A LITERATURE SURVEY: LOAD FREQUENCY CONTROL OF TWO AREA POWER SYSTEM USING FUZZY CONTROLLER

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Abstract:
The objective of the control strategy is to generate and deliver power in an interconnected system as economically and reliably as possible while maintaining the voltage and frequency within permissible limits. In this report the extensive discussion have been made on load frequency control. The survey includes the detail discussion of single area and double area power system and different control strategy that is the control techniques of conventional power system and soft computing techniques which can be used in load frequency control system.
Keywords:- Interconnected system, automatic generation control, tie-line, PID controller and Fuzzy controller

I Introduction

Modern Power Systems, with increasing electrical power demand are becoming more and more complicated. Large interconnected power systems consists of interconnected control areas which are connected through tie lines. Maintaining power system frequency at constant value is very important for the health of the power generating equipment and the utilization equipment at the customer end. The job of automatic frequency regulation is achieved by governing systems of individual turbine generators and Automatic Generation Control (AGC) or Load frequency control (LFC) system of the power system. Automatic generation Control (AGC) is used to maintain scheduled system frequency and tie line power deviations in normal operation and small perturbation. The changes in real power affect mainly the system frequency. In each area, an Automatic Generation Controller (AGC) monitors the system frequency and tie-line flows, computes the net change in the generation required (generally referred to as area control error – ACE) and changes the set position of the generators within the area so as to keep the time average of the ACE at a low value [new-1]. Therefore ACE, which is defined as a linear combination of power net-interchange and frequency deviations, is generally taken as the controlled output of AGC. As the ACE is driven to zero by the AGC, both frequency and tie-line power errors will be forced to zeros [new-2]. Hence, AGC function can be viewed as a supervisory control function which attempts to match the generation trend within an area to the trend of the randomly changing load of the area, so as to keep the system frequency and the tie-line power flow close to scheduled value.

The growth in size and complexity of electric power systems along with an increase in power demand has necessitated the use of intelligent systems that combine knowledge, techniques and methodologies from various sources for the real-time control of power systems. The methods developed for control of individual generators, and eventually control of large interconnections, play a vital role in modern energy control centers. The AGC problem has been augmented with the valuable research contributions from time to time, like AGC regulator designs incorporating parameter variations, load characteristics, excitation control, and parallel ac/dc transmission links. The LFC issues have been tackled with by the various researchers in different time through AGC regulator, excitation controller design and control performance with respect to parameter variation/uncertainties and different load characteristics. As the configuration of the modern power system is complex, the oscillation incurred subjected to any disturbance may spread to wide areas leading to system blackout. In this context, advance control methodology such as optimal control, variable structure control, adaptive control, self tuning control, robust and intelligent control were applied in LFC problem. The further research in this area has been carried out by use of various soft computing techniques such as artificial neural network (ANN), neuro-genetic etc. To tackle the difficulties in the design due to nonlinearity in various segregated components of the controller. The controller parameters play a vital role for its performance, thus it should be tuned properly with suitable optimization techniques. In this context, the application of genetic algorithm (GA), particle swarm optimization (PSO), simulatedannealing (SA) etc. is exploited to address the optimization objective. Due to non linearity in the power system components and also the uncertainty in the system parameters, the performance differs from actual models, so robust control design is indispensible to achieve acceptable deviation in frequency about the nominal operating point. Various robust control techniques such as Riccati equation, H∞, m-synthesis, robust pole assignment, loop shaping, linear matrix inequality (LMI) has been adopted to tackle the LFC problems. Now, there is rapid momentum in the progress of the research to tackle the LFC in the deregulated environment, LFC with communication delay, and LFC with new energy systems, FACTS devices, and HVDC links as well.

II load frequency control

The operation objectives of the load frequency control are to maintain reasonably uniform frequency, to divide the load between generators, and to control the tie-line interchanged schedules. the change in frequency and tie line real power are sensed , which is a measure of the change in rotor angle δ, i.e the error Δδ to be corrected. The error signal, i.e, Δf and ΔP_{tie} , are amplified , mixed , and transformed into a real power command signal ΔPv, which is sent to the prime mover to call for an increment in the torque. The prime mover, therefore, brings changes in the generator output by an amount ΔP_g which will change the values of Δf and ΔP_{tie} within specified tolerance. When constant frequency is needed the turbine speed can be adjusted by varying the governor characteristic. The relationship between active power and frequency, three level automatic generation controls have been proposed by power system researchers [1]. Generally, ordinary LFC systems are designed with Proportional-Integral (PI) controllers[2].

Many studies have been carried out in the past on this important issue in power systems, which

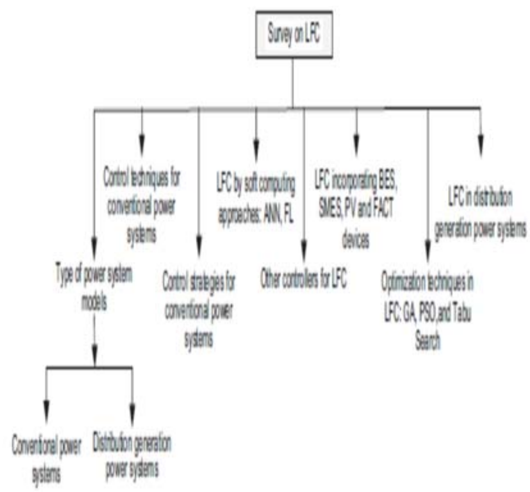


Figure 1. Illustration of survey on LFC

is the load frequency control. As stated in some literature , some control strategies have been suggested based on the conventional linear control theory [3-7]. These controllers may be improper in some operating conditions. This could be due to the complexity of the power systems such as nonlinear load characteristics and variable operating points. In this study, different intelligent techniques such that Fuzzy Logic, *Genetic Algorithm* (GA) and *Particle*

Swarm Optimization (PSO) algorithms will be used to determine the parameters of a PID controller according to the system dynamics. In the integral controller, if the integral gain is very high, undesirable and unacceptable large overshoots will be occurred. However, adjusting the maximum and minimum values of proportional (kp), integral (ki) and integral (kd) gains respectively, the outputs of the system (voltage, frequency) could be improved. In this simulation study, two area power system with two different parameters are chosen and load frequency control of this system is made based on PID controller. This work is an improvement of which assumes that the two areas of the power system have the same parameters which is not usually practical assumption for the real power system networks [8]. This work is also an improvement of by using the three different tuning techniques (Fuzzy Logic , GA and PSO) and by using saturation for the control valve while the previous work uses only one technique and don't take the saturation into consideration [9-11]. This work is also an improvement of that two power system areas connected are used instead of single power system area in the previous works[12-14]. The overshoots and Settling times with the proposed Genetic-PID controller are better than the outputs of the conventional PID controllers tuned by Ziegler-Nicholas technique, fuzzy technique and Particle Swarm Optimization.

III Automatic Gain Control

If the load on the system is increased, the turbine speed drops before the governor can adjust the input of the steam to the new load. As the change in the value of speed diminishes, the error signal becomes smaller and the position of the governor flyballs gets closer to the point required to maintain a constant speed. The way to restore the frequency to its nominal value is to add an integrator. The integral unit monitors the average error over a period of time and will overcome the offset. Because of its ability to return a system to its set point, integral action is known as *the rest action*. Thus, as the system load changes continuously, the generation is adjusted automatically to restore the frequency to the nominal value. This scheme is known as *the automatic generation control (AGC)*. In an interconnected system consisting of several pools, the role of AGC is to divide the loads among system, stations, and generators so as to achieve maximum economy and correctly control the scheduled interchanges of tie-line power while maintaining a reasonably uniform frequency.

III.1 AGC in a Single & Double Area System

Generally, power systems obligate composite & multi-variable configurations and they have many non minimum and nonlinear phase systems. Power networks are distributed by tie lines into regulator Areas. Generators are expected to maintain synchronism with the tie line and connected Areas. From experimentations on different power networks, it's realized that individual Area requires precise control of its tie line power & system frequency. There are basically two types of control mechanism to control frequency in interconnected power systems i.e. first one is primary speed control & second one is secondary speed controller . The first speed control creates the preliminary rough alteration of frequency. For its activities, the variation in load is being tracked by the generators and share among them according to their ratings. The inherent time lags of the system and the turbine itself is the major cause for the slow response of the system.

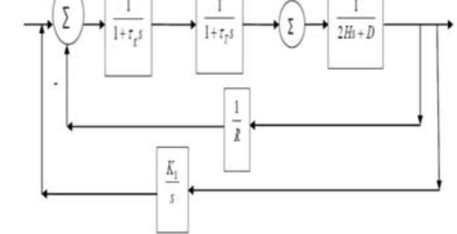


Figure 2. Isolated Power System Model

Liable on the turbine kind, the primary loop classically responds in 2–18 s. The later speed control follows the well alteration of frequency by varying the frequency inaccuracy to zero by an integral control action. The association among the load and speed is accustomed by varying a load set point input. In exercise, the tuning of the load reference mark point is being done by functioning the speed changing motor. In production of every division at a specified system frequency is changed only by varying its load reference, which manages to change the speed-droop characteristic up and down.

The closed loop transfer function of the control system is given by:

$$-\frac{\Delta\Omega(S)}{\Delta P_L(S)} = \frac{S(1+\tau_g S)(1+\tau_T S)}{S(2Hs+D)(1+\tau_g S)(1+\tau_T S)+K_1+\frac{S}{R}}$$

This control is significantly sluggish and drives to action only when the job is done by the primary speed control. Reaction period can be very low like I minute. Regulation of the frequency is done by the speed-governing system. The isochronous governor changes the turbine valve/door to get the frequency once again to the ostensible or booked rate. An isochronous governor performs attractively when a generator is providing a disconnected load or when one and only generator in a multi generator framework is obliged to react to the heap variations.

For power and load imparting around generators joined with the framework, speed regulation or droop attributes must be given.

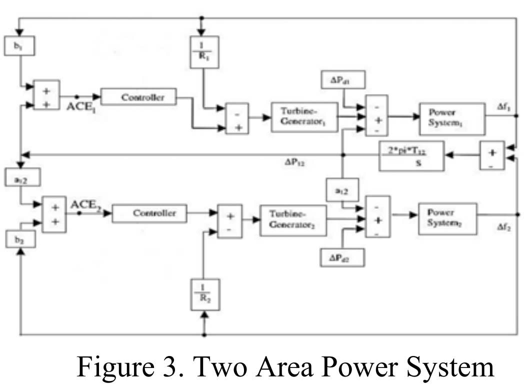


Figure 3. Two Area Power System

The speed-droop or regulation trademark can be acquired via including an unfaltering state sentiment circle about the integrator.

Electric power is generated by converting mechanical energy into electrical energy. The rotor mass, which contains turbine and generator units, stores kinetic energy due to its rotation. This stored kinetic energy accounts for sudden increase in the load. Let us denote the mechanical torque input by T_m and the output electrical torque by T_e . Neglecting the rotational losses, a generator unit is said to be operating in the steady state at a constant speed when the difference between these two elements of torque is zero. In this case we say that the accelerating torque

$$T_a = T_m - T_e \text{.........(1)}$$

When the electric power demand increases suddenly, the electric torque increases. However, without any feedback mechanism to alter the mechanical torque, T_m remains constant. Therefore the accelerating torque given by (1) becomes negative causing a deceleration of the rotor mass. As the rotor decelerates, kinetic energy is released to supply the increase in the load. Also note that during this time, the system frequency, which is proportional to the rotor speed, also decreases. We can thus infer that any deviation in the frequency for its nominal value of 50 or 60 Hz is indicative of the imbalance between T_m and T_e. The frequency drops when $T_m < T_e$ and rises when $T_m > T_e$.

$$-R = \frac{\Delta f}{\Delta P_m} \text{..............(2)}$$

where R is called the regulating constant .

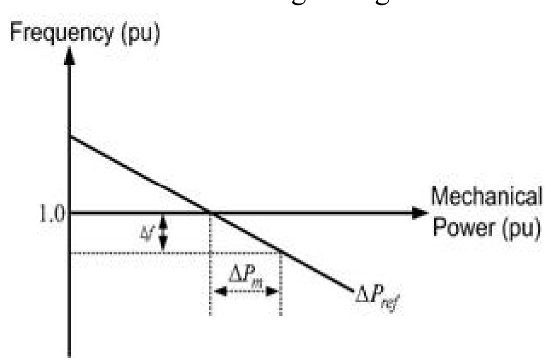


Figure 4 A typical steady-state power-frequency curve.

$$\Delta P_m = \Delta P_{ref} - \frac{1}{R}\Delta f \ldots\ldots(3)$$

From this figure we can write the steady state power frequency relation as

Suppose an interconnected power system contains N turbine-generator units. Then the steady-state power-frequency relation is given by the summation of (3) for each of these units as

$$\Delta P_m = \Delta P_{m1} + \Delta P_{m2} + \cdots + \Delta P_{mN}$$

$$= (\Delta P_{rd1} + \Delta P_{rd2} + \cdots + \Delta P_{rdN}) - \left(\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}\right)\Delta f \quad \ldots(4)$$

$$= \Delta P_{rd} - \left(\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}\right)\Delta f$$

In the above equation, ΔP_m is the total change in turbine-generator mechanical power and ΔP_{ref} is the total change in the reference power settings in the power system. Also note that since all the generators are supposed to work in synchronism, the change is frequency of each of the units is the same and is denoted by Δf. Then the frequency response characteristics is defined as

$$\beta = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N} \ldots\ldots\ldots\ldots(5)$$

We can therefore modify (4) as

$$\Delta P_n = \Delta P_{rd} - \beta\Delta f \ldots\ldots\ldots\ldots(6)$$

Modern day power systems are divided into various areas. For example in India , there are five regional grids, e.g., Eastern Region, Western Region etc. Each of these areas is generally interconnected to its neighboring areas. The transmission lines that connect an area to its neighboring area are called tie-lines . Power sharing between two areas occurs through these tie-lines. Load frequency control, as the name signifies, regulates the power flow between different areas while holding the frequency constant. As we have above that the system frequency rises when the load decreases if ΔP_{ref} is kept at zero. Similarly the frequency may drop if the load increases. However it is desirable to maintain the frequency constant such that $\Delta f=0$. The power flow through different tie-lines are scheduled - for example, area- i may export a pre-specified amount of power to area- j while importing another pre-specified amount of power from area- k . However it is expected that to fulfill this obligation, area- i absorbs its own load change, i.e., increase generation to supply extra load in the area or decrease generation when the load demand in the area has reduced. While doing this area- i must however maintain its obligation to areas j and k as far as importing and exporting power is concerned. A conceptual diagram of the interconnected areas

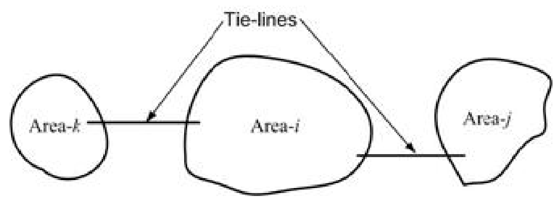


Figure 5 Interconnected areas in a power system

We can therefore state that the load frequency control (LFC) has the following two objectives:

Hold the frequency constant ($\Delta f = 0$) against any load change. Each area must contribute to absorb any load change such that frequency does not deviate.

Each area must maintain the tie-line power flow to its pre-specified value.

The first step in the LFC is to form the area control error (ACE) that is defined as

$$ACE = (P_{tie} - P_{sch}) + B_f\Delta f$$

$$= \Delta P_{tie} + B_f\Delta f \ldots\ldots\ldots\ldots(7)$$

where P_{tie} and P_{sch} are tie-line power and scheduled power through tie-line respectively and the constant B_f is called the frequency bias constant .

The change in the reference of the power setting $\Delta P_{ref,\ i}$, of the area- i is then obtained by the feedback of the ACE through an integral controller of the form

$$\Delta P_{ref,i} = -K_i \int ACE\, dt \text{ ……….(8)}$$

where K_i is the integral gain. The ACE is negative if the net power flow out of an area is low or if the frequency has dropped or both. In this case the generation must be increased. This can be achieved by increasing $\Delta P_{ref,\ i}$. This negative sign accounts for this inverse relation between $\Delta P_{ref,\ i}$ and ACE. The tie-line power flow and frequency of each area are monitored in its control center. Once the ACE is computed and $\Delta P_{ref,\ i}$ is obtained from (8), commands are given to various turbine-generator controls to adjust their reference power settings.

Literature Survey

IV Control techniques for conventional power systems

IV.1 Classical control approaches

Conventionally, for issues related to automatic generation control (AGC), the frequency deviation is minimized by the flywheel type of governor of synchronous machine. However, the significant control is not achieved for the LFC objective. In this context, the supplementary control is introduced to the governor via signal directly proportional to the frequency deviation plus its integral action. The initial stage of research work carried out by Cohnetal is reported in [15-19]. Quazz proposed the approach with non-interaction between frequency and tie-line power control and each control are a responsible for its own load variations [20]. Aggarwal and Bergseth investigated study on large signal dynamics of systems [21]. The technique based on coordinated system-wide correction of time error and in advertent interchange is incorporated for AGC study by Cohn [22]. A number of classical control techniques namely, Nyquist, Bodereveal that closed loop transient response will result in to relatively large overshoots and transient frequency deviation [23-25].

IV.2 Optimal control approaches

The LFC regulator design techniques using modern optimal control theory enable the power engineers to design an optimal control system with respect to given performance criterion. The optimal control theory has made a new direction to solve the large multivariable control problems in a simplified form. The control scheme considers the state variable representation of the model and an objective function to be minimized. Fosha and Elgerd , used a state variable model and regulator problem of optimal control theory to develop new feedback control law for two-area interconnected non-reheat type thermal power system [26]. Milon Calovic presented linear regulator design for the load frequency control based on optimal line a regulator theory [27]. The author has investigated the effect of plant response time on the closed loops poles, designed using linear optimal control theory [28]. A more realistic model of the LFC system is developed and studied, by including the voltage regulator excitation system and optimal responses are computed under various load conditions [29]. Kwatny et al. presented there view of recent efforts in applying optimal linear regulator theory with intent to clarify the objectives of LFC, particularly as regard to the application of modern control theory [30]. Hsu and Chan presented a systematic approach to design an optimal variable-structure controller (VSC) for the LFC in the interconnected power system [31].

The feasibility of an optimal AGC scheme requires the availability of all state variables for feedback. However, the see efforts seem unrealistic, since it is difficult to achieve this. Then, the problem is to reconstruct the unavailable states from the available Outputs and controls by an observer design. Considering state reconstruction, many significant contributions have been made [32-37]. Bohn and Miniesy have studied the optimum LFC of a two area interconnected power system by making the use of (i) Differential approximation and (ii) a Luenberger observer and by introducing an adaptive observer for identification of unmeasured states and unknown deterministic demands, respectively [32]. Exploiting the fact that the non linearity of the power system model, namely, the tie-line power flow, is measurable, the observer has been designed to give zero asymptotic error, even for the nonlinear model. AGC schemes based on an optimal observer, which is a state estimator with decaying error at a desired speed, using a nonlinear transformation and reduced order models with a local observer have been discussed [33-34]. An observer for nonlinear system is presented in [38]. A simplified generating unit model oriented towards LFC and the method for its transfer function identification based on a two stage procedure indirectly reducing both noise effects and transfer function order is presented in [37].

IV.3 Sub-Optimal control approaches

The computational complexity of a multi area system leads to solve the optimal control problem in a modified form. Therefore, sub optimal control strategy is explored for the LFC problem. In order to remove the practical limitations in the implementation of regulators based on full order state feedback, suboptimal AGC regulator designs were considered [39-41]. Moorthi and Aggarwal presented sub optimal and near-optimal control using modern control theory [39]. The AGC schemes based on an optimal observer, which is a state estimator with decaying error at a desired speed, using a non linear transformation and reduced-order models with a local observer is discussed [42-43]. Hain etal reported a simplified generating unit model oriented towards LFC and the method for its transfer function identification based on a two stage procedure in directly reducing both noise effects and transfer function order [44] . The sub optimal AGC regulator design of a two area interconnected reheat thermal power system using output vector feedback control strategy is presented in [45]. The design method employing modal and singular perturbation techniques to affect decoupling of the interconnection in to its subsystem components is considered in [46]. In the method, after achieving the decoupling, local controllers for each subsystem are designed individually to place the closed-loop poles of each subsystem in some prespecified locations in the complex plane, and then, the resulting controllers are used to generate local control inputs, using local information only. The AGC regulator design using Lyapunov's second method and utilizing minimum settling time theory is proposed in [47]. The importance of the dominant time constant of the closed-loop systems in designing the regulators has been emphasized. The author has reported a bang–bang AGC policy based on this method.

V. Soft computing techniques in LFC

With increased size and changes in structure of the power system due to integration of renewable energy sources,the traditional LFC may not be feasible.In the robust control scheme,the structural complexity and reshaping of the plant may be required.To circumvent this problem,the intelligent control scheme with use of soft computing techniques such as artificial neural network (ANN), fuzzy logic, genetic algorithm

(GA), particle swarm optimization(PSO) algorithms, etc. has been explored. In this context to address the non linearities, system uncertainties, the intelligent LFC scheme may be the suitable alternative,than the traditional controls. Over the years, number of soft computing techniques has been applied in LFC problem for better control objective.

V.1. Artificial neural network (ANN)

The ANN is a black box which correlates the non-linear relationship between output and input without information of system structure. The ANN has been applied to achieve better control strategies especially in a non-linear complex power system. Beaufaysetal. [48] discussed the application of layered neural networks in nonlinear power systems, while Birchetal. [49] investigated the use of neural networks to act as the control intelligence in conjunction with a standard adaptive LFC scheme. Chaturvedi etalhave developed an automatic load fre quency controller using ANN to regulate the power output and system frequency by controlling the speed of the generator through water or steam flow control [50]. Demirorenetal designed the controller, taking into account the governor dead band effect and reheat effect in two area inter connected power system [51]. Ahamed et al have viewed AGC problem as a stochastic multistage decision making problem or a Markov Chain control problem and have presented algorithm for design of AGC based on a reinforcement learning approach [52]. Talaq etal proposed an adaptive controller which requires less training patters as compared with a neural net work based adaptive scheme and performance is observed better than fixed gain controller [53].

V.2. Genetic algorithms (GAs)

The GA is a global search optimization technique based on operation of natural genetics and Darwinian survival of the fittest with a randomly structured information exchange. The GAs have been widely applied to solve complex nonlinear optimization problems in a number of engineering fields in general and in the area of AGC of power systems in particular [54,55,56–62]. The use of basic genetic algorithm on a digital computer to identify a hydro-generator plant is discussed in [55]. Dangprasert etal proposed GA based intelligent controller for LFC problem [63]. The GA based fuzzy gain scheduling approach for power system LFC is discussed in [64-65]. Magid and Dawoud proposed their study on optimal adjustment of the classical AGC parameters using GA [57]. The use of controllers to regulate the power output and system frequency by controlling the speed of the generator with the help of fuel rack position control is presented in [56]. The authors proposed GA for parameter optimization of PID sliding mode LFC for AGC in multi-area power systems with nonlinear element in [66]. Rerkpreedapong etal obtained a higher order robust dynamic performance with LFC design based on GA and LMIs [54]. Next, Ghoshal proposed GA/GA-SA-based fuzzy AGC scheme in a multi-area thermal plant [62]. The hybrid GA-SA technique yields more optimal gain values than GA. DuandLi proposed on line fuzzy logic controller realization by GA in AGC problem [67]. The LFC by fuzzy PI controller is proposed in [68]. The optimization of control parameters for robust decentralized frequency stabilizer by using micro GA is presented in [69]. A new design of multi objective evolutionary algorithm based decentralized load frequency controllers for interconnected power system with AC-DC parallel tie lines is proposed in [70]. Comparison of artificial intelligence methods for LFC study is discussed in detailed in [71]. The authors have discussed the design of load frequency controller in multi-area power system by use of multi-agent reinforcement learning approach in [72]. The LFC problem for four-area power system with discrete-sliding mode control using GA for proper tuning of the gains is discussed in [73]. The multi-objective optimization based GA used to optimize the gains of PI/PID-controllers for LFC of three-area thermal power systems is presented in [74].

V.3. Particle swarm optimization (PSO) algorithms

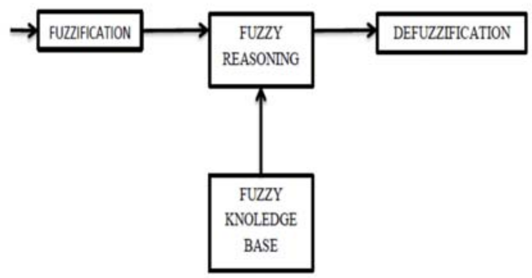
The PSO conducts searches using a population of particles which correspond to individuals in the GA. The PSO is a population based stochastic optimization technique, inspired by social behavior of bird flocking or fish schooling. To ease the design effort and there by improve the performance of the controller, the design of fuzzy PI controller by hybridizing GA and PSO is presented in [68]. With the use of control scheme based on adaptive neuro fuzzy inference and PSO with gains being updated in real time, a better dynamic and steady state response is obtained in [75]. Similarly the design of multi objective PID controller for LFC based on adaptive weighted particle swarm optimization in two area power system is described in [76-77]. Since PSO is less susceptible to local optima unlike GA, SA, the heuristic evolutionary search technique based hybrid particle swarm optimization has been adopted for determination of optimal PID gains for LFC in four area power systems having deregulation environments [78].

V.4. Fuzzy Controller

Fuzzy set hypothesis and fuzzy rationale secure guidelines of a nonlinear plotting. Utilization of fuzzy sets gives a premise to a organized path for the requisition of indeterminate and inconclusive prototypes. Fuzzy controller is focused around a legitimate structure termed fuzzy rationale is very nearer in soul to human intuition and regular dialect than established intelligent systems. These days fuzzy rationale is utilized as a part of very nearly all parts of manufacturing and science. From those LFC is one. The primary objective of LFC in connected power networks is to secure the harmony among handling and utilization. In light of the multifaceted nature and multi-parameterized states of the power system, traditional controller strategies possibly will not give acceptable results. Then again, their strength and unwavering quality make fuzzy controllers helpful in understanding an extensive variety of control issues. The fundamental constructing units of a Fuzzy Logic Controller are a fuzzification unit, a fuzzy rationale thinking unit, a learning base, and a defuzzification unit. It is the procedure to change the convinced fuzzy control movements to a fresh control movement.

Assumptions in FLC system:

- The input and output variables can be witnessed and calculated.
- An acceptable result, not certainly a best, is adequate.
- A linguistic design may be created centered on the facts of a human expert.
- The human expert helps in modeling the linguistic model based on his knowledge



The basic building block of a fuzzy logic controller consist of four parts namely fuzzification of input followed by fuzzy reasoning and rule base to make perfect decisions. Then this block is being followed by knowledge base which defines all variables and parameters. The last block is the defuzzification block whose main function is to convert the fuzzy outputs to definite crisp values

Conclusion

The techniques and strategies of LFC for conventional systems attracted much discussion in the recent past. An effort has been made to present critical and comprehensive revive on this subject. Emphasis has been given how to tackle the LFC issues in power system. A detail survey has been done and presented. Light has been thrown on categorizing various power system structure/ layout reported in the literature that focuses on LFC control techniques adopted and their shortcomings. This survey paper will serve as a valuable reference for researchers to work on LFC problem in two area power system.

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