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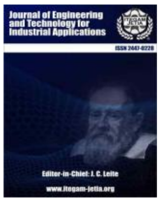

RESEARCH ARTICLE

OPEN ACCESS

OPTIMAL TUNING OF PID CONTROLLER PARAMETERS FOR AGC OF A WIND INTEGRATED INTERCONNECTED POWER SYSTEM

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ABSTRACT

The interconnected power systems response control has become more challenging with the integration of wind energy due to the variable range of wind speed and power output. In addition to load perturbations, fluctuations in wind power can also impact system frequency. Therefore, enhancing current control strategies is essential to maintain the stability of the frequency in these complex power system scenarios. The Controller is tuned in three methods. The new tuning methods are introduced to the conventional proportional-integral and derivative controller such that the system gives best performance. These tuning methods are Genetic Algorithm (GA) and Harmony Search Algorithm (HSA) used to study the system performance in comparison between them on Time Domain Analysis. The system is also tested for its robustness in three cases as the nominal loads for both the areas and with the load disturbance and the controller by its gain variations. The system's results are acquired through the utilization of the MATLAB/Simulink software.

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I. INTRODUCTION

The network developed to supply, transfer and use electric power by the electrical component is a Power System. To increase the reliability of power system, increase the efficiency of plants and to reduce the operating cost (cost of power generation) an Interconnected Power System is introduced. This interconnected power system is the direct connection between two or more power systems. Generally, the integration of power systems is done between the Renewable Resources to a power network such as Power Grid and Renewable Resources like Photovoltaic (PV), Wind Turbines, Fuel Cells (FC) and Energy Storage Systems etc.., The expansion of renewable energy sources is being driven by various factors, including a shortfall in generation capacity, rising fuel costs, environmental problems, and the threat of global warming. In this project, a two-area interconnected power system is employed, each area containing multiple generators closely linked to form a coherent group where the overall system response can be observed in different cases i.e., the problems which must be phased during its operations.

The integration of renewable energy causes the disturbance to the system like synchronizing problem, frequency control, voltage control and their stability. The main objective of this project is to nullify the deviations from the load frequency regulations and tie-line power from their initial values. The deviations can be observed in the Area Control Error (ACE), and this is reduced by an ancillary service like Automatic Generation Control (AGC). The main objective of this AGC is to select the appropriate speed regulation which can reduce the frequency fluctuations. To tune control parameters an optimization algorithm is very much useful like SOS Algorithm, CRSO Algorithm, GA, HSA, etc.., which gives better performance and stable response. Since, the considered power system may contain nonlinearities like governor dead band, boiler dynamics, appropriate controllers are to be selected where cascading of the controller is possible.

This study focuses on analysing the system, where area-1 incorporates one thermal plant integrated with wind power, while area-2 comprises a single Thermal Plant.PID control strategy will be proposed for designing of controller in both the areas. To tune PID controller parameters, conventional and optimization methods will be used. The comparative analysis will be carried out by using different tuning methods. The entire project will be conducted within the MATLAB/Simulink environment.

II. THEORETICAL REFERENCE

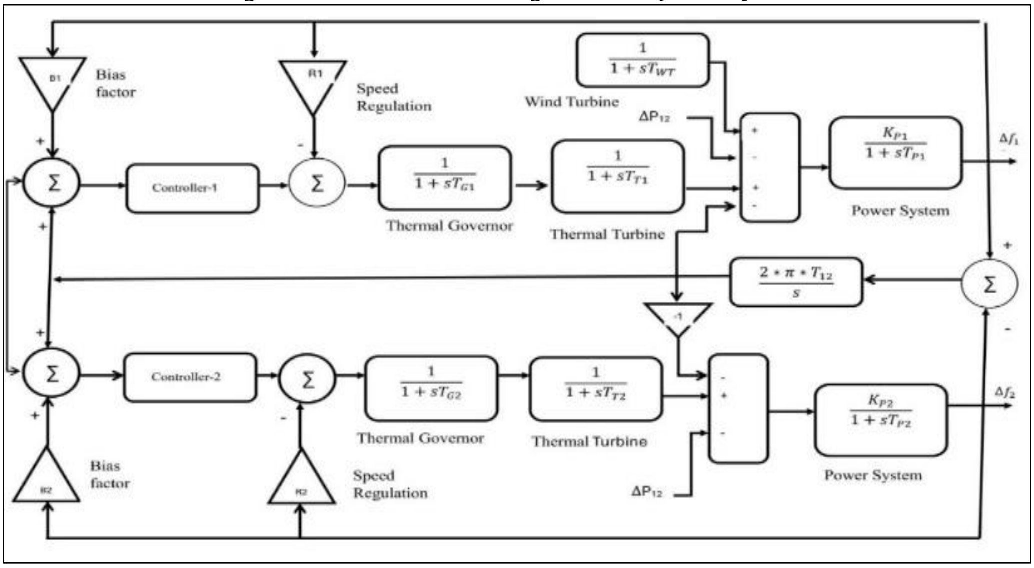
The basics of an interconnected power system and its problem is analysed by [1] and the solution of their problem is explained in [2] which is AGC strategy and how the interconnected systems burden the existed control system is explained in [3]. The different controllers used in AGC strategy and its mathematical models explaining the difference of performances between them in [3]. The robustness of the system different cases is observed in [4]. The response of the interconnected system by SOS algorithm based PID Controller in [5]. The performance of the system with two 2DOF-PID controllers in [6] and the optimization algorithm i.e., CRSOA and for the robustness of the system different cases are observed in [7] & [8]. The Controller tuned with fuzzy in [9]. The response of the system by Algorithm based PID Controller in [10].

III. SYSTEM STUDIED

An interconnected power system with two areas, incorporating wind and thermal units in each area, is analysed to evaluate the effectiveness of a new controller tuning. Figure 1 depicts the system block diagram, where area 1 accommodates a thermal plant integrated with sufficient wind generation, while area 2 relies solely on a thermal unit.

The investigation encompasses three cases to showcase enhanced stability within the system with the new controller under two wind cases. In Case 1, load perturbance are introduced in a specific area while wind unit remains constant. In Case 2, wind speed variations are limited, coinciding with regular load changes, with wind's overall impact on the system frequency constrained by demand fluctuations. In both cases, wind-induced changes insignificantly influence frequency oscillations compared to load perturbations. However, in Area I, wind speed/power alterations outweigh load disturbances, leading to pronounced frequency oscillations.

Figure 1: The Schematic Diagram of the power system.



Source: [1].

Hence, it is crucial to design effective controllers to alleviate frequency disturbances arising from fluctuations in the system. Load perturbations are generated using step functions, while wind unit is represented using modelling techniques. System response is analysed employing a PID controller with Harmony Search Algorithm (HSA) tuning, contrasting with conventional PID and PID controllers with Genetic Algorithm (GA) tuning methods. A MATLAB/Simulation is conducted on the power system.

IV. CONVENTIONAL PID DESIGN

A conventional type of the PID controller is introduced for AGC of the two-area Interconnected power system. For the tuning of the gain parameters a conventional method i.e., Ziegler-Nichols Method is one of the practices among all the other tuning methods. By using this method, the PID controller is designed by the following.

Table 1: The formulae to determine the controller parameters.

Control type	K_p	K_i	K_d
Conventional PID	$0.6K_u$	$1.2K_u/T_u$	$0.075K_u*T_u$

Source: [6].

Here, Kp represents the proportional gain, Ki denotes the integral gain, and Kd signifies the derivative gain.

Here, K_u is the ultimate Gain, defined as 1/M, where M is the ratio of the amplitude which is derived from the closed loop response of the two-area interconnected system without the controller. To find the K_u, Initially, set the integral (K_i) and derivative (K_d) gains of the controller to zero, only the proportional gain (K_p) is used. By increasing the K_p gradually until the input system starts to oscillate (these oscillations are known as steady-state oscillations) with a constant amplitude. This K_p gain is considered as the ultimate gain (K_u). To measure the period of oscillations (T_u), which is the time it takes for the output waveform to complete one full cycle during steady-state oscillations.

From these parameter gains, when applied to the system by the Controller gives the controlled response of system. The controller gains derived as follows,

K_p=1.9987 K_i=1.98578 K_d=1.9928

V. GENETIC ALGORITHM BASED PID CONTROLLER DESIGN

In many controllers designed to reduce frequency oscillations in power plants, two reference input signals are commonly used: ACE and Δf. Traditionally, a controller employs the error signal as a standard in a scenario involving a system, while it uses Δf in an isolated scenario. However, since both signals are available in each area, employing Δf as the reference signal for the component in the controller proves advantageous. This method removes extra noise at the boundaries in the LFC and streamlines real-time applications, ensuring uniformity of the control problem's dimension even with changes in the areas. To enhance the tuning of these controller parameters, the GA is to fine-tune the parameters of the interconnected system comprising two areas. This utilization of GA aims to improve the system's performance and stability by tuning the controller's gains.

Genetic Algorithm is an intelligent exploitation of a random search. This algorithm works for this optimization problem as firstly, by selecting the fitness function, is formulated based on the load parameters and the objective function (J), which relies on selection of control parameters. Given a system with two areas and three output variables Δf in area 1 (Δf1), Δf in area 2 (Δf2), and power transfer in the system (ΔP12), the objective function is as follows:

Objective function

$$J = \int_0^t ((\Delta f1)^2 + (\Delta f2)^2 + (\Delta P12)^2) \quad (1)$$

Secondly, Initialize a population of chromosomes representing potential solutions to the optimization problem. The initial population could be generated randomly as

Population_size=30
Chromosome_length=24
Delta_Length=12
Generation_max=20

Evaluate the fitness of each chromosome in the population based on response of the objective function and constraints. In this system, fitness could be assessed based on stability, generation costs, tie-line power flows by giving optimum as [0 0 0 0] ,flag=0 and the generation=1.

By these, chromosomes derived as the matrix forms giving different parameter relations giving the optimal solutions as,

BestS= [Kpga Kiga]
Kdga= Kpid

Where Bests gives the gains of the proportional and integrator parameters Kd is the gain of the derivative parameter. If not, chromosomes from the current population to serve as parents for the creation of the next generation. Higher-fitness chromosomes are likely to be preferred, but some level of diversity should be maintained to avoid premature. The chromosomes can also be observed by parameters like damping ratio and setting time.

Apply crossover (recombination) to pairs of selected parent chromosomes to create offspring chromosomes for the next generation. Crossover entails swapping genetic material between parent chromosomes, enabling exploration of novel regions within the search space.

Introduce random changes (mutation) to some offspring chromosomes to maintain genetic diversity and explore new ranges of the search area. Mutation helps prevention in the algorithm from staying in local ranges. Replace current population with the offspring population created through selection, crossover, and mutation. Check termination conditions to determine whether the optimization process should be stopped. Termination criteria may encompass reaching a maximum generation, attaining an acceptable solution, or reaching a predetermined level of convergence.

Finally, Analyse the final population of chromosomes to pick out the best solution for the optimization problem. Evaluate the performance of optimized system with respect to chosen J and constraints. The final output can be observed as,

BestS = 89.2695 0.6113 25.5601

After number of iterations, the PID Controller parameters derived from the Genetic Algorithm are.

K_p=0.0012 K_i=-0.6000 K_d=89.2695

The Figure 2 explain the algorithm in the form of a Flow Chart for better understanding of its mechanism,

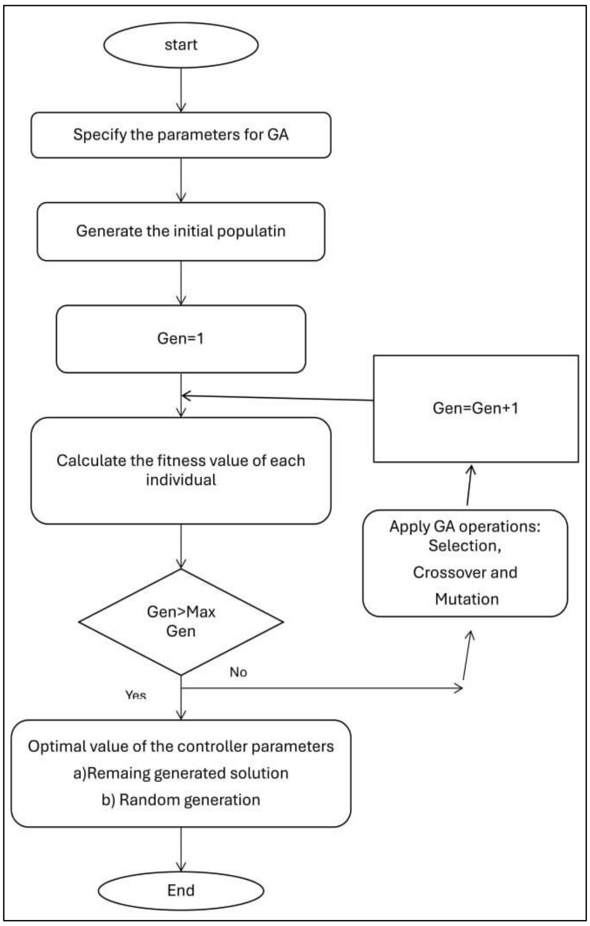


Figure 2: The flow chart of Genetic Algorithm.
Source: [11].

VI. HARMONY SEARCH ALGORITHM BASED PID CONTROLLER DESIGN

As Genetic Algorithm is a Random Optimization where the Harmony Search Algorithm is more of memory build i.e., the initial solution is taken from the genetic algorithm solutions and within that range this HSA derives the better optimal solution such that the two-area interconnected system in its AGC and Frequency changes (Optimization problems)

The HSA is a optimization approach inspired by the innovative process seen in musicians aiming to achieve harmonious melodies.

HSA mimics the process of creating harmonious music by continuously improving solutions to optimization problems. Renowned for its simplicity, straightforward implementation, and efficacy in resolving issues. various optimization problems, including engineering design, parameter tuning, and scheduling. It provides a harmonious blend of exploring the search space and exploiting promising areas, making it suitable for a extensive of applications.

Initially, solution of the genetic algorithm is noted. From the initial memory for the Harmony Search Algorithm. Initially, define the objective function and constraints for the optimization problem. In a system, the objective function could aim to minimize system operating costs, maximize system stability. Constraints may include power balance, line flow limits, and generator limits. Its Objective function (J), which is same as (1).

Initialize the Harmony Memory, which stores a set of harmonies (random solutions). Each harmony represents a possible configuration of the interconnected power system. Initialize other parameters such as harmony memory size (HMS), harmony memory consideration rate (HMCR), pitch adjustment rate (PAR), and bandwidth (BW).

HMS=5
HMC=0.9
PAR=0.3
BW=0.001*ones (1, N)

Generate initial harmonies randomly within the feasible space i.e., the min and max defined by the problem constraints, with N=100.

Ensure that the generated harmonies satisfy the constraints of the system. Evaluate each harmony in the Harmony Memory using the defined J and constraints. Calculate the fitness value for every harmony based on its performance in optimizing the system.

Harmony Memory equation,
HM(i,j)=xmin(j)+rand()*(xmax(j)-xmin(j)) (2)

Band Width equation,
B(j)=xmin(j)+rand()*(xmax(j)-xmin(j)) (3)

First Memory history
1(i)=min(HM(:,N+1)) (4)

Best memory best
1(ni)=min(HM(:,N+1)) (5)

Define termination criteria to determine when to end the process. End criteria could include relaying a maximum iterations, getting a satisfactory solution, or reaching a predefined level of convergence.

If generated harmony is not a better solution, then generate a new harmony by combining elements from existing harmonies in the Harmony Memory. Randomly select elements from different harmonies with a probability determined by the HMCR. This encourages exploration of the search space. Apply pitch adjustment to the selected elements with a probability determined by the PAR. Pitch adjustment introduces small random changes to the selected elements, promoting exploitation of promising ranges of the search space.

Evaluate newly generated harmony using the J and constraints. Compare the fitness of recent harmony with the previous harmony in the HM. If the recent harmony is better than the previous harmony, replace that with the recent one. This maintains the best solutions found so far in the HM.

Iterate the process of generating new set of harmonies, evaluating them, and updating the HM until the End criteria are met.

Once the optimization process terminates, analyse the solutions stored in the HM Identify the best solution(s) that optimize the system according to the defined J and constraints. Interpret the optimized solution(s) and implement them in the actual power system to achieve improved performance, stability, or other desired objectives. The optimized solution after number of iterations, the PID Controller parameters derived from the Harmony Search Algorithm are.

K_p=-1.0000e-03 K_i=-0.5240 K_d=87.9542

The above procedure is given in the Flow Chart for the better understanding of the mechanism of the HSA in Figure 3 as.

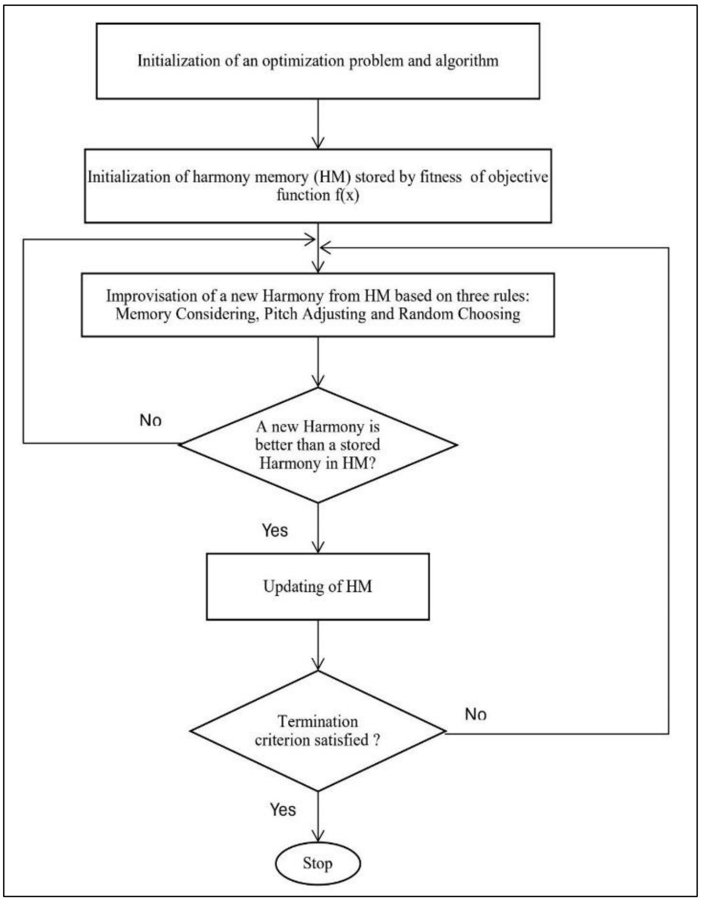


Figure 3: The flow chart of Harmony Search Algorithm.
Source: [11].

VII. RESULTS AND DISCUSSIONS

The input system considered is a two-area interconnected power system with area-1 input sources as thermal and wind integration and area-2 input sources as thermal only. For this system, a PID controller is introduced to stabilize the optimization problem with two algorithms as Genetic algorithm and Harmony search algorithm. Its simulation diagram is observed in fig from the MATLAB Simulation.

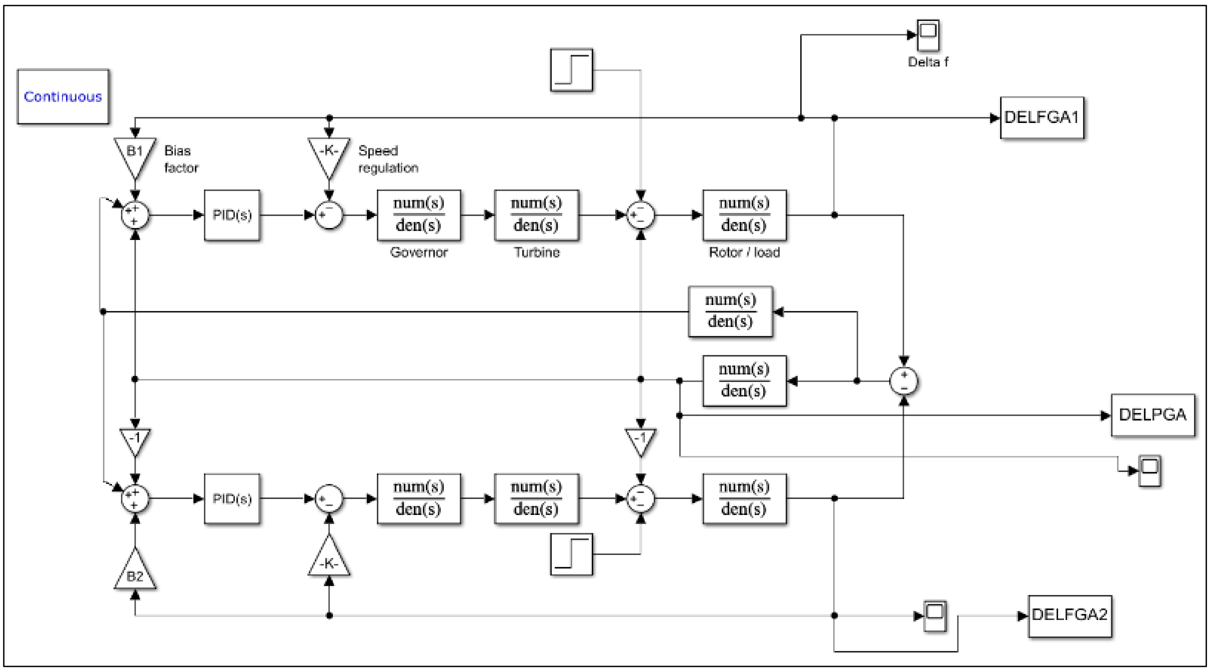


Figure 4: The Simulation Diagram of the power system.
Source: Authors, (2024).

Here, thermal input source is in the forms of a governor and a turbine by a first-order system transfer function and the wind sources in the form of a turbine by a first-order system transfer function. The respective nomenclature is observed from the figure 1 i.e., the schematic block diagram and its value respectively.

The response of this input system with area-1 as thermal with wind integration and area-2 as thermal only is observed through Conventional PID Controller, PID Tuning with Genetic Algorithm (GA) and PID Tuning with Harmony Search Algorithm (HSA) are three cases. They are.

Case-1: Nominal load conditions for the input system.
Case-2: Load with Wind distribution of +3% at 20s and -6% at 40s to the system.
Case-3: Nominal load with proportional gain (Kp) variations for +25% and -25% to its original value to the system

VII.1 CASE 1

The responses of the input system is observed for the nominal load with constant wind power as:

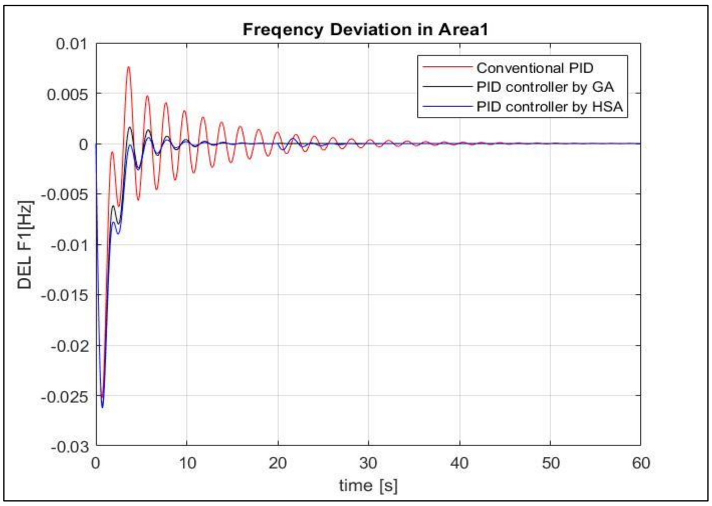


Figure 5: The system response to the load in area-1 incorporating wind integration.
Source: Authors, (2024).

From figure 5, the system response i.e., the frequency deviation between variables with the wind integration in the area-1 are observed with conventional PID, tuning with GA and HSA. From this it concludes that settling time (Ts) decreases from conventional to hsa i.e., 40.8718 sec, 21.0701 sec and 18.9294 sec also Rise time (Tr) decreases from 1.43107 sec, 1.36484 sec and 1.29597 sec respectively. It shows that the input is stable when the pid controller tuning done by the harmony search algorithm than the other two scenarios. Its time domain specifications are shown in table 2.

Table 2: Comparative Analysis of area-1 in system with Conventional PID, GA based PID and HSA based PID.

S. N0	Parameter	PID	GA -PID	HSA-PID
1	Tr (sec)	1.4310	1.3648	1.2959
2	Ts (sec)	40.872	21.0701	18.929
3	Peak Overshoot	16.690	4.1725	2.0862

Source: Authors, (2024).

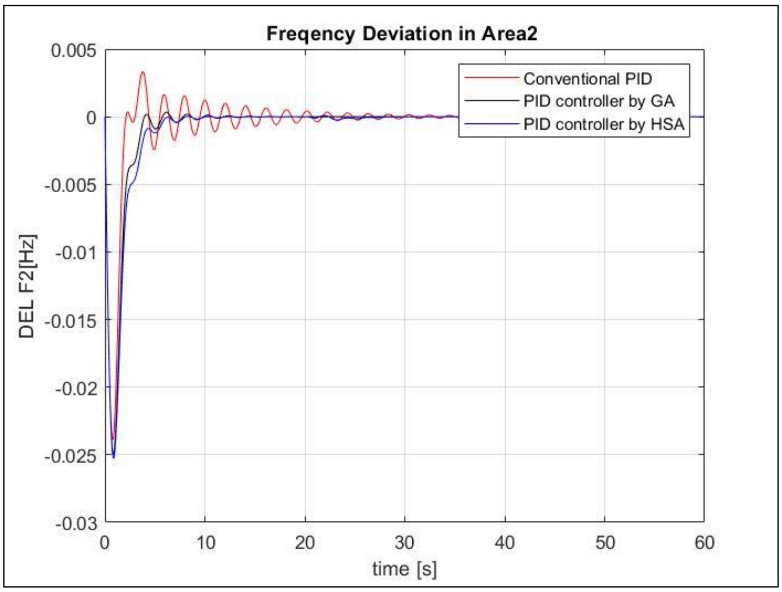


Figure 6: The system response of the load in area2 without wind unit.

Source: Authors, (2024).

From figure 6, the system response i.e., the frequency deviation between the input and output variables without the wind integration in the area-2 are observed with conventional PID, tuning with GA and HSA. From this it concludes that settling time (Ts) decreases from conventional to hsa i.e., 41.9282 sec, 20.1758 sec and 17.3359 sec also Rise time (Tr) decreases from 1.696466 sec, 1.41297 sec and 1.29597 sec respectively. It shows that the input is stable when the pid controller tuning done by the harmony search algorithm than the other two scenarios. Its time domain specifications are shown in table 3.

Table 3: Comparative Analysis of area-2 in system with Conventional PID, GA based PID and HSA based PID.

S. N0	Parameter	PID	GA -PID	HSA-PID
1	Tr (sec)	1.6947	1.4129	1.296
2	Ts (sec)	41.928	20.176	17.336
3	Peak Overshoot	19.619	4.6925	2.4275

Source: Authors, (2024).

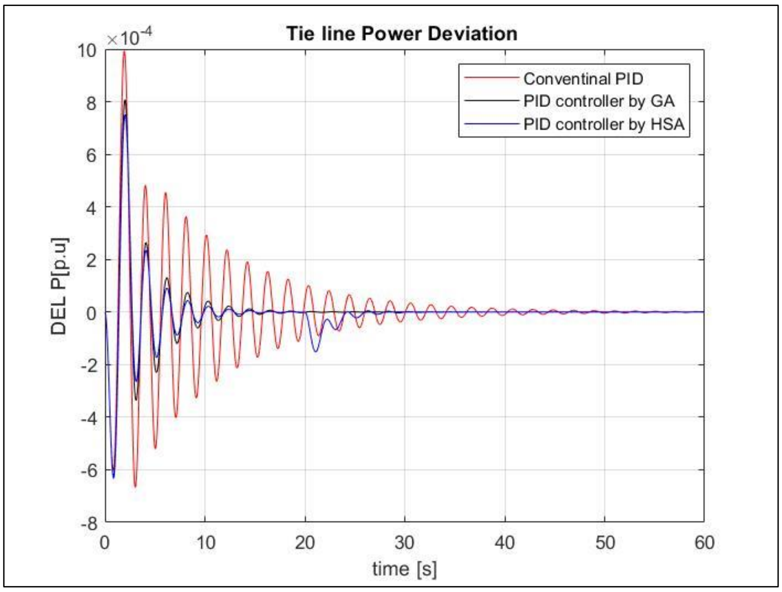


Figure 7: The response of the system with the tie line power change between two areas.

Source: Authors, (2024).

From figure 7, the system response of tie line power deviation which is the frequency deviation between the area-1 and area-2 where area-1 with wind integration and area-2 without wind integration settles at settling time (Ts) which decreases from conventional to hsa i.e., 52.4927 sec, 32.1967 sec and 19.8815 sec also Rise time (Tr) decreases from 1.69466 sec, 1.58744 sec and 1.5012 sec respectively. It shows that the input is stable when the pid controller tuning done by the harmony search algorithm than the other two scenarios. Its time domain specifications are shown in table 4.

Table 4: Comparative Analysis of Tie line power deviation in system with Conventional PID, GA based PID and HSA based PID.

S. N0	Parameter	PID	GA -PID	HSA-PID
1	Tr (sec)	1.6946	1.5874	1.5012
2	Ts (sec)	52.4927	32.1967	19.882
3	Peak Overshoot	45.8114	30.876	29.645

Source: Authors, (2024).

VII.2 CASE 2

Incorporating wind power into the power system often leads to an increase in relative frequency oscillations, attributed to the distinct characteristics of wind. To evaluate the enhancements in controller performance compared to conventional controllers, an initial investigation is carried out on a system with consistent wind unit. This scenario closely mirrors a system without wind unit in either area. In this situation, two load perturbance are assessed, and output responses are compared to demonstrate effectiveness of the controller.

Figure 8,9 &10 illustrates the performances of the three controllers amidst load changes and variations in wind penetration in area1. Two variations are observed in area1, encompassing wind perturbation of +3% at 20 s and -6% at 40 s, alongside output fluctuations. Among all the tuning methods, the HSA based controller exhibits superior performance in reducing system frequency oscillations, even when confronted with wind-induced disturbances. Conversely, the signals produced by the other two demonstrate relatively lower efficacy. The parameters optimized for each controller are drawn below.

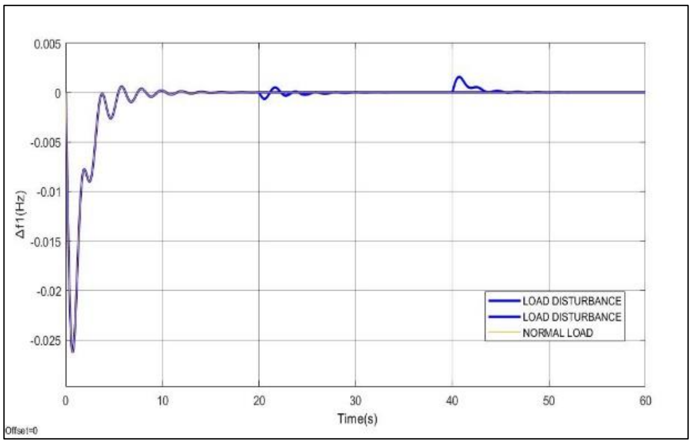


Figure 8: The system response to the load in area-1 incorporating wind integration.

Source: Authors, (2024).

From figure 8, the system response i.e., the frequency deviation between the input and output variables with the wind integration in the area-1 is observed at load changes and wind disturbances of+3% at 20s and -6% at 40s. From this it can be stated that even in the disturbances the input system is stable after oscillating from the short term of time. Its settling time is obtained as 49.95 sec while the normal load settled as 18.9294 sec.

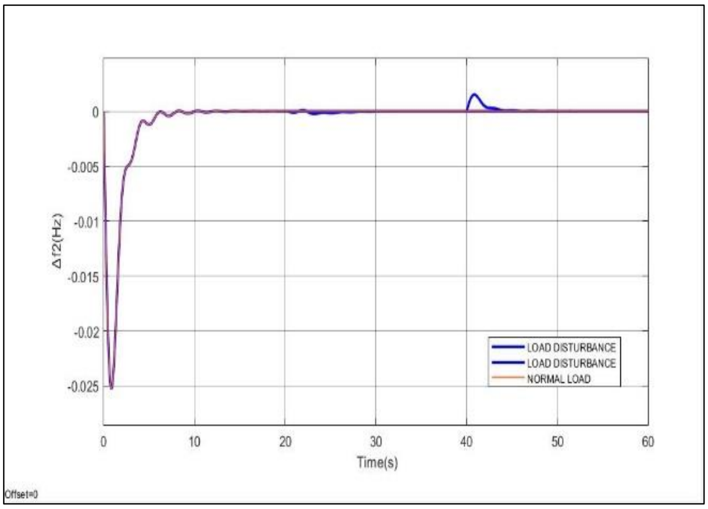


Figure 9: The system response of the load in area2 without wind unit.

Source: Authors, (2024).

From figure 9, the system response i.e., the frequency deviation between the input and output variables with the wind integration in the area-1 is observed at load changes and wind disturbances of+3% at 20s and -6% at 40s. From this it can be stated that even in the disturbances the input system is stable after oscillating from the short term of time. Its settling time is obtained as 46.99 sec while the normal load settled as 17.33359 sec.

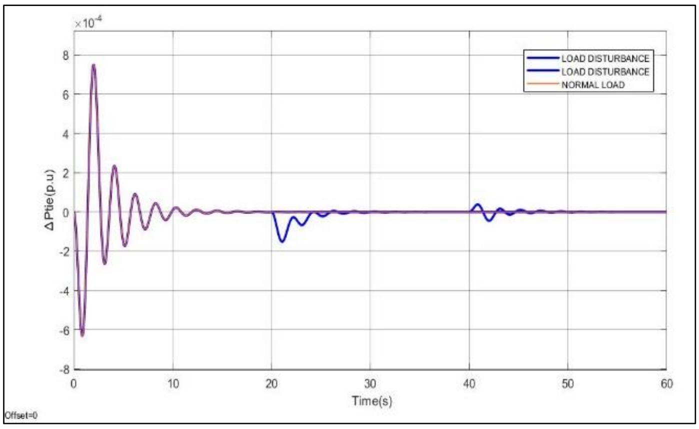


Figure 10: The response of the system with the tie line power change between two areas.

Source: Authors, (2024).

From figure 10, the system response of tie line power deviation is observed at load changes and wind disturbances of+3% at 20s and -6% at 40s. From this it can be stated that even in the disturbances the input system is stable after oscillating from the short term of time. Its settling time is obtained as 50.95 sec while the normal load settled as 19.8815 sec.

VII.3 CASE 3

In this instance, we are evaluating the impact of varying system parameters on the output response of the system. Out of all parameters, system gains, and time constants display notable variability owing to the dynamic characteristics of these parameters during operation. However, upon integrating the controller into the control loop of the interconnected power system, the variations in parameters become insignificant. The subsequent figures depict the frequency variations in controller gains fluctuate by +25% and -25%.

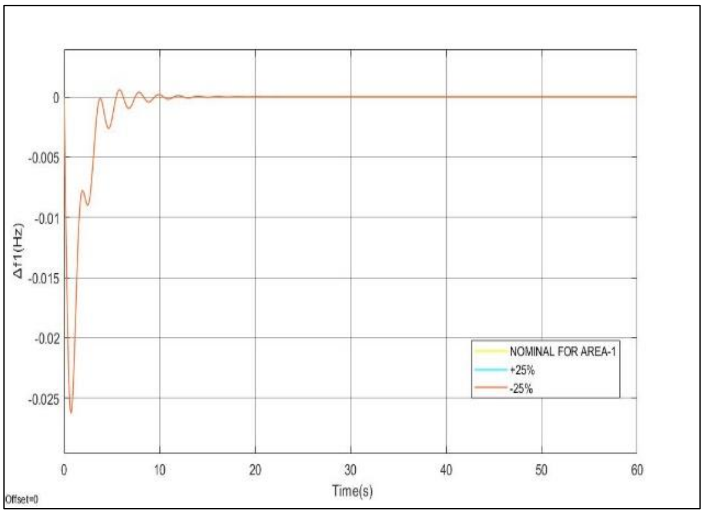


Figure 11: The system response to the load in area-1 incorporating wind integration.
Source: Authors, (2024).

From figure 11, the system response i.e., the frequency deviation between the input and output variables with the wind integration in the area-1 with +25% and -25% of proportional gain (Kp) variation in the pid controller settles at settling time (Ts) 17.3359sec same as the nominal pid controller as well as the rise time (Tr) 1.29597sec which shows that the system is stable for the gain disturbances also.

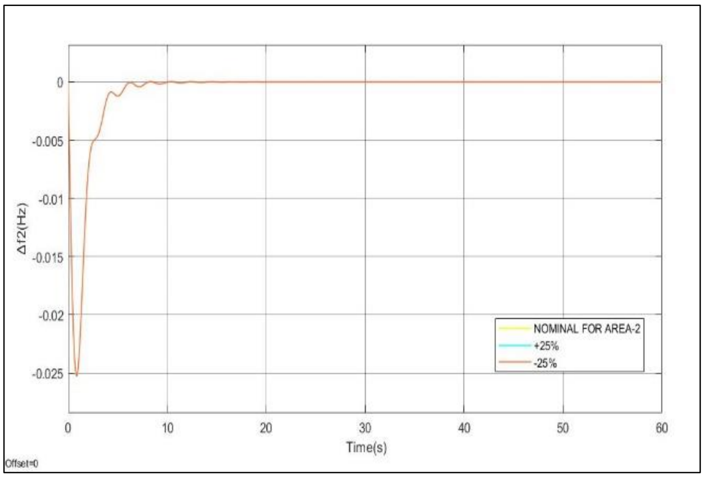


Figure 12: The system response of the load in area2 without wind unit.
Source: Authors, (2024).

From figure 12, the system response i.e., the frequency deviation between the input and output variables without the wind integration in the area-2 with +25% and -25% of proportional gain (Kp) variation in the pid controller settles at settling time (Ts) 19.8815sec same as the nominal pid controller as well as the rise time (Tr) 1.5012sec which shows that the system is stable for the gain disturbances also.

VIII. CONCLUSIONS

Based on the constraints of the conventional controller applied to system, a new algorithm-based tuning (GA, HSA) for the controller is observed its output responses and the system output performance for disturbances. From these observations, it can conclude that the system's performance is superior when utilizing a PID controller tuned by the Harmony Search Algorithm, exhibiting reduced peak overshoot and shorter settling time. The robustness of the system is verified by adjusting both the load and the Kp of the controller, demonstrating the system's inherent robustness. In summary, the PID controller fine-tuned by the Harmony Search Algorithm emerges as the optimal option for LFC applications, particularly in systems integrated with renewable power sources, ensuring stable frequency and power flows. Through case studies, it is observed that for the load variations and controller parameter variations, the system is robust in nature. For further study on this system, Hybrid Intellectual Control Mechanisms can be implemented.

IX. AUTHOR'S CONTRIBUTION

Conceptualization: Gottam Venkata Supriya, M Ramasekhara Reddy and P Bharat Kumar.
Methodology: Gottam Venkata Supriya, M Ramasekhara Reddy and P Bharat Kumar.
Investigation: Gottam Venkata Supriya, M Ramasekhara Reddy and P Bharat Kumar.
Discussion of results: Gottam Venkata Supriya, M Ramasekhara Reddy and P Bharat Kumar.
Writing – Original Draft: Gottam Venkata Supriya.
Writing – Review and Editing: Gottam Venkata Supriya, M Ramasekhara Reddy and P Bharat Kumar.
Resources: M Ramasekhara Reddy and P Bharat Kumar.
Supervision: M Ramasekhara Reddy and P Bharat Kumar.
Approval of the final text: Gottam Venkata Supriya, M Ramasekhara Reddy and P Bharat Kumar.

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