GWO ALGORITHM BASED INTEGRAL CONTROLLER FOR AGC OF TWO AREA INTERCONNECTED HYDRO – HYDRO POWER SYSTEM WITH SMES UNITS

[1]P.Ganesan, [2]V.Rajaguru, [3]R.Sathya and [4]M.Abirami

[1]Associate Professor, Department of EEE, Government College of Engineering, Srirangam, Trichy, Tamilnadu, India.
[2]Assistant Professor, Department of EEE, SRM TRP Engineering College, Trichy, Tamilnadu, India.
[3]Assistant Professor, Department of EEE, Krishnasamy College of Engg & Tech., Cuddalore, Tamilnadu, India.
[4]Assistant Professor, Department of EEE, Government College of Engineering, Srirangam, Trichy, Tamilnadu, India.

Abstract : This article presents Grey Wolf Optimization (GWO) technique based Automatic Generation Control (AGC) of two area interconnected hydro – hydro power system with Superconducting Magnetic Energy Storage (SMES) units. GWO is a recently developed metaheuristic algorithm based on the behaviour of grey wolves in nature. The optimal gain of integral controller is obtained by using proposed GWO algorithm employing Integral Square Error (ISE) based fitness function. SMES unit is integrated to the AGC system to enhance the dynamic performance of the system. The proposed system is simulated using MATLAB / SIMULINK software. The simulation result demonstrates that the hydro – hydro power system with SMES units provides better dynamic enactment in terms of peak overshoot, system oscillations and settling time.

IndexTerms - **Grey Wolf Optimization, Automatic Generation Control, Hydro – Hydro Power System, Integral Square Error Technique, SMES unit, Integral Controller.**

I. INTRODUCTION

Since, the power system comprises of numerous interconnected control areas, any abrupt changes in the load causes frequency eccentricities. In order to provide consistent and virtuous quality of power supply, load frequency control in the interconnected power system is an essential task. The frequency regulation in a hydro power system can also be disrupted by fluctuations in water flow which leads to a difference between power generation and load demand. As a consequence, frequency swerves from its nominal value. The primary tasks of load frequency control are to sustain frequency and power exchanges with interconnected control areas at the intended values. Many research works have been carried out in this area and are as follows:

Manoj Kumar et al. (2017) have analyzed hybrid differential evolution–Grey Wolf Optimization Algorithm (GWO) based optimal fuzzy – PID controller for Automatic Generation Control (AGC) of a multi-source interconnected power system [1]. For the first time in the literature of AGC (three area thermal systems), Yatin and Saikia (2015) have implemented GWO, the computational evolutionary algorithm for the optimization of secondary controller gains. Ruby Meena and Senthil Kumar (2014) have investigated AGC of an interconnected four area hydro-thermal system using Superconducting Magnetic Energy Storage (SMES) unit. Ramanand Kashyap and Sankeswari (2014) have presented a simulation model for load frequency control in an interconnected hydro power system using fuzzy PID controller and it is demonstrated that fuzzy logic controller affords improved control performance. To maintain frequency and power interchange, Prajod and Carolin Mabel (2013) have employed PI controller design using Maximum Peak Resonance Specification (MPRS). Further, in this method, overshoot and settling time has been controlled and the stability of the system is retained efficiently. Ramanand Kashyap et al. (2013) have utilized fuzzy PI controller in order to investigate load frequency control in interconnected hydro power system. Liu et al. (2013) have designed a robust distributed model predictive control scheme for load frequency control of interconnected power system.

Suresh Babu et al. (2012) have analyzed application of load following in multi-area hydro thermal system in restructured environment. Naimul Hasan et al. (2012) have investigated real time simulation of AGC in interconnected hydro - nuclear power system. An inclusive digital computer exemplary of a two area interconnected power system comprising of GDB non-linearity, steam reheat constraints and the boiler dynamics is modeled by Tripathy et al. (1992). Using the model (Tripathy et al, 1992), the enhancement in AGC with the addition of a small capability SMES unit is examined. Deepak, (2014) has presented coordinated control of SMES system in AGC of a multi-source interconnected two area power generation system.

II. TRANSFER FUNCTION MODEL OF TWO AREA INTERCONNECTED HYDRO - HYDRO POWER SYSTEM

As shown in Fig. 1, a two area system comprises of two single area systems, joined through a power line called tie-line. Each area feeds its user pool and the tie line permits electric power to flow amongst the areas. Tie line power variations provide information about the local area.

It is expediently assumed that each control area can be signified by an equivalent turbine, generator and governor system. Fig.1 elucidates the block diagram of the two area interconnected hydro power system. This model contains the conventional integral controller gains (K_{11}, K_{12}). Each power area has numerous generators which are closely linked together so as to form a comprehensible group. Such a coherent area in which the frequency is assumed to be the same is named as the control area.

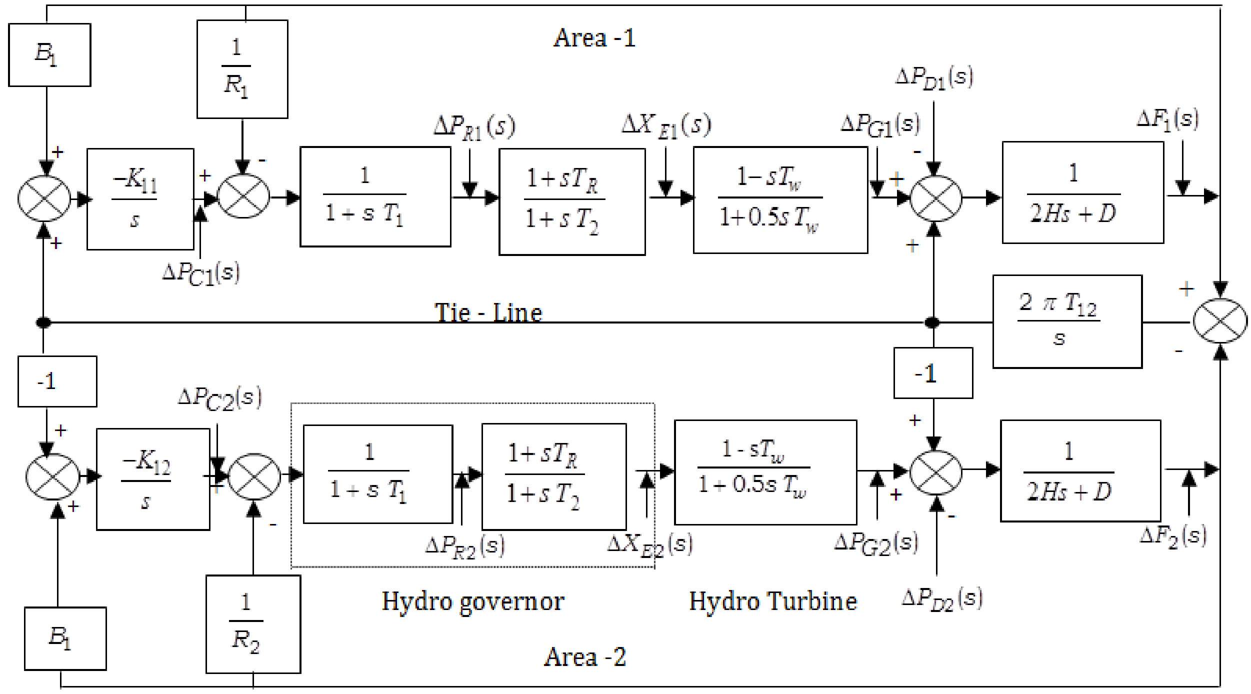


Fig.1. Two area interconnected hydro – hydro power system - Transfer function model.

2.1 SMES Unit

An SMES unit comprises of a big superconducting coil at the cryogenic temperature. Fig. 2 illustrates the block diagram of the SMES unit. The superconducting coil is sustained at the cryogenic temperature which is maintained by a cryostat or dewar that encompasses helium or nitrogen liquid vessels. The SMES unit is connected to an AC power system through a power conversion or conditioning system and it is utilized to charge or discharge the coil.

When there is an abrupt increase in the demand of load, the stored energy is almost instantly released as line quality AC through the PCS to the grid. The coil charges rear to its preliminary value of current, since the governor and other control mechanisms begin working to set the power system to the new equilibrium condition and the same action takes place while abrupt release of loads. The coil instantly gets charged towards its complete value, thus some portion of the excess energy in the system is absorbed and as the system returns to its steady state, the excess energy absorbed is released and the coil current reaches its normal value. The operation of SMES units, that is, charging, discharging, the steady state mode and the power modulation in the dynamic oscillatory period are regulated by the application of the proper positive or negative voltage to the inductor. This can be accomplished by regulating the firing angle of the converter bridges.

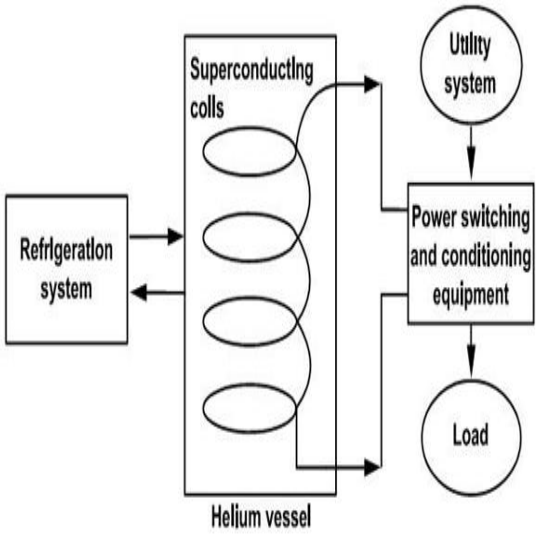


Fig. 2. SMES unit – Block diagram.

The DC voltage equation after neglecting transformer and converter losses is written as,

$$E_d = 2V_{do}\cos\alpha - 2I_d R_c \tag{2.1}$$

Where,

E_d =DC voltage applied to the inductor (KV)

α = firing angle (degrees)

I_d = current through the inductor (KA)

R_c = equivalent commutating resistance (Ω)

V_{do}= maximum open circuit bridge voltage of each six-pulse convertor at α=0 degree (KV).

By applying small positive voltage, inductor is initially charged to its rated current, I_{do}. Once the current has attained the rated value, it is seized constant by decreasing the voltage idyllically to zero as the coil is superconducting. A diminutive voltage is needed to conquer the commutating resistance.

The stored energy at any instant is given by,

$$W_L = \frac{1}{2}(LI_d^2), MJ \tag{2.2}$$

Where,

L = inductance of SMES, in Henry

I_d = current through the inductor (KA).

In LFC operation, DC voltage applied to the inductor is unceasingly controlled by the input signal given to the SMES control logic. The inductor current must be reinstated to its nominal value rapidly following a system disturbance as it can retort to the next load disturbance instantly. Hence, in order to enhance the current restoration to its steady state value, the inductor current deviation is utilized as a negative feedback signal in the SMES control loop. Based on the aforementioned discussion, the applied inductor and inductor current due to converter voltage deviations are given as follows:

$$\Delta E_{di}(S) = \frac{K_{SMES}}{1+ST_{dci}} U_{SMESi}(S) - \frac{K_{id}}{1+ST_{dci}} \Delta I_{di}(S) \tag{2.3}$$

$$\Delta I_{di}(S) = \frac{1}{SL_i} \Delta E_{di}(S) \tag{2.4}$$

Where,

$\Delta E_{di}(s)$ =Converter voltage deviation applied to inductor in SMES unit

K_{SMES} = Gain of control loop SMES

T_{dci} = Convertor time constant in SMES unit

U_{SMES} = control signal of SMES unit

K_{id} = gain for feedback ΔI_d in SMES unit

$\Delta I_{di}(s)$= deviation of inductor current in SMES unit.

The ACE_i is described as follows:

$$ACE_i = B_i \Delta F_i + \Delta P_{tie,i} \tag{2.5}$$

Where,

B_i = Frequency bias in area i

ΔF_i = Frequency deviation in area i

$\Delta P_{tie,i}$ = Net tie line power flow deviation in area i.

The aberration in the inductor real power of SMES unit can be articulated in time domain as follows:

$$\Delta P_{SMES,i} = \Delta E_{di} I_{doi} + \Delta I_{di} \Delta E_{di} \tag{2.6}$$

Where, ΔP_{SMESi} = Deviation in the inductor real power of SMES unit in area i.

For transfer from AC grid to DC, this value is presumed to be positive. Fig.3 shows the mathematical model of SMES unit.

2.2 Integral controller

The integral control composed of a frequency sensor and an integrator. The frequency sensor measures the frequency error Δf and this error signal is fed into the integrator. The input to the integrator is called Area Control Error (ACE). The ACE is the change in area frequency, which when utilized in an Integral-control loop, forces the steady-state frequency error to zero.

The integrator yields a real-power command signal ΔPc that is given by,

$$\Delta P_c = -K_i \Delta f \, dt \tag{2.7}$$

$$= -K_i ACE \, dt \tag{2.8}$$

Where, ΔPc = input of speed –changer

K_i = integral gain constant.

The value of K_i is so selected such that the retort will be damped and non-oscillated.

Integral controller gain K_I has to be determined by using Integral Square Error (ISE) criterion. The objective function is given by,

$$J = \int_0^t (\Delta F_1^2 + \Delta Ptie_1^2) dt \tag{2.9}$$

Where,

Δf_1= change in frequency in area 1

ΔP_{tie} = change in tie-line power

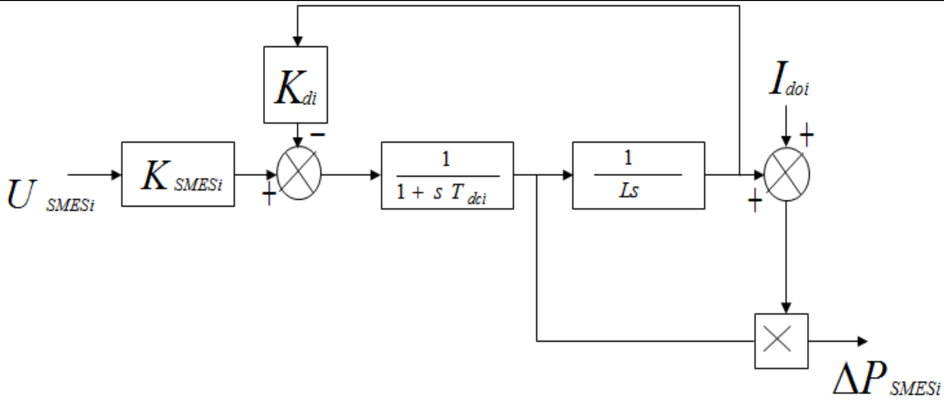


Fig. 3. Mathematical Model of SMES unit

III. GREY WOLF OPTIMIZATION (GWO)

Mirjalili et al., have proposed GWO algorithm [12], which reflects the behavior of grey wolf in searching and hunting of their prey. Grey wolves desire to live in a cluster size of 5–12 members on an average. Group is termed as a pack. They have very stringent social dominant hierarchy. A male and a female are the leaders of the pack and alpha (α), beta (β), delta (δ) and omega (ω) are the four categories in a pack. Alpha is the first level and is mostly liable for decision making. The decisions of alpha are decreed to the pack. It is not necessary that the alpha is the most powerful member of the pack but they are the best in managing the group. This behavior of the pack shows that association and discipline of a group are vital than its strength. Beta is the second level and they assist the alpha in decision making or in other deeds. The beta wolf can be either male or female. Beta can take charge of the pack in the absence of alpha. Beta wolf supports alpha's command throughout the pack and provides feedback to the alpha. Delta is the third level and this level comprises of scouts, sentinels, hunters and caretakers. Scouts are liable for watching the precincts of territory and they issue caveat to the pack in case of any danger. Sentinels are liable for the protection of the pack. While hunting the prey, hunters help the alphas and betas. Omega is the lowest ranking in the pack and they have to succumb to all the dominant wolves. They are the last wolves that are endorsed to eat. The prime process of hunting of grey wolves are searching and encircling the prey and attacking the prey. The pseudo code of GWO algorithm is as follows:

Generate an initial population and initialize all the relevant parameters of the algorithm.
Calculate the fitness of each search agent based on the objective function.
Corresponding to the best three results assign the values of X_α, X_β, X_δ as the position of alpha, beta and delta.
While (t < Maximum number of iterations)
for each search agent.
The current search agent's position is updated.
end for
Each individual search agent is updated.
Fitness of all search agents is calculated.
The positions of alpha, beta and delta wolves are updated.
Iteration=Iteration+1
end while
X_α is displayed as the best wolves.

IV. SIMULATION MODEL AND RESULTS

The simulation diagram of GWO based Integral Controller for AGC of two area interconnected hydro – hydro power system with and without SMES unit is shown in Fig. 4. The finest values of K_I are provided in the Appendix.

The convergence curve of GWO technique are plotted for two different cases (system without and with SMES unit), which is shown in Fig. 5(a) and Fig. 5(b). Figure 6 demonstrates the simulation results of GWO based integral controller for AGC of two area interconnected hydro – hydro power system with and without SMES units. Fig. 6(a) and Fig. 6(b) illustrates the frequency response of area-1 (i.e. Δf_1) and area-2 (i.e. Δf_2) respectively for the system with and without SMES unit. Fig. 6(c) elucidates the tie line power deviation (Δp_{tie}) for the system with and without SMES units.

It can be inferred from the simulation results, that the dynamic performance (such as frequency oscillations, peak overshoot and settling time) of the hydro – hydro power system is significantly improved when the SMES units are incorporated in a system.

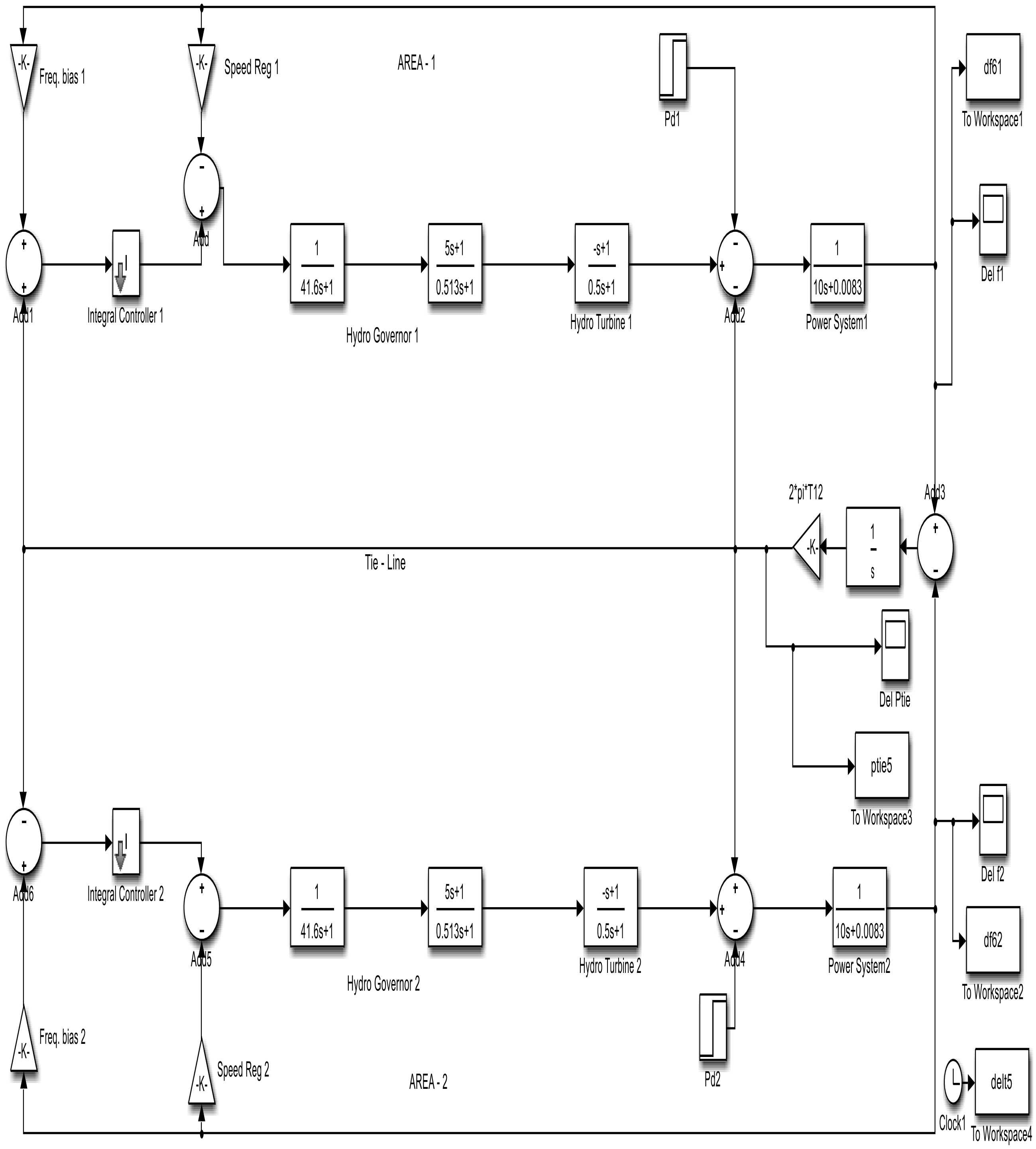


Fig. 4(a). GWO based Integral Controller for AGC of Two Area Interconnected Hydro – Hydro Power System without SMES Units

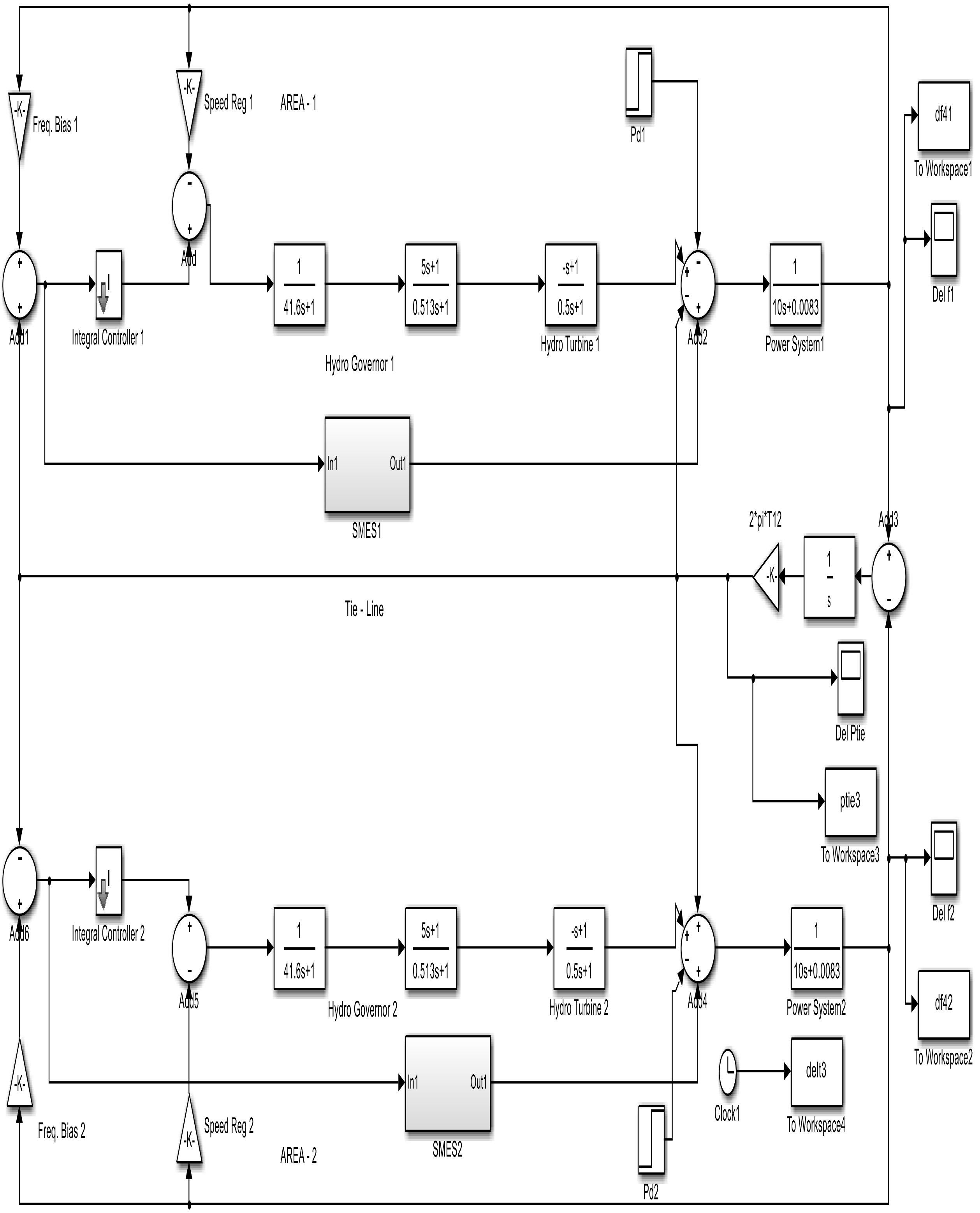
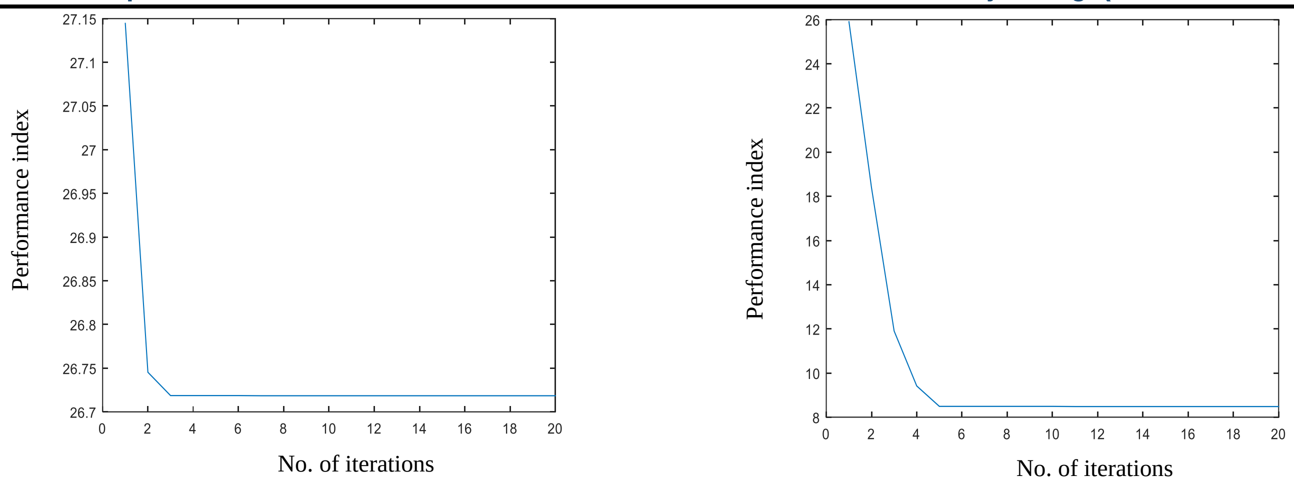


Fig. 4(b). GWO based Integral Controller for AGC of Two Area Interconnected Hydro – Hydro Power System with SMES Units



(a) (b)

Fig. 5. Convergence characteristics of GWO for a system. (a) without SMES units, (b) with SMES units.

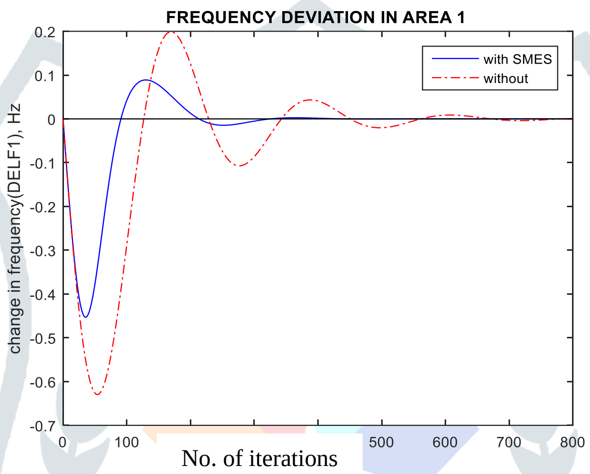


Fig. 6(a). Frequency Response of Area-1 (Δf_1).

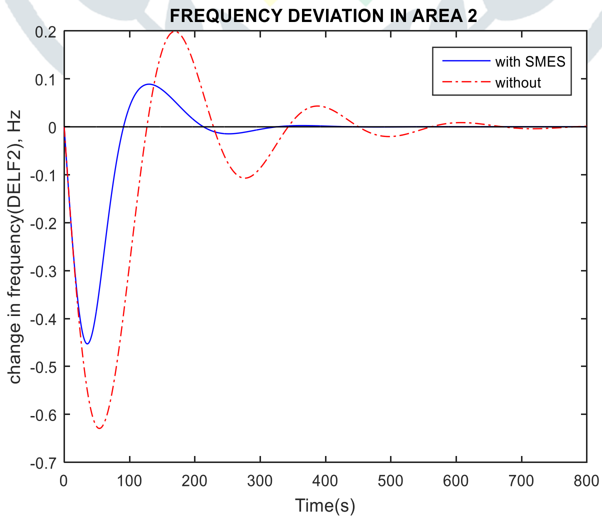


Fig. 6(b). Frequency Response of Area-2 (Δf_2).

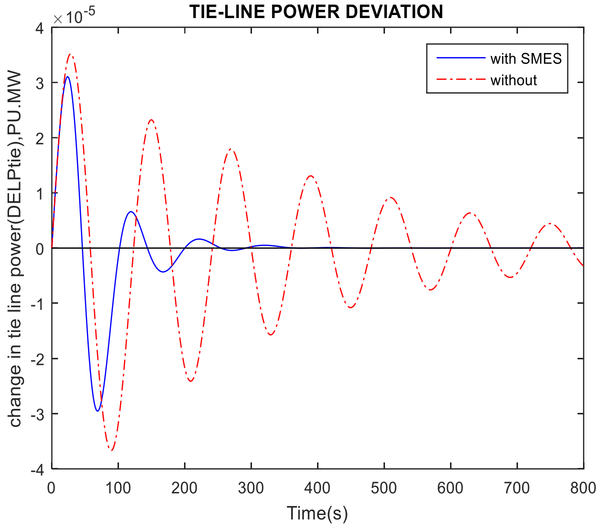


Fig. 6(c). Tie line power deviation of area-1 and area-2 ($\Delta p_{tie\ 1,\ 2}$).

V. CONCLUSION

AGC provides a relatively simple, yet extremely effective method of adjusting generation to minimize frequency deviation and regulate the tie – line power flows. In this paper, GWO algorithm based Integral Controller for AGC of two area interconnected hydro - hydro power system with SMES unit is investigated. The power system model consists of hydro - hydro units with SMES units and without SMES units are considered for this study and the system performance are observed for 1% step load disturbance. Further, the integral controller gain K_I has been optimized for two different cases (for the system without and with SMES Unit) by using GWO algorithm employing ISE criterion. The simulation result proves that the dynamic performance of the system (such as frequency oscillations, peak overshoot and settling time) is significantly improved when the SMES units are incorporated in a two area interconnected hydro – hydro power system.

APPENDIX

A.1 System Data

P_{r1}= P_{r2} = 2000MW, T1= 41.6 sec,
T_2 = 0.513 sec, T_R = 5 sec, T_W = 1 sec,
H = 5 sec, D = $8.33*10^{-3}$ Pu. MW/Hz,
B = 0.425 Pu.MW/Hz,
R = 2.4 Hz/Pu.MW,
K_I (With SMES unit) = 0.026488.
K_I (Without SMES unit) = 0.011217.

A.2 Data for SMES block

L =2.65 H, T_{dc}= 0.03 sec,
K_{SMES} = 50 KV/unit MW
K_{di}= 0.2 KV/KA, I_{do}= 4.5 KA.

REFERENCES

[1] Manoj Kumar, D, Ranjan Kumar, M and Binod Kumar, S. 2017. Application of hybrid differential evolution–grey wolf optimization algorithm for automatic generation control of a multi-source interconnected power system using optimal fuzzy–pid controller. Electric Power Components and Systems, 0(0): 1-14.
[2] Yatin, S and Saikia, L.C. 2015. Automatic generation control of a multi-area st – thermal power system using grey wolf optimizer algorithm based classical controller. Electrical Power and Energy systems, 73(1): 853-862.
[3] Ruby Meena, A. and Senthil Kumar, S. 2014. Load Frequency Stabilization of four area hydro thermal system using Superconducting Magnetic Energy Storage System. International Journal of Engineering and Technology, 6(3): 1564-1572.
[4] Ramanand Kashyap and S.S. Sankeswari. 2014. A simulation model for LFC using fuzzy PID with interconnected hydro power systems. International Journal of Current Engineering and Technology, 3: 183-186.
[5] Prajod, V.S. and Carolin Mabel. M. 2013. Design of PI controller using MPRS method for Automatic Generation Control of hydropower system. International Journal of Theoretical and Applied Research in Mechanical Engineering, 2(1): 1-7.
[6] Ramanand Kashyap, Sankeswari, S.S. and Patil, B.A. 2013. Load frequency control using fuzzy pi controller generation of interconnected hydropower system. International Journal of Emerging Technology and Advanced Engineering, 3 (9): 655-659.
[7] Liu, X, Huiyun Nong, Ke Xi and Xiuming Yao. 2013. Robust distributed model predictive Load Frequency Control of interconnected power system. Mathematical Problems in Engineering, 1-10.
[8] Suresh Babu, A. Saibabu, Ch. and Sivanagaraju, S. 2012. Implementation of load following in multiarea hydrothermal system under restructured environment. International Journal of Engineering Sciences and Emerging Technologies, 3(1): 13-21.
[9] Naimul Hasan, Ibraheem and Shuaib Farooq. 2012. Real time simulation of automatic generation control for interconnected power system. International Journal of Electrical Engineering and Informatics, 4(1): 40-51.
[10] Tripathy, S. C. Balasubramanian, R. and Chanramohanan Nair, P. S. 1992. Effect of superconducting magnetic energy storage on automatic generation control considering governor dead band and boiler dynamics. IEEE Transactions on Power Systems, 3(7): 1266–1273.
[11] Deepak, M. 2014. Improving the dynamic performance in load frequency control of an interconnected power system with multi source power generation using SMES. International Conference on Advances in Green Energy.
[12] Seyedali Mirjalili, Seyed Mohammad Mirjalili and Andrew Lewis. 2014. Grey wolf optimizer. Advances in Engineering Software, 69: 46–61.