A Novel Fuzzy tilt controller for AGC of multi-source power system for constrained economic operation

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Abstract

The robust design and application of a novel type-II fuzzy tilt controller (T2-FTC) has been well demonstrated in this manuscript for automatic generation control (AGC) of a multi-area hybrid power system in concern to the optimal scheduling of the power generation. The combined action of AGC and optimal scheduling of a power system is referred as economic AGC or commonly ECO-AGC. At the initial stage of the analysis, the concept of only AGC has been discussed through various robust approaches. Then the extensive study on ECO-AGC of the proposed power system has been progressed under various controller actions. Further, the proposed Type2-FTC controller is designed optimally with suggesting a novel quassi-opposition path finder algorithm (QO-PFA) under various operating conditions. The effectiveness and the viability of the proposed Type2-FTC controller has been verified over type-I fuzzy PID and conventional PID controllers for AGC and ECO-AGC of the multi area power system as well. In controller comparison study, it has been revealed that proposed Type2-FTC is a potential candidate to improve frequency stability of system. Further, the analysis over technique study justifies supremacy of the suggested QO-FPA algorithm over standard FPA and PSO algorithms for optimal designing all implemented controllers.

Keywords: Automatic generation control (AGC); Economic load dispatch (ELD); Type-II fuzzy controller; quassi-opposition path finder algorithm (QO-PFA); Fitness function; Robust analysis.

1. Introduction

In today's scenario the reliability of the human activity is largely dependent on the electrical energy. Further, the luxury of human life style and growth of industrialization enhances the importance of electrical energy abruptly. In response to full fill electrical demand, electrical power generation is required as per the requirement of the electrical demand. The basic component for generating electrical power is synchronous generator. The synchronous generators are located at various power plants with suitable arrangements. The objective of the power plant is to facilitate mechanical energy and finally generates electrical energy through an appropriate conversion processes. The power plant utilizes the available forms of energy i.e Kinetic energy of water, coal chemical energy and finally provides electrical energy for the purposes. The standard level of generated voltage at various power plant is 11Kv. Further. this generated voltage is stepped up through transmission level. Finally, the required demand voltage will be available at the end of the distribution section. The prime objective of a power system is to facilitate rated voltage and frequency at the demand end [1]. Since the modern power system exhibits large dynamics, a great care has to be required to maintain nominal frequency and voltage irrespective of the load uncertainty and system dynamics. It has been noted that any power mismatch between power generation and demand results instability over system frequency and terminal voltage [2]. So an action called automatic generation control (AGC) is required to monitor active power generation irrespective of the load demand [3]. The AGC incorporates with different control actions to do needful over active power generation [4]. At the primary stage of the AGC analysis, the concept has been implemented successfully on single area power systems [5]. Then the AGC phenomenon has been incorporated on two area as well as three area power sector for smooth control of frequency and tie-line power under various load dynamics [6]. The concept and analysis of AGC with single area power system is well addressed in [7] for monitoring power generation of the system. Further, the AGC study with various multi-area power system is demonstrated in [8] for controlling frequency as well tie-line of the system. The modern power system is incorporated with different power plants for generation of required power.In today's scenario an increasing interests towards renewable energy sources has been focused for generation of power [9]. Since renewable energy sources are the key factor to produce green energy, the modern power systems are incorporated with various renewable energy sources and lead to make hybrid structure [10]. The complex hybrid power system is also involved with various uncertainties of the renewable source [11]. The uncertainties like wind fluctuations [12], solar intensity variation [13] and uncontrolled load dynamics causes instability issues in the hybrid power system. In order to obtain stability over system performances under such uncertainties, AGC plays vital role for system stability [14]. The AGC of multi area power system has been well discussed through various research articles with implementing novel techniques and approaches[15]. It is observed since last decades that AGC study on both single area and multi area has been reported frequently with suggesting various conventional approaches [16]. Further the invention of fuzzy based controller makes AGC analysis so improved and has been reported through various research articles [17].Sahu et. al employed a fuzzy based fractional order PID controller for AGC of a hybrid electrical grid under different loadings [18]. Moreover, the AGC analysis is well analyzed with suggesting various robust and type-II fuzzy controllers [19]. In above discussed articles, the AGC performances are investigated under only load dynamics and no constraint over optimal scheduling. The generations are monitored as per the demand without considering economic dispatch [20]. This research articles addresses the AGC of a hybrid power system in constraint to the economic dispatch with employing improved novel approaches. As per the economic scheduling, the generations are monitored in such a manner to have cost effective with minimum operating cost. The research work on the combined action of AGC and economic load dispatch is commonly refereed as Optimal AGC [21]. Since controllers play vital role for AGC of corresponding power systems but creates huge challenges for power engineers for its optimal design. The invention of soft computing techniques makes easier the task of power engineers for obtaining optimal controllers in AGC of different power systems. Further, the development of various improved and hybrid techniques solve the optimal designing issues seriously. Adopting such soft computing techniques, Arya et. al suggested an imperial algorithm to optimal design a robust fractional order fuzzy controller for AGC of multi area power system [22]. In order to design a degree of freedom controller optimally, Nayak et. al. employed a teaching learning based algorithm for AGC of hybrid power system [23]. Sahu et. al. designed optimally to a fractional order fuzzy controller with employing a novel i-SCA algorithm for frequency control of a hybrid power system [24].

Literature review on AGC confirms limited research work on combined AGC and economic load dispatch (ELD) of multi area power system. Motivating with ELD, this research article extends the AGC study in collaboration with ELD in a common research frame. The study employs a robust type-II fuzzy tilt controller to obtain necessary control actions for AGC and ELD of the power system. In controller optimal design concern, the work suggests a novel quassi oppositional- path finder algorithm (QO-PFA) under different operating.

The basic objective of this research work are:

1. In Simulink environment, a three area multi source power system is modelled with suitable controller and constraints.
2. In order to pertain necessary control actions for AGC and ELD, the work employs a robust type-II fuzzy tilt controller (Type2-FTC) under different operating regions.
3. The suggested Type2-FTC controller has been designed optimally with employing a novel quassi oppositional – path finder algorithm for AGC and ELD of multi area power system.
4. To exhibit superiority of the proposed Type2-FTC controller, its performances are verified over type-I fuzzy controller and conventional PID controller in a common research frame.
5. An assignment over comparison study in technique level has been synthesized to defend supremacy of the proposed QO-PFA algorithm over original PFA and standard PSO techniques in response to optimal design the suggested controller.
6. A close comparison sensitive study has been carried out to exhibit robust nature of the proposed Type2-FTC controller under various functional conditions.

The rest section of this research article is designed as:

The modelling and transfer function detail of the proposed three area hybrid power system is well demonstrated in section2. The modelling and theoretical concept of the proposed Type2-FTC controller is demonstrated in section3. The section4 highlights the basic principle and application of the proposed QO-PFA algorithm. Section5 notes on result and discussion of this proposed research work. Finally, the conclusion of this research study is well addressed in section6.

2. System under Study

The suggested power system model is a hybrid structure that incorporates three different control areas. The area 1 is modelled with different generating sources including a thermal power plant, hydropower plant and gas power plant. The area 2 has been designed to allow thermal, hydro and nuclear power system. The area 3 on the other hand is essentially a micro grid system that has been built to integrate a variety of distribution generation (DG) based micro sources. The micro-grid is connected to a different renewable energy based DGs, including wind turbines [25], solar photovoltaic systems [26], Fuel cells [27], and geo-thermal [28], as well as few traditional DGs, such as micro-turbines [29], diesel generators and so on. To improve the stability of the system, the micro-grid has been equipped with energy storage devices such as battery energy storage (BES) and flywheel energy storage (FES). The rating of whole system is 2200 MW, with a load of 1850 MW estimated. Area 1 and 2 each produce 1000 MW, however only 200 MW is contributed by area 3. For the realization of system field effectiveness, thermal hydro systems have a physical constraints known as the generation rate constraint (GRC). The figure 1 shows a model of a proposed hybrid system. The following is a list of the transfer function expressions for each generating source.

Thermal unit:

Governor modeling$G_G(s) = \frac{\Delta P_V(s)}{\Delta P_G(s)} = \frac{1}{T_g(s)+1}$;

Turbine (reheat) modeling,$G_T(s) = \frac{\Delta P_T(s)}{\Delta P_V(s)} = \frac{K_r.T_r\,s+1}{T_r(s)+1}$ (1)

Hydro unit;

Governor modeling $G_G(s) = \frac{\Delta P_V(s)}{\Delta P_g(s)} = \frac{1}{T_{gh}(s)+1}$; Droop modeling $G_D(s) = \frac{\Delta P_{V1}(s)}{\Delta P_V(s)} = \frac{T_{rs}(s)+1}{T_{rh}(s)+1}$ (2)

Penstock modeling $G_P(s) = \frac{\Delta P_T(s)}{\Delta P_{V1}(s)} = \frac{-T_w(s)+1}{0.5\, T_w(s)+1}$ (3)

Gas unit:

Valve modelling, $G_V(s) = \frac{\Delta P_g(s)}{\Delta P_p(s)} = \frac{1}{B_g(s)+C_g}$; Governor modeling $G_G(s) = \frac{\Delta P_S(s)}{\Delta P_g(s)} = \frac{X_g(s)+1}{Y_g(s)+1}$ (4)

Combustion modelling, $G_C(s) = \frac{\Delta P_R(s)}{\Delta P_S(s)} = \frac{-T_{CR}(s)+1}{T_f(s)+1}$; Compressor modeling $G_{CO}(s) = \frac{\Delta P_{CD}(s)}{\Delta P_R(s)} = \frac{1}{T_{CD}(s)+1}$ (5)

***Microgrid Modelling*:**

Wind plant modelling: $G_W(s) = \frac{\Delta P_{WO}(s)}{\Delta P_{WI}(s)} = \frac{1}{T_{WTG}(s)+1}$ (6)

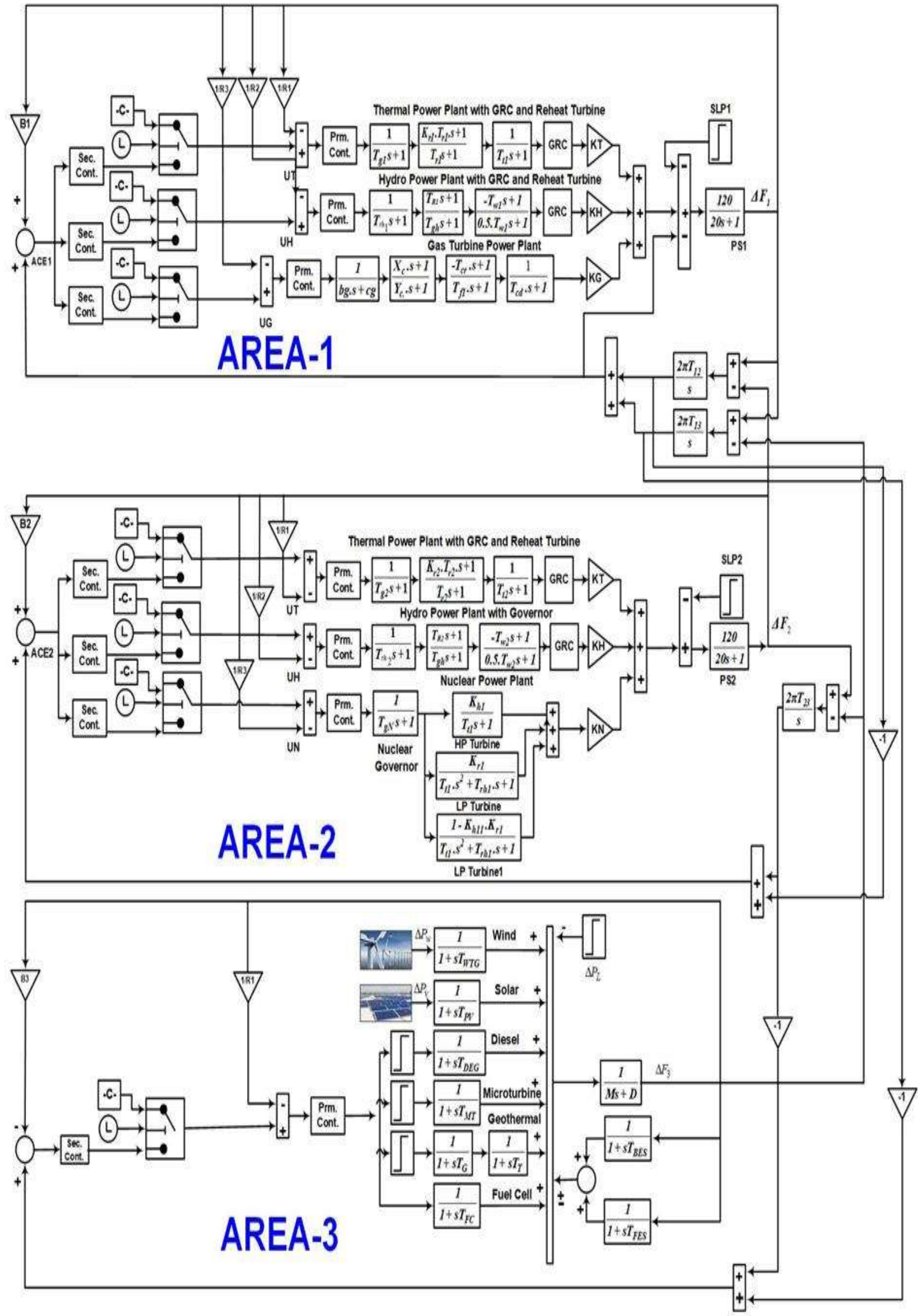
Solar plant modelling: $G_{PV}(s) = \frac{\Delta P_{SO}(s)}{\Delta P_{SI}(s)} = \frac{1}{T_{PV}(s)+1}$ (7)

Diesel plant modelling: $G_{DEG}(s) = \frac{\Delta P_{DO}(s)}{\Delta P_{DI}(s)} = \frac{1}{T_{DEG}(s)+1}$ (8)

Fuel Cell modelling: $G_{FC}(s) = \frac{\Delta P_{FO}(s)}{\Delta P_{FI}(s)} = \frac{1}{T_{FC}(s)+1}$ (9)

The nomenclatures and parameter details are givenin Appendix section.

Fig.



1 DG based hybrid power system model

2.1 CombinedAGC and ELD analysis

The existing AGC study of the power system has been further extended with integrating economic load dispatch and the combined action is called AGC-ELD. In only AGC concern, though the system frequency and tie-line power comes back to nominal state with employing various control actions but scheduled generation from respective generating units may not be economic. The generation may violate the standard generation limit which could put adverse effect over power plants and also total operating cost[30]. To obtain cost effective generation within scheduled value and frequency stabilization, a maiden work on AGC-ELD of the hybrid system has been proposed in this section.It has been discussed through various research article that AGC loop requires an addition loop called secondary loop except from governor to obtain necessary control over system frequency and tie-line power. The controllers suggested for this secondary loop are called secondary controller. The secondary controller only looks after the actions of AGC under any abnormal conditions. However, to monitor generation as per the command given for economic cost and not to violate generation limit an additional controller called primary controller is required for the action. The objective of the primary controller is to govern the generation in response to the demand with minimizing cost and simultaneously schedule generation within the limit. In this proposed study, the ELD has been actioned without considering the loss. The objective of the AGC-ELD analysis is to

1. Maintain stability over system frequency under any uncertainty.
2. Maintain stability over new scheduled tie-line power since tie-line power varies with generation and always flows from units with lower incremental cost to higher incremental cost.
3. Control the generation so as to achieve minimum fuel cost i.e minimize cost function.

For this analysis the cost function $F = \sum_{i=1}^{n} f_i\,(P_i)$ Where Pi is the power generation in i^{th} unit. The quadratic function of $P_i$may be expressed as

$$f_i(P_i) = a_i + b_i P_i + c_i P_i^2$$
(10)

Where a_i, b_i and c_i are the cost coefficients. The ELD satisfies both equality and non-equality constraints.

Equality constraint: $\sum_{i=1}^{n} P_i = P_D + P_{LOSS}$; P_D = Demand, P_{LOSS} = Power loss

Inequality constraint: $P_{imin} \leq P_i \leq P_{imax}$; P_{imin}= Min Power generation limit, P_{imax}= Max generation limit.

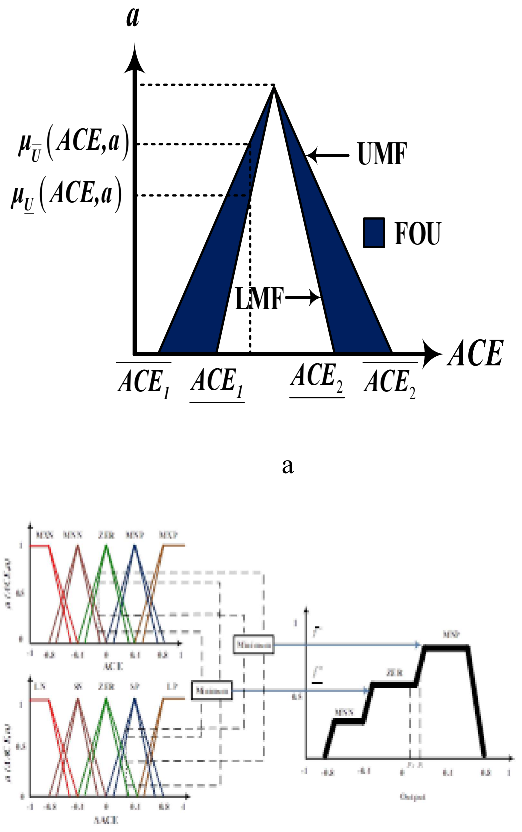
The details command are assigned with AGC-ELD action through suitable switching actions in MATLAB platform.

2.2 AGC-ELD Model description:

For this research study, a three area hybrid power system has been proposed for both AGC & ELD analysis under different loadings. The individual generating sources are designed with proper switching arrangements in order to activate secondary controller and primary controller as per the requirement. The secondary controller only meant for the AGC analysis and is activated for a period from 0 (zero) to 15 second. However, the primary controller is meant both for AGC and ELD actions and remains in active from 15 second to 30 second. The simulations are done overall in a period from 0 to 30 second. The various command for both AGC & ELD are given through economic dispatch switch (EDS) and are interlinked by terminal ‘1’ of the switch. The primary controller or economic dispatch controller (EDC) takes care for both AGC-ELD actions in the system. Whenever the switch contacts to terminal ‘2’ the commands for ELD are disabled and now the secondary controller (AGC controller) comes in to picture and tries to reduce the area control error (ACE) for obtaining AGC in the system. The switch contacts terminal ‘2’ for a period from time 0 to 15 second and closes terminal ‘1’ from time 15 second to 30 second. For easy understanding the arrangements for AGC and AGC-ELD through suitable switching actions are well visualized in Fig,1. Further, the internal connection structure of the proposed switch for both AGC and AGC-ELD are well organized in Fig.2.

3. Design and analysis of type-II Fuzzy tilt Controller (Type2- FTC)

The complexity in power system model and probability to have high uncertainty requires improved and robust control structure to make control action over various parameters of the system. The conventional controllers though simpler in structure and easy to implement but gets inferior to apply in large non-linear systems. To mitigate the drawbacks of the conventional controller (PI & PID), fuzzy rule base controllers are designed to fetch improved results in most of non-linear systems. However, the fuzzy based PID controllers are not capable to produce improved performances in the system having large uncertainty and dynamic. The proposed model for this research study is associated with huge uncertainty. In order to amend necessary control actions in this proposed model, the work has proposed a robust type-II fuzzy tilt controller with mitigating drawbacks of the conventional fuzzy controller. The type-II fuzzy controller is cascaded with a tilt based TID controller and combined the controller is referred as type-II fuzzy TID controller. Unlike conventional PID controller, the TID controller holds three different gain parameters i.e. tilt gain *(K_T)*, integral gain (*K_I*) and derivative gain (*K_D*). As compared to the proportional gain of PID controller the tilt gain has an additional parameter so as to improve the control action gracefully. The block diagram of the type-II fuzzy TID controller is depicted in Fig.3 (a).



a

b

Fig.3 (a) 3-D structure membership function (b) Details membership function for all linguistic variables

The various stages of the proposed type-II fuzzy controller are demonstrated as followings.

Fuzzification :

The fuzzification is a process of converting numerical crisp value to the useful fuzzy set. The fuzzy variables are developed through various membership functions. For this study proposed controller employs five different membership functions. These are negative strong value (NSV), negative weak value (NWV), zero (ZR), positive weak value (PWV) and positive strong value (PSV). Each membership functions are designed by taking two different type-1 membership function and are structured in such a manner to create 3 dimensional structure with two different distinct points on the base [31]. One such type of membership function is illustrated in Fig.3(a). At the base, each membership function has been splited with two different values like upper membership face (UMF) and lower membership face (LMF). These structure facilitates a foot print of uncertainty (FOU) structure at the base. The obtained FOU gracefully imprecise the fuzzy data and helps to access the high uncertainty data in precise manner. The 3D structure and FOU both able to magnify the degree of freedom of the controller and able to produce improved actions especially in large uncertainty systems. The detailed membership function for all linguistic variables are well organized in Fig.3(b).

Table:1 Proposed fuzzy rules

$\dot{e}$ \ e	NSV	NWV	ZR	PWV	PSV
NSV	NSV	NSV	NWV	NWV	ZR
NWV	NSV	NWV	NSV	ZR	PWV
ZR	NWV	NWV	ZR	PWV	PWV
PWV	NWV	ZR	PWV	PWV	PSV
PSV	ZR	PWV	PWV	PSV	PSV

Fuzzy Inference System (FIS:

The objective of FIS system is to transfer input fuzzy set to useful fuzzy variable through different *if* and *then* fuzzy rules. The practical data are accessed through this fuzzy rules to give appropriate output in the system. The work employs Mamdani fuzzy rule platform to access FIS system in this fuzzy process. The detailed fuzzy rules for this proposed type-II fuzzy controller is demonstrated in Table.1.

Defuzzification:

The defuzzification process finally converts these fuzzy variables to useful crisp value in the fuzzy system. Before converting crisp numerical value, at first the type-II fuzzy variables are converted to type-1 fuzzy set by order reduction process. For this study, the work employs center of sum (COS) method to access all defuzzification process. The block diagram of the proposed GIT2-FPID controller is depicted in Fig.4(a).

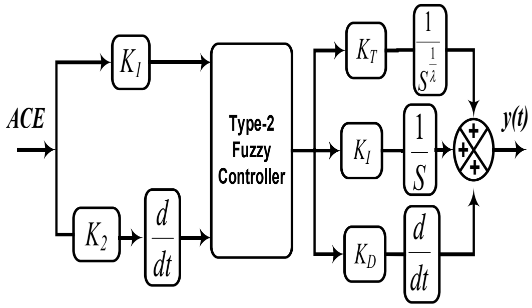


Fig.4(a) Block diagram of tile gain basedtype-2 fuzzy system

4. Quassi- Oppositional Path Finder Algorithm (QO-PFA)

The searching process of animal herd to get best food spot is the prime inspiration of the path finder algorithm. The animals are guided by a single animal called leader in the group. In a hyper dimensional domain, each individual of herd is activated as the solution candidate. The members in the swarm which gets best food area is referred as leader or path finder. The other member of the swarm is governed by the path finder [32]. The prime focus of the algorithm is the independent action of the leader as compared to other swarm based optimization technique.

The position of the leader (path finder) is controlled by the following expression.

$$E_P(x+1) = E_P(x) + 2.r(x).\left(E_P(x) - E_P(x-1)\right) + A(x)$$
(11)

$E_P(x)$ = Vector with dimension $d \times 1$ gives position of leader

$$E_p = \left[E_P^1(x), E_P^2(x) \dots \dots \dots \dots E_P^d(x)\right].^T$$
(12)

d = No. of variables associated with search agent.

r(x) = random matrix of order $d \times d$ whose elements are within 0 to 1.

*A (x)*is a matrix of order $d \times 1$ and is expressed by

$$A\,(x) = u_1(x).e^{-2\,x/_{iterax}}$$
(13)

$u_1(x)$ = random vector with dimension $d \times 1$ whose elements lie within [-1, 1]

The dynamic position of each agent (except leader) in search space is designed mathematically as

$$E_i(x+1) = E_i(x) + \alpha(x) r_2(x).\left(E_j(x) - E_i(x)\right) + \beta(x) r_3(x).(E_P(x) - E_i(x) + \epsilon(x) i \geq 2$$
(14)

$E_i(x)$ = Position of i^{th}search agent and may be expressed as

$$E_i(x) = \left[E_i^1(x), E_i^2(x) \dots \dots \dots \dots E_i^d(x)\right].^T$$
(15)

$E_j(x) =$ Dynamic position of j^{th} agent ; $r_2(x), r_3(x)$ = random matrixes with order $d \times d$

$\alpha(x)$ = Interaction coefficient shows degree of agent motion.

$\beta(x)$ = Attraction coefficient helps to set random distance.

$\epsilon\,(x)$ is the matrix of dimension $d \times 1$ and is expressed as

$$\varepsilon(x) = \left(1 - \frac{x}{itermax}\right).u_2(x).d_{ij}(x) \qquad (16)$$

$$d_{ij}(x) = | \quad |K_i(x) - K_j(x)|\,| \qquad (17)$$

$u_2(x)$ = random vector with dimension $d \times 1$ whose elements are within [-1, 1]

$d_{ij}(x)$ = Space betweeni^{th} andj^{th} member , $\varepsilon(x)$ = random movement of the agent.

Since the technique is employed to optimal design the proposed type-II fuzzy tilt controller, the position of the search agent is structured as $E_i(x)$ in related to the controller parameters.

$$E_i(x) = [K_1(x), K_2(x), K_{T1}(x), K_{I1}(x), K_{D1}(x), n_1(x), (x), K_{D2}(x), n_2(x)).^T \qquad (18)$$

K_1, K_2= Scaling factor, K_T= Tilt gain ,K_I= Integral gain, K_D= Derivative gain, *n* = order of tilt gain.

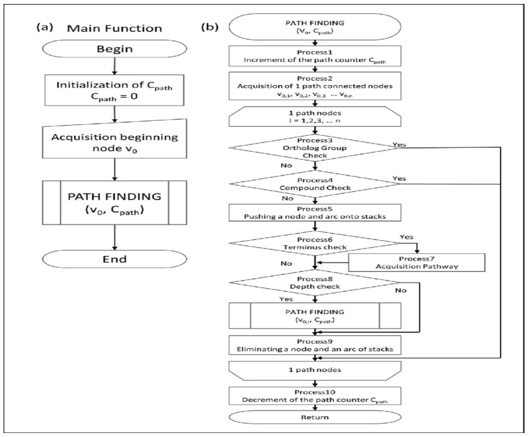
The proposed QO-PFA technique is employed to get optimum parameters of the type-II fuzzy tilt controller at minimum ITAE value. The ITAE can be mathematically expressed as

$$ITAE(x) = f\ [|\Delta F1|, |\Delta F2|, |\Delta P12] \qquad (19)$$

$$= g\ [K_1(x), K_2(x), K_{T1}(x), K_{I1}(x), K_{D1}(x), n_1(x), K_1] \qquad (20)$$

The above two expressions are represented as two non-linear functions.

The flow chart of the proposed quassi oppositional path finder algorithm in depicted in Fig.4(b)



(b) Flow Chart of QO-PFA algorithm

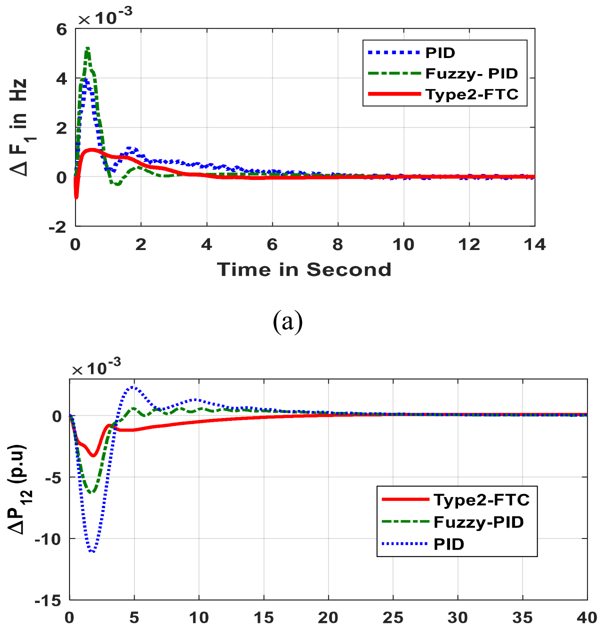
5. Results and Analysis

The outcomes of this proposed study along with the performances of the proposed techniques and methodologies are well demonstrated in this section. At the initial level, the transfer function model of the hybrid power system model is designed in the MATLAB Simulink software of version 2018. The model of proposed Type2-FTC controller also designed in the Simulink software and the necessary coding of the suggested QO-PFAtechnique are written in the .m file of the MATLAB software. Since the proposed work deals with AGC and ELD, the coding related to the ELD are also written in the .m file of MATLAB software. The overall analysis on results and outcomes are addressed in two different categories such as, 5.1: Analysis over only AGC study, 5.2: Analysis over combined AGC & ELD. In this proposed study a robust Type2-FTC controllers is proposed to amend suitable control actions in the system. In optimal concern, a novel QO-PFA algorithm is employed for tuning the gains of the proposed controller. The performance of the suggested Type2-FTC controller is validated over Fuzzy-PID and PID controller through a close comparison study. In technique level, the effectiveness of the suggested QO-PFA technique over standard PFA and PSO algorithms has been well synthesized through various dynamic responses. Finally, a sensitive study on proposed Type2-FTC controller is carried out to validate robustness of the proposed Type2-FTC controller.

5.1: Analysis over only AGC

This section of the research analysis demonstrates the power generation control and subsequent frequency control of a three area multi unit power system under dynamic loads and uncertainties. These abnormal situation creates mismatch in power generation and demand and results a frequency variant issues in the power system. In order to solve these problems, this study adopts few advance approaches to maintain balance in power generation and demand. Since AGC relies on highly controllability, the work has proposed a robust type-II fuzzy tilt controller (Type2-FTC) to control power generation in response to active demand of the system. Further, a close comparison analysis has been synthesized to expose superiority of the proposed Type2-FTC over conventional fuzzy controller and standard PID controller. In order to formulate problem in the system, a step load has been injected as the disturbance and controlled dynamic responses of area1 frequency deviation (ΔF_1) and tie-line power variation (ΔP_{tie}) are illustrated in Fig 5(a) and Fig.5(b) respectively. The results are obtained in the Simulink environment with employing proposed Type2-FTC controller. To justify superiority of the proposed Type2-FTC approach over basic fuzzy and PID controller. a close comparison analysis has been synthesized in common platform.

In optimal concern, a novel QO-PFA algorithm is employed make fit parameters of the suggested controller with ten different runs, however the best set of parameters are selected to simulate the proposed hybrid model. The optimal parameters of the proposed QO-PFA algorithm are given in Table2. A close comparison study on results and outcomes justifies outstanding actions of Type2-FTC controller for AGC of the hybrid power network.



(b)

The AGC as well as the performances of the proposed Type2-FTC controller are investigated with the action of random and stochastic load disturbance. The responses of time variant random load and stochastic load are depicted in Fig.5(c) and Fig.5(e) respectively. Under the disturbance of random load, the controlled response of variation in are1 frequency is depicted in Fig.5(d), however the controlled response of tie-line power deviation under the action of stochastic load is depicted in Fig.5(f). A close comparison analysis over all responses exhibit superiority of the proposed Type2-FTC approach for power generating governing of hybrid system.

5.2: Analysis over combined AGC and ELD

This section of the result and discussion address the AGC action of the multi area power system in constraint to the optimal dispatch. The combined AGC and ELD actions are obtained in a common platform with employing suitable controllers i.e. primary controller and secondary controller. The secondary controller is only meant for the AGC action, however the primary controller is responsible both for the AGC and ELD actions. To demonstrate concisely, the combined AGC & ELD analysis has been progressed through three different steps.

Step1: Controller Analysis, *Step2*: Methodology Analysis, *Category3*: Sensitive Analysis

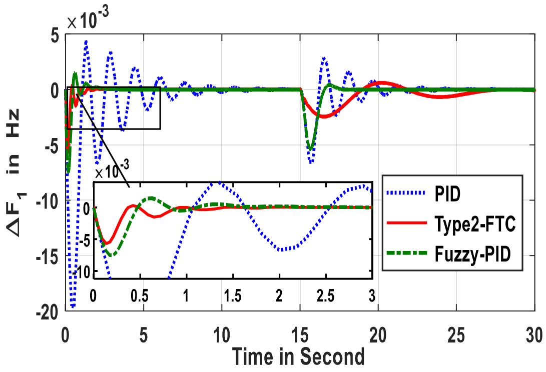
Step.1: Controller Analysis

The performance and the effectiveness of the proposed Type2-FTC over fuzzy controller and standard PID controller has been well synthesized in this section. The performance study is carried out in regard to AGC and ELD of the proposed system. For this study, the analysis over only AGC has been synthesized with activating secondary controller for a period from 0 to 15 second. However, the combined AGC-ELD analysis has been synthesized from 15 second to 30 second with activating only primary controller. The dynamic behavior of all implemented controllers are tested with a common techniquei.e. proposed QO-FPA technique under different loadings. With the realization of stet load uncertainty, the optimal parameters of the proposed QO-PFA designed Type2-FTC controller as both primary/ED controller (15s-30s) and secondary controller (0-15s) are given in Table2. The standing performance of the Type2-FTCapproach is examinedthrough various simulated dynamic responses and are addressed in this section. In AGC-ELD concern, the generation limit of each area along with cost coefficients are addressed in Table.3. The overall analysis has been progressed under various disturbances.

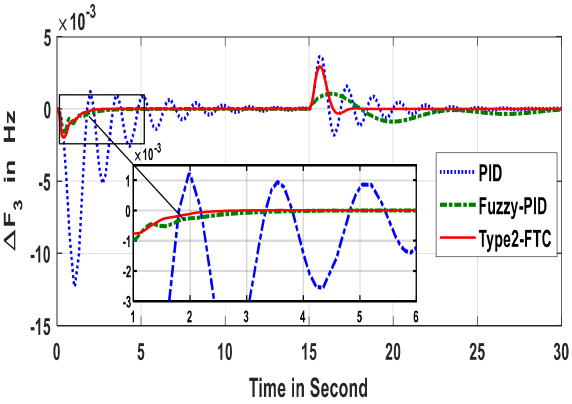
Case 1: Performance study under a step load disturbance of 1% at area1 only.

Area/ Technique/ Controller		QOPFA optimized Type2-FTC as Secondary Controller				QO-PFA optimized Type2-FTC as Primary/ED Controller			
		K_1 K_I	K_2 K_D	K_T λ		K_1 K_I	K_2 K_D	K_T λ	
Ar.1	Thermal	1.112 -1.348	1.678 0.102	0.764	1.330	1.675 -1.204	0.228 0.322	-0.086	1.246
	Hydro	1.248 -1.405	1.120 0.524	1.028	0.905	0.117 -0.930	1.7934 0.692	1.778	-0.621
	Gas	0.762 -0.0098	0.455 0.082	-1.664	1.11	1.827 0.663	0.321 -1.789	-1.675 0.902	-
Ar.2	Thermal	1.125 -0.762	0.116 0.338	0.395	-0.831	0.274 -0.675	0.092 0.882	-1.894	1.789
	Hydro	0.004 1.028	1.287 -1.874	- 1.005 0.704	-	1.443 1.899	1.782 -0.8998	0.0242 0.746	-
	Nuclear	0.904 -0.897	0.786 0.568	- 1.846	0.432	0.5408 0.784	1.678 -1.6746	-0.9024 0.882	
Ar.3	Microgrid	1.562 -1.004	1.897 0.028	0.226	- 1.457	1.386 1.2288	0.677 -0.6476	1.3346 0.694	-
		ITAE = 4.8696				ITAE = 12.1212			

The case study demonstrates the performance of the of the suggested controller under the injection of 1% step load at area1 only. The performance analysis has been carried out in regard to AGC and ELD of the proposed hybrid system. The injected step load disturbance creates frequency and tie-line power instability issues in the system.The research study has been advanced with the realization of an advanced QO-PFA algorithm for producing optimum parameters of the proposed Type2-FTC controller. Since the study involves few comparison study, additional two standard controllers like simple fuzzy controller and PID controller are also employed for this study. The only technique called QO-PFA takes necessary care to produce optimum gains in all above controllers. Applying a step load as disturbance, the stable frequency responses of area 1 and area3 are illustrated in Fig.6 (a-b) respectively. In similar manner the responses of deviation in tie-line powers between area1 and ara2 along with area2 and area3 of the proposed power system are depicted from Fig.6 (c) to Fig.6 (d) respectively. This has been concluded from all frequency responses that proposed QO-PFA based Type2-FTC approach is more advanced to reduce frequency deviation to zero in related to standard fuzzy and PID controllers for both AGC and AGC-ELD concern. However, the tie-line power deviation reduces to zero only in AGC concern (0-15s) but it settles for a new value as per the AGC-ELD concern since power always flows from the generation with lower incremental cost to higher incremental cost. In settling and damp out concern, proposed Type2-FTC controller exhibits superior performance over other implemented controllers. The simulated improved dynamic response deals with damp oscillation and reduced settling time.



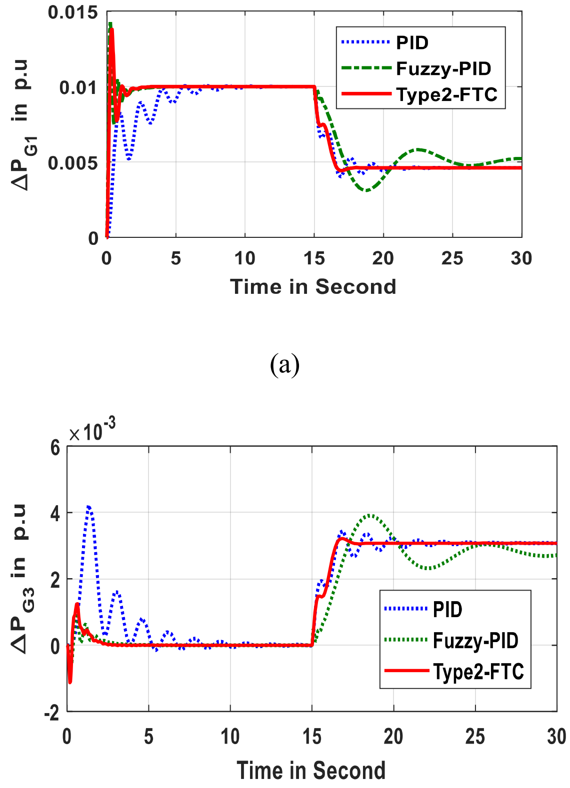
(a)



(b)

Economic Generation Analysis:

Since an incremental load of 1% is effected at area1 only, it is to be needed to upgrade the generation as per the new demand. Under such 1% incremental load, the change in power generation of area1 and area3 are illustrated in Fig,7(a) to Fig,7(b) respectively. In AGC concern, the area1 has increased its generation by 0.01 p.u to meet the increased demand. It shows the area1 has generated fully required power to meet the demand. The area3 generation power unaltered and having few dynamics at the instant of load deviation. In AGC-ELD concern, the increased load of 0.01 has been shared economically among all control areas to meet minimum operating cost. The details scheduling of generation has been well organized in Table.4. It has been seen from dynamic responses that for AGC-ELD (15s-30s) action, to meet increased load of 1% (0.01p.u) area1 contributes 0.005 p.u, area2 and area3 participates for 0.0022 p.uand 0.0028 p.u respectively. The percentage of load sharing are obtained by each generating area irrespective of their cost. In stability concern, proposed QO-PFA designed Type2-FTC controller is found to be more superiority over FL-PID and PID controller in response to control the generation of each individual area.



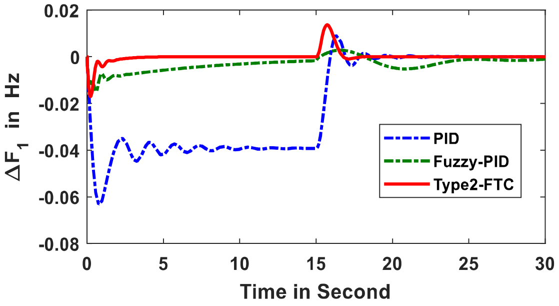
(a)

(b)

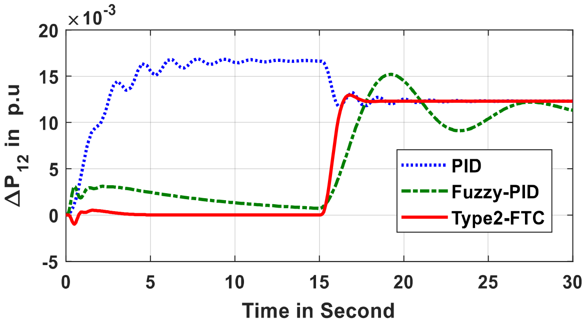
Fig.7(a) Response of incremental change in area-1 power generation (b) Area-3 power generation response

Case 2: Performance study under a 2% step disturbance at area1 and 5% at area2.

In this case study an extensive study on frequency stability and interline power regulation along with generation schedule has been synthesized under the realization of a step load disturbance of 2% and 5% at area1 and area2 respectively. Under such load dynamics, the controlled responses of deviation in area1 frequency and tie-line power between area1 & area2 are depicted in Fig.8(a-b) respectively. In stability concern, the proposed Type2-FTC controller is more effective over Fuzzy-PID and PID controllers to damp out the oscillation as well as settles faster. Moreover, the proposed Type2-FTC controller is able to maintain nominal frequency and scheduled tie-line power in the system faster under step load disturbances. In AGC concern, the deviation in tie-line power settles to zero but in AGC-ELD (15s-30s) concern the tie-line power deviation settles to a new value rather zero since power flows from generation with lower incremental cost to generation with higher incremental cost.



(a)



(b)

Fig.8(a) Response of incremental change in area-1 frequency (b) Tie-line power digression between area1 and area2

Economic Generation Analysis:

In this case study, an incremental load of 2% and 5% are effected at area1 and area2 respectively. So it is required to upgrade the generation as per the new demand. Under such incremental load disturbance, the change in power generation of area1 and area3 are illustrated from Fig,8(c) andFig,8(d) respectively. In AGC concern, the area1 has increased its generation by 0.02 p.u to meet its own increased demand. The area2 also increased its generation by 0.05 (5%) to meet its own area increased demand. Since no load disturbances are associated at area3, there is no need to change the generation of area3.The generation of area3 is little bit oscillated at the instant of disturbance then it settles to zero through suitable control action. It indicates to take increased load demand only area1 and area2 are upgrading their generation in order to face their own increased demand. However, for AGC-ELD concern all area has to regulate their generation economically so as to meet increased demand as well cost optimization successfully. As per the cost function, it has seen that area1 participates for 0.0323 p.u, area2 and area3 contributes by 0.0215 p.u and 0.0162 p.u respectively in order to minimize overall cost. The details scheduling of generation has been well organized in Table.4. In stability concern, proposed QO-PFA designed Type2-FTC controller is found to be more superiority over Fuzzy-PID and PID controller in response to control the generation of each individual area.

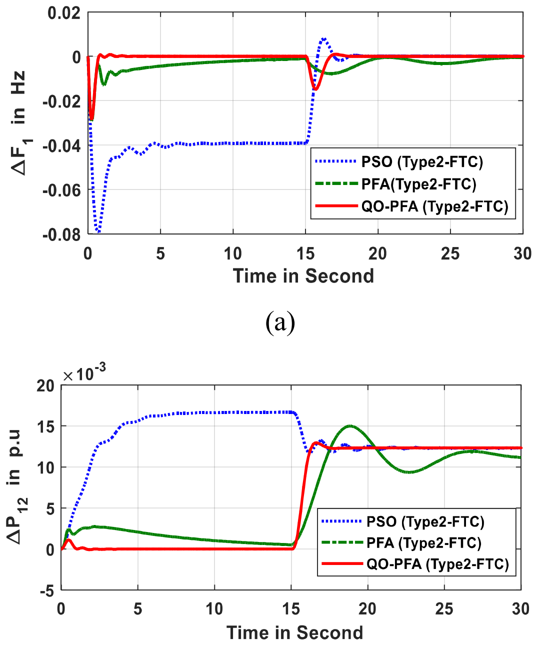
Table.4 Generation scheduling as per the new demand

Generation	Loading Case 1($1*10^{-2}$pu)	Loading Case 2($7*10^{-2}$pu)	Loading Case 3 ($9*10^{-2}$pu)
Change in G_1 power (pu)	$0.50*10^{-2}$	$3.23*10^{-2}$	$4.23*10^{-2}$
Change in G_2 power (pu)	$0.28*10^{-2}$	$2.15*10^{-2}$	$2.12*10^{-2}$
Change in G_3 power (pu)	$0.22*10^{-2}$	$1.62*10^{-2}$	$2.65*10^{-2}$
Change in $P_{tie,12}$ power (pu)	$-0.54*10^{-2}$	$1.23*10^{-2}$	$2.42*10^{-2}$
Change in $P_{tie,23}$ power (pu)	$0.23*10^{-2}$	$-3.38*10^{-2}$	$-1.38*10^{-2}$

Step.2: Methodology Study

The performance and the action of a controller relies on the property of the optimization technique to be implemented in the study. In this step study the effectiveness of the suggested QO-PFA technique are discussed through quantitative analysis and dynamic responses.In order to justify the effectiveness of QO-PFA technique, the performances are compared standard PFA and PSO algorithms. These techniques are implemented separately to tune the gains of proposed Type2-FTC controller. Table.5 depicts the tuned parameters of the proposed controller with employing all above three techniques.

The property and dynamic behavior of the proposed technique has been verified subject to 1% step load disturbance at area1 only. This disturbance creates abnormal condition in the power system and also results consequent frequency instability issues. But the presence optimized Type2-FTC controller tries to wash out instabilities of the parameters in the system. Finally, the variant dynamic responses of area1 frequency and tie-line power with employing proposed QO-PFA and standard PFA and PSO designed Type2-FTC controller are given in Fig.9(a-b) respectively.



(a)

(b)

Fig.9 (a) Response of incremental change in area-1 frequency (b) Tie-line power deviation between area1 & area2

The critical study on outcomes and resulted dynamic responses demands superiority and outstanding performance of the suggested QO-PFA technique for obtaining polished parameters of the proposed Type2FTC controller in this study. The fit polished parameters able to extract improved responses in the system.

Table: 6 various characteristic parameters of the response given in Fig.9

Step 3: Sensitive Study

The sensitive study is a platform to validate robustness of the controller in most of control scenario. The robustnees of controller is an improved performance which avoids frequent tuning under the subjection of the variation in system parameter. The sensitive study is associated with wide regulation of system parameter with untouched controller parameter. Under unique controller parameter, if the system performance is unaffected with wide variation of system parameter then proposed controller performance is said to be robust. In this proposed study, the sensitive study has been carried out with wide variation of thermal system govenror time constant (T_g) and microgrid inertia constant (M). The parameters are regulated with ± 30% from their standard values. The system performances are investigated with proposing QO-PFA based Type2-FTC controller and the parameters of the controller are obtained under standard system parameters. Under the regulation of T_g, the response of deviation in area1 frequency is illustarted in Fig.10(a), However, the dynamic response tie-line power with wide regulation of $M$are depicted in Fig.10(b). The parameters reltaed stability like peak overshoot, undershoot and most settling are gathered in Table.7. The simulated responses reveal under wide variation of system parameter, the unregulated controller parameters are able to obtain improved performance withot affecting the system performance. So suggested Type2-FTC controller is justified as most robustness in response to AGC and AGC-ELD of the hybrid systm

Table: 7 Performance parameters of the responses for sensitive analysis

Conclusion

This section of the research study highlights the outcomes and also novelty of the overall study. Since this proposed study has been associated with various control actions as well as optimal strategies, the dynamic behaviour and effectiveness of the proposed approaches over few standard techniques are clearly synthesized in this section. Critical analysis on result section gives following conclusion and are discussed as followings

1. The suggested Type2-FTC controller acts as an active candidate and capable to make system stable immediately under the action of load dynamics and uncertainties. It is observed from result analysis that proposed Type2-FTC controller is able to wash out the error instantly and improves the settling time of ΔF_1 by 43.8% and 218.8%over conventional fuzzy-PID and PID controller respectively. All the controllers are actuated with a novel technique called QO-FPA algorithm. This shows proposed Type2-FTC controller exhibits an outstanding performance in concern to the AGC and combined AGC-ELD analysis of the system,
2. In optimal design concern, the proposed QO-PFA technique brilliantly produces the optimal parameters of the all implemented controllers which helps to obtain improved dynamic responses of the system. In common Type2-FTC action, the proposed QO-PFA technique able to improve the fitness function (ITAE) by 116.6% and >200% over basic PFA and PSO algorithms respectively.
3. In combined AGC and ELD concern, the proposed approaches guide to share the additional load economically and also help to generate power without deviating the generation limit. Secondly, the response of tie-line power variation settles to a new stable value rather zero as in case of only AGC analysis.
4. Since controller action decides the performance of the system, it is necessary to examine the sensitive property of the

system. The sensitive study validates the robustness of the proposed controller. From result section, it confirms progressive variation of model parameters has no impact over system performance in the presence of common controller.

5. Overall analysis concludes outstanding performance of the proposed QO-PFA designed Type2-FTC approach in response to stability study in AGC and combined AGC-ELD of the multi-source based hybrid power system.

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