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Multi Objective Optimization for Load Frequency Control in Single Area Power System using NSGA-II Tuned PID Controller

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***Abstract*—This paper presents an algorithm known as Non-dominated Sorted Genetic Algorithm for optimization of Single Area, Non-reheat power system to damp out the oscillations of system frequency. The PID controller parameters are tuned using Non-dominated Sorted Genetic Algorithm (NSGA-II) and thus the proposed controller is simulated in MATLAB/SIMULINK. To considering the fluctuations occurring on load or demand side, a perturbation of twenty percent is provided to ensure robustness or stability. The presented method enhances the performances of power system in terms of time specifications. The results are compared with the other tuning methods provided in literature and found to be vigorous**

***Keywords*— Load frequency control (LFC), Multi-Objective Optimization, NSGA-II, Proportional-Integral-Derivative Controller (PID), ITAE, Settling Time, Overshoot Introduction (Heading 1)**

I. INTRODUCTION

A power system is the system of electrical components which is utilized to Generate, Transmit and Distribute electricity to end users. A power system network of high capacity is connected with multiple tie-lines to supply electricity and frequency is an important factor in power system since frequency is an indicator of balance between total power generation and total load including losses [1]. Deviation in frequency can cause oscillation in generator with leads to instability in power system. This instability is the reason of loss of synchronism of a system and series of such events can cause blackouts in system. With a view to making the generation and load demand balance in terms of steadiness and genuineness load frequency control (LFC) is required. It is clearly known that power operator's role is maintain the system frequency in the nominal values. Considering the balance between load and generation, there are several conventional controllers used to keep frequency within nominal values such as Proportional Controller (P), Proportional Integral controller (PI), Proportional Derivative Controller (PD), Proportional- Derivative-Integral Controller (PID) etc. are used. But these controllers have drawbacks also. A Proportional Controller quickly stabilize frequency when a sudden load change occurs. and improves the damping of oscillations but it cannot eliminate steady state error. That's why Proportional Controller often used in combination. Proportional-Integral controller provides fast response, zero steady state error [2] but it is more complicated to tune P and I. Proportional-Derivative Controller reduces overshoot and improves stability but cannot eliminate steady state error. PID controller provides fast response, zero steady-state error and handles transient and steady state performance effectively but it is most complicated to tune. The performance of the above controllers is sluggish and poor [3], so there is a need of AI-intelligent controller to reduce oscillation and eliminate steady state error, hence the deviations in frequency. There are many soft computing-based optimization techniques are available to tune the controllers. Objectives functions are used to achieve a setpoint from the optimization algorithm. Four types of objective functions are used i.e. Integral Squared Error (ISE), Integral Time Absolute Error (ITAE), Integral Time Squared Error (ITSE), Integral Absolute Error (IAE). In 2017, Sambariya et. al. [3] tune PID controller using Elephant Herding Optimization (EHO) using ISE as main objective function. In 2018, Manmadha Kumar et. al. [4] used firefly algorithm to obtain PID controller parameters. In 2018, Singh et. al. [5] constructed a 2DOF-IMC-PID controller and used Model Order Reduction (MOR) to reduce higher order two area power plant. In 2020, Hote el. al [6] presented IMC based PID controller. In 2020, S. S. Mohamad et. [7] Al design a fuzzy self-tuning fractional order PID controller (STOFOPID) with self-adaptive global harmony research (SGHS) technique to obtain gain values of PID controller. In 2023, Ogar et. Al [8] tune PID controller using Particle Swarm Optimization. In 2024, Sambariya et. al [9] use Particle Swarm Optimization (PSO) with Integral Time Absolute Error as objective function to tune PID parameters. In 2024, Isarar Ahamad et. al [10] design a fuzzy cascaded PID controller to optimize PID parameters. In 2024, Sunil Semwal et. al [11] present a two-area thermal reheat power system model for load frequency control using Tilted-Integral-Derivative (TID) and Proportional-Integral-Derivative (PID) controllers. In 2025, Yuwen Hu [12] optimize PID controller parameters using Distributed Model Predictive Control (MPC) for load frequency control. In this paper, Non-Dominated Sorting Genetic Algorithm (NSGA-II) is used for multi objective optimization such as reduced settling time, reduced overshoot by using ITAE objective function.

II. PROBLEM FORMULATION

A. System Description

The basic block diagram model of single area non-reheat power system with PID controller shown in Fig 1. Generator, turbine, load and inertia are the main components of the model. AGC is also a main component of modern power system that adjusts the output of multiple generator during the event of change in frequency which is generally occur due to sudden change in load or fault. It is necessary to ensure that the frequency and the voltage of the power system are maintained within the acceptable range. Power system gives steady state deviations only when primary loop (LFC) is considered. To remove these frequency deviations a reset action must be provided. This is done by connecting a controller in secondary loop.

The transfer functions used in the model are given below:

- *Governor Model*

$$G_G(s) = \frac{\Delta P_v(s)}{\Delta P_g(s)} = \frac{1}{1+\tau_g s} \quad (1)$$

- *Prime mover model:*

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1+\tau_T s} \quad (2)$$

0.2 < τ_T <2 seconds

- *Load and inertia model:*

$$\frac{\Delta\omega(s)}{\Delta P_m - \Delta P_t} = \frac{1}{2H + D} \quad (3)$$

- *Frequency Bias Factor (AFRC):*

$$B = D + \frac{1}{R} \quad (4)$$

The basic block diagram of single area power system can be drawn by using Eq.1 to Eq.4 and is shown in Fig.1.

TABLE I. PARAMETERS OF SINGLE AREA SYSTEM

Symbol	Abbreviation	Nominal Value
R	Speed Regulation	0.05
D	Load Frequency Constant	0.8
B	Area Frequency response characteristics (AFRC)= D+1/R	20.8
H	Inertia Constant	5
τ_G	Governor time constant	0.2
τ_T	Turbine time constant	0.5

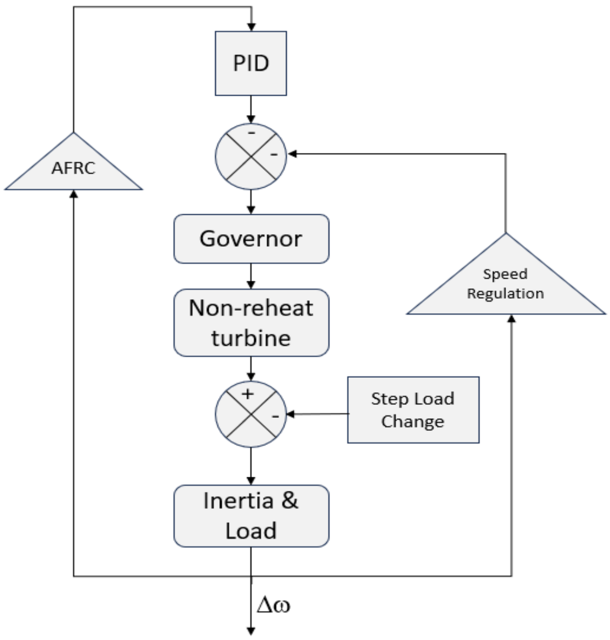

Fig.1. Block Diagram Reprsentaion of Single Area Non-Reheat Power System

B. Objective Function

Objective function is select to optimize the parameters of controllers. From literature survey, it is found that minimize integral time absolute error (ITAE), minimize Settling time and minimize overshoot function are most commonly used objective functions. The aim of the paper is to find PID controller parameters *i.e.* Kp, Ki, Kd to obtain above described objective functions. Based on performance criterion, selection of appropriate objective function is made.[9]

1) ITAE- Integral time absolute error (ITAE)

ITAE is a performance gauge is employed in the control system tuning due to its ability to:

- The time weighting (t |e(t)|) penalizes persistent errors which results in faster settling time.
- Yields lower overshoot and reduced oscillations which leads to a stable system.
- Enhanced tuning sensitivity leads to precise controller optimization.
- Quicker recovery from external disturbances.

$$ITAE = \int_0^{t_s} t\,|e(t)|dt \quad (5)$$

In order to generate a rapidly settled response, iterations are performed to minimize ITAE, keeping the error to minimum over time.

Here, Δω obtained from single area non reheat model is fed to the ITAE model shown below in Fig.2.

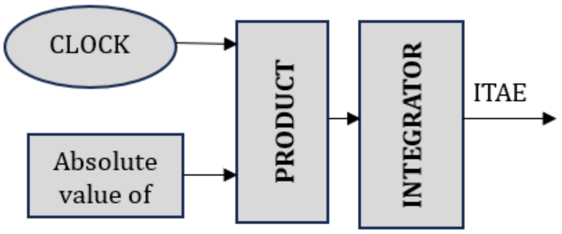

Fig.2. Block Diagram of ITAE

2) Overshoot (%OS)

Overshoot quantifies how much system output exceeds the desired value before settling. High overshoot indicates instability, energy waste or damages in some applications.

$$\%OS = \frac{M_{peak} - M_{final}}{M_{final}} \times 100 \quad (6)$$

3) Settling time

This is the time needed for system output to settle within a small percent (±2% or ±5%) of its final steady state value after disturbance.

III. NSGA -II-PID-CONTROLLER STRUCTURE/ DESIGN

A. Conventional PID controller

A PID controller is most commonly used control mechanism in control systems. It consists of three control terms *i.e.*, Proportional, Integral and Derivative. It works by continuously calculating error value between a desired set point (SP) and a processed variable (PV). The block diagram of PID controller is shown in *Fig.3.*

B. Non- dominated Sorting Genetic Algorithm (NSGA-II)

NSGA-II is far and wide applied algorithm for multi-objective-optimization where two or more competing objectives are to be optimized simultaneously. In contrast to single-objective-optimization, the aim of NSGA-II is to locate a diverse set of trade-off solutions known as “Pareto Front”-solutions in which no objective can be further upgraded without compromising other.

Important features of NSGA-II

- Non- dominated Sorting
  The population is ranked into various fronts on the basis of dominance. The first front has solutions that are not dominated by other, the second front is dominated by the first front alone and so on.
- Crowding Distance
  A crowding distance is employe to preserve solution diversity by calculating closeness of solution to the neighbors in objective space- solution that are farther from other are preferred to keep spread-out pareto front.

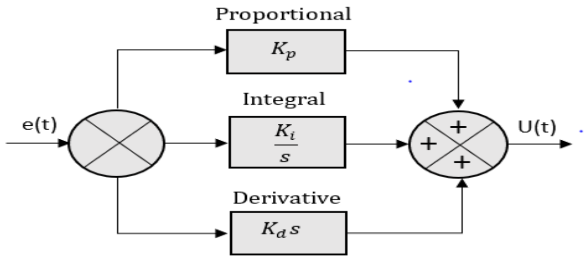

Fig.3. Block Diagram of PID Controller

- Elitism
  Parents and offsprings are mixed into a new generation then the best solutions are opted based on front rank and crowding distance.
- Binary Tournament Selection
  Two solutions are compared when choosing parents for crossover by the front rank (lower is better) and by the crowding distance (higher is better), if in the same front [13].
- No Sharing Parameter
  Unlike other algorithms, NSGA-II does not need a predetermined sharing parameter for diversity, which simplifies implementation.
  The parameters used in NSGA-II algorithm are given below in *Table II.*

TABLE II. NSGA-II PARAMETERS

Parameters of NSGA-II	**Values**
Variables	3
Upper Bound	[10 10 10]
Lower Bound	[0 0 0]
Population Size	20
Maximum Generations	30

The PID gains are tuned by posing LFC parameter as a multi-objective problem, typically minimizing indices such as Settling time, Overshoot and ITAE. NSGA-II represents PID parameters as individuals, sorting and crowd mechanism to maintain both convergence and diversity along the pareto front of optimal solutions. The Algorithm of NSGA-II is shown in Algorithm 1.

C. Related Equations

The equation of PID controller in time domain can be written as:

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \quad (7)$$

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In frequency domain (s-domain) the equation can we written by taking laplace transform of equation (7):

$$U(s) = K_p + \frac{K_i}{s} + K_d s \tag{8}$$

where, U(t)= variable of PID controller
U(s)= transfer function of PID controller
e(t)= error value
de= change in error
kp= Proportionality gain constant
ki= Integral gain constant
kd= Derivative gain constant

D. Parametrs of PID Controller

The list of proposed PID controllers and comparison with the gains obtained from literature work is shown below in Table III.

TABLE III. LIST OF PID CONTROLLER PARAMETERS

Author	Kp	Ki	Kd
J. Singh 2018[5]	4.3000	7.6000	1.3000
Y. V. Hote 2020[6]	4.0854	10.3749	1.2820
V. N. Ogar 2023[8]	0.9994	0.7741	0.1858
D. K. Sambariya 2024[9]	5.000	5.000	2.0149
Proposed NSGA-II	2.2781	5.4098	0.5274

Algorithm 1. NSGA-II

```
function nsga2_lfc()
    %% Parameter bounds
    pop_size = 20;
    gens = 30;
    var_min = [0 0 0];  % Kp, Ki, Kd min
    var_max = [10  10    10];      % Kp, Ki, Kd max
    n_var = 3;

    %% Initialize population
    pop = initialize_population(pop_size, var_min, var_max, n_var);

    %% Evaluate and sort
    for gen = 1:gens
        % Evaluate objectives: [ITAE, MaxDeltaF]
        for i = 1:pop_size
            [f1, f2] = evaluate_objectives(pop(i).Position);
            pop(i).Cost = [f1, f2];
        end

        % Non-dominated Sorting
        [pop, fronts] = non_dominated_sorting(pop);

        % Crowding distance
        pop = calculate_crowding(pop, fronts);

        % Generate offspring using crossover & mutation
        offspring = genetic_operators(pop, var_min, var_max);

        % Combine and select next generation
        pop = environmental_selection([pop, offspring], pop_size);
    end

    %% Final Pareto Front
    plot_pareto(pop);
end
```

IV. SIMULATION RESULT

A step load disturbance of 0.2 per unit is applied at t=0 for modelling purposes. The simulation is done using the MATLAB R2023a-simulink program. The simulation was executed on a machine equipped with an intel i3 7th generation processor running at 2.30 GHz, 8GB of RAM and operating on Windows 10. A comparison of proposed technique with the literature is given in *Table IV*. Problem and parameters of the single area non-reheat power system given in the *Table I* are taken from Chapter 12 of power system analysis by Hadi Saadat. [14]

TABLE IV. COMPARISON OF PERFORMANCE PARAMETERS

Author	Overshoot	Settling time
J. Singh 2018[5]	1.2246e+08	4.1370
Y. V. Hote 2020[6]	5.1728e+08	6.0683
Y. N. Ogar 2023[8]	1.0389e+09	8.7976
DK sambariya 2024[9]	3.8522e+06	1.7656
Proposed NSGA-II	3.1598e-02	1.0376

A. Plot of deviation in frequency versus time

The system is designed using parameters given in Table I. With the use of NSGA-II algorithm the parameters of PID controller are optimized and a plot on deviation in frequency (Δω) on y-axes with respect to time on x-axes for single non-reheat power system, when a step load disturbance occur is 20 percent, is given below in *Fig.5*. A comparison of settling time with optimized kp, ki, kd using NSGA-II or settling time from literature work is given below in *Fig. 4* and responses such as overshoot and settling time are recorded.

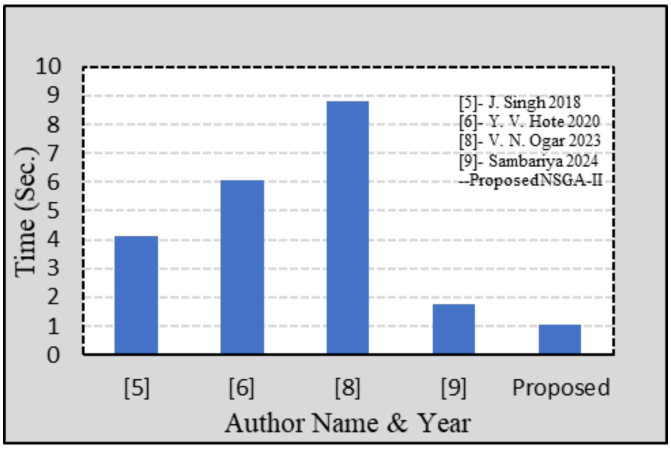

Fig.4. Comparison of Settling Time

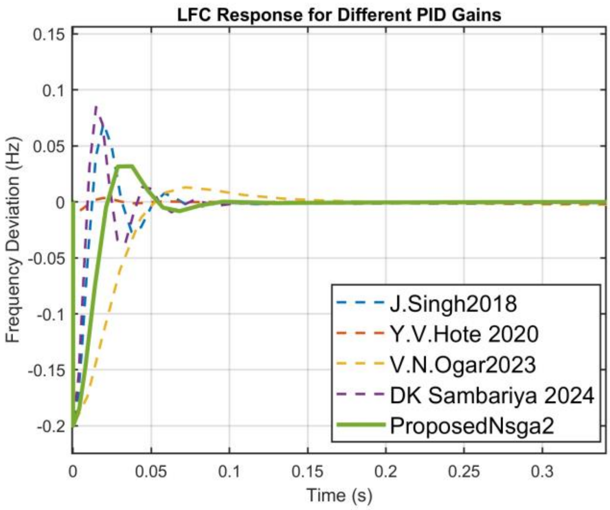

Fig. 5. Frequency Deviation vs Time

V. CONCLUSION

Compared to conventional tuning methods, NSGA-II allows simultaneous fulfillment of multiple goals, enhance dynamic performance and, offers a portfolio of trade-off solutions for controller tuning. Proposed work proves that NSGA-II tuned PID controller yield improved overshoot, shorter settling times and improved robustness against disturbance in interconnected system performing better than classical methods or single-objective optimizers.

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