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DESIGN OF ABC ALGORITHM BASED LOAD FREQUENCY CONTROLLER FOR HYDRO-NUCLEAR INTERCONNECTED POWER SYSTEMS WITH REDOX FLOW BATTERIES

***Murugan, C. K., Ramesh Kumar, S., Ganapathy, S. and Velusami, S.**

Department of Electrical Engineering, Annamalai University, Annamalai Nagar, India

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ABSTRACT

This paper proposes an application of redox flow battery (RFB) for the improvement of Load Frequency Control (LFC) of a two-area interconnected hydro-nuclear power system using Artificial Bee Colony (ABC) optimization algorithm. The Redox Flow Battery, which is not aged due to the frequent charging and discharging, has a quick response and outstanding function during overload conditions. In addition to leveling load, the battery is advantageous for secondary control in the power system and maintenance of power quality of distributed power resources. The redox flow batteries can efficiently damp out electromechanical oscillations in the power system because of their efficient storage capacity in addition to the kinetic energy of the generator rotor, which can share the sudden changes in power requirements. The Artificial Bee Colony optimization algorithm, a very simple, robust and population based stochastic optimization algorithm, is used to optimize the parameters of the PI controller. Simulation studies reveal that the transient performance is improved significantly when RFB is considered.

INTRODUCTION

Load Frequency Control (LFC) is an important function in modern Energy Management Systems. The successful operation of interconnected power system requires the matching of total generation with total load demand and associated system losses. As the demand deviates from its nominal value with an unpredictable small amount, the operating point of power system changes, and hence, system may experience deviations in nominal system frequency and scheduled power exchanges. The main tasks of load frequency control are to hold system frequency at or very close to a specified nominal value and to maintain the correct value of interchange power between control areas (Singh Parmar *et al.*, 2012). In real situations, the power systems consist of conventional forms of electrical power generations like, thermal, hydro, and nuclear as a major share of electrical power. The configuration of today's integrated power system becomes more complex due to these power plants with widely varying dynamic characteristics. Nuclear units owing to their high efficiency are usually kept at base load close to their maximum output with no participation in system Load Frequency Control (LFC). But with integration of nuclear power plants in the power system, it is also required to study the behavior of LFC for the interconnected power system considering nuclear power plant (Naimul Hasan *et al*., 2012). Gas power generation is ideal for meeting varying load demand. However, such plants do not play very significant role in LFC of a large power system, since these plants form a very small percentage of total system generation. Gas plants are used to meet peak demands only. Thus the natural choice for LFC falls on either thermal or hydro units. In this work, interconnected hydro-nuclear power system has been considered.

During the last decades, many techniques have been developed for LFC problem (Ibraheem *et al.*, 2005). Most of these techniques use the conventional proportional plus integral controller, where the load frequency controller is based upon tie line bias control where each area tends to reduce the Area Control Error (ACE) to zero. In an interconnected power system, during the presence of small load disturbances and with optimized PI controller gains, the frequency oscillations and tie-line power deviations exist for longer time duration. During such conditions, the governor may not be able to absorb the frequency fluctuations due to its slow response. To compensate for the sudden changes in load, an active power source with fast response such as Redox flow Battery (RFB) can be expected to be most effective (Tetsuo Sasaki *et al*., 2004). The Redox Flow Batteries (RFB) are found to be

****Corresponding author: Murugan, C. K.*** *Department of Electrical Engineering, Annamalai University, Annamalai Nagar, India.*

superior over the other energy storing devices because of their easy operability at normal temperature, very small loss during stand by and have a long service life, flexibility in layout, easy to increase the capacity and free from degradation due to fast charging and discharging action (Chidambaram and Paramasivam 2012).

Over the past decades, various control techniques (Ibraheem *et al.*, 2005; Omveer Singh *et al.*, 2013) such as classical control, variable structure control, optimal control, and robust control, have been applied to the LFC problem. The classical controllers exhibit poor dynamic performance and are therefore, not suitable for all operating conditions. The variable structure controllers, optimal state feedback controllers, and robust control methods on the other hand show good dynamical response, however, most of them require the availability of all state variables, which seems unrealistic. Therefore, it is not easy to effectively solve the LFC problem depending only on the conventional approaches. The most recent advancement is the application of soft computing techniques (Sathans and Akhilesh Swarup 2011) to the load frequency control of interconnected power systems having nonlinear models and continuously changing operating conditions. In this paper, the Artificial Bee Colony (ABC) algorithm, which mimics the food foraging behavior of swarms of honey bees, has been used for optimizing the controller PI gain values of the proposed interconnected hydro-nuclear power system.

Statement of problem

The block diagram representation of a two area hydro-nuclear interconnected power system with RFB is shown in Fig.1. The dynamic behavior of the LFC system is described by the state space equation

$$\dot{X} = Ax + Bu + \Gamma d \tag{1}$$

where **A** is system matrix, **B** is the input distribution matrix, **Γ** is the disturbance distribution matrix, **x** is the state vector, u is the control vector and d is the disturbance vector.

A step load disturbance of 1% has been considered as a disturbance in the system. For the frequency and tie-line power deviations to be zero at steady state, the Area Control Error (ACE) should be zero. To meet the above design requirements, the ACE is defined as

$$[ACE_i] = \lfloor \Delta P_{tiei} + \beta_i \Delta F_i \rfloor \tag{2}$$

where, β_i is the frequency bias constant.

The objective is to obtain the optimum value of the controller parameters which minimize the performance index (Manoranjan Parida and Nanda *et al.,* 2005).

$$J = \int_0^t [\Delta F_1^{\,2} + \Delta F_2^{\,2} + \Delta P_{tie}^{\,2}]dt \tag{3}$$

Redox flow battery system and modeling

RFBs are rechargeable batteries and are becoming very opular due to their quick responses (Singh Parmar 2014). RFBs are not aged by frequent charging and discharging and perform outstanding function during overload conditions. Simple operating principle, long service life, suitability for high capacity systems, quick start up and ease in maintenance are the salient features of these batteries. Recently, RFBs have been integrated in LFC scheme to improve the system

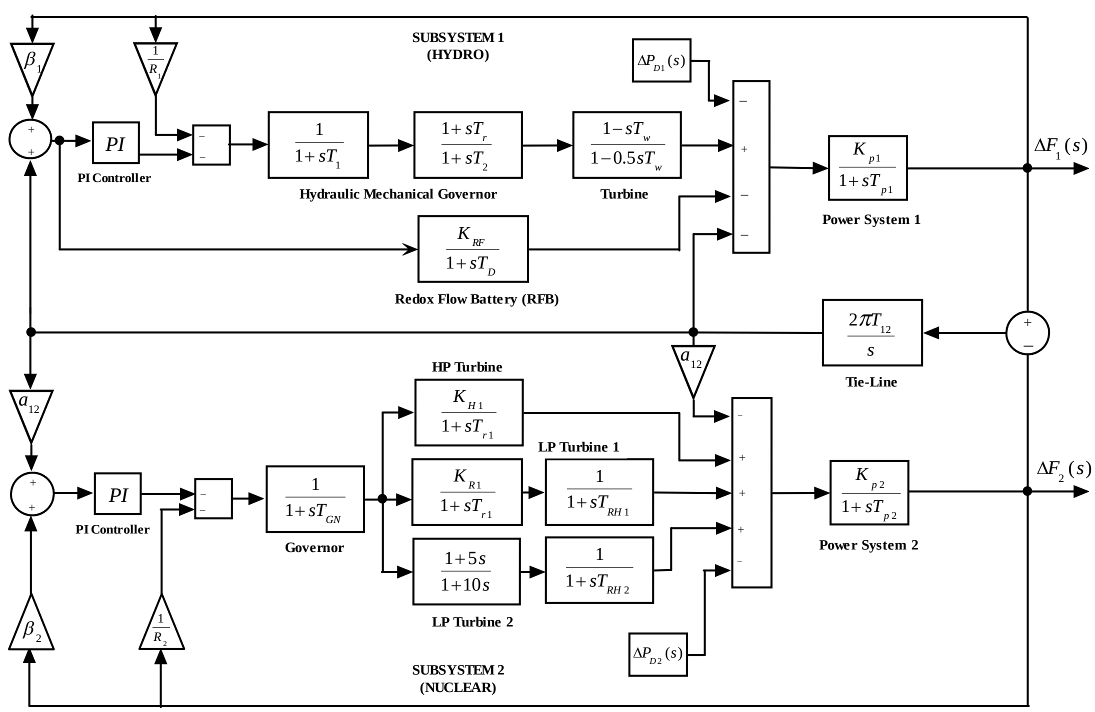

Fig. 1: Block diagram of a two area hydro-nuclear interconnected power system

response in wake of small load disturbances . A basic diagram of the integration of RFB to the power system is shown in Fig. 2.

During the low load periods, battery charges and delivers the energy back to the system during the peak load demands or sudden load changes. The dual converter performs both AC-DC and DC-AC conversions.

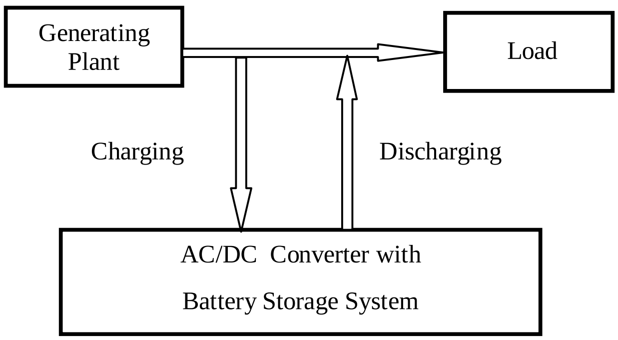

Fig. 2. Integration of RFB Energy storage system to a power system

A simplified transfer block of the RFB is given in the Fig. 3. Area Control Error (ACE) is used as the input command signal for the RFB in controlling the output response in the LFC system . The RFB transfer function block is shown in the Fig. 3.

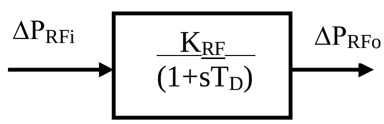

Fig. 3: Simplified transfer function block diagram of the RFB system

Artificial Bee Colony Algorithm

Karaboga and Basturk (Dervis Karaboga *et al.,* 2012) have described an Artificial Bee Colony (ABC) algorithm based on the foraging behavior of honey-bees for numerical optimization problems. Its foraging behavior, learning, memorizing and information sharing characteristics has recently been one of the most interesting research areas in swarm intelligence. It is a very simple, robust and population based stochastic optimization algorithm. Compared with the usual algorithms, the major advantage of ABC algorithm lays in that it conducts both global search and local search in each iteration, and as a result the probability of finding the optimal parameters is significantly increased, which efficiently avoids local optimum to a large extent. In the ABC algorithm, the artificial bee colony contains three groups of bees: employed bees, onlooker bees and scout bees. A bee waiting on the dance area for making decision to choose a food source is called an onlooker and a bee going to the food source visited by it previously is named an employed bee. A bee carrying out random search is called a scout. Communication among the bees about the quality of food sources is being achieved in the dancing area by performing waggle dance.

In ABC algorithm the position of the food sources determines the solution and the amount of nectar represents the fitness of the respective solution. The foraging strategy is governed by three process namely initialization, Reproduction and Replacement of bee and selection (Dervis Karaboga *et al.*, 2007).

Initialization

A randomly distributed initial populations solutions (X_i=1, 2, 3...D) is being spread over the D dimensional problem space.

Reproduction

An artificial onlooker bee chooses a food source depending on the probability value associated with that food source, P_i calculated by the following expression,

$$P_i = \frac{f_i * t_i}{\sum_{n-1}^{N} f_i * t_i} \tag{4}$$

where f_i is the fitness value of the solution i which is proportional to the nectar amount of the food source in the position i and N is the number of food sources which is equal to the number of employed bees. In order to produce a candidate food position from the old one in memory, the ABC uses the following expression.

$$V_{ij} = x_{ij} + \varphi_{ij}\left(x_{ij} - x_{kj}\right) \tag{5}$$

where k Є (1,2,3..D) and j Є (1,2,3...N) are randomly chosen indices. Although k is determined randomly, it has to be different from i. φ_{ij} is a random number between (-1,1).

Replacement of Bee selection

In ABC, providing that a position cannot be improved further through a predetermined number of cycles, then that food source is assumed to be abandoned. The value of pre determined number of cycles is an important control parameter of the ABC algorithm, which is called "limit" for abandonment . Assume that the abandoned source is X_i and J=(1,2,3,...), then the scout discovers a new food source to be replaced with X_i. This operation can be defined as

$$X_i^j = X_{\min}^j + rand(0.1) * \left(X_{\max}^j - X_{\min}^j\right) \tag{6}$$

After each candidate source position V_{ij} is produced and then evaluated by the artificial bee, its performance is compared with that of its old one. If the new food has equal or better nectar than the old source, it replaces the old one in the memory. Otherwise, the old one is retained in the memory.
Detailed pseudo-code of the ABC algorithm is given below as in (Dervis Karaboga *et al.*, 2009):

1 : Initialize the population of solutions X_i, i = 1, . . . , D
2 : Evaluate the population
3 : cycle = 1
4 : repeat

5 : Produce new solutions t_i for the employed bees by using (5) and evaluate them
6 : Apply the greedy selection process for the employed bees
7 : Calculate the probability values P_i for the solutions X_i by (4)
8 : Produce the new solutions t_i for the onlookers from the solutions X_i selected depending on P_i and evaluate them
9 : Apply the greedy selection process for the onlookers
10: Determine the abandoned solution for the scout, if exists, and replace it with a new randomly produced solution X_i by (6)
11: Memorize the best solution achieved so far
12: cycle = cycle + 1
13: until cycle = MCN (Maximum Cycle Number)

Optimization of PI Controller parameters using ABC Algorithm

The effective application of artificial bee colony algorithm is to optimize the parameters in load frequency control (LFC) of a two area interconnected hydro-nuclear power system with RFB. The proportional gains (K_p) and integral gains (K_i) have been optimized to ensure best performance of the system, minimizing the tie-line deviation and frequency deviations of both the areas. The system investigated is a two area hydro-nuclear interconnected power system with RFB, the areas being connected via tie-line. Each area has a governor and turbine which is controlled by both the primary controller (governor speed regulation) and a secondary controller (PI controller). The block diagram, as in fig.1 has been developed in MATLAB Simulink. The values of the several parameters used in the model are given in Table 1. To find the optimum values of the controller gains (K_p and K_i), the fitness function, that has been used is:

$$J = \int_0^t [\Delta F_1^2 + \Delta F_2^2 + \Delta P_{tie}^2] dt \qquad (7)$$

where, ΔF_1 and ΔF_2 are the frequency deviations of the respective areas and ΔP_{tie} is the tie-line power exchange deviation between area 1 and area 2. The problem is to obtain a set of values for the PI controller gains, of both the areas, so that the error/deviation in system frequency and tie-line power exchange is minimized to zero in minimum possible time, i.e. the errors should reduce to zero as fast as possible. For this, the fitness function J has been minimized.

The implementation of ABC algorithm for the design of Load Frequency Controller involves following steps.

1. The objective function (J) is calculated for each set of K_p and K_i.
2. The objective function values are then mapped into a fitness value of each set.
3. When fitness values are found, ABC algorithm works using greedy selection process, evaluation of probability and memorize the best solution.

These steps are repeated until the values get converged producing near value of optimum K_p and K_i.

Simulations Results and Observations

The following ABC algorithm control parameters are used in this study: Food number (the number of colony size i.e. employed bees and onlooker bees)=20; limit (A food source which could not be improved through "limit" trials is abandoned by its employed bee)=1000; max cycle=30. Table I gives the optimum values for the proportional gain K_p and integral gain K_i for the system considered. The optimal parameter set is given in the below table 1:

Table 1. Optimal gain parameters

System Description	Gain	Without RFB	With RFB
Hydro System	K_{p1}	0.60	3.80
	K_{i1}	0.02	0.95
Nuclear System	K_{p2}	13.92	11.18
	K_{i2}	1.50	0.31
Performance Index (J)		0.08845	0.002939

The system is simulated with the proposed ABC algorithm based PI controller for a 0.01 p.u. MW step load change in both area and the corresponding frequency deviations in area 1, area 2 and tie-line power deviation are plotted with respect to time as shown in fig.4, fig.5 and fig.6 respectively. It can be seen that the oscillations are practically damped out rapidly and also the amplitudes of the deviations in frequency and tie-line power are reduced considerably by including RFB. The settling of response is also very fast when RFB is considered. It is clearly evident from table 1, that the cost function (J) is drastically reduced while tuning the parameters with consideration of RFB.

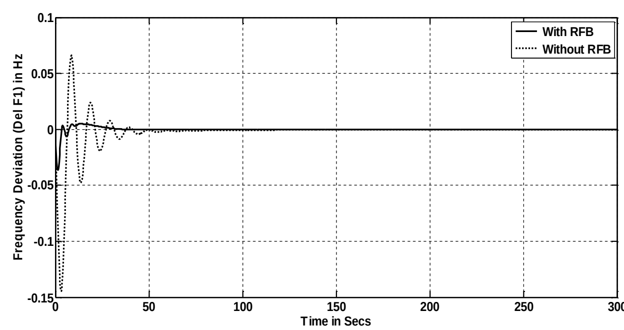

Fig. 4. Frequency deviation of area-1

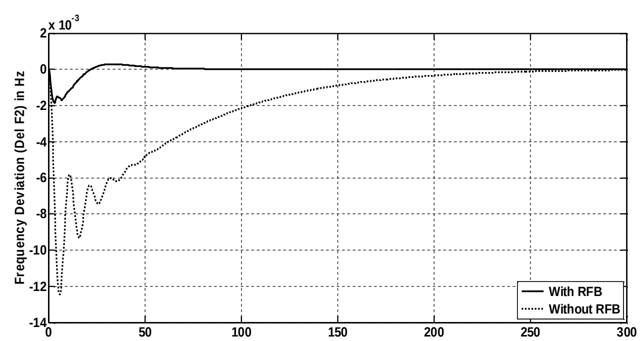

Fig. 5. Frequency deviation of area-2

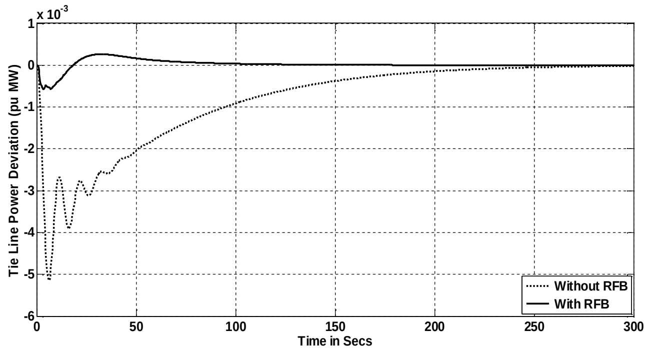

Fig. 6. Tie-line power deviation

Conclusion

LFC of a two-area interconnected hydro-nuclear power system is presented using Artificial Bee Colony (ABC) optimization algorithm. ABC algorithm based PI controller is used in the secondary loop of the LFC system. The dynamic responses have been obtained with and without consideration of RFB in the LFC system. Examination of dynamic responses show that application of RFB improves the transient responses greatly. The ability to jump out the local optima, the convergence precision and speed are remarkably enhanced by using ABC algorithm. It is observed that the ABC algorithm based load frequency controller effectively suppresses the oscillation and stabilize the system effectively.

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APPENDIX

(A). Data for Hydro-Nuclear Power System

f = 60 Hz, $R_1 = R_2 = 2.4$ Hz/p.u.MW, $T_1 = 48.7$ sec, $T_2 = 0.513$ sec, $T_r = 5$ sec, $T_w = 1$ sec, $T_{p1} = T_{p2} = 20$ sec, $K_{p1} = K_{p2} = 120$ Hz/p.u.MW, $T_{GN} = 0.08$ sec, $T_{r1} = 0.5$ sec, $T_{RH1} = 7$ sec, $T_{RH} = 9$ sec, $K_{H1} = 0.2$, $K_{R1} = 0.3$, $\beta_1 = \beta_2 = 0.425$ p.u.MW/Hz, $a_{12} = -1$, $2\pi T_{12} = 0.01$ p.u.MW/Hz.

(B). Data for RFB

$K_{RF} = 0.67$, $T_D = 0$ sec.

REFERENCES

Chidambaram I.A. and B. Paramasivam, "Control performance standards based load-frequency controller considering redox flow batteries coordinate with interline power flow controller" *Journal of Power Sources*, Vol. 219, pp. 292-304, July 2012.

Dervis Karaboga and Bahriye Akay, "A comparative study of Artificial Bee Colony algorithm", *Applied Mathematics and Computation*, Vol. 214, pp. 108–132, 2009.

Dervis Karaboga and Bahriye Basturk, "Artificial Bee Colony (ABC) Optimization Algorithm for Solving Constrained Optimization Problems", Proceedings of *the 12th international Fuzzy Systems Association world congress on Foundations of Fuzzy Logic and Soft Computing, Springer*, pp. 789–798, 2007.

Dervis Karaboga, Beyza Gorkemli, Celal Ozturk and Nurhan Karaboga, "A comprehensive survey: artificial bee colony (ABC) algorithm and applications", Artificial Intelligence Review, *Springer*, DOI 10.1007/ s10462-012-9328-0, March 2012.

Ibraheem, P. Kumar and D.P. Kothari, "Recent Philosophies of Automatic Generation Control Strategies in Power Systems", *IEEE Transactions on Power Systems*, Vol. 20, No.1, pp. 346-357, Feb. 2005.

Manoranjan Parida and J. Nanda, "Automatic Generation Control of a Hydro-Thermal System in Deregulated Environment", Proceedings of *the Eighth International Conference on Electrical machine systems*, , Vol.2, No.2, pp.942-947, 2005.

Naimul Hasan, Ibraheem and Shuaib Farooq, "Real Time Simulation of Automatic Generation Control For Interconnected Power System", *International Journal on Electrical Engineering and Informatics*, Vol. 4, No. 1, pp. 40-50, March 2012.

Omveer Singh, Prabhakar Tiwari, Ibraheem and Arunesh Kr. Singh, "A Survey of Recent Automatic Generation Control Strategies in Power Systems" *International Journal of Emerging Trends in Electrical and Electronics"* Vol. 7, Issue. 2, pp. 1-14, Sep-2013.

Sathans and Akhilesh Swarup, " Intelligent Load Frequency Control of Two-Area Interconnected Power System and Comparative Analysis", Proceedings of *International Conference on Communication Systems and Network Technologies*, pp. 360-365, 2011.

Singh Parmar K. P., "Load Frequency Control of Multi-Source Power System with Redox Flow Batteries: An Analysis", *International Journal of Computer Applications*, Vol. 88, No.8, pp. 46-52, Feb. 2014.

Singh Parmar K.P., S. Majhi and D.P. Kothari, "Load frequency control of a realistic power system with multi-source power generation", *Electrical Power and Energy Systems*, Vol. 42, pp. 426-433, June 2012.

Tetsuo Sasaki, Toshihisa Kadoya and Kazuhiro Enomoto, "Study on Load Frequency Control Using Redox Flow Batteries", *IEEE Transactions on Power Systems*, Vol. 19, No. 1, pp. 660-667, Feb. 2004.

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