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Dandelion Optimizer-Based Frequency Controller for a Hybrid power systems Considering Renewables

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Abstract

For power quality enhancement, voltage, frequency, and power flow between control areas in an interconnected power system are required to be maintained. Hence, the voltage and frequency should be continuously controlled to maintain the balance of real and reactive power during load variation. Integration of renewable energy sources (RES) in the power system leads to inertia losses and mismatches between load demand and generation capacity; hence, the load frequency controller should overcome these challenges.

In this paper, a Dandelion optimizer (DO)-based tilted-integral-derivative (TID) controller is introduced for load frequency control (LFC) of a single-area power system considering renwables pentration. A single-area power system with both solar and wind power plants as renewables and reheat-thermal, hydraulic, and gas power plants as conventional power plants is modeled using the Matlab toolbox. The controller-based DO optmizer is tested under different loading variations to verify its robustness. The sperm swarm and black widow optimization algorithms are compared with the introduced algorithm to verify its superior dynamic responses for loading variation.

Keywords: *Load frequency control, Hybrid power systems, TID controller, Dandelion Optimizer.*

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1. Introduction

To mitigate global warming and environmental impacts, stabilize energy prices, and enhance the flexibility of power systems, the integration of RES into power systems has gained significant attention in recent years. Despite all these benefits, increasing RES penetration produces several challenges that must be addressed to ens/ure the reliable and efficient operation of power systems. Examples of these challenges include intermittency, grid stability, energy storage, and policy frameworks. The power system faces challenges in maintaining frequency stability due to the entire inertia being reduced (Almasoudi et al., 2023). As a result, the integration of RESs into interconnected power systems provides several control challenges, including issues associated with the disparity between load demand and generated power. Hence, load frequency control (LFC) emerges as a crucial component for maintaining grid frequency stability during continuous variations in load demand (Khudhair et al., 2022).

Within the electrical power system, the interconnecting lines facilitating communication between multiple control areas are termed tie lines. In both static and dynamic scenarios, generators can be systematically manipulated to adjust their synchronized speed (acceleration or deceleration) to achieve a specific frequency and power angle that deviate within the predetermined levels. The concept of LFC revolves around the task of regulating the real power output of generation units in response to fluctuations in system frequency and tie line power, ensuring stability within defined limits. Consequently, there is a continuous quest for the most effective controller capable of efficient LFC operation within varying load conditions. Additionally, a critical consideration lies in determining the optimal parameter values for the frequency controller to maximize its performance (Magdy et al., 2022).

Earlier research attempts have introduced proficient controllers aimed at enhancing the frequency stability criterion. Notably, multistage controllers and fractional-order (FO) controllers have emerged as effective solutions, proving their efficacy across various technical applications recently. Within the realm of FO controllers, TID and fractional-order proportional-integral-derivative (FOPID) controllers stand out as primary variants, showcasing superior control responses compared to conventional integer-order controllers (Alharbi et al., 2023). Hence, these controllers have gained widespread adoption in recent years, with their effectiveness contingent upon precise adjustments to their parameters. For optimal performance, numerous artificial intelligence techniques, including optimization algorithms, have been employed for parameter selection and tuning, surpassing the capabilities of traditional tuning methods such as Cohen Coon or Ziegler-Nichols (Ahmed et al., 2022b). Recently, for fine-tuning the LFC controller parameters, different optimization algorithms have been introduced in the literature to enhance the dynamic response of the system, which is contingent upon deviations in system frequency levels and fluctuations in tie-line power. From these optimization algorithms Particle Swarm Optimizer (PSO), Improved Particle Swarm Optimizer (IPSO), Wild Horse Optimizer (WHO), Archimedes Optimization Algorithm (AOA), Black Widow Optimization Algorithm (BWOA) are proposed in the literature (Abdelkader et al., 2023; Morsali et al., 2018).

The LFC-based TID controller considering renewables was introduced in many literature (Tabak & Duman, 2023). In this paper, an effective LFC based on a TID controller is proposed to enhance the frequency stability of multi-area power systems, considering RESs. Using the Integral Time Square Error (ITSE) objective function, the parameters of the TID controller are optimized using a DO and Sperm Swarm Optimizer (SSO); which have not been previously utilized in LFC studies but have been applied in other contexts to minimize the system frequency deviations. The effectiveness of this approach was evaluated using a single-area power system model under different loading variation scenarios, including a small load disturbance (SLD) of 0.1 per unit (pu) and integration of RESs into the grid. The performance of the proposed algorithm is compared with that introduced by(Shehadeh, 2021) based on Proportional-Integral-Derivative (PID) and TID controllers and SSO, the algorithm based on Black Widow Optimization Algorithm (BWOA) introduced by (Dahiya & Saha, 2022), and the algorithms introduced by (Ranjan & Shankar, 2022).

2. Modelling of a single-area power system

In this study, the stability of a single-area power system consisting of conventional power systems and RESs is tested using the proposed TID-based frequency controller with tuning parameters optimized by DO to evaluate its dynamic responses during different loading conditions. Firstly, a single-area with conventional power plants is modeled and tested for different loading conditions, then the impacts of RES integration is tested. To mold a single area power system with its power plants, the MATLAB toolbox is used; for further detail on this model, the reader can refer to (Gupta et al., 2017)

The modeled single-area power system consists of reheated thermal, hydraulic, and gas as traditional power plants, also solar, and wind power plants as renewables, alongside load; see Figure 1. Generation dead band (GDB) and generation rate constraints (GRC) are examples of nonlinearities that are taken into account because many previous studies disregarded these realistic nonlinear behaviors. The area has a nominal load of 1740 MW and a rated power of 2000 MW.

For more details about the system parameters with their descriptions and pre-defined values, refer to (Magdy et al., 2022; Mohanty et al., 2014).

The proposed controller's robustness is evaluated under different loading conditions, such as a step load disturbance (SLD) SLD, integration of intermittent RESs. Using MATLAB toolbox, it can simulate random wind speed and unsteady solar radiation using the white noise block and other components of solar and wind block designs, as shown in Figures 2 and 3. (Latif et al., 2020) .

3. Controller and Optimization algorithm.

3.1 TID Controller.

Much like a PID controller, the TID arrangement includes a proportionate tilted element characterized by a transfer function of $1/s^{1/n}$ (Magdy et al., 2018). This approach involves fractional-order characteristics, where the order of integral and derivative terms deviates from integers. The concept of fractional order (FO) relies on extending traditional integer order integration and differentiation to a fractional order operator. As stated by (Lurie, 1994), the transfer function of a TID controller is as in Equation (1), for more details refer to (Ahmed et al., 2022b; Zaid et al., 2023).

$$TID(s) = K_T s^{(-1/n)} + \frac{K_I}{s} + K_D s \qquad (1)$$

Three movable parameters—the tilt, integral, and derivative gains, respectively are represented by the symbols K_T, K_I, and K_D. The proportional part of the TID controller is denoted by the fractional-order transfer function $s^{-(1/n),}$ where n is a real number that is non-zero. Figure. 2 displays the block diagram that represent the TID controller(Alharbi et al., 2023).

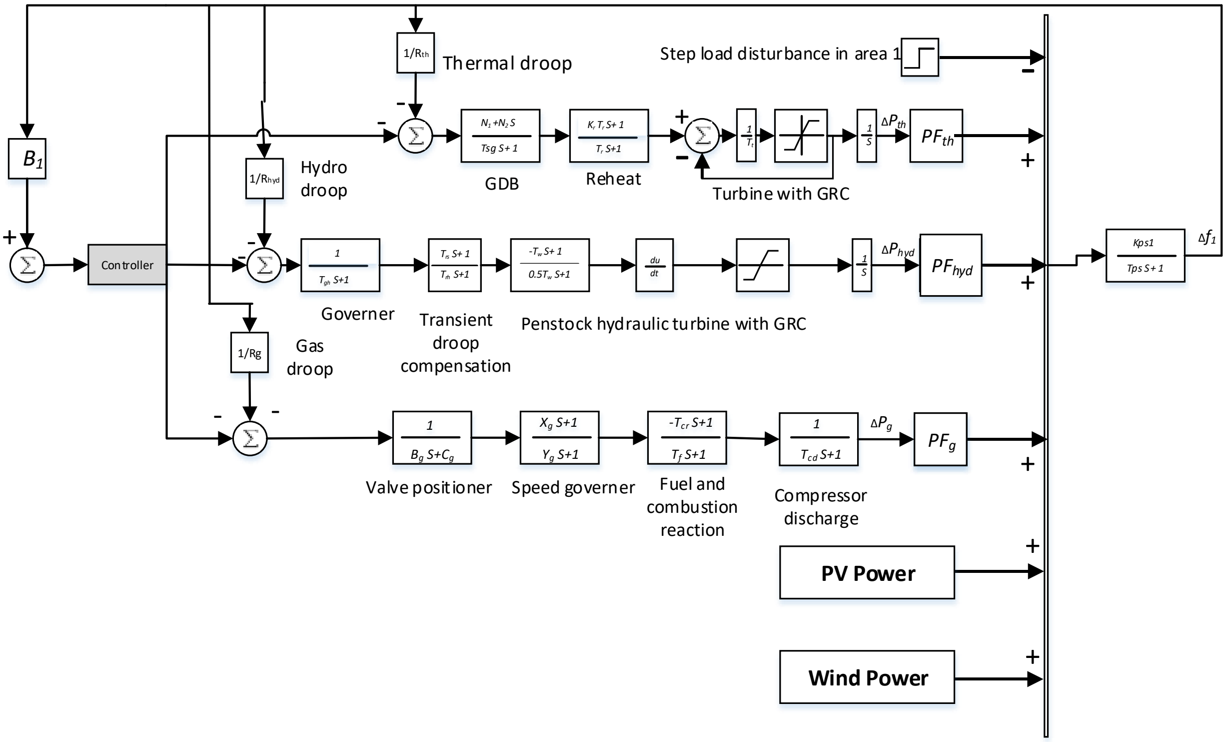

Figure 1 Single area power system architecture.

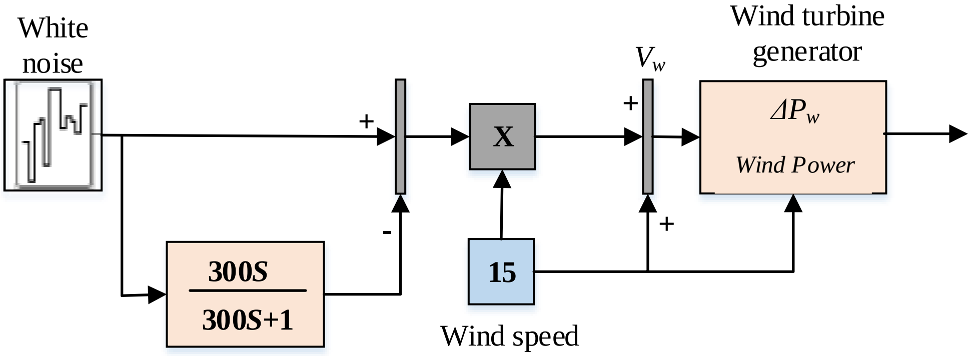

Figure 2 Model of wind power generation, where, V_w (wind speed), and P_w (wind power).

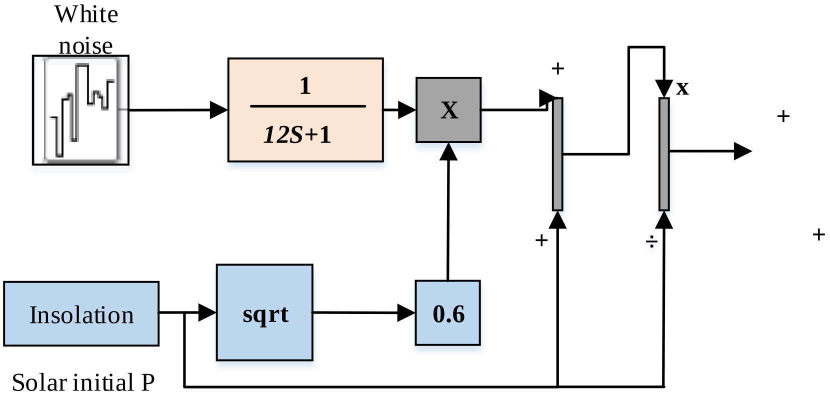

Figure 3 Model of solar power generation.

3.2 Objective Function

For fast tuning of PI controllers, there are different types of objective functions that have been introduced in the literature; the most commonly used functions include the integral time square error (ITSE), the integral square error (ISE), the integral absolute error (IAE), and the integral time absolute error (ITAE)(Sahib & Ahmed, 2016). The equations that resemble these objective functions are provided in Equations (2)–(5) for two area power system model ; a disadvantage of the IAE and ISE criteria is that they may result in a response with a relatively small overshoot but a long settling time because they weigh all errors uniformly over time (Mohanty et al., 2014) . Since, the single area power system is used to evaluate the performance of the proposed controller, the ITSE objective function is reduced, as in Equation (6), where the integral time square error of the area frequency due to loading disturbances is used(Sahib & Ahmed, 2016).

$$ITSE = \int_0^{t_{sim}} t \cdot [(\Delta f_1)^2 + (\Delta f_2)^2 + (\Delta P_{tie})^2] \cdot dt \qquad (2)$$

$$ISE = \int_0^{t_{sim}} [(\Delta f_1)^2 + (\Delta f_2)^2 + (\Delta P_{tie})^2] \cdot dt \qquad (3)$$

$$IAE = \int_0^{t_{sim}} [|\Delta f_1| + |\Delta f_2| + |\Delta P_{tie}|] \cdot dt \qquad (4)$$

$$ITAE = \int_0^{t_{sim}} t \cdot [/\Delta f_1/ + /\Delta f_2/ + /\Delta P_{tie}/] \cdot dt \qquad (5)$$

$$ITSE_{single\_area} = \int_0^{t_{sim}} t \cdot [(\Delta f_1)^2] \cdot dt \qquad (6)$$

Where t_{sim} is the simulation time used in optimization.
Δf_1 and Δf_2 are the frequency deviation of area$_1$ and area$_2$ respectively, and ΔP_{tie} is the tie line power deviation.

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In the design methodology of the PI controller, the most widely utilized functions are the time domain integral error performance criteria, which compute the error signal between the input reference signal and the system output. In this study, to evaluate the performance of the controller, the ITSE is used as an objective function [15], and DO, BWOA, and SSO are used as optimization tools for tuning the settings of TID and PID controllers. Furthermore, for n of TID, the lowest and upper bounds of the gains of the two controllers utilized are [0, 100] and [1, 10].

3.3 Dandelion Optimizer.

Dandelion optimization (DO), a recently developed optimization technique that is able to achieve more precise and less iterative convergence than previous metaheuristic algorithms. It does this by magnifying the flight patterns of dandelion seeds. The three phases that the dandelion seeds go through are as follows:

- Above a dandelion seed during its rising stage, an air vortex forms. The pulling force of the wind and sunshine causes the seed to ascend.
- During the falling stage, the seeds gradually begin to descend after they reach a particular height.
- The wind-driven landing stage produces immature dandelions when the seed falls haphazardly in a certain spot (Zhao et al., 2022).

The DO algorithm was primarily inspired by the three stages of rising, descending and landing that dandelions take to spread their seeds to the next generation in order to grow their population; as indicated in the flow chart of this dandelion optimizer which can be found in references (Abdelkader et al., 2023; Ahmed et al., 2022a; Alharbi et al., 2023).

4. Simulation and results.

The first step involves simulating DO, BWOA, and SSO in order to assess their performance and adjust the PID and TID controller parameters during the 0.01 pu step-load disturbance. The convergence curve of the three optimizer-based PID controllers, as shown in Figure 4, indicates that the DO algorithm exhibits superior performance. This superiority is further demonstrated in Figure 5, where the DO method, when used to optimize the TID controller's settings, performs better than the other two optimizers in the convergence curve. Table 1 shows the optimized parameters of both controllers for each of the three optimization procedures as well as the ITSE objective functions value for each case. These outcomes support the conclusions drawn from the convergence curves, showing that the DO optimizer performs better than the other two optimizers.

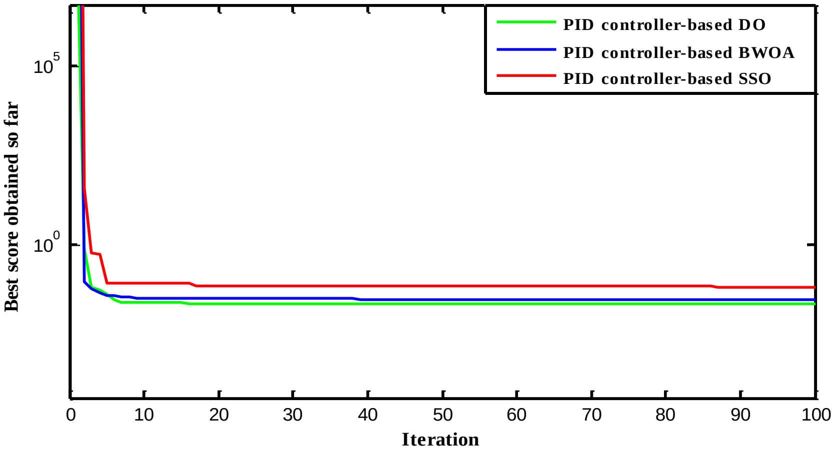

Figure 4 Convergence Curves of PID Controller based on the three optimizers.

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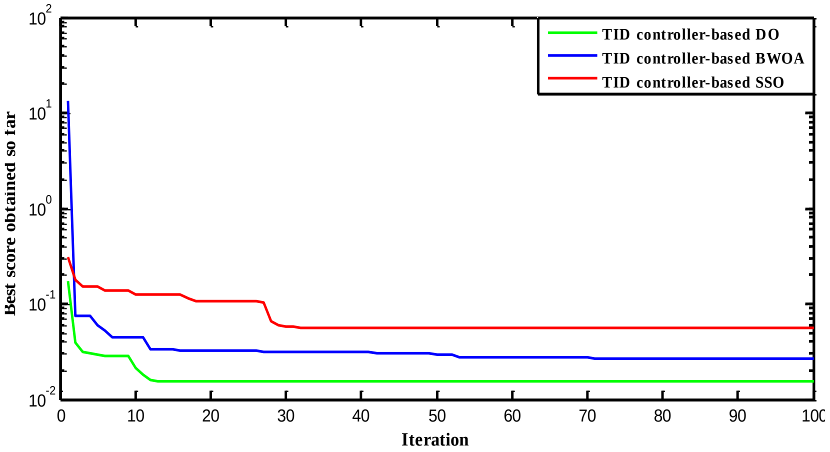

Figure 5 Convergence Curves of TID Controller based on the three optimizers.

Table 1 Controllers parameters tuned by different optimizers.

Controller parameters		PID Controller			TID Controller		
		DO	BWOA	SSO	DO	BWOA	SSO
Area 1	KP1	2.85020	1.32350	0.00020	-	-	-
	KT1	-	-	-	8.39905	1.95699	3.59330
	KI1	27.78430	1.63510	0.21250	32.86060	8.72010	4.41730
	KD1	15.32430	1.74720	1.28160	32.86060	11.46310	0.19470
	n1	-	-	-	2.57460	2.20034	3.42050
ITSE		0.02109	0.03659	0.06300	0.01524	0.02825	0.05571

For a step load disturbance of 0.1 pu occurs at 50 sec, the two controllers-based DO algorithm are tested, and their responses are compared. When the aforementioned conditions are met, Figure 6 and 7 shows the area frequency deviation performances of the single area-based PID and TID controllers whose settings are optimized by DO algorithms. This makes it clear that the TID-DO algorithm performs better considering settling time (t_s), maximum overshoot (OS), and minimum overshoot (US). Two significant characteristics, as seen in Figure 6 and 8 can be used to characterize the system's transient reaction: the output's proximity to the reference (desired) input and its speed of response. The increase and peak timings indicate how quickly a response is made. However, the maximum overshoot and settling time indicate how well the output matches the intended response.

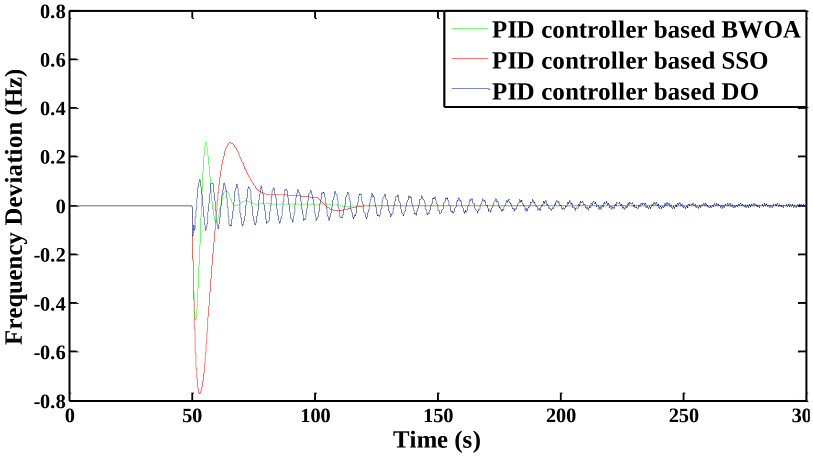

Figure 6 The responses of PID controllers based on BWOA, SSO, and DO algorithms under 10% SLD of the grid capacity.

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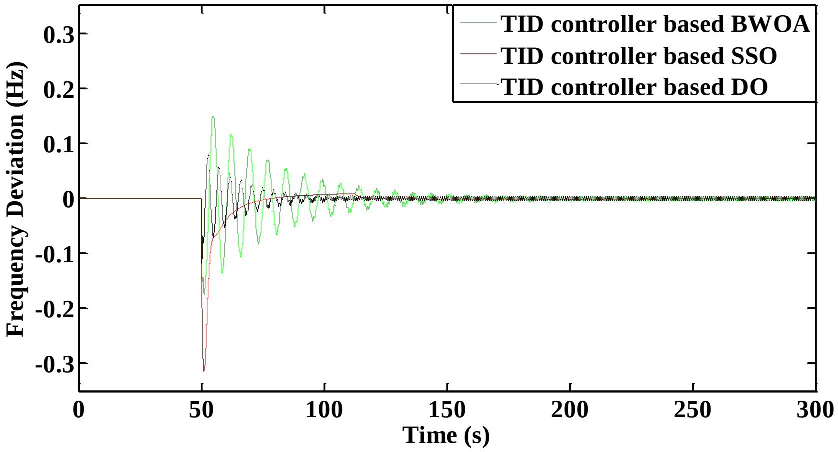

Figure 7 The responses of TID controllers based on BWOA, SSO, and DO algorithms under 10% SLD of the grid capacity.

For a step load disturbance of 0.1 pu occurs at the 50 sec, followed by a 220 MW-solar power (0.1pu of the grid capacity) switched on at 150 sec, and finally at 300sec, a 470 MW wind power (0.235pu of the grid capacity) is switched on, PID and TID controllers are evaluated. Power profiles of solar and wind plants are depicted in Figures 8 and 9, respectively. Figure 10 illustrates that the TID-DO algorithm provides superior performance compared to the PID-DO algorithm in terms of settling time and overshoot.

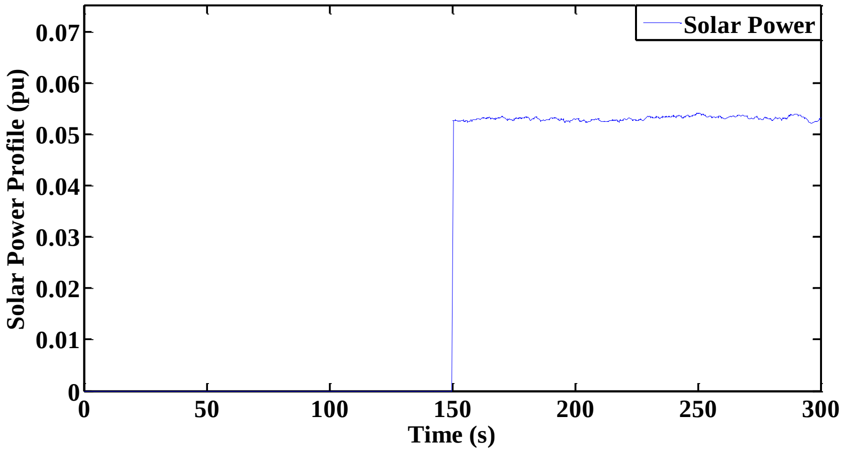

Figure 8 Solar Power Generation Profile.

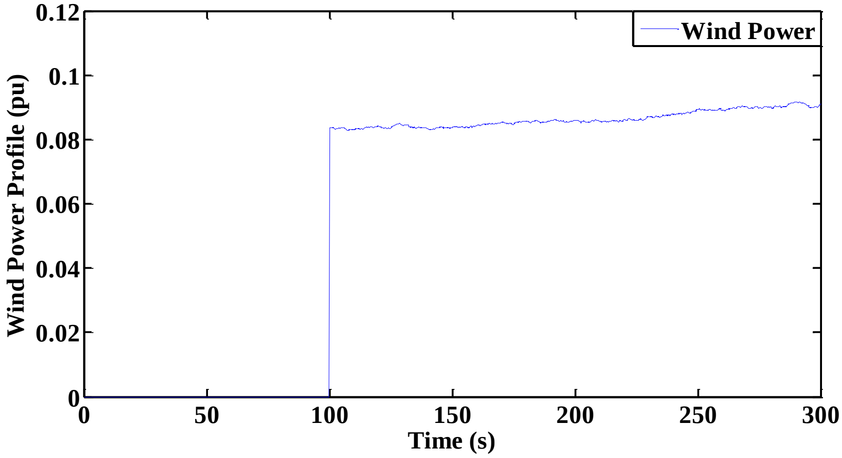

Figure 9 Wind Power Generation Profile

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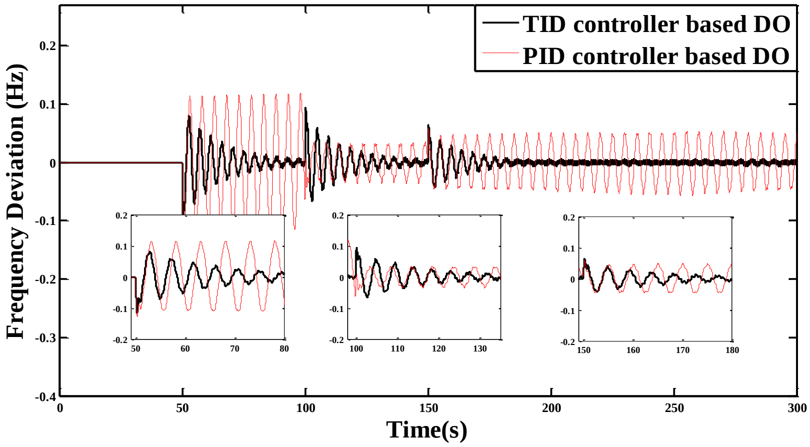

Figure 10 The performance of DO-based TID and PID controllers during 10% SLD, followed by the installation of solar and wind power of the single area power system.

5. Conclusion.

The design and performance evaluation of DO-based TID controller for LFC of a single area power system, considering renewables, are proposed in this study. For the controller parameters optimization, the ITSE objective function is used for fine-tune of TID and PID controller. The single-area power system includes reheated thermal, hydraulic, and gas power plants as traditional power plants, as well as solar and wind power plants as renewable energy sources, alongside the loads is simulated. Different loading disturbances are simulated to test the dynamic responses of the TID-based LFC controller. Based on the simulation results, it can be concluded that the proposed control strategy, which is optimized with a DO, achieves better dynamic performances compared to BWOA and SSO. The superiority of the proposed approach has been shown by comparing the its response to the DO-based PID controller for the same single area power system. It is observed that the proposed DO optimized TID controller outperforms the DO optimized PID controller.

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