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Redox Flow Battery with Secondary Controller for Load Frequency Control in Inter Connected Power Systems

KEYWORDS: PID controller, Redox Flow Batteries, Mean square error, MATLAB simulation

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ABSTRACT *For maintaining the load frequency control of power systems, as supplementary controllers, PID controller with redox flow battery are employed in the current paper to study the system's response. The system was simulated and the output responses of frequency deviations in area 1 and area 2 for 1% step-load disturbance have been obtained. The frequency deviations for two area interconnected thermal power systems are compared with PID controller with Redox Flow Batteries (RFB) using MATLAB simulations. The results reveal that the PID controller with Redox flow battery improves the performance drastically. The mean square error is also calculated. In respect of PID controller with Redox flow battery in area1 is 7.2631E-09 and in area2, the error is 1.36E-08.*

I. Introduction:

Extensive research has been initiated in the field of Automatic generation control in Power Systems. In this paper some light is thrown on the analogy of frequency response in case of two area systems. Three different cases have been tried for two area system. In Case 1 –No secondary controller is included. In Case-2- PID Controller, in Case-3 –PID controller coupled with Redox Flow Battery have been introduced. In all the above cases the frequency response has been simulated and the results obtained are analyzed and discussed in this paper.

Methods and Materials

In this paper, using MATLAB simulation on the block diagram pertaining to two area inter connected power systems, frequency variations are obtained as a graphical representation.

Dynamic response in respect of two area system

$$\bar{X} = Ax + Bu + Fd \qquad .....(1)$$

where A,B,F are the system and input distribution and disturbance distribution matrices respectively. x, u and d are state, control and disturbance vectors respectively. States to be minimized are the frequency deviation and time integral of the frequency error. The control signal is to be weighted and included in the cost function so that a too large a control is not required.

***B*. Methodology adopted:**

The performance of the system in respect of single area and two area are analyzed using the following methods. Case I: Without any secondary controller. Only inbuilt Governor speed control mechanism is included. Case-II: With PID Controller, frequency response is observed. Case-III: With PID controller and Redox flow battery (RFB) the frequency response is observed.

Case-I : Initially the performance is observed without any secondary controller but with the primary controller of Governor steady state speed regulator (R). The results are noted.

Case –II: In case –II, as detailed in the papers studied by (S. Pothiya, I. Ngamroo &W. Kongprawechnon, 2007), (N. Sinha, L. L. Lai &V. Gopal Rao,2008), (Amit Kumar, Ashwani Kumar & S. Chanana,,2011) using PID controller, the performance of the system is proposed for the analysis. PID controller consists of Proportional Action, Integral Action and derivative action. PID controller is mostly used in feedback loops. The proportional, integral and derivative terms that can be represented in transfer function form as

$$K(s) = K_p + \frac{K_i}{s} + K_d s \qquad ....(2)$$

where K_p represents the proportional gain, K_i represents the integral gain, and K_d represents the derivative gain, respectively. By tuning these PID controller gains, the controller can provide control action designed for specific process requirements. By trial and error method for different values, the performance is analyzed and the output is plotted for the optimum values of kp, ki and kd using MATLAB simulations, the results are plotted The performance of the power system using PID controller in two area system using MATLAB simulink is plotted.

Case-III: The performance of the system is compared using a Redox flow battery system along with PID controller in the Automatic generating Control system. The operating principle of the Redox flow battery is provided as studied in the papers by N.Tokuda,1998, Paramasivam Balasundaram & Chidambaram Ilangi Akilandam, 2012 and Ravi Shankar, Kalyan Chatterjee & T.K. Chatterjee, 2012 and the block diagram of the redox Flow Battery is as shown in Fig.1.

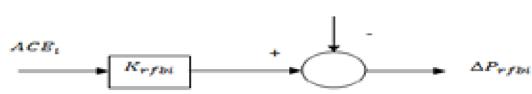

Fig.1– Reduced form of Redox flow battery block-diagram

RFB helps in secondary control of the power system. So, hunting will not occur due to response delay. Area control error (ACE) is acting as the controlling signal to the redox flow batteries. The design process starts from the reduction of two area system into one area which represents the Inertia centre mode of the overall system. The controller of RFB is designed in the equivalent one area system to reduce the frequency deviation of inertia centre. The equivalent system is derived by assuming the synchronizing coefficient T_{12} to be large. The state equations are shown below:

$$\frac{\Delta PT_{12}}{(2\pi T_{12})} = \Delta f1 - \Delta f2 \qquad ....(3)$$

If the T_{12} is infinity, then $\Delta f_1 - \Delta f_2 = 0$ i.e $\Delta f_1 = \Delta f_2$

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$$\frac{\frac{-1}{K_{P1}} - \frac{1}{K_{P2} * a_{12}})}{\frac{T_{p1}}{K_{P1}} + \frac{T_{p2}}{K_{P2} * a_{12}}} \Delta f + \frac{1}{\frac{T_{p1}}{K_{P1}} + \frac{T_{p2}}{K_{P2} * a_{12}}} \Delta P_{RFB} + C\Delta P_D \quad ..(4)$$

Where the load change in this system ΔP_D is additionally considered, here the control $\Delta P_{RFB} = - K_{RFB} \Delta f$ is applied then.

$$\Delta f = \frac{C}{A+B * K_{RFB}} \Delta P_D \quad ...(5)$$

Where

$$A = \frac{\frac{-1}{KP1} - \frac{1}{KP2*a12})}{\frac{Tp1}{KP1} + \frac{Tp2}{KP2*a12}} \qquad B = \frac{1}{\frac{Tp1}{KP1} + \frac{Tp2}{KP2*a12}}$$

Since the control purpose of RFB is to suppress the deviation of ΔF quickly against the sudden change of ΔP_D, the percent reduction of the final value after applying a step change ΔP_D can be given as a control specification. In the final values with $K_{RFB} = 0$ and with $K_{RFB} \neq 0$ are $\frac{C}{A}$ and $\frac{C}{A+B * K_{RFB}}$ respectively therefore the percent reduction is represented by

$$\frac{C}{A} + \frac{C}{A+B * KRFB} = \frac{R}{100} \quad ...(6)$$

For a given value of speed regulation coefficient- R, the control gain of RFB is calculated as

$$K_{RFB} = \frac{A\,(100-R)}{BR} \quad ...(7)$$

The block diagram representation of

$$RFB = \frac{K_{RFB}}{1 + T_{di}} \quad ...(8)$$

The response of power system with variations in the frequency with PID controller and RFB in area1 and PID controller in area2 are observed and the values are plotted. The Fig. 2 shows the PID controller with Redox flow battery in area 1 in two area system. The MATLAB simulation results are plotted.

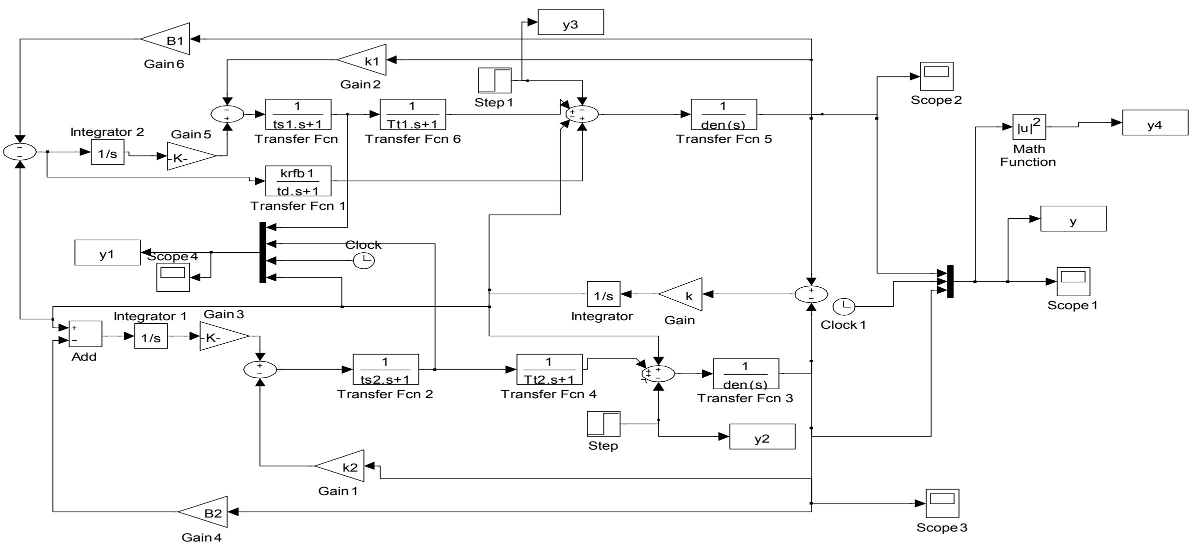

Fig.2- Two area system- with PID controller and Redox flow battery in area1.

III Results and Discussions:

The system is simulated in" MATLAB SIMULATION TOOLBOX". The performance of the proposed controller in this paper has been studied for the load change of 0.01pu for given two area interconnected power system and its frequency deviation graphs case by case are given in Figure- 3 to Figure-5 .

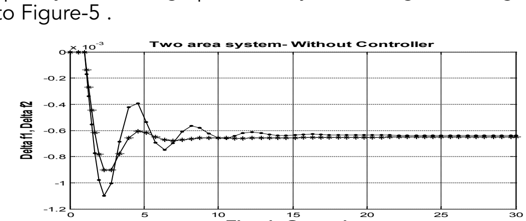

Fig.-3- Frequency deviation in two area system- without controller

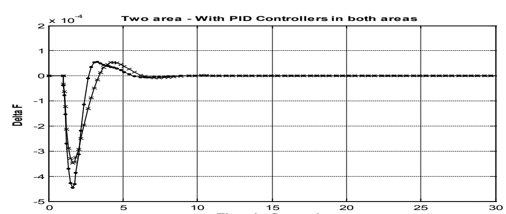

Fig.-4- Frequency deviation in two area system- with PID controllers in both the areas

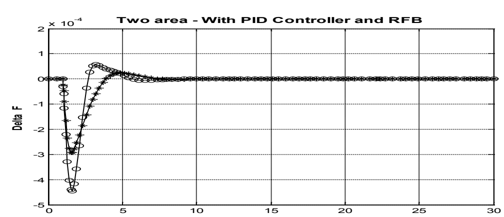

Fig.-5- Frequency deviation in two area system- with PID controller and RFB in area1 and PID controller in area2.

IV. Comparative analysis:

The time taken in each case for the power system to reach steady state in respect of each case under study is shown in "Table-1-two area system". It is inferred from the results that

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the steady state error win Case-I is improved by the introduction of secondary controller. Out of the secondary controllers used PID controller and PID controller with redox flow battery, the analysis on the results is as given under.

Table-I- Settling time and mean square error

Description.	Settling time		Mean square error	
	Area 1-Δf1	Area2- Δf2	Area 1-Δf1	Area2-Δf2
Without secondary controller	6.3787	11.1058	4.27556E-07	4.22574E-07
With PID controller	4.7734	3.6477	9.90119E-09	1.36E-08
With PID controller and RFB	3.4058	3.6664	7.2631E-09	1.36E-08

The system response is fastest with the implementation of Redox flow battery along with PID controller. The Mean square error is also minimum at 7.2631E-09. With redox flow battery, the response shows no oscillations.

V. Conclusions:

In this paper, to enhance the load frequency control of two area system, PID controller with redox flow battery is proposed. The MATLAB simulation results show that the performance of the PID controller with redox flow battery is better and the mean square error is minimum. In comparison with the latest studies: In the study by H S. Farook, P. Sangamasmeswara Raju ,2011, the results as per all the DISCOs participating in power sharing with GENCos in area1 and area2 are shown in "Table-2"

Table-2 -Comparison with the study of H S. Farook, P. Sangamasmeswara Raju ,2011

Variation in frequency - Settling Time(sec) as per the paper			
	Uncontrolled	Feedback controller	PID controller
del f1	20.963	10.103	10.671
del f2	23.855	11.752	9.865
Variation in frequency - Settling Time(sec) as per the current paper			
del f1	6.3787	4.7734	
del f2	11.1058	3.6477	
Along with RFB - del f1		3.4058	
Along with RFB in area 1 and no RFB in area2 -del f2		3.6664	

From the table-2, it is inferred that the results obtained in the present study are comparable. The settling time is much lesser than that of the paper to which it is compared. This is what is expected in an industry and hence this work has to be seen in the real world situation and if it is done with the simulated one as it is in the present communication it will be worthwhile to claim for the industry so that quality power can be transferred to the clients.

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