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Research paper



Analysis of Energy Storage Device in Hydro-Thermal Power Systems Using Fuzzy Logic Controller

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Abstract

This work presents the Automatic generation control in an interconnected hydro-thermal power system to stabilize the frequency oscillations due to load changes. Advantage of facts devices are utilized here to improve the stability of the system. Thyristor controlled phase shifter (TCPS) is added in the tie line whose input is the area control error. The output of the phase shifter is the change in phase angle based on the error. The TCPS-RFB (Redox flow battery) and TCPS - SMES (Superconducting magnetic energy storage) combinations are compared against each other in terms of peak overshoot and settling time. The results proves that SMES is most effective than RFB. Then the LFC of hydrothermal plant with TCPS in tie line and SMES in one area is analyzed with different controllers like P, PI, PID and Fuzzy logic controller to find the best controller for these specific applications. The criterion for comparison remains to be the same. And finally fuzzy logic controller is found to best among the ones under consideration.

Keywords: *Automatic generation control; Energy storage device; Fuzzy logic; Superconducting magnetic energy storage;Thyristor controlled phase shifter*

1. Introduction

Electrical power systems are interconnected through tie lines to provide secure and economical operation. The interconnected power system is divided into control areas, with each consisting of one or more power utility companies. The main objective of automatic generation control is to maintain the balance between the generation and demand of a particular power system. Load- frequency control is an important task in electrical power system design and operation. Since the load demand varies without any prior schedule, the power generation is expected to overcome these variations without any voltage and frequency instabilities. Therefore, voltage and frequency controllers are required to maintain the generated power quality in order to supply constant voltage and frequency to the utility grid. The frequency control is done by load-frequency controllers, which deals with the control of generator loadings depending on the frequency deviation.[1] In recent some days there is a tremendous development of electronics devises takes place which enhanced and improve the concepts of stability and control of the power system dynamics. This development leads to introduce the wide uses and application of flexible alternating current transmission (FACTS) devices in the tie line of the power system. Which ensure the improvement of the different transient performance, more reliable power supply and also the high speed operation of these devices in the power system which enhanced the quality and stability of the electrical power system. One such facts devices is used here thyristor control phase shifter (TCPS) which change the relative phase angle between the system voltage and thus can be able to regulate the real power of the system and able to stabilize the frequency oscillation ultimately enhanced the power system stability. So, here a study and implementation of combination of TCPS, SMES and RFB in AGC of interconnected power system has been performed, to improve the performance of power system parameters. Finally fuzzy logic controller hasbeen utilized to optimize the result.[4,9].

1.1 Objective

The objective of the work can be pointed out as follows

1. The Control of Real Power of a thermal Turbine Plant, in order to keep the system in steady state.
2. The objective is to generate and deliver power in an inter connected system as economically & reliably as possible while maintaining the frequency within permissible limits.
3. Changes in real power mainly affect the system frequency. So the Load Frequency Control (LFC) loop controls the real power and frequency.
4. The controllers and the FACTS devices to be incorporated with the interconnected system are to be analyzed.

2. Modeling o Load Frequencycontrol

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. 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

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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 is shown in Fig. 2.[5]

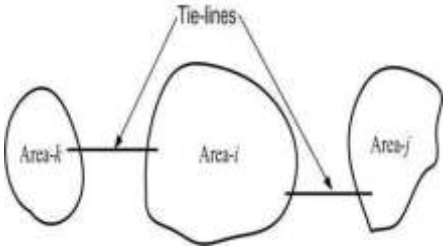


Fig. 1:. Interconnected areas in a power system.

2.1 Problem Formulation

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

$$\Delta P_{refi} = -K_i \int ACE\,dt \qquad (2.1)$$

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 $\Delta P_{ref,}$

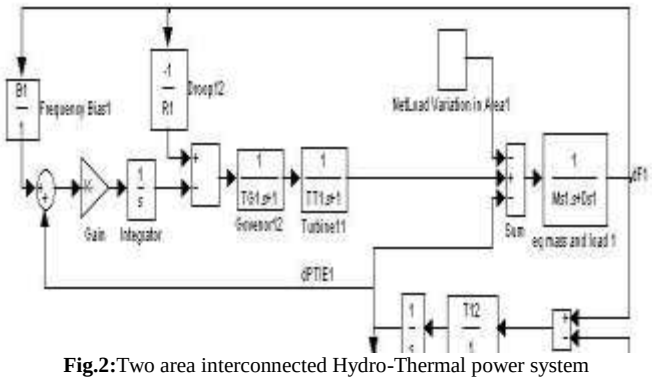


Fig.2: Two area interconnected Hydro-Thermal power system

3. Thyristor Controlled Phase Shifter

Recent improvements in electronic applications have laid down the way to improve the stability and the performance of the system. The improvised devices which prove to be very indispensable part of power system are called FACTS (flexible alternating current devices). These FACTS devices are capable of controlling one or more parameters at a time as desired for the current application. One such device is thyristor control phase shifter (TCPS) which change the relative phase angle between the system voltages and thus the real power flow can be maintained and eliminates the frequency deviation and finally enhance the power system stability.[7]

In the below figure two interconnected power system block diagram is shown. A TCPS is installed in series with tie line, area 1 represent the thermal unit and area 2 represent thehydro unit of the power system, and they are interconnected via tie-line. Resistance of the tie-line is neglected and resistance of the tie-line is considered. Logic of Tcps with Tie Line In Series $\Delta error_1$ can be any signal such as thermal area frequency deviation [ΔF_1] or hydro area frequency deviation [ΔF_2] or ACE (area control error) to the TCPS unit to control the TCPS phase shifter angle which in turn controls the tie line power flow. Thus, with $\Delta error_1 = \Delta F_1$ equation 3. can be written as[3]

$$\Delta\varphi(s) = (K_\varphi / (1+sT_{TCPS}))\,\Delta f_1(s) \qquad \textbf{(3.1)}$$

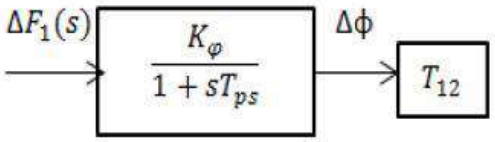


Fig.3.:TCPS model

3. Energy Storage Devices

Redox Flow Battery

The redox (reduction-oxidation) cell is a reversible fuel cell in which all electrochemical components are dissolved in the electrolyte. The energy capacity of the redox flow battery is fully independent of its power, because the energy available is related to the electrolyte volume (amount of liquid electrolyte) and the power to the surface area of the electrodes. Redox flow batteries are rechargeable (secondary cells). Because they employ heterogeneous electron transfer rather than solid-state diffusion or intercalation they are more appropriately called fuel cells than batteries. In industrial practice, fuel cells are usually, and unnecessarily, considered to be primary cells, such as the H2/O2 system. The unitized regenerative fuel cell on NASA's Helios Prototype is another reversible fuel cell. The European Patent Organization classifies redox flow cells (H01M8/18C4) as a sub-class of regenerative fuel cells (H01M8/18). Examples of redox flow batteries are the vanadium redox flow battery, polysulfide bromide battery (Regenesys), and uranium redox flow battery. Redox fuel cells are less common commercially although many systems have been proposed.[2].

4.1 Super Conducting Energy Storage Device (SMES)

Superconducting Magnetic Energy Storage (SMES) systems store energy in the magnetic field created by the flow of direct current in a superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature. A typical SMES system includes three parts: superconducting coil, power conditioning system and cryogenically refrigerator. Once the superconducting coil is charged, the current will not decay and the magnetic energy can be stored indefinitely. The stored energy can be released back to the network by discharging the coil. The power conditioning system uses an inverter/rectifier to transform alternating current (AC) power to direct current or convert DC back to AC power. The inverter/rectifier accounts for about 2–3% energy loss in each direction. SMES loses the least amount of electricity in the energy storage process compared to other methods of storing energy. SMES systems are highly efficient; the round-trip efficiency is greater than 95%.[9] Due to the energy requirements of refrigeration and the high cost of superconducting wire, SMES is currently used for short duration energy storage. Therefore, SMES is most commonly devoted to improving power quality. If SMES were to be used for utilities

it would be a diurnal storage device, charged from base load power at night and meeting peak loads during the day.[9]

4.2. Modeling of SMES

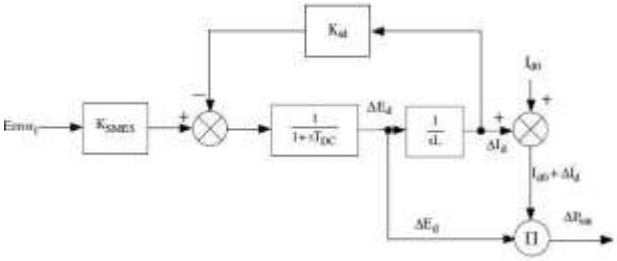


Fig.4:. logic implementation of SMES block in AGC

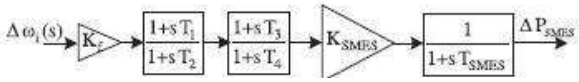


Fig.5:. Structure of SMES as a frequency controller

5. Fuzzy Logic Controller

As far as transfer functions are concerned, the industrial controllers are normally designed, the PID controller, either using frequency domain approach or time domain approaches. All of you might have heard about root locus method that is under time domain approach, using Bode plot Nyquest diagram, this is the frequency domain. In state feedback controller, you must have heard about pole placement, linear quadratic regulator; this is an optimal control and also, robust controller. This is another type of controller,when we assume these plant models are not exact; they are inexact. This is a kind of an overview of the linear systems; that is, we have state space model or a transfer function model of an actual plant and for these two models, we design various types of controllers.[3,6]

Table.1:.fuzzy rule base

Δ/Δf	M	N	O	P	Q
M	M	M	N	N	O
N	M	N	N	O	O
O	N	N	O	P	P
P	N	O	P	P	Q
Q	O	P	P	Q	Q

6. Simulation Results

Hydrothermal System with Energy storage device comparison

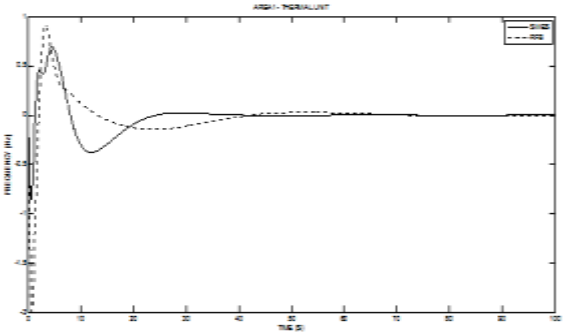


Fig.6: Comparison frequency response in thermal system

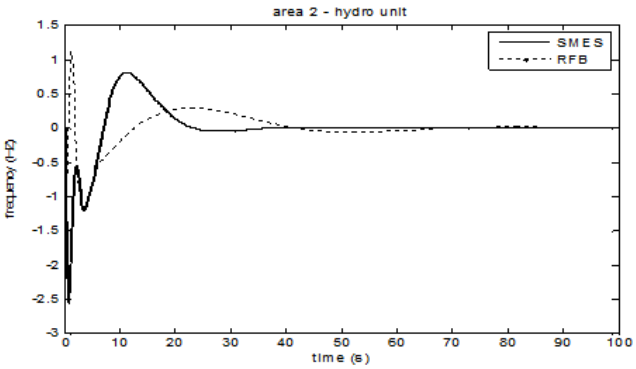


Fig.7. :Comparison frequency response in hydro system

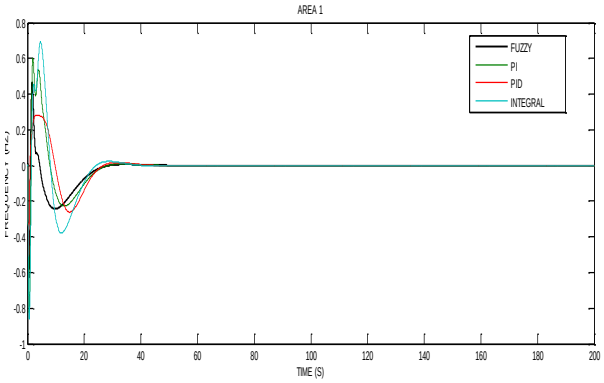


Fig.8: Comparison frequency response in araea-1

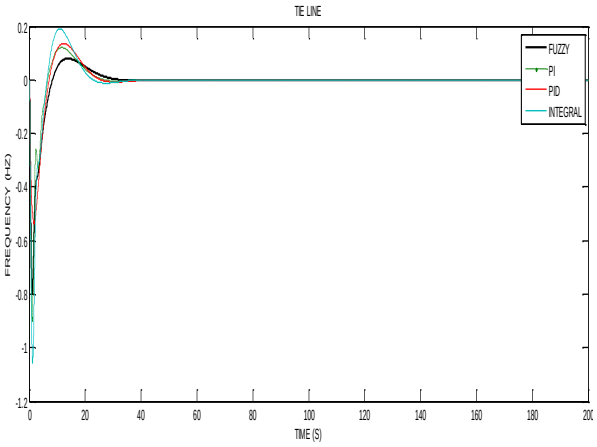


Fig.9:. Comparison frequency response in araea-2

6.1Quantitative Comparison of Hydro –Thermal Unit

Table 2:. Comparison of controllers in Thermal unit

Controller	Settling time (s)	Peak over-shoot(Hz)	Steady state error
Fuzzy	38	0.464	4.853e-14
PI	45	0.6	6.5e-14
PID	44	0.27	5.993e-14
I	50	0.7	5.808e-15

Table3:. Comparison of controllers in Hydro unit

Controller	Settling time (s)	Peak over-shoot(Hz)	Steady state error
Fuzzy	32	0.08	-1.097e-13
PI	38	0.12	-2.621e-14
PID	40	0.14	2.849e-14
I	40	0.2	-3.495e-15

7 .Conclusion

For an interconnected hydrothermal system under consideration, if there is any step change in load it is not possible for the system settle to the original position firstly. Hence, there are chances for the system to go out of synchronism. Therefore, to prevent the system during that kind of circumstances following steps are taken. Initially, TCPS (thyristor controlled phase shifter) is added on the tie line of the system and the system is simulated. The input to the TCPS is the Area control error, which is the sum of frequency deviation and tie line power flow deviation. The output results show fine improvement. But in power system, anything might happen within a fraction of second. So it is mandatory to improve the performance further. Consequently, batteries were introduced. TCPS-SMES combination was evaluated against TCPS-RFB combination. They were compared in terms of peak overshoot and settling time (time to taken to come back to normal after a fault). The results show the superiority of SMES over RFB battery. Then the hydrothermal system with TCPS and RFB is analyzed with different controllers to find the best controller. The controllers under consideration are P, PI, PID and Fuzzy logic controller. The conventional controllers were tuned manually. The results show that the fuzzy logic controller establishes to be the best among the controllers under consideration.

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Appendix

PR1=PR2=1200MW, KP1=KP2=120 Hz/P.u,

TP1=TP2=20s TT=0.3s, Kr=0.5s, 1/R=0.416,

T1=41.6, T2=0.513s, TW= 1s,

TR= 5s, T12=0.0866s, R1=R2= 2.4 Hz/P.u,
D1=D2= $8.33*10^{-3}$ P.u, TPS=0.1s,

B1=B2= 0.4249 P.u MW/Hz, $K\phi$= 1.5 rad/Hz,

$\phi MAX = 10^{O}$, $\phi MIN = -10^{O}$,
Krfbi= 1.8, Tdi=0, Tr=0.
For SMES :

T1=0.159, T2=0.016,

T3=0.718, T4=0.239,
TSMES=0.029, KSMES=0.253