A Brief Survey: Automatic Generation Control of Two-Area Hydro-Thermal Electric Power Systems

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Abstract: Worldwide researchers are trying to propose various AGC strategies to sustain the system frequency and tie-line power flow at their desired values during normal operation and during small load perturbations as reviewed critically in this paper. The literature survey analysis reveals that various types of control approaches in association with various types of optimization techniques have been suggested by researchers in the recent decades for AGC performance enrichment of power systems. It has been found that a classical controller optimized at a specific operating condition may not perform adequately at altered operating condition. With the classical AGC controller being optimized at definite operating condition, the power system may lead to instability at changed operating condition due to its random and nonlinear behavior. To enhance AGC performance of power system under changed operating conditions, some researchers are working to improve the traditional PI, PID controllers to achieve constant required frequency in least time according to load variations. In this paper, basic building blocks of a two-area hydro-thermal generation unit have been briefed for the understanding of the working of general hydro-thermal energy generation units.

Index Terms: **PID controller, Two area hydro-thermal generation units, AGC, Load variations etc.**

I. INTRODUCTION

Power system control is the most significant task for its secure operation because of dynamic variations in loads. The main objective of the LFC is to maintain the system frequency and the power flow in the tie-line as per the contract made between the areas and to do the generation scheduling optimally. The frequency and tie-line power variations are retrieved to nominal value with the help of speed governor in the control area. Speed governor acts as primary controller matches the generation with the demand and fine tuning is carried out by secondary controller. Practically, each area will have both hydro and thermal power plant. Such system is named to be multi source multi area hydro thermal system . The researchers failed to focus the LFC problem of Multi Source Multi Area (MSMA) system considering the non-linearities such as, dead band, boiler dynamics and reheat steam turbine. Moreover, LFC problem is dealt by various researchers, are based on equal area capacities and with unit step load disturbance. In practice, area capacities are not same and the system is subjected to random load variations. Taking into account the impact of non-linarites in multi-source multi area system under unequal area capacities with random load variations is identified as the LFC problem in modern research. Conventionally, PI controller is used for controlling the tie-line power and frequency oscillations along with the speed governor. but ZN method and FGS are also used for the PI tuning. In PI controller, P improves the transient response but weakens the steady state. Similarly, I controller improves the steady state but spoils the transient behavior. This problem is overcome by Variable Structure System (VSS) controller which switches between P to PI during transient to steady state period.

II. EXISTED WORK

Sahu et al. [1] proposed a hybrid fuzzy PI controller for automatic generation control of multi area systems. Initially a two area thermal power system is considered and the input scaling factors and gains of fuzzy PI controller are simultaneously optimized using a hybrid Particle Swarm Optimization and Pattern Search (hPSO-PS) technique. The proposed hybrid technique takes advantage of global exploration capabilities of PSO and local exploitation capability of PS. The advantage of proposed hPSO-PS technique over PSO has also been demonstrated.

Arya et al. [2] presentedImperialist competitive algorithm (ICA) optimized output scaling factors (SF) based FPIDF- II controller for AGC problem solution of two-area interconnected electrical power systems. At first, a well accepted two-area non-reheat thermal power system with and without considering GDB nonlinearity is examined. The simulation results are carried out with 1% and 5% SLPs in area-1. The study is further extended to two-area re- heat thermal power system with 1% SLP in area-1, two-area PV-reheat thermal grid system under 10% SLP in area-2 and two-area multi-source hydrothermal power system with 1.5% SLP in area-1.

Lua et al. [3] proposed a robust PI controller with its parameters optimized by CPEO embedded by TCH method to handle the constraint called CPEO-LMI-PI control scheme, wherein the LMI technique is applied to describe the H∞ constraints and ITAE taking error performance requirement constraint is employed as another constraint for improving the control performance and dealing with some nonlinear terms.

Chandra et al. [4] demonstrated AGC of two area diverse energy source based non linear power system in different system parametric conditions. The proposed fuzzy controller has an ability to improve system performance significantly under different uncertainties. In order to obtain precious gains of proposed type-II fuzzy controller a hybridized hyGWO-SCA technique has been applied. It has been investigated through different dynamic responses that dynamic responses associated with proposed hyGWO-SCA tuned type-II fuzzy PID controller are improved significantly in regards to different performance index parameters.

Yogendra et al. [5] proposed a new fuzzy aided ICA optimized PIDN-FOI controller for AGC of two-area interconnected power systems. At first, a well approved two-area non-reheat thermal power system is examined under 5% SLP in area-1. The dynamic performance of the proposed controller is compared with PID/PIDN/FPI/FPID controller optimized via various intelligent techniques like TLBO/JA/hPSO-PS/PSO/PS reported in state-of-the-art literature and PID/PIDN/FPIDN controller designed in the study.

Chandrakala et al. [6] considered combined LFC–AVR model for analysing multi source multi area system under unequal area capacities with non-linearities. The system is subjected to unit step load disturbance only in area 1. The speed governor of the LFC loop helps in matching the generation with the demand. But, fine tuning of frequency, tie-line power flow and voltage variations is achieved by PID controller. PID controller of multi source multi area system was tuned using SA and ZN techniques

Hakimuddin et al. [7] presents the design and implementation of PID structured centralized and decentralized controllers for AGC of a more realistic power system model with multi source power plants in each area.GA optimization technique has been applied to obtain the optimal gains of centralized and decentralized AGC controllers by developing ISE performance index as an objective function.

Diggavi et al. [8] done investigation of two area and three area systems with PI and fuzzy logic controllers. Considering the disturbance as 1%, the result for different cases are compared and it shows that fuzzy logic controller gives improved dynamic response than PI controller. With the aid of fuzzy controller the transients in the frequency response reduced to a great extent.

Sinha et al. [9] proposed a two area system comprising of a hydro and a thermal system in each area. 2-DOF PID controller is employed as the secondary controller in both areas with the controller gains tuned by GSA. The system performance is tested under a step load disturbance in area 1 with ITAE as evaluative function. The respective plots indicate the efficacy and the rapid response of the system under the proposed controller as compared to PID controller. The robustness analysis of the method by applying the sudden load changes establishes the supremacy of the controller over the traditional PID controller.

III. MODELING OF MULTI SOURCE MULTI AREA HYDRO THERMAL SYSTEM

A. Modeling of Thermal System

Practically, non-linearities in thermal power plant are; dead band, boiler dynamics and reheat steam turbine [10]. The mathematical model of thermal power plant furnished by IEEE committee report and researchers [11] with the non-linearities is shown in Figure 1.

In thermal power plant, dead band results due to the function of overlapping of the valves in the hydraulic relays, backlash effects and coulomb friction caused in different governor linkages. It is the magnitude of the frequency deviation of the system which impinges the effect of the dead band on the speed governor response [10]. The speed governor dead band nonlinearity is deduced out of describing function approach [10]. In conventional thermal power plant, drum type boiler is basically used. As per the requirement of the generation to meet with the demand, the turbine control valves are controlled by means of immediate control action imparted by the boiler by sensing the change in steam flow and the drum pressure. This type of control response imparted by the boiler leads to long term dynamics. Generally, researchers concentrate mostly on non-reheat steam turbine but in practice reheat turbine is used. Reheat steam turbine is of second order type since it has different stages due to high and low pressure steam [10].

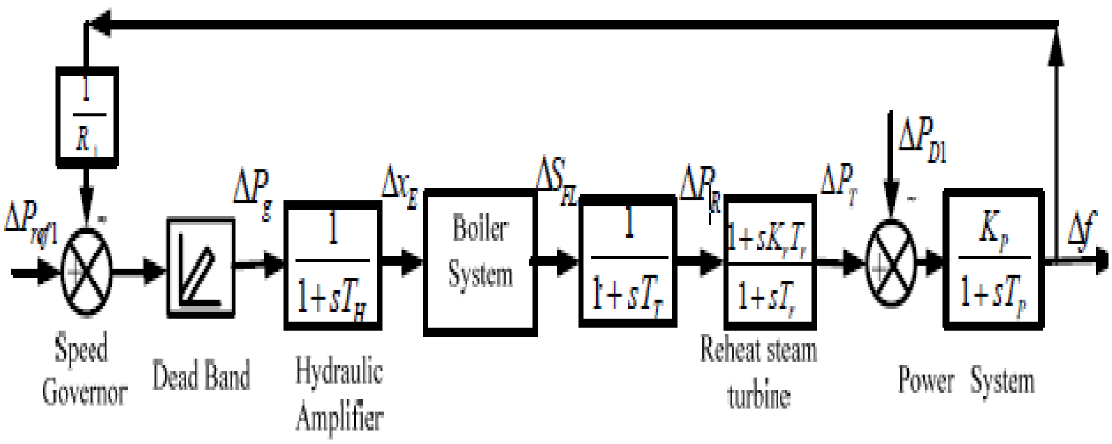

Figure 1: Transfer function model of thermal power plant with governor dead band, boiler dynamics and reheat turbine

The transfer function of reheat steam turbine is represented in Equation (1).

$$\frac{\Delta P_G}{\Delta P_R} = \frac{1 + sK_r T_r}{1 + sT_r} \quad (1)$$

The turbine power output drives the generator which provides the electrical power to the power system. The transfer function of the power system comprising of generator with load disturbance is given in Equation (2) as;

$$\Delta P_T - \Delta P_{D1} = \frac{K_{p1}}{1+sT_{p1}} \Delta f_1 \qquad (2)$$

B. Modeling of Hydro System

The transfer function model of hydro power plant as furnished by the IEEE committee report [12] is shown in Figure 2.

Variable Structure Fuzzy Gain Schedule Based Load Frequency Control

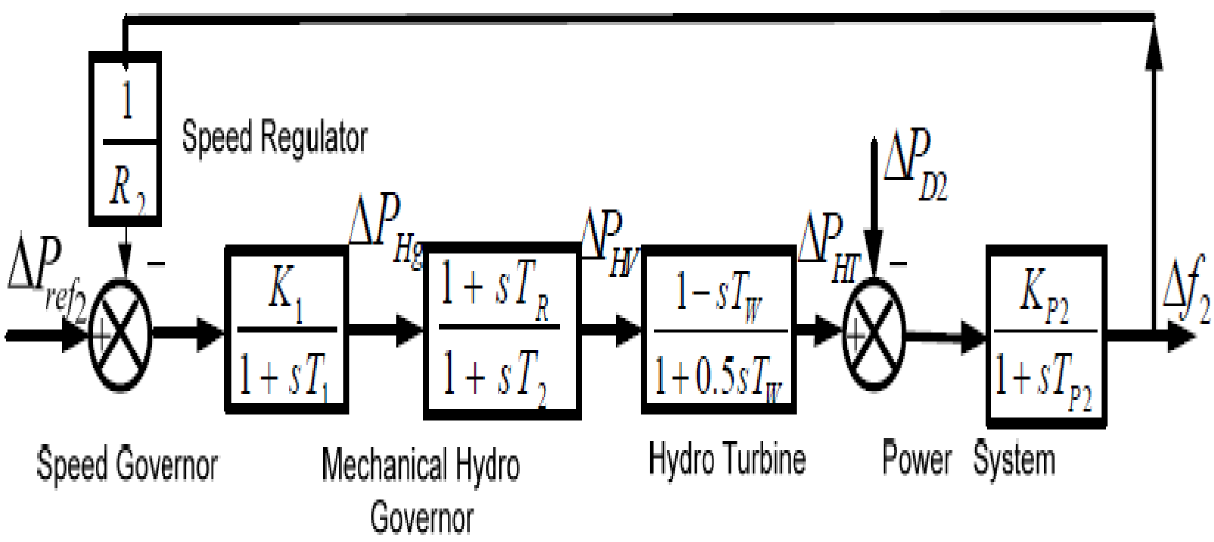

Figure 2: Transfer function model of hydro power plant.

The functioning of speed governor of hydro power plant is similar to that of steam power plant. The transfer function of hydro governor [13] is given by Equation (3) as;

$$\Delta P_{HV} = \frac{1+sT_R}{1+sT_2} \Delta P_{Hg} \qquad (3)$$

where;

$$\Delta P_{Hg} = \frac{K_1}{1+sT_1}(\Delta P_{ref\,2} - \frac{1}{R_2}\Delta f_2)$$

The reset time R T is given in Equation (4)

$$T_R = [5.0-(Tw-1.0)0.5]\mathrm{T}_W \qquad (4)$$

in which; TW is the water time constant whose value varies between 1sec to 4secs for low head hydro turbines. T1 is transient droop time constant in sec which is given in Equation (5)

$$T_1 = \frac{R_{TD}}{R_{PD}} T_R \qquad (5)$$

where;

R_{TD} is the temporary droop which is given in Equation (6)

$$R_{TD} = [2.3-(T_W-1.0)0.15]\frac{T_W}{T_M} \qquad (6)$$

in which TM is equal to 2H ; where H is Inertia constant.

Water is used as an inlet to drive the turbine which is controlled by hydro governor. The transfer function of hydro turbine is given in Equation (7)

$$\Delta P_{HT} = \frac{(1 - sT_{W})}{(1 + 0.5sT_{W})} \Delta P_{HV} \qquad (7)$$

The transfer function of generator connected to power system with a provision to give load disturbance is similar to that in thermal power system as furnished in Equation (2).

C. Modeling of Tie-line

The control areas are interconnected by means of a tie-line to improve the reliability and stability of the system [14]. The power flow through the transmission line is expressed in Equation (8) as;

$$\Delta P_{tie12} = \frac{2\Pi T}{s}(\Delta f_1 - \Delta f_2) \qquad (8)$$

D. Modeling of Multi Source Multi Area Hydro Thermal System

The transfer function model of multi source multi area hydrothermal system shown is developed is shown in Figure 3.

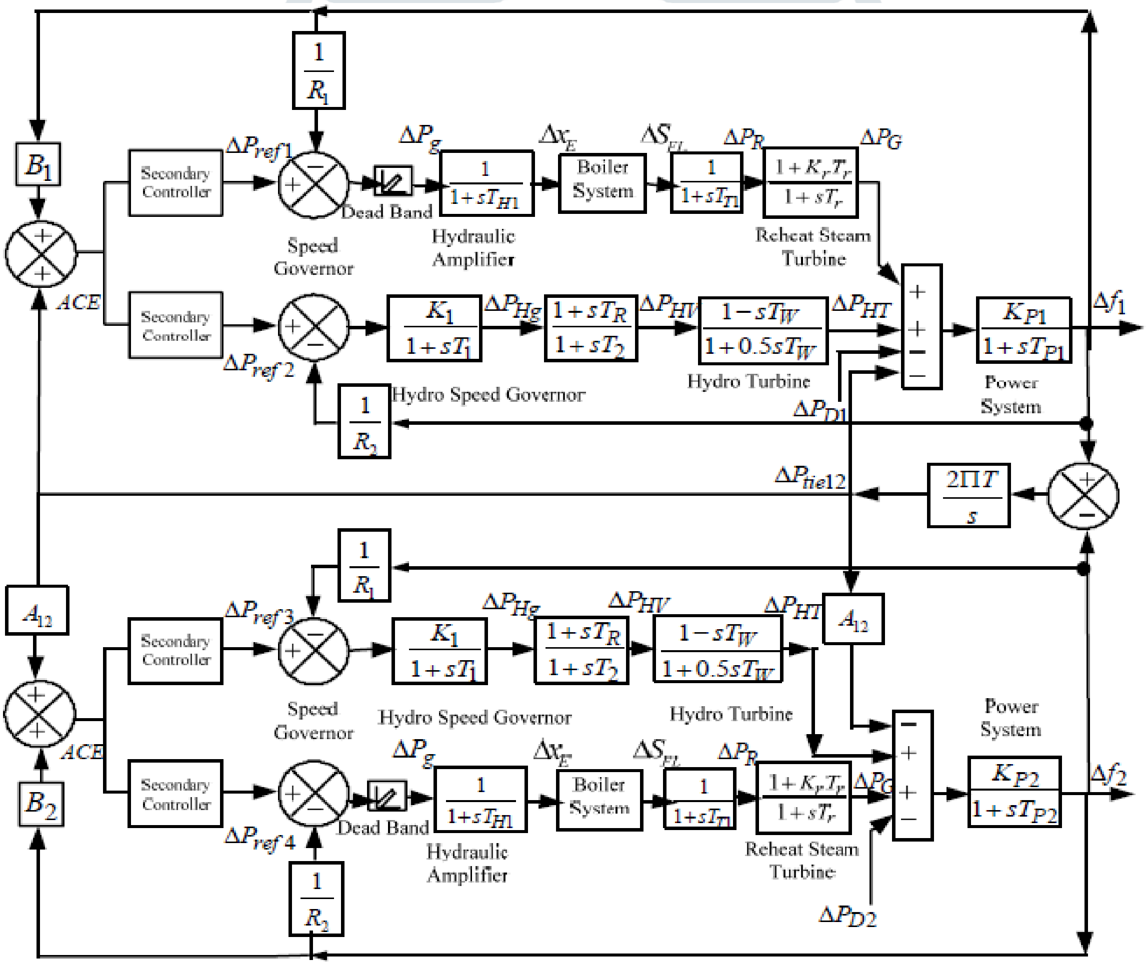

Figure 3: Transfer function model of multi source multi area hydro thermal system with secondary controller including non-linearties with different area capacities Multi source multi area system is designed to operate at a capacity of 2000 MW with nominal operating load in area1 and area2 of 1250 MW and 750 MW respectively.

IV. PI CONTROLLER TUNING METHODS

When the system is subjected to disturbance, based on the error signal, the optimal secondary PI controller tuned using the following methods will control the frequency and tieline power flow by adjusting the power reference setting of the governor.

A. Zeigler Nichols' Method

In this method, the process is kept under closed loop P control, the gain of the P controller at which the loop is at the threshold of instability is the ultimate gain (Kcu). Ultimate period (Tu) is the time for one cycle during the period of sustained oscillations. PI controller is tuned using these parameters Kcu and Tu[15]. The tuned values of Kp and Ki for the MSMA system shown in Figure 3 are 0.27 and 0.135 respectively.

B. Fuzzy Gain Scheduled PI Controller

The PI controller as discussed in the section 3.1 has fixed gain values irrespective of the system changes. Depending on the system conditions, the PI controller gains Kp and Ki have to vary. This is accomplished by scheduling the gain values of PI controller using Fuzzy Gain Scheduling (FGS) [16]. The inputs to the FGS are ACE and derivative of ACE (ACE1). The output of the FGS is Kp of P controller and Ki of I controller. Seven linguistic variables are used for both the inputs and outputs namely Large Negative (LN), Medium Negative (MN), Small Negative (SN), Zero (Z), Small Positive (SP), Medium Positive (MP) and Large Positive (LP). LN and LP are of trapezoidal, where as the remaining are of triangular membership functions. The rules of FGSPI [17] controller is furnished in Table 1.

Table 1: Fuzzy rules for scheduling Kp and Ki

ACE¹ \ ACE	LN	MN	SN	Z	SP	MP	LP
LN	LP	LP	LP	MP	MP	SP	Z
MN	LP	MP	MP	MP	SP	Z	SN
SN	LP	MP	SP	SP	Z	SN	MN
Z	MP	MP	SP	Z	SN	MN	MN
SP	MP	SP	Z	SN	SN	MN	LN
MP	SP	Z	SN	MN	MN	MN	LN
LP	Z	SN	MN	MN	LN	LN	LN

C. Variable Structure Fuzzy Gain Scheduled (PI) Controller

Based on error, VSS helps to switch between P to PI to uphold the predominance action of P during transient period and PI during stead state only. This nullifies the effect of I controller during transient period. VSS does the switching, based on the error signal and Fuzzy incorporates conventional design (PI) and fine tune it to certain plant non-linearities due to universal approximation capabilities. To adapt w.r.t varying system conditions, VSS is integrated with the FGS to form VSFGS for faster switching control action. The functional diagram of VSFGS [18] is represented in Figure 4. Kp and Ki values of PI controller are decided by Fuzzy based on ACE and ACE. Meanwhile, the VSS switches the PI controller from P to PI based on ACE i.e. if ACE is greater than ε, then P controller alone will be in action whose gain is decided by FGS. If ACE is less than equal to ε, then PI controller will take the control action whose gains are scheduled by Fuzzy.

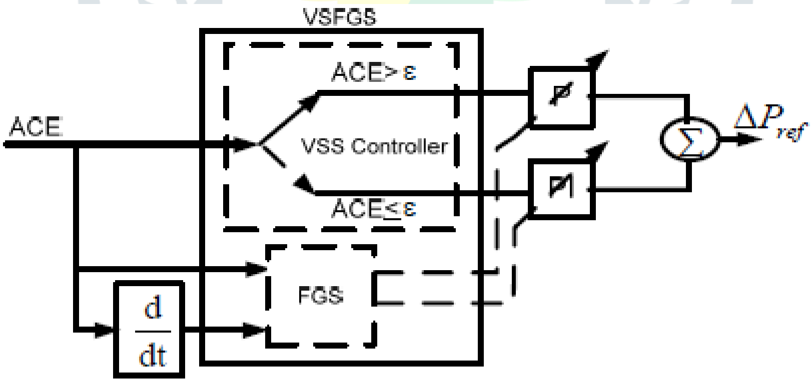

Figure 4: Schematic diagram of Variable Structure Fuzzy Gain scheduling

VSFGS holds the system variations under varying conditions in control and improves the controller flexibility when compared to the fixed gain imparted by conventional PI controller.

V. CONCLUSION

In this paper, a brief survey has been carried out for hydro-thermal unit controllers which controls the amount of fuel according to load or frequency variations. It has been found that a modern power system network consists of a number of control areas interconnected together via tie-lines used to exchange the power among them. For stable operation of power system, both constant frequency and constant tie-line power flow are required. Variation in frequency affects the speed of induction/synchronous motors badly. A significant drop in frequency may be a cuase for the high magnetizing current in transformers and induction motors. The variation in frequency also affects the electric clocks and other timing devices adversly. Frequency depends on the balance between generation and demand of the power in power system . Due to the variable nature of consumer power demands, it is not an easy task to hold the frequency at its rated value. In the dynamic demand conditions, oscillations in frequency and power signals are amplified and the power system may face a non desirable instability problem. With the proper design of automatic generation control (AGC) system, the variation in frequency/power signals can be damped and hence the stability and dynamic performance of the power system networks can be enhanced effectively. The AGC system tracks the system frequency and tie-line power flow, computes the necessary increase/decrease in the power generation as per the variation in consumer demand and adjusts the set position of the speed changer in the control area to retain the time average of area control error (ACE) at a least value. Thus, AGC regulates ACE to zero and consequently, both frequency and tie-line power error turn to zero. The supplementary control does the fine alteration of the frequency by turning the frequency error to zero via classical integral (I) or proportional-integral (PI) control actions. An improper gain adjustment of classical I/PI controller may deteriorate the system dynamic performance having large oscillations leading to system instability. Thus, a sophisticated AGC control strategy is required for successful operation of the interconnected electric power system which has been set as a major objective for our future research work.

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