic controller, a two area system with three generating source is set through 10% step load increase both the two areas. A comparative analysis of ΔF_1, ΔF_2 , ΔP_{tie} with PI and FLC are shown in Fig.7.

Figure.7 exhibits the change in control area frequency and interchange tie line power for the three source two area system which is completely unstable with PI controller and the dynamic responses never settled down.

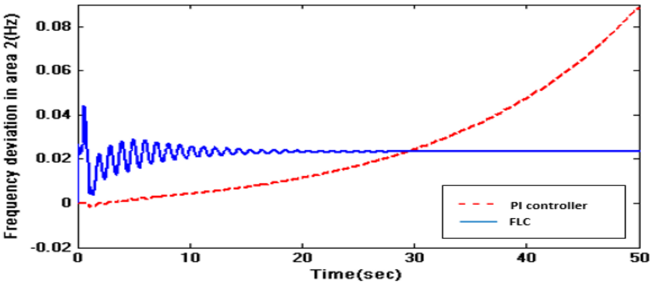
The frequency response in area 1 with PI controller is appeared with minimum oscillation but the settling time of the response increases infinitely exhibiting a completely unstable system. With fuzzy logic controller, the system response exhibits minimum oscillation and the frequency deviation ΔF_1 is stabilized at 25.1 sec as represented in Fig.7 (a).

In Figure.7 (b), the frequency response in area 2 presented that with PI controller in the system, dynamic response of the frequency is absolutely unstable with a rising settling time whereas with FLC, the frequency deviation ΔF_2 became stable at 21.2 sec with an acceptable oscillation.

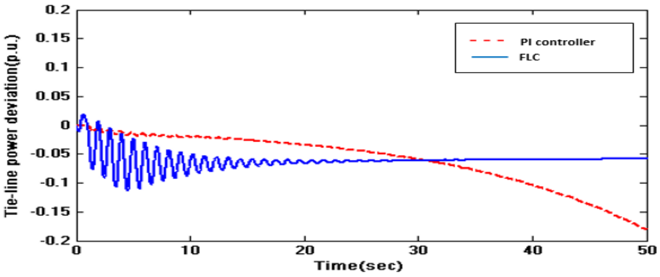
The tie line power flow (ΔP_{tie}), as shown in Fig.7 (c) represents the superior behavior of fuzzy logic controller over conventional PI controller. The figure explains that with PI controller the tie line power flow between the control areas falls endlessly leading to an unstable system. The deviation (ΔP_{tie}), with PI controller is effectively put down by FLC with a settling time of 21.6 sec.



(a) Deviation in frequency F_1 in area 1



(b) Deviation in frequency F_2 in area 2



(c) Deviation in tie line power P_{tie}

Fig. 7. Dynamic response of the three source two area system with 10% step load increase

5.3.2. With a variable load

The above realistic three source two area system is investigated for a randomly changing load of 24 hour duration. The MW load variation of 24 hour used in this study is tabulated in Table 2.

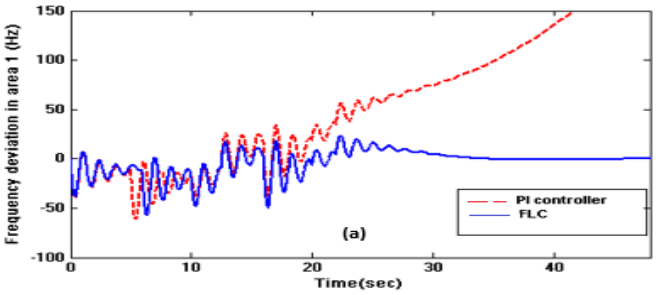
A comparative analysis of ΔF_1, ΔF_2 , ΔP_{tie} with PI and FLC are shown in Fig.8 (a),(b,(c).

Figure.8 shows that, with PI controller, the dynamic response of the system turned to be worse for a realistic variable load and the system never achieve stability. The change in area frequency is oscillatory and the response unceasingly increases to infinity when performed with PI controller. The superiority of FLC over PI controller can be observed from Fig 8.The proposed fuzzy logic controller can effectively improve the frequency response ΔF_1 in an acceptable settling time of 29.67 sec. and ΔF_2 at 23.7 sec. as represented in Fig.8 (a) and 8(b)

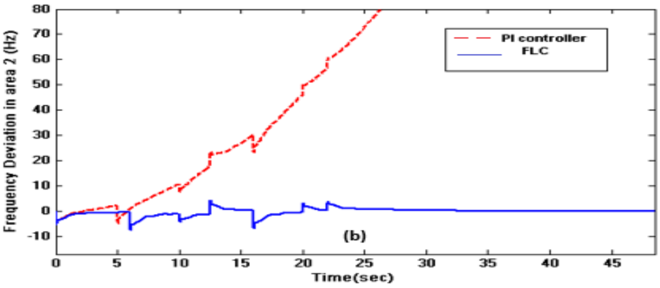
It is observed in Fig.8 (c) that the decreasing behavior of (ΔP_{tie}) with PI controller is effectively suppressed through FLC.

Table.2. variable load data

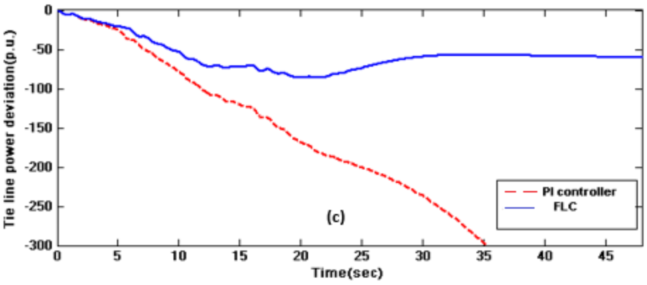
Hours	12midnight-6am	6am-10am	10am-12noon	12noon-4pm	4pm-8pm	8pm-10pm	10pm-12 midnight
Load In MW	30	70	90	60	100	80	60



(a) Deviation in frequency F_1 in area 1



(b) Deviation in frequency F_2 in area 2



(c) Deviation in tie line power ΔP_{tie}

Fig. 8. Dynamic response of three source two area system with a variable load

From the study it is concluded that, FLC can efficiently improve the deviations found in system frequency unlike PI controller. The comparison of settling time (T_s) can be summarized in Table 3.

6. Conclusion

In this paper, a rule based fuzzy logic controller is implemented to prevail over the problems found with PI controller in a MSMA system when subjected to variable loading conditions. The multi source system is designed for different possible combinations of power plants which includes wind and diesel power along with the conventional energy sources. The suggested system models are examined for PI and fuzzy logic controller and the results are compared. Moreover the deviation found in control area frequency and power flow through tie line in the MSMA system, for 10% step load and a variable load are compared to look at the superiority of FLC on PI. The simulation results explain that, by implementing fuzzy logic controller in the system, the offsets found in change in frequency and power flow through tie-line, are improved and the response settles down quickly with a reduced settling time. The proposed fuzzy logic controller performs excellently with MW load variation of 24 hour and it settles a completely unstable system response within an accepted value of settling time.

Table.3. Comparative analysis of simulation results.

Controller	Single Area System	TSTA System		MSMA SYSTEM			
	T_s (sec)	T_s (sec)		10% step load		Variable load	
				T_s (sec)		T_s(sec)	
	ΔF	ΔF_1	ΔF_2	ΔF_1	ΔF_2	ΔF_1	ΔF_2
PI	22.8	20.56	20.43	Unstable	Unstable	Unstable	Unstable
FLC	11.2	12.17	12.22	25.1	21.2	29.67	23.7

Appendix A

Single area hydro thermal system [19]
$R_1 = R_2$=2.4Hz/p.u. MW
T_g=0.08sec
K_{rt}=0.333
T_{rt} =10sec
T_t =10 sec
$K_{gh} = 1$
T_{gh} =48.7sec
T_r =5sec
T_2=0.513sec
T_{wh}=1 sec
K_{ps}=120Hz/p.u
T_{ps}= 20sec

Appendix B

Two source two area hydro thermal system [19,20]
$R_1 = R_2 = R_3 = R_4$ =2.4Hz/p.u MW
$B_1=B_2$= 0.425p.u. MW/Hz
Thermal power plant parameters
$T_{g1} = T_{g2}$ =0.08sec
$K_{rt1} = K_{rt2}$ = 0.333
$T_{rt1} = T_{rt2}$ =10sec
$T_{t1} = T_{t2}$= 10 sec
Hydro power plant parameters
$K_{gh1}=K_{gh2}$=1
$T_{gh1} = T_{gh2}$ =48.7sec
$T_{r1} = T_{r2}$ =5sec
$T_{21} = T_{22}$=0.513sec
$T_{wh1} = T_{wh2}$=1 sec
$K_{ps1} = K_{ps2}$ =120Hz/p.u.
$T_{ps1}=T_{ps2}$= 20sec
A_{12}= -1

Appendix C

Three source two area hydro thermal system [19, 20]
$R_1 = R_2 = R_3 = R_4 = R_5 = R_6$ =2.4Hz/p.u
$B_1=B_2$= 0.425p.u. MW/Hz
Thermal power plant parameters
$T_{g1} = T_{g2}$ =0.08sec
$K_{rt1} = K_{rt2}$ = 0.333
$T_{rt1} = T_{rt2}$ =10sec
$T_{t1} = T_{t2}$= 10 sec
Hydro power plant parameters
$K_{gh1}=K_{gh2}$=1
$T_{gh1} = T_{gh2}$ =48.7sec
$T_{r1} = T_{r2}$ =5sec
$T_{21} = T_{22}$=0.513sec
$T_{wh1} = T_{wh2}$=1 sec
Wind power plant parameters
K_{p1} =1.25
K_{p2} =1.24
T_{p1} =6 sec
T_{p2} =0.041 sec
Diesel power plant parameters
$K_{ps1} = K_{ps2}$ =120Hz/p.u.
$T_{ps1}=T_{ps2}$= 20sec
K_{dis}=16.5
T_{dis}= 0.025 sec
A_{12}= -1

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