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Load Frequency Control of Multi-Area Multi-Source Power System by Gray Wolf Optimization Technique

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***Abstract*: Now a day's power system is expanding due to increasing load demand. It is also typical task to maintain load demand on behalf of stability limits. To meet load demand energy generator plays important role which uses automatic generation control process to maintain stability limits and load demand. In this presented work we designed PID controller for multi area power system for AGC. MAMS power system is considered for this purpose. For this purpose, MAMS power system is considered. PID controller optimization parameters are achieved using GWO technique. Superiority of results of developed optimization technique is compared with various optimization methods.**

Proposed system model includes Boiler Dynamics, Generation Rate Constraints and non-linearity of Governor Dead Band. Obtained simulation results indicates the effectiveness of derived approach which gives better response by comparing its results with other techniques. Sensitivity analysis can also done by changing parameters of system and various loading conditions within limit of ±25% for its rated values to check the robustness of presented work. Results of proposed approach is compared with some recent algorithms like TLBO and DE for same interconnected power system. To obtain optimized parameters of controller gain GWO technique is used. Minimization of an objective function provides better stability of the system.

***Keywords*: AGC, GWO Algorithm, LFC, PID Controller, Non Linearity.**

1. Introduction

Due to increasing load demand power system becomes more complex to maintain their system parameters within permissible limits. To make system frequency and tie line power constant to its nominal values are also a vital problem. AGC play major role to maintain system frequency and tie line power constant [1]. Due to sudden load changes and disturbances produced active power becomes less than power demanded which resulting into decreasing in frequency and vice versa. Decrement of frequency like this is undesirable and required to damp out quickly to manage tie line power constant to its prescribed limit. For this purpose, concept of AGC is used because constant frequency cant achieved by speed governor alone. So a robust control system with AGC is required to keep the load changes in permissible limits and maintain system frequency and damp out oscillations [2].

In this presented work, MAMS is used with various power plants and analysis of system consists boiler dynamics, GRC&GDB. Performance of system is evaluated with PID controller which optimized using GWO algorithm to damp out oscillations. GWO technique is used to optimize controller parameters to provide better stability of the system. Steady state error is removed integral term and also it makes transient response worse. To stabilize the system derivative term is used, as result overshoot decreases and improvement in transient response is seen. For PID controller result analysis is performed using GWO algorithm for MAMS Power System.

A. *Objective Function*

Main purpose the paper is to achieve load frequency constant within prescribed limit to maintain voltage stability and power quality. ITAE based objective function criterion is used for performance analysis which is given by:

$$J = ITAE = \int_0^{tsim} (|\Delta Fi| + |\Delta \mathrm{P}_{Tie-i-k}|)\mathrm{t.\,dt} \qquad (1)$$

Where,

ΔFi= incremental change in frequency of area I,

$\Delta P_{\mathrm{Tie-i-k}}$=Tie line power incremental change between area i & k

subject to,

$$\mathrm{K_p^{min}} \le \mathrm{Kp} \le \mathrm{K_p^{max}} \qquad (2)$$

$$\mathrm{K_I^{min}} \le \mathrm{K_I} \le \mathrm{K_I^{max}} \qquad (3)$$

$$\mathrm{K_D^{min}} \le \mathrm{K_D} \le \mathrm{K_D^{max}} \qquad (4)$$

t_{sim} = Time range of simulation.

2. System model

A. *AGC in a MAMS Power System*

Ability of GWO optimized PID controller is tested over realistic multi area multi source interconnected power system. Where Area-1 includes reheat thermal, hydro &wind power plants while Area-2 includes reheat thermal, Diesel & hydro power plants.

Governor dead band is stated as overall amount of a continue speed change within which there is no change in valve position. Due to GDB an raise /fall of speed occur before the position of

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valve changes. In the given work 0.0.5% backlash nonlinearity for the thermal system & 0.02% for hydro system is considered. GRC is defined as a maximum rate of power generation which we can change in power system [10].

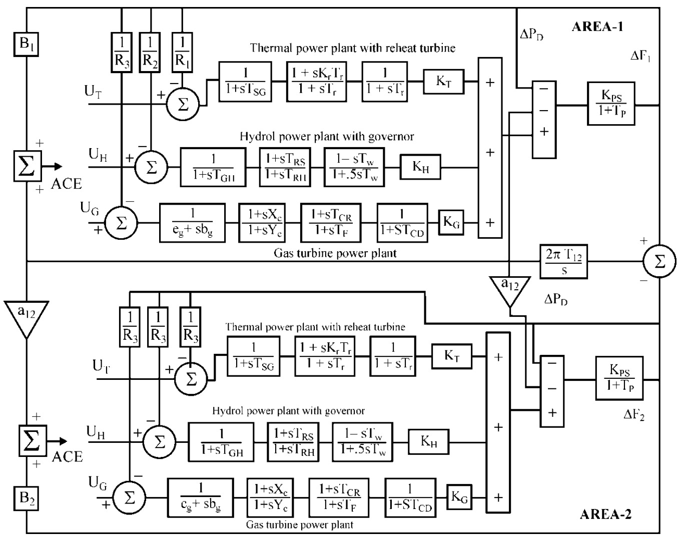

Fig. 1. Multi-area multi-source power system

3. GWO Tuned PID Controller

A. Grey Wolf Optimizer (GWO)

To solve complex engineering design problems and real application GWO results proves that proposed algorithm is more suitable for challenging tasks with unknown search space. GWO results found more competitive and challenging then above mentioned techniques like PSO, GSA, DE, ES and EP. So we choose GWO technique for PSS optimization which is explained in detail. Proposed optimization method is applicable to get the best placement and no.of the PSSs in multi machine power systems. With respect to above explanation these wolves live pack and are subjected to Canidae family. Live in pack so they have a leader who is alpha which indicates their strict social dominant hierarchy.

As these, live in pack they have a leader who is Alpha indicating their strict social dominant hierarchy. As Alpha is the leader, most of the decision for group is taken by him hence his decision should be followed by other members of the pack. Common decision includes sleeping place, hunting, waking time etc. ɑ may not be the strongest member of the pack but the best to manage the whole group. Such characteristics implies the discipline and organization in the pack is considered prior to the strength.

Pack considered subordinates too so ß (also known as advisor) helps ɑ in the process of decision making and maintain the discipline in pack. These are also the next in line to become ɑ if the present ɑ passes away or has become old. It obeys the Alpha and gives command to other wolfs. ß also provides feedback to the ɑ.

Wolfs which are at the lowest rank are Omega, which follows all other dominant wolfs. These play the role of scapegoat. They are the last to eat in pack. Omega may be considered least to give any significance but if the pack looses them it may cause an internal fighting. It is because of absence of all frustration and violence of all wolfs by Omegas. It helps in maintaining the dominance structure in the pack as well as satisfaction among them. In many cases, Omega also plays the role of babysitter. If wolf doesn't belong to any rank then they comes under Delta wolfs which are above Omega wolfs and it means these follows other two ranks in the pack.

Category of wolves falls under like hunters, elders, sentinels, caretakers and scouts. Keeping watch on pack territory and alerting for danger is the responsibilities of Scouts. Duty of guard and providing protection to the pack is done by Sentinels. Elder wolfs are the one who once were Alpha or Beta in their life time and most experienced ones. Hunters Assists ɑ &ß while hunting and arranging food for the pack. As the name suggest caretakers wolfs take care of wolfs which are weak or ill or wounded in the pack.

Group hunting is among the many features of their social environment. The main phases in hunting are,

1. Tracking the prey, then chasing them and at last approaching them.
2. Act of encircling, pursuing and harassing of prey until it stops moving.
3. Last is attack on prey.

B. Mathematical Model and Algorithm

It is a versatile algorithm. Wolfs lives in social pack and hunts too in pack. This is the very appealing behavior of algorithm. GWO mimics this. Here is the outline of the process showing how it does it [13].

1) Social Hierarchy

First best solution is α, second best solution is ß and third best solution is δ. Apart from these all the candidate solutions falls under ω.

2) Prey Encircling

Prey is encircled by Grey wolfs while hunting. To reflect it mathematically,

$$\vec{D} = |\vec{C}.\vec{X}_p(t) - \vec{X}(t)| \quad (5)$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \quad (6)$$

t, represents current iteration

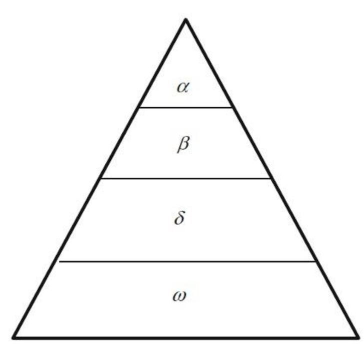

Fig. 2. Grey wolf social hierarchy

$\vec{A}$ & $\vec{C}$=vector coefficients

$\vec{X}_p$= Vector for prey position

$\vec{X}$= Grey wolf position vector

$\vec{A}$ &$\vec{C}$ are given by,

$$\vec{A} = 2\vec{a}.\vec{r}_1 - \vec{a} \quad (7)$$

$$\vec{C} = 2.\vec{r}_2 \quad (8)$$

As iteration progresses $\vec{a}$ components falls from 2 to 0.

$\vec{r}_1, \vec{r}_2$ are random vectors lies between in [0, 1].

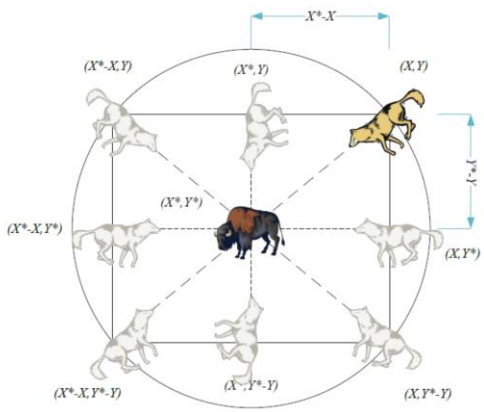

Fig. 3. 2D Position vector with possible next location

In the above figure, it is clear that as the position of prey (X*, Y*) changes a grey wolf will also change its position (X, Y). Adjustment in $\vec{A}$ and $\vec{C}$ various places around the best agent is meet with respect to present location. Like, to reach (X*-X, Y*), $\vec{A}$= (1,0) and $\vec{C}$=(1,1) is set.

C. Hunting

ɑ guides the hunting while ß and δ might take part in it sometimes. Grey wolfs can identify prey location and encircle them. Although, in a search space the location of prey is unknown i.e. optimum. To simulate the hunting by grey wolf mathematically, it is assumed that the Alphas i.e. best candidate solution; ß and δ have the better knowledge regarding prey possible location.

1) Attacking

The moment prey stop moving, grey wolf initiate attacking it i.e. the step after hunting. It is the process of exploitation.

2) Prey Searching

Searching depends upon the alpha, beta and delta positions. At, first they diverge and then they converge for attack. For mathematical realization of divergence, A ⃗ is used having random values > 1 or <-1 to depict the action of diverge of search agent. It emphasizes on exploration allowing GWO to search globally. It is shown in fig. 4.7 with |A| > 1, for getting the fitter prey. Exploration favors by vector C ⃗. It is clear from the eqn., it has random values in [0, 2]. study.

3) PID Controller

PID controllers are also used for improving transient response to decrease error amplitude with every oscillation and then output is eventually settled to required final value. We can say in another word better margin of stability is meet by PID controllers. Output of PID controller depends upon the error signal e(t) generated by comparing desired set point with the processed variable. The error is then corrected based on integral, proportional and derivative control.

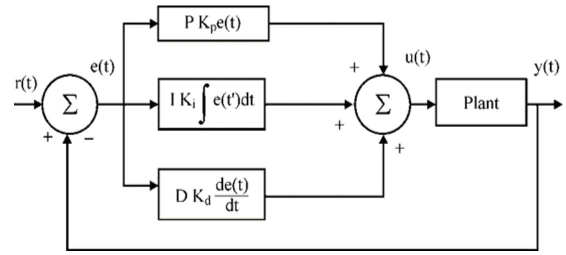

Fig. 4. Structure of PID Controller

It can be represented as,

$$u(t) = K_p e(t) + K_i \int e(t')dt' + K_d \frac{de(t)}{dt} \quad (9)$$

4. Result and discussions

In this proposed approach multi area multi source power system is simulated using GWO optimized PID controller. Proposed system is categorized into two areas which connected via tie line. Area-1 consists of three kinds of plants such as thermal, wind &hydro power plant & Area-2 consists of thermal, diesel & hydro power plant. Boiler dynamics is including in thermal power plant and this is use to changes in the steam flow and deviation in pressure and all action in turbine valve and boiler control. The backlash nonlinearity for thermal system is 0.05% and for hydro system is 0.02%. The participation factor for thermal is 0.575 and hydro is 0.3 and wind and diesel is 0.125 is assumed.

Performance of system is evaluated in MATLAB/ SIMULINK environment and multi-area multi source is tested at various condition as nominal loading conditions and parameter variation, time constant of steam turbine(T_T), time constant of main servo hydro turbine speed governor (T_{GH}), hydro turbine speed governor transient droop time constant (T_{RH}) & governor regulation parameters (R). The GWO optimized shows superior response than other recently publish algorithm as same interconnected system and finally proposed system shows robust and satisfactory result at all disturbances.

The various parameters need to be provided like maximum number of iterations, search agent, lower bound of scaling factor, upper bound of scaling factor, number of dimension. The GWO can work effectively only when these parameters are chosen carefully. The various parameters chose for GWO are given in Table 1 below.

Table 1
Various Parameters of GWO

S.No.	Parameter	Value
1.	Maximum No. of Iterations	50
2.	Number of Search Agent	30
3.	Lower Bound of Scaling Factor	0
4.	Upper Bound of Scaling Factor	05
5.	Dimension	18

Case-1: 1% SLP in area 1 with 25% Increase/decrease in Nominal Loading

Fig. 5 to 8 shows the dynamic response analysis of multi-area multi source power system analysis with 25% increase/decrease in nominal loading conditions. It's clear from Table 1 that the dynamic performance with proposed GWO optimized PID controller is found better in nominal loading condition and system shows stable operation.

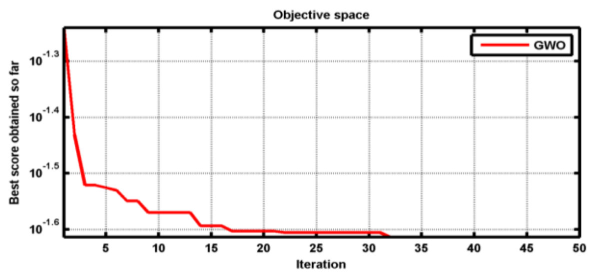

Fig. 5. Shows the best cost function with an iteration of GWO algorithm

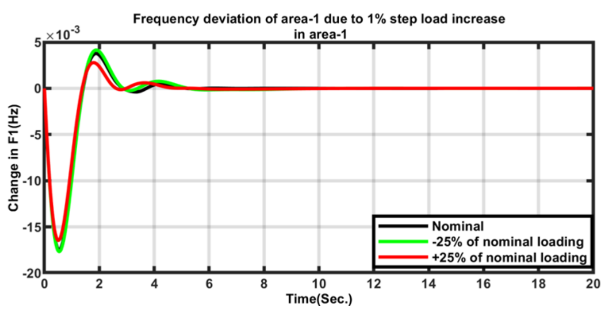

Fig. 6. Frequency deviation of area-1 with variation of nominal loading Conditions

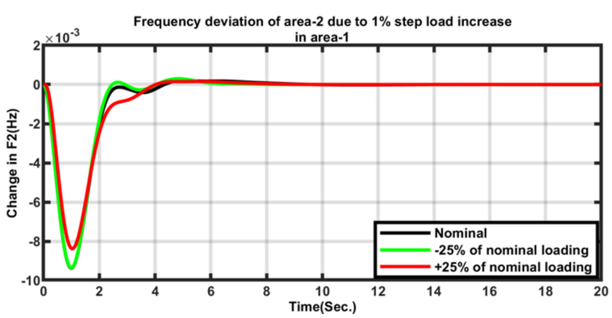

Fig. 7. Frequency deviation of area-2 with variation of nominal loading conditions

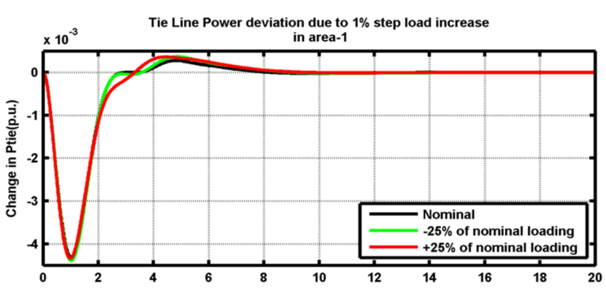

Fig. 8. Tie line power deviation with variation of nominal loading conditions

Table 2
Different settling time of nominal loading conditions

% Change in Nominal Loading	Settling Time(Second)		
	ΔF_1	ΔF_2	ΔP_{tie}
+25	4.1722	3.7845	7.5582
-25	4.7927	5.4311	7.5155

Case-2: 1% SLP in area 1 with 25% increase/decrease in T_t & R

Fig. 9 to 11 shows the dynamic response analysis of MAMS power system analysis with 25% increase/decrease in turbine time constant T_t & R. Table 2 conclude that ITAE and settling time values are change only acceptable limit and all system do not require reset again when apply loading condition So proposed GWO optimized PID controller shows effective response.

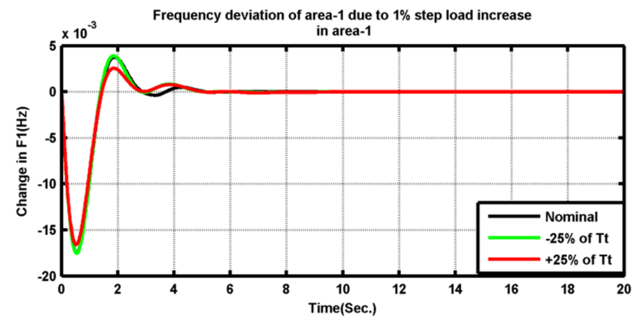

Fig. 9. Frequency deviation of area-1 with parameter variation of T_t

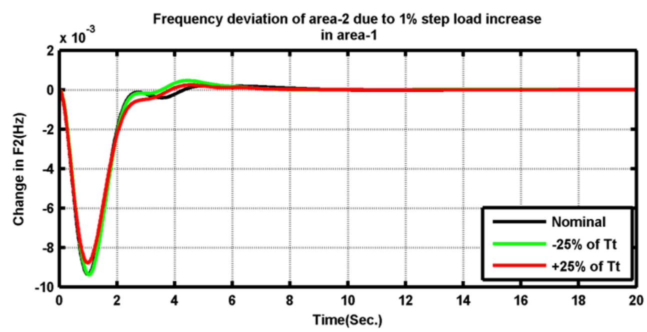

Fig. 10. Frequency deviation of area-2 with parameter variation of T_t

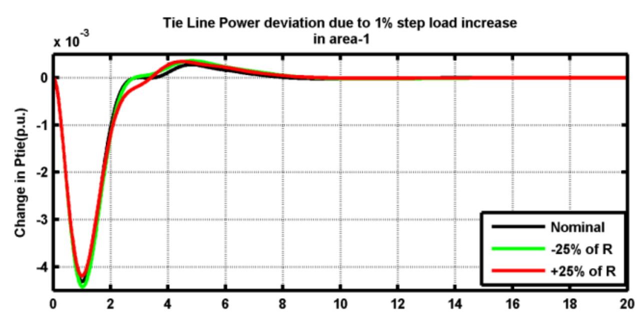

Fig. 11. Tie line power deviation with parameter variation of R

Table 3
Different settling time of change in T_t & R

% Change in T_t & R	Settling Time(Second)					
	ΔF_1		ΔF_2		ΔP_{tie}	
	T_t	R	T_t	R	T_t	R
+25	4.5254	4.4054	5.0538	5.1843	7.3335	7.4290
-25	4.4533	4.3927	5.8417	3.9382	5.5107	7.5035

Case-3: 1% SLP in area 1 with 25% Increase/Decrease in T_{GH} & T_{RH}

Fig. 12 to 14 shows the dynamic response analysis of MAMS power system analysis with 25% increase/decrease in T_{GH} & T_{RH}. Table 3, shows the designed controllers are emphatic and carry out the satisfactory operation when employs GWO PID controller.

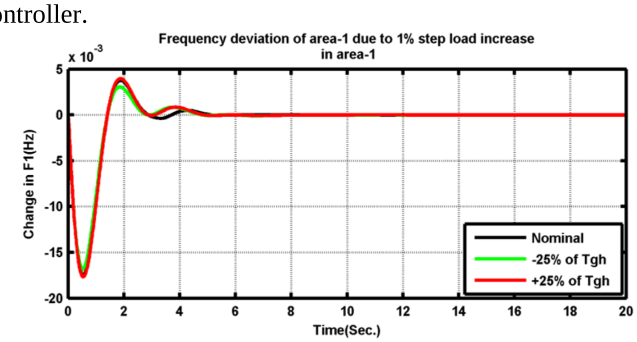

Fig. 12. Frequency deviation of area-1 with parameter variation of T_{GH}

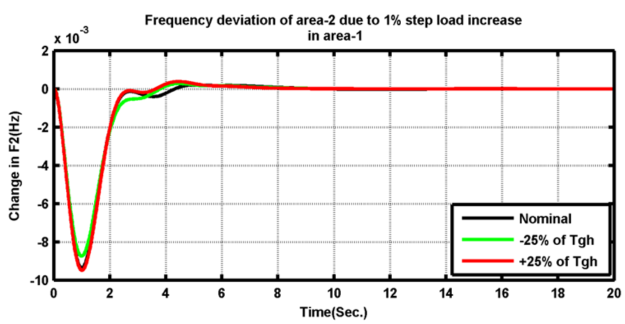

Fig. 13. Frequency deviation of area-2 with parameter variation of T_{GH}

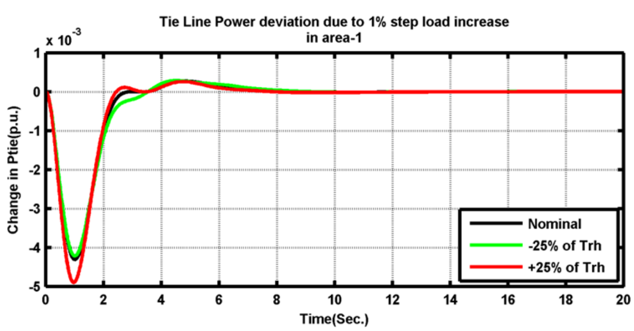

Fig. 14. Tie line power deviation with parameter variation of T_{RH}

Table 4
Different Settling Time of Change in T_{GH} & T_{RH}

% Change in T_{GH} & T_{RH}	**Settling Time(Second)**					
	ΔF_1		ΔF_2		ΔP_{tie}	
	T_{GH}	T_{RH}	T_{GH}	T_{RH}	T_{GH}	T_{RH}
+25	4.4474	4.9494	5.3757	5.9480	5.8277	5.9523
-25	4.3912	4.4189	5.2233	4.9099	7.2223	7.2209

5. Conclusion

Load frequency control of MAMS power system has various sources of power generation. The system three types of non-linearity include as boiler dynamics, GRC & GDB and system study with various cases of sensitivity analysis but Its observed that, the dynamic performance of proposed controller is improved & designed system is tough and is not affected by changes in the loading condition when system is optimized GWO based optimized PID controller.

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