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Load Frequency Control of an Interconnected Power System using Grey Wolf Optimization Algorithm with PID Controller

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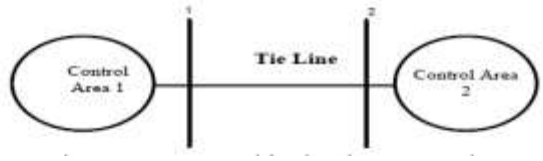
Abstract - *The interconnected two area LFC system has number of generators are connected together and run in unison manner to meet the load demand. In this project a GWO optimization with PID controller techniques are proposed for load frequency control is used to improve the dynamic response of the system. The load frequency control system is modeled and simulated using MATLAB-SIMULINK environment and the control parameters are tuned based on GWO algorithm. The main objective is to obtain a stable, robust and controlled system by tuning the PID controllers using GWO algorithm. The power system is subjected to a load disturbances to validate the effectiveness of the proposed GWO optimized PID controller. The incurred value is compared with the PI controller and is proved that the PID with GWO gives better optimal solution. The simulated results are obtained for different load configurations of the GWO based controller. The proposed approach has superior feature, including easy implementation, stable convergence characteristics and very good computational performance efficiency.*

Key Words: Load frequency control, PID controller, Grey Wolf Algorithm,

1. INTRODUCTION

In interconnected power systems, a nominal system frequency depends on a balance between produced and consumed real power. A real power inequality in which occurs any where of the system is perceived in a whole network as a frequency deviation. Nevertheless, if it is taken into consideration that the properly working of industrial loads connecting to the power system depends on quality of electric energy, this balance is had to keep for holding the steady-state frequency error between acceptable values. The balance of real power in an interconnected power system is provided by the amount of production of the synchronous generators connected to the system is made sense for frequency deviations. If the amount of produced power is less than the demanded one, the speed and also frequency of the generators decrease, and vice versa. For bringing frequency deviation to desired level back is provided by control of the turbines which turn the generators. For this purpose, the PI-controller is classically used, and by tuning the controller gains, the steady-state error of the system frequency is minimized. However, due to the complexity of the power systems such as nonlinear load characteristics and variable operating points, the PID controllers tuning with conventional methods may be unsuitable in some operating conditions. In literature, some different control strategies have been suggested based on the digital, self-tuning, adaptive, variable structure systems and intelligent/soft computing control. Recently, different GWO based controllers are commonly used in literature as a self tuning control strategy for LFC. In this study, a GWO algorithm is used to optimizing the PID controller gains for load frequency control of a two area thermal power system including governor dead-band. To obtain the best convergence performance, new cost function with weight coefficients is derived by using the tie-line power and frequency deviations of the control areas and their rates of changes according to time. An algorithm needs to have stochastic operators to randomly and globally search the search space in order to support this phase. However, exploitation refers to the local search capability around the promising regions obtained in the exploration phase. Finding a proper balance between these two phases is considered a challenging task due to the stochastic nature of meta-heuristics. This work proposes a new SI technique with inspiration from the social hierarchy and hunting behavior of grey wolf packs.



1.1 Block diagram of two area system

The power systems, frequency are dependent on active power and voltage dependence on reactive power limit. The control power system is separated into two independent problems. The control of frequency by active power is called load frequency control. An important task of LFC is to maintain the frequency deviation constant against due to continuous variation of loads, which is referred as unknown external load disturbance. Power exchange error is an important task of LFC. Generally a power system consists of several generating units are interconnected through tie lines to become fault tolerant. This use of tie line power creates a new error in the control problem, which is the tie-line power exchange error. Area controlled error [ACE] is play major role in interconnected power system and also minimizing error function of the given system.

Load frequency control (LFC) is of importance in electric power system operation to damp frequency and voltage oscillations originated from load variations or sudden changes in load demands. In a deregulated environment load-frequency control (LFC) is very important in order to supply reliable electric power with good quality and to provide better conditions for the electricity trading. The main goal of LFC is to maintain zero steady state errors for frequency deviation and good tracking load demands in a multi-area power system, it is treated as an ancillary service essential for maintaining the electrical system reliability at an adequate level. LFC is one of the important power system control problems in deregulated power systems, which there have been considerable control strategies based on robust and optimal approaches. In an interconnected power system that consists of several control areas, as the system varies, the tie-line power will change and the frequency deviations will occur. The load–frequency control is a part of the automatic generation control (AGC) system. The objective of LFC is to damp the transient deviations in area frequency and tie-line power interchange. This signal is used to regulate the generator output power based on network load demand. Different types of controllers have been proposed in literature for the load frequency control. To maintain the balances of both the active and reactive powers without control. As a result of the imbalance, the frequency and voltage levels will be varying with the change of the loads. Thus a control system is essential to cancel the effects of the random load changes and to keep the frequency and voltage at the standard values.

The foremost task of LFC is to keep the frequency constant against the randomly varying active power loads, which are also referred to as unknown external disturbance. Another task of the LFC is to regulate the tie-line power exchange error. A typical large-scale power system is composed of several areas of generating units. In order to enhance the fault tolerance of the entire power system, these generating units are connected via tie-lines. The usage of tie-line power imports a new error into the control problem, i.e., tie-line power exchange error. When a sudden active power load change occurs to an area, the area will obtain energy via tie-lines from other areas. But eventually, the area that is subject to the load change should balance it without external support. Otherwise there would be economic conflicts between the areas. Hence each area requires a separate load frequency controller to regulate the tie-line power exchange error so that all the areas in an interconnected power system can set their set points differently. Another problem is that the interconnection of the power systems results in huge increases in both the order of the system and the number of the tuning controller parameters. As a result, when modeling such complex high-order power systems, the model and parameter approximations can not be avoided. Therefore, the requirement of the LFC is to be robust against the uncertainties of the system model and the variations of system parameters in reality.

In summary, the LFC has two major assignments, which are to maintain the standard value of frequency and to keep the tie-line power exchange under schedule in the presences of any load changes. In addition, the LFC has to be robust against unknown external disturbances and system model and parameter uncertainties. The high-order interconnected power system could also increase the complexity of the controller design of the LFC.

2. TWO AREA POWER SYSTEM CONTROL MODELING

Modern day power systems are divided into various areas. For example in our India, there are five regional grids. Each of the regional area is generally interconnected to its neighboring areas. The transmission lines which connect an area to its neighboring area are called tie-lines. The power sharing between two area is dine through these tie-lines. Load frequency control, its name signifies that it regulates the power flow between different areas while keeping the frequency constant. An extended power system can be divided into a number of load frequency control areas interconnected by means of tie lines. Without loss of generating, we shall consider a two-area case connected by a single tie line. The control objective now is to regulate the frequency of each area and to simultaneously regulate the tie line power as per inter-area power contracts. As in the case of frequency, proportional plus integral controller will be installed so as to give zero steady state error in the tie line flow as compared to the contracted power.

If there is interconnection exists between two control areas through tie line than that is called a two area interconnected power system. A two area power system where each area supplies to its own area and the power flow between the areas are allowed by the tie line. In this case of two area power system an assumption is taken that the individual areas are strong and the tie line which connects the two area is weak. Here a single frequency is characterized throughout a single area; means the network area is 'strong' or 'rigid'. There may be any numbers of control areas in an interconnected power system. The control strategy is termed as tie line bias control and is based upon the principle that all operating pool members must contribute their share to frequency control in addition to taking care of their own net interchange. It is possible to divide an extended power system (say, national grid) into sub-areas in which the generators are tightly coupled together so as to form a coherent group. Such a coherent area is called a control area in which the frequency is assumed to be the same throughout in static as well as dynamic conditions.

A control area is interconnected not only with one tie-line to one neighboring area, but with several tie lines to neighboring areas in the power pool.
Area control error, $ACE_i = \sum_{j=1}^{m} \Delta Pij + b\Delta fi$

The Net interchange = $\sum_{j=1}^{m} \Delta Pij$

The reset control is implemented by sampled data techniques. At sampling intervals of one second, all tie-line power data are fed into the central energy control area, where they are added and compared with predetermined power. Now this error is added with biased frequency error, to give ACE results. Under normal operating condition, each control area should have the capacity to meet its own load from its own spinning generator, plus the scheduled interchange between the neighboring areas. Under emergency condition, the energy can be drawn from the spinning reserves of all the neighboring areas immediately due to the sudden loss of generating unit.

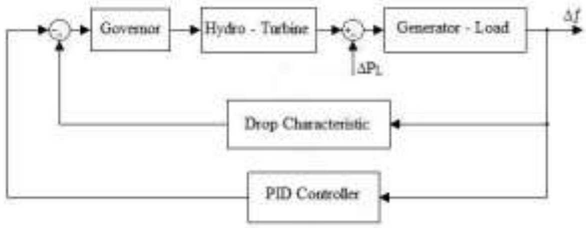
The Load frequency control involves the sensing of the bus bar frequency and compares with the tie-line power frequency. The difference of the signal is fed to the integrator and it is given to speed changer which generates the reference speed for the governor. Thus, the frequency of the tie-line is maintained as constant. The basic role of Automatic Load Frequency Control(ALFC) is to maintain desired megawatt output of a generator unit and assist in controlling the frequency of the larger interconnection. Static response of an ALFC loop will inform about frequency accuracy, whereas, the dynamic response of ALFC loop will inform about the stability of the loop.

3. PID CONTROLLER

The PID controller improves the transient response so as to reduce error amplitude with each oscillation and then output is eventually settled to a final desired value. Better margin of stability is ensured with PID controllers. The mathematical equation for the PID controller is given as.

$$y(t) = Kpe(t) + Ki \int_0^t e(\tau)d\tau + Kd \frac{d}{dt} e(t)$$

Where y (t) is the controller output and u (t) is the error signal. K*p*, K*i* and K*d* are proportional, integral and derivative gains of the controller. The limitation conventional PI and PID controllers are slow and lack of efficiency in handling system non-linearity. Generally these gains are tuned with help of different optimizing methods such as Ziegler Nicholas method, Genetic algorithm, etc., the optimum gain values once obtained is fixed for the controller. But in the case deregulated environment large uncertainties in load and change in system parameters is often occurred. The optimum controller gains calculated previously may not be suitable for new conditions, which results in improper working of controller. So to avoid such situations the gains must be tuned continuously. A proportional controller (Kp) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error. An integral control (K_i) will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Kp, Ki, and Kd are dependent of each other. In fact, changing one of these variables can change the effect of the other two. For this reason, the table should only be used as a reference when you are determining the values for Ki, Kp and Kd. Traditional LFC employs an integral controller. Famously, it is a great integral gain can fail power scheme achievement, producing great fluctuations and instabilities. Accordingly, the integral gain has to make regular stage and then supply compromise among wanted transient regaining and small overshoot in the dynamic output response of the complete system. In fact, the trouble with PID plan and tuning for load frequency control exists for a power system model of second order and usually under-damped. The majority of present PID tuning methods focus on over-damped operations, thus straight request for present PID tuning methods at LFC has been never correct as illustrated in Fig.



3.1 Closed Loop Control of LFC with PID Controller

4. GREY WOLF OPTIMIZATION ALGORITHM

This work proposes a new meta-heuristic called Grey Wolf Optimizer (GWO) inspired by grey wolves. The GWO algorithm mimics the leadership hierarchy and hunting mechanism of grey wolves in nature. Four types of grey wolves such as alpha, beta, delta, and omega are employed for simulating the leadership hierarchy. In addition, the three main steps of hunting, searching for prey, encircling prey, and attacking prey, are implemented. The results show that the GWO algorithm is able to provide very competitive results compared to these well-known meta-heuristic. Meta-heuristic optimization techniques have become very popular over the last two decades. Surprisingly, some of them such as Genetic Algorithm (GA), Ant Colony Optimization (ACO) , and Particle Swarm Optimization (PSO) are fairly well-known among not only computer scientists but also scientists from different fields. In addition to the huge number of theoretical works, such optimization techniques have been applied in various fields of study. There is a question here as to why meta-heuristics have become remarkably common. The answer to this question can be summarized into four main reasons: simplicity, flexibility, derivation-free mechanism, and local optima avoidance.

First, meta-heuristics are fairly simple. They have been mostly inspired by very simple concepts. The inspirations are typically related to physical phenomena, animals' behaviors, or evolutionary concepts. The simplicity allows computer scientists to simulate different natural concepts, propose new meta-heuristics, hybridize two or more meta-heuristics, or improve the current meta-heuristics. Moreover, the simplicity assists other scientists to learn meta-heuristics quickly and apply them to their problems.

Second, flexibility refers to the applicability of meta-heuristics to different problems without any special changes in the structure of the algorithm. Meta-heuristics are readily applicable to different problems since they mostly assume problems as black boxes. In other words, only the input(s) and output(s) of a system are important for a meta-heuristic. So, all a designer needs is to know how to represent his/her problem for meta-heuristics. Third, the majority of meta-heuristics have derivation-free mechanisms. In contrast to gradient-based optimization approaches, meta-heuristics optimize problems stochastically. The optimization process starts with random solution(s), and there is no need to calculate the derivative of search spaces to find the optimum. This makes meta-heuristics highly suitable for real problems with expensive or unknown derivative information.

Finally, meta-heuristics have superior abilities to avoid local optima compared to conventional optimization techniques. This is due to the stochastic nature of meta-heuristics which allow them to avoid stagnation in local solutions and search the entire search space extensively. The search space of real problems is usually unknown and very complex with a massive number of local optima, so meta-heuristics are good options for optimizing these challenging real problems.

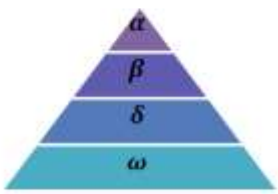


Fig.4.1 Hierachy of grey wolf

The leaders are a male and a female, called alphas. The alpha is mostly responsible for making decisions about hunting, sleeping place, time to wake, and so on. The alpha's decisions are dictated to the pack. However, some kind of democratic behavior has also been observed, in which an alpha follows the other wolves in the pack. In gatherings, the entire pack acknowledges the alpha by holding their tails down. The alpha wolf is also called the dominant wolf since his/her orders should be followed by the pack . The alpha wolves are only allowed to mate in the pack. Interestingly, the alpha is not necessarily the strongest member of the pack but the best in terms of managing the pack. This shows that the organization and discipline of a pack is much more important than its strength. The second level in the hierarchy of grey wolves is beta. The betas are subordinate wolves that help the alpha in decision-making or other pack activities. The beta wolf can be either male or female, and he/she is probably the best candidate to be the alpha in case one of the alpha wolves passes away or becomes very old. The beta wolf should respect the alpha, but commands the other lower-level wolves as well. It plays the role of an advisor to the alpha and discipliner for the pack. The beta reinforces the alpha's commands throughout the pack and gives feedback to the alpha.

The lowest ranking grey wolf is omega. The omega plays the role of scapegoat. Omega wolves always have to submit to all the other dominant wolves. They are the last wolves that are allowed to eat. It may seem the omega is not an important individual in the pack, but it has been observed that the whole pack face internal fighting and problems in case of losing the omega. This is due to the venting of violence and frustration of all wolves by the omega(s).

The main phases of grey wolf hunting are as follows:

- Tracking, chasing, and approaching the prey .
- Pursuing, encircling, and harassing the prey until it stops moving.
- Attack towards the prey.

Fig 4.2 Hunting behaviour of grey wolves: (A) chasing, approaching and tracking prey (B-D) Pursuiting, harassing and encircling (E) Stationary situation and attack

4.1. Mathematical model and algorithm

In this subsection the mathematical models of the social hierarchy, tracking, encircling, and attacking prey are provided. Then the GWO algorithm is outlined.

4.2. Social hierarchy:

In order to mathematically model the social hierarchy of wolves when designing GWO, we consider the fittest solution as the alpha (α). Consequently, the second and third best solutions are named beta (β) and delta (δ) respectively. The rest of the candidate solutions are assumed to be omega (ω). In the GWO algorithm the hunting (optimization) is guided by , , and . The wolves follow these three wolves.

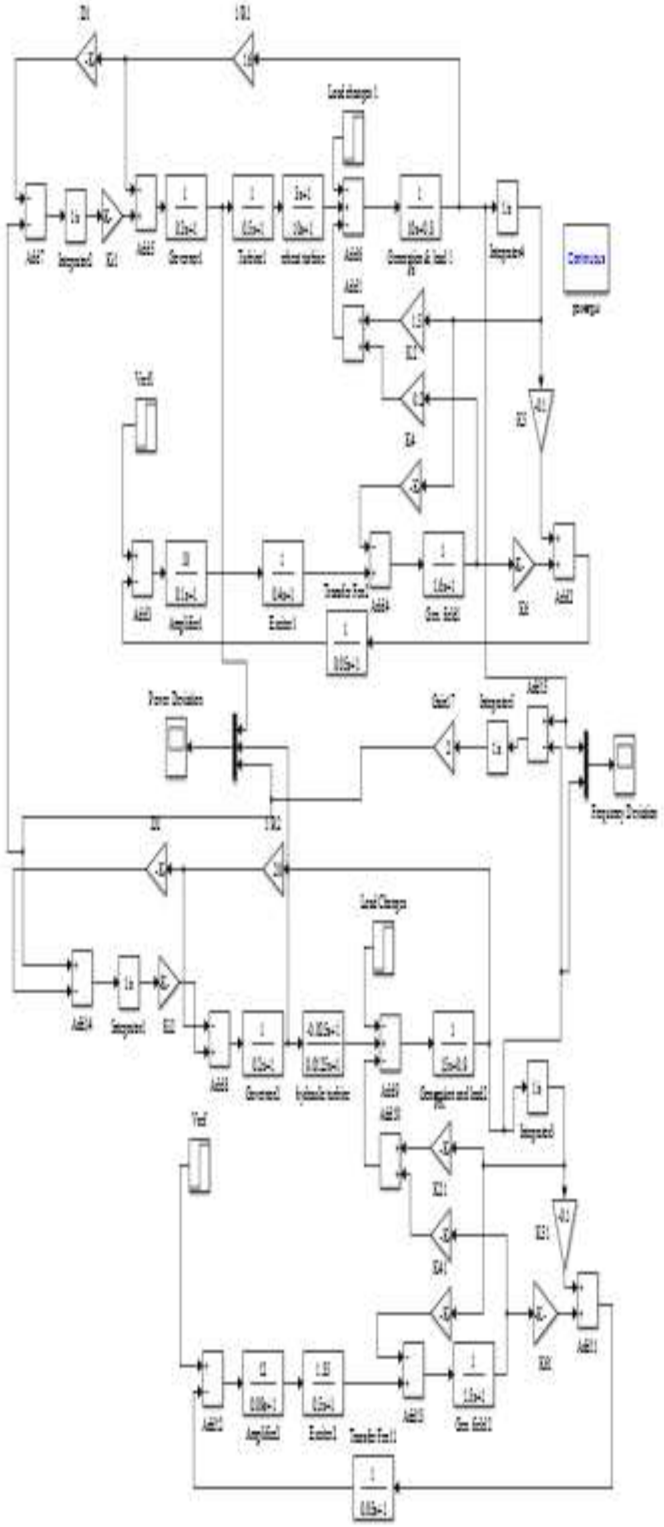


Fig 4.3 Simulation diagram of LFC control of two area system

4.3 No Disturbance

When there is no disturbance that time the frequency and tie line power performance for area 1 and area 2 is compared with PI and PID controller. The frequency and power response is obtained by following graph. Thus the graph is drawn between frequency and time. The maximum deviation of frequency and power is represent the per unit value.

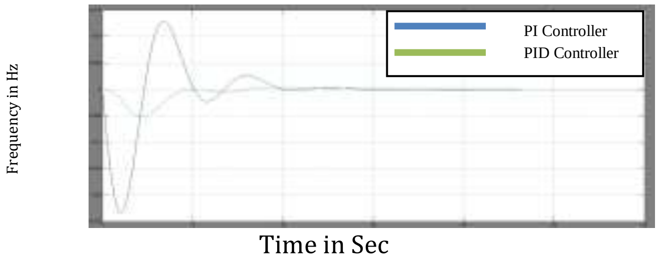


Fig.4.3.1. Change in frequency in area 1

When no load condition the frequency response for area 1 is compared with PI and PID controller. The settling time of PI controller is 25sec and PID controller is 12sec.

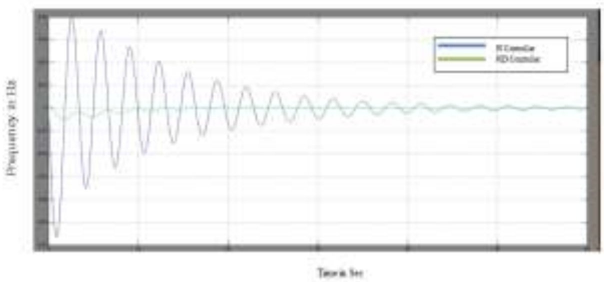


Fig 4.3.2 Change in frequency in area 2

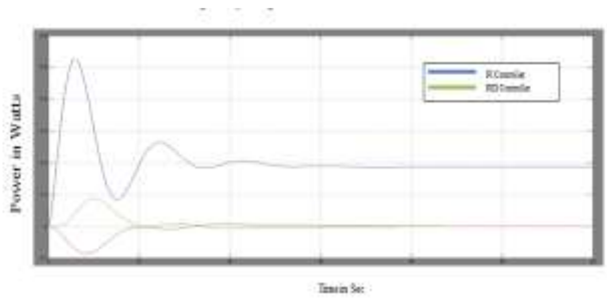


Fig 4.3.3 Change in tie line power

Table 1: System performance for 0% disturbance

Controller	Change in frequency in area 1		Change in frequency in area 2		Change in Tie line power	
	Settling time (sec)	Maximum deviation (p.u)	Settling time (sec)	Maximum deviation (p.u)	Settling time (sec)	Maximum deviation (p.u)
GWO-PI	25	0. 0063	20	0. 0012	23	0.1874
GWO-PID	10.5	0. 0057	12	0. 00013	14.5	0. 0010

4.4 2% disturbance

When there is 2% disturbance that time the frequency and tie line power performance for area 1 and area 2 is compared with PI and PID controller. The frequency and power response is obtained by following graph. Thus the graph is drawn between frequency and time. The maximum deviation of frequency and power is represent the per unit value.

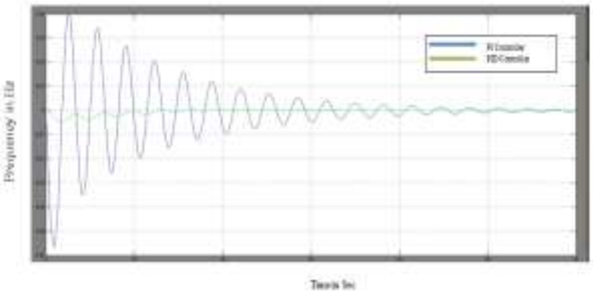


Fig 4.4.1 Change in frequency in area 1

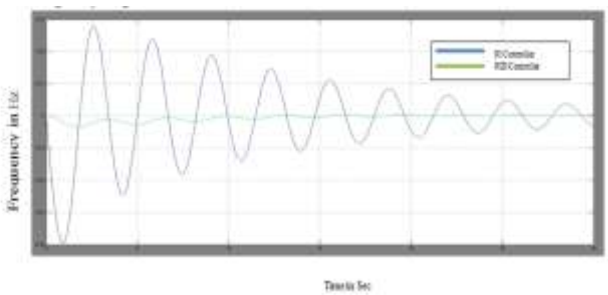


Fig 4.4.2 Change in frequency in area 2

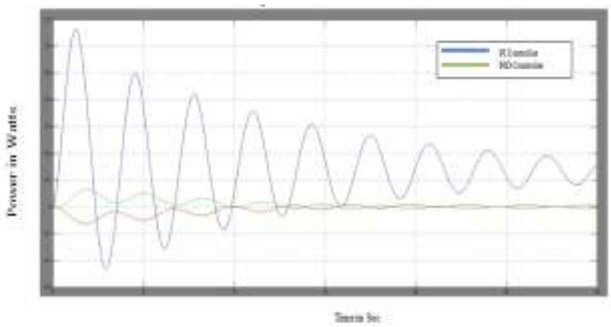


Fig 4.4.3 Change in tie line power

Table 2: System performance for 2% disturbance

Controller	Change in frequency in area 1		Change in frequency in area 2		Change in Tie line power	
	Settling time (sec)	Maximum deviation (p.u)	Settling time (sec)	Maximum deviation (p.u)	Settling time (sec)	Maximum deviation (p.u)
GWO-PI	50	0. 0011	55	0. 0031	40	0.1924
GWO-PID	12	0. 0002	15	0. 0001	13	0. 0043

Table: 3 System performance for 3% disturbance

Controller	Change in frequency in area 1		Change in frequency in area 2		Change in Tie line power	
	Settling time (sec)	Maximum deviation (p.u)	Settling time (sec)	Maximum deviation (p.u)	Settling time (sec)	Maximum deviation (p.u)
GWO-PI	40	0. 0076	23	0. 0086	40	0. 0069
GWO-PID	10	0. 0062	20	0. 0001	13	0. 0056

4.5 3% disturbance

When there is 3% disturbance that time the frequency and tie line power performance for area 1 and area 2 is compared with PI and PID controller. The frequency and power response is obtained by following graph. Thus the graph is drawn between frequency and time. The maximum deviation of frequency and power is represent the per unit value.

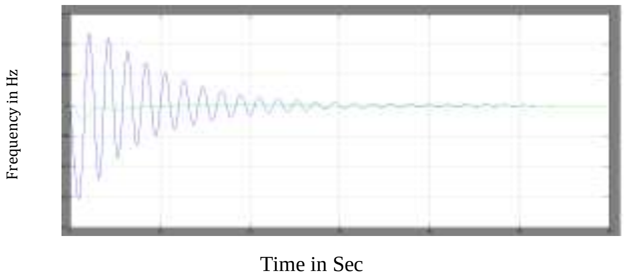


Fig 4.5.1 Change in frequency in area 1

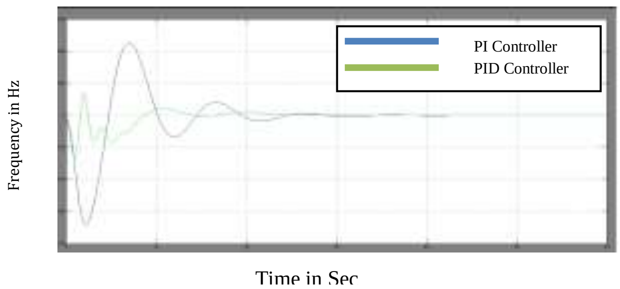


Fig 4.5.2 Change in frequency in area 2

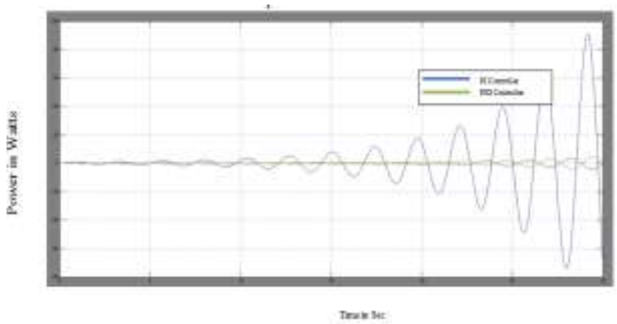


Fig 4.5.3 Change in tie line power

CONCLUSION

In this study, a new grey wolf optimized LFC has been investigated for automatic load frequency control of a two area interconnected power systems. It is shown analytically and graphically that there is a substantial improvement in the time domain specification in terms of lesser rise time, peak time, settling time as well as a lower overshoot. The proposed controller using GWO algorithm with PID controller is proved to be better than the conventional PI controller. The simulation results are given to validate the disturbances for LFC. From the simulation results, the tabulated settling time of 2% and 3% disturbances are shown in graphical representation. Therefore, the proposed GWO-PID controller is recommended to generate good quality and reliable electric energy. In addition, the proposed controller is very simple and easy to implement since it does not require many information about system parameters. Comparison of the proposed GWO-PID controller with Genetic, Particle Swarm, Flower Pollination, Fire Fly, Ant Colony Optimization Algorithms along with PI-PID controllers in multi-area interconnected power system will be subject to the future work.

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