FUZZY LOGIC CONTROLLER BASED MULTI AREA THERMAL POWER SYSTEM WITH TANDEM AND CROSS COMPOUND TURBINE

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Abstract— This paper describes the Load Frequency Control (LFC) of interconnected tandem reheat and cross reheat thermal system using Proportional – Integral and Fuzzy Logic Controller (FLC). Multi area thermal power system is designed with non-linearities like governor dead band and generation rate constraint. This paper proposes a sophisticated application of Redox flow batteries (RFB) coordinated with Static Synchronous Series Compensator. To improve the dynamic response of load frequency control, redox flow batteries are added to both the areas due to their quick response and lower time constant. Ziegler Nichols method is used to tune the PI controllers. During large load disturbance in the areas, conventional controllers alone are incapable of reducing frequency deviations and tie-line power oscillations due to the slow response of the speed governor mechanism. To overcome this drawback fuzzy logic controller is implemented in the system. Simulation studies reveals that the effectiveness of the fuzzy logic controller, especially in terms of overshoots, undershoots and settling time, thereby improving the performance of LFC in the deregulated power system.

Keywords—Load Frequency Control (LFC), Automatic Generation Control (AGC), Static Synchronous Series Compensator (SSSC), Redox Flow Battery (RFB), Governor Dead Band (GDB), Generation Rate Constraint (GRC), Fuzzy Logic Controller (FLC).

I. INTRODUCTION

Load frequency control maintains the real power balance by sensing the frequency variation. Large frequency deviation affects not only the connected motor loads but also the generating units. Automatic Load frequency Control interacts with the governing systems of the prime movers to regulate frequency. For efficient load frequency control, the power generation should be increased or decreased as quickly as possible. The frequency of a single machine connected to an isolating load or the interconnected grid is controlled by adjusting the generation to match with the load. The variation in frequency would cause the generations of all the machines to change automatically according to the droop characteristic when the frequency deviation exceeds the dead band, due to primary control action [7]. This however would not be able to completely restore the balance between generation and load in case of load demand excursions. The load set points of selected machines are also to be adjusted to change the generations deliberately. This function is performed by the automatic load frequency control system.

To get an accurate insight into the AGC problem, it is necessary to include the important physical constraints in the system model. The major physical constraints that influence the power system performance are GRC and GDB. All governors in the power system have dead bands like mechanical friction, backlash, valve overlaps in hydraulic relays, which are important for speed control even under small disturbances, so the speed governor dead band has denoting effect as the dynamic performance of LFC system [19]. The power plant response capability depends on the plant character and also on the controller gains. The thermal power plant response depends on the governor load controller gains, turbine and boiler time constants.

Frequency is an important indicator of the quality of power system control. Variation in frequency from 50 Hz should be kept to the minimum to avoid damage to the generating equipment as well as to the connected loads. The size and duration of the total system frequency deviations determines frequency quality [15]. The synchronous areas are designed to be able to withstand a reference incident within the design parameters under assumption that system frequency is at its nominal frequency when the disturbance occurs. Therefore, the larger and the more persistent the frequency deviations, the more likely the synchronous area could experience a large disturbance at the time where there with an already existing frequency deviation leading to an event outside of the design parameters.
II. SYSTEM INVESTIGATED

A. System Model

The transfer function model of two area reheat thermal power system with single tandem compound reheat turbine, boiler dynamics and SMES is shown in the fig.1. The system is also incorporated with governor dead band and generation rate constraint. Matlab version 2017 has been used to obtain dynamic response of change in frequencies Δf1, Δf2 and ΔPtie for 1% step load perturbation. Proper assumptions and approximations made to linearize the mathematical equations which describe the system and transfer function model. The system has been designed for nominal system frequency.

B. Boiler Dynamics

Boiler is a device for producing steam under pressure. Figure 2 shows the model to represent the boiler dynamics. Basically, this model is drum type boiler. An oil/gas fired boiler system has been considered in this study, because such boilers respond to load demand changes more quickly than coal fired units. Drum type boiler is otherwise known as recirculation boilers which rely on natural or forced circulation of drum liquid to absorb energy from the hot furnace walls, called water walls for generating steam [13].

The boiler receives feed water which has been preheated in the economizer and provides saturated steam outflow. Recirculation boiler make use of a drum to separate steam flow from the recirculation water so that it can proceed to the super heater as a heatable vapour, hence, recirculation boiler are referred to as drum type boiler. For boiler control strategies or modes
of operation, there are four methods available, namely, boiler leading, turbine leading, coordinated boiler turbine control and sliding pressure control, here, boiler leading or turbine following mode of control is considered. With this operation, the MW demand signal is applied to combustion controls. Steam flow and MW output closely follow steam production in the boiler. Boiler following controller tends to be fairly sensitive to AGC signals, on the order of 3% min G1 for 30% excursion particularly if fueled by oil or gas. The AGC signal usually drives the speed-load set point adjusts on the speed-governor control action which in turn, causes turbine valve movement. The boiler control senses the changes in steam pressure to adjust flows of air, fuel etc.

C. Governor Dead Band

Governor dead band is defined as the total magnitude of a sustained speed change within which there is no resulting change in valve position. Mechanical friction and valve over laps in hydraulic relays are the sources of governor [13]. As a consequence of this, even though the input signal increases, the speed governor may not immediately respond until the input reaches the particular value. Similarly when the input signal decreases, the output does not follow it but remains constant till it decreases to certain value [18]. Dead band introduces non-linearity in the system model and has the effect of broadening the speed governor regulation. The presence of dead band makes the system more oscillatory.

D. Generation Rate Constraint

In practical steam turbine system, due to thermodynamic and mechanical constraint, there is a limit to the rate at which its output power can be changed. This limit is referred to as generation rate constraint. The main reason to consider GRC is that the rapid power increase would draw out excessive steam from the boiler system to cause steam condensation due to adiabatic expansion. The condensation of steam may produce minute water drops to abrade the turbine blade by hitting. The steam valve of the high pressure (HP) turbine acts as a control valve associated with the LFC [20]. Since the temperature and pressure in the HP turbine are normally very high with some margin, it is expected steam condensation would not occur with about 20% steam flow change unless the boiler steam pressure itself does not drop below a certain level. The long time abrasion of the turbine blader due to minute water drops can be serious problem while short time abrasion given little effects as the turbine blader.

The boiler can afford to keep its steam pressure to be constant for a while, and thus it is possible to increase power generation up to certain limit of normal power during the first tens of seconds. Generation rate constraint block diagram is shown in the Fig.3. After the generation has reached this marginal upper bound the power increase of the turbine should be restricted by the GRC.

III. TANDEM AND COMPOUND TURBINE

A steam turbine derives its source from the boiler of a nuclear reactor or fossil fuels furnaces and its converts the high pressured steam into rotating energy at high temperature which in turn is converted into electrical energy. Building of steam turbines always rests upon the unit size and steam conditions. Turbines have a set of moving blades called rotors or buckets and stationary blades called vanes or nozzle sections [3]. Through these nozzles steam is accelerated with high velocity and this steam is converted to shaft torque by the buckets. Usually turbines are with multiple sections. They may be either tandem compound or cross compound turbine [17]. Tandem turbine has one shaft which hold all the sections and with single generator. Cross compound has two shafts connected to two separate generators and it is being run by one or more turbine sections. Still it is considered to be as one unit and controlled with one of controls. It is obvious that cross compound improves efficiency and increase the capacity.

IV. CONVENTIONAL CONTROLLER

The controller is an impedance bridge which is at the balance when the frequency is 50 Hz. When the frequency varies (by a
small value as 0.005 Hz) an unbalance current flows, the direction of current depending on whether the change in the frequency is positive or negative [16]. The steady state frequency can be adjusted to the desired value by adjusting the speed changer setting of the governor.

In this paper dynamic performance of automatic load frequency control of two area power system is done by using PI controller. Ziegler Nichols method is used to optimize the gain values of PI controller. The proportional term produces an output value that is proportional to the current error value [14]. The proportional response can be adjusted by multiplying the error by a constant $K_p$, called the proportional gain constant. The proportional term is given as follows,

$$P_{out} = K_p e(t) \quad (1)$$

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. It is expressed as follows,

$$I_{out} = K_i \int_0^t e(\tau) d\tau \quad (2)$$

The Ziegler Nichols tuning method is a heuristic method of tuning a PID controller. It was developed by John G. Ziegler and Nathaniel B. Nichols. The $K_i$ and $K_d$ gains are first set to zero. The proportional gain is increased until it reaches the ultimate gain $K_u$, at which the output of the loop starts to oscillate. $K_u$ and the oscillation period $T_u$ are used to set the gain. Formula to calculate the gain value is shown in table I.

<table>
<thead>
<tr>
<th>Control type</th>
<th>$K_p$</th>
<th>$K_i$</th>
<th>$K_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>0.50 $K_u$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>0.45 $K_u$</td>
<td>1.2 $K_u/T_u$</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>0.60 $K_u$</td>
<td>2 $K_u/T_u$</td>
<td>$K_u/T_u/8$</td>
</tr>
</tbody>
</table>

V. SUPER CONDUCTING MAGNETIC ENERGY STORAGE

SMES was originally proposed as a bulk energy storage technology for electric power systems. SMES systems have attracted the attention of both electric utilities and the military due to their fast response and high efficiency (charge-discharge efficiency over 95%). SMES systems are still costly when compared with other currently available energy storage technologies, but the ongoing development of high temperature superconductors should make SMES increasingly cost effective due to reductions in refrigeration needs [4]. SMES’ efficiency and fast response capability (MW/millisecond) have been exploited in electric power system applications at all levels. Since the 1970’s, numerous potential utility applications have been proposed. SMES development continues in power conversion systems and control schemes, evaluation of design and cost factors, and analyses for various power system applications [21]. Currently, there are a number of utility application SMES projects installed or in development throughout the world.

VI. STATIC SYNCHRONOUS SERIES COMPENSATOR

It is assumed that a large load with rapid step load change has been experienced by area1. This load change causes serious frequency oscillations in the system. Under this situation, the governors in an area 1 cannot sufficiently provide adequate frequency control. On the other hand, the area 2 has large control capability enough to spare for other area. Therefore, an area 2 offers a service of frequency stabilization to area 1 using the SSSC. Since SSSC is a series connected device, the power flow control effect is independent of an installed location. In the proposed design method, the SSSC controller uses the frequency deviation of area 1 a local signal input [1,2]. Therefore the SSSC is placed at the point near area1. Moreover the SSSC is utilized as the energy transfer device from area 2 to area1. As the frequency fluctuation in area 1 occurs, the SSSC will provide the dynamic control of the tie-line power by exploiting the system interconnections as the control channels and the frequency oscillation can be stabilized [4,12].
VII. REDOX FLOW BATTERY

A sulfuric acid solution containing vanadium ions is used as the positive and negative electrolytes, which are stored in respective tanks and circulated to battery cell [9, 10]. The Redox Flow Batteries offer the following features, and are suitable for high capacity systems that differ from conventional power storage batteries. The battery reaction only involves a change in the valence of a vanadium ion in the electrolyte. There are none of the factors which reduce the battery service life seen in other batteries that use a solid active substance, such as loss are electro depositions of the active substance [6,11].

Furthermore, operations at normal temperatures ensure less deterioration of the battery materials due to temperature. Pumps and piping that are widely used in facilities such as chemical plants are usable as established technologies. The system configurations are such that battery output (cell section) and battery capacity (tank section) can be separated, therefore the layout of the sections can be altered according to the place of installation. For example, the tank can be placed underground. The design can be easily modified according to the required output and capacity. The charged electrolyte is stored in separate positive and negative tanks when the battery has been charged, therefore no self-discharge occurs during prolonged stoppage nor is auxiliary power required during stoppage [8]. Furthermore, start-up after prolonged stoppage requires only starting of the pump, thus making start-up possible in only a few minutes. The electrolyte (i.e., the active substance) is sent to the each battery cell from the same tank, therefore the charging state of each battery cell is the same, eliminating the need for special operation such as uniform charging. So that, maintenance is also easy because the electrolyte is relatively safe and the operating are at normal temperature and assures superior environmental safety. Waste vanadium from generating stations can be used so it can be superior recyclability. Furthermore, the vanadium in the electrolyte can be used semi-permanently.

The RFB systems are incorporated in the power system to suppress the load frequency control problem and to ensure an improved power quality. The simplified transfer function model of redox flow battery is shown below.

\[
\frac{\Delta P_{RF}}{\Delta P_{RF0}} = \frac{K_{RF}}{(1 + sT_D)}
\]

Fig.4 Simplified Transfer Function Model of RFB

VIII. FUZZY LOGIC CONTROLLER

The concept of fuzzy set theory was introduced by Zadeh in 1965 (Zadeh 1965) and it was first introduced in 1979 for solving power system problems. Fuzzy set theory can be considered as a generalization of the classical set theory. In classical set theory an element of the universe either belongs to or does not belong to the set. Thus the degree of association of an element is crisp [5]. In a fuzzy set theory the association of an element can be continuously varying. Mathematically, a fuzzy set is a mapping (known as membership function) from the universe of discourse to the closed interval [0,1]. The membership function is usually designed by taking into consideration the requirement and constraints of the problem. Fuzzy logic implements human experiences and preferences via membership functions and fuzzy rules. Due to the use of fuzzy variables, the system can be made understandable to a non-expert operator. In this way, fuzzy logic can be used as a general methodology to incorporate knowledge, heuristics or theory into controllers and decision makers. FLC block diagram is shown below.

Fig.5 Fuzzy Logic Controller Block diagram
The first step in designing a fuzzy based controller is to decide the input variables or signals to the controller. For the proposed fuzzy logic based load frequency control, input variables selected are area control error and change in area control error. After selecting the input variables, it is required to decide the linguistic variables. The number of linguistic variables specifies the quality of the control. MF specifies the degree to which a given input belongs to a set. Here seven membership functions namely Negative Big (NB), Negative medium (NM), Negative Small (NS), Zero (ZO), Positive Small (PS), Positive Medium (PM), Positive Big (PB) are used. Defuzzification to obtain crisp value of FLC output is done by center of area method. Fuzzy rules specify the relationship among the fuzzy variables. These rules help us to explain the control action in qualitative terms.

The various simulation results for the proposed block diagram are shown below.
IX. CONCLUSION

In this paper the responses of two area thermal-thermal power system is analyzed with the presence of SMES, SSSC and Redox unit. PI controller is optimized using Ziegler Nichols method. The system is simulated for a step load disturbance of 1% on either area of the system. Various types of turbines namely tandem compound and cross compound are simulated and the simulation results for tandem and cross compound is shown in the figure above. The simulation result shows that fuzzy logic controller yields better performance than conventional controller.

References


