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# Comparison of PSO, DE and Hybrid DE-PSO for LFC of Wind Power Systems

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***Abstract*—This paper investigates the performance of particle swarm optimization (PSO), differential evolution (DE), and hybrid particle swarm optimization- differential evolution (HDEPSO) for solving load frequency control (LFC) problems. Wind power systems LFC model is used to compare the performance of PSO, DE and HPSODE for solving LFC problems. All the simulation are carried out in MATLAB/SIMULINK environment. From the simulation results, it is noticeable that by designing LFC of wind power system using HPSODE, the overshoot and settling time of the wind power system can be reduced and accelerated.**

***Keywords*—Clean energy technology, Hybrid DEA-PSO, Load torque, PI controller, PSMS, Speed response.**

## I. INTRODUCTION

In the 4.0 industrial era, the application artificial intelligence (AI) for solving complex engineering problems has been increasing significantly. Generally, artificial intelligence (AI) can be divided into three major categories. These three major categories are artificial neural network (ANN), fuzzy logic and nature inspired algorithm.

For solving optimization problems, nature inspired algorithm is better compared to ANN and fuzzy logic. There are many researches using nature inspired algorithm for solving optimization problems such as. In [1], particle swarm optimization is used to optimize the workflow problems. Research effort in [2], attempt to use PSO for sizing battery energy storage. From the simulation results, it is found that by optimizing battery energy storage using PSO, the frequency stability performance of microgrid can be enhanced.

In Ref [3], differential evolution (DE) is used to coordinated between thyristor controlled series compensator (TCSC) and power systems stabilizer (PSS). From their research, it is found that the dynamic performance of power system can be enhanced significantly by designing TCSC and PSS simultaneously using DE. Authors in [4], proposed a way for enhancing the doubly feed induction generator (DFIG) performance by using DE. It is found from their research that designing the controller of DFIG using DE resulting on increasing performance of DFIG (from all of DFIG output).

From reference above, it is noticeable that PSO and DE can be used for designing controller as well as solving optimization problems. Hence, in this paper, the research compared the methods of PSO and DE as well as hybrid DE-PSO (HDEPSO) for optimizing controller. Frequency stability performance of wind power system is chosen as the problem for comparing three algorithms. The rest of the paper is organized as follows: Modelling and fundamental theory of load frequency control, wind power system, PSO, DE and HDEPSO are described in Section 2. Section 3 provides a method for designing wind power system controller using PSO, DE and HDEPSO. The results and discussion are provided in Section 4. Finally, conclusions are explained in Section 5.

## II. FUNDAMENTAL THEORY

### A. Load Frequency Control

Frequency is one of the important parameters along with voltage in power system. By controlling the frequency of power system, a constant rotation of the synchronous generator can be guaranteed. If the synchronous generator operated in constant rotation under disturbance, the active power of the generator can be maintained as the operator requirement [5].

To stabilize the frequency and the active power of the power system a concept called load frequency control (LFC) is crucial. Generally, LFC can be done by giving a feedback signal to the valve control or governor. Before going to the valve control, the feedback signal is multiplied with integrator. The controller are able to adjust and control the speed of synchronous Generator. The schematic diagram of this process can be captured using Fig. 1. In this paper, the wind power system frequency is controlled, to control this system capturing the dynamic behaviors of wind power system is crucial [5].

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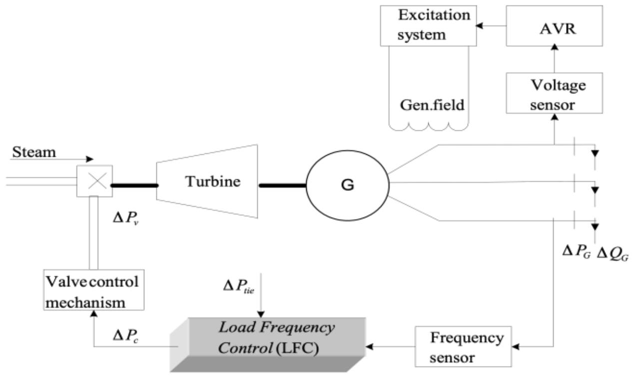


Figure. 1 Schematic diagram of LFC.

*B.Wind Power System Model for LFC Study*

For simulation purpose, mathematical model of wind power system is crucial. In this section, the mathematical model of wind power system for LFC study is thoroughly investigated. When there is a changing in the wind speed, acceleration or de-acceleration of the rotor speed could be happened. This condition results on the frequency fluctuation in the system. By understanding this phenomenon, the dynamic behaviors of frequency fluctuation of wind power system can be captured using (1) [6, 7].

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H_\omega}\left(\Delta P_m + \Delta P_w\right)$$

Where wind power input from the generator and inertia constant of wind turbine can be described using $\Delta P_w$ and $H_w$. While mechanical power of the turbine and frequency response of the wind power system is presented as $P_m$ and $\Delta\omega$. The next parts of this system is the fluid coupling. The purpose of the fluid coupling is to transform the difference between angular speed and the frequency into power. Output of this block will be connected to PI controller and this PI controller will be controlling the blade pitch angle of wind turbine. The mathematical model of this process can be captured using (2)-(4) [6, 7].

$$\frac{d\Delta x_2}{dt} = K_{p2}\frac{d\Delta x_1}{dt} + K_{p2}\Delta x_1$$

$$\Delta x_1 = \Delta P_{max} - \Delta P_{wtg}$$

$$\Delta P_{wtg} = K_{FC}\Delta\omega_2$$

Furthermore, by substituting $\Delta P_{wtg}$ and $\Delta P_{max}$ ($\Delta P_{max} = 0$), further calculation can be form as presented in (5) [6, 7].

$$\frac{d\Delta x_1}{dt} = -K_{FC}\frac{d\Delta x_2}{dt}$$

Moreover, the rest of mathematical representation can be captured through (6), (7), (8), and (9). Finally, all of the equation can be formed in block diagram as depicted in Fig. 2 [6, 7].

$$\frac{d\Delta x_2}{dt} = -\frac{K_{FC}K_{p2}}{2H_\omega} + \left(\Delta P_w + \Delta P_m - \Delta P_{load}\right) - K_{FC}K_{p1}\Delta\omega_2$$

$$\frac{dx_3}{dt} = K_{p1}T_{p1}\frac{d\Delta x_2}{dt}K_{p2}\Delta x_2 - \Delta x_3 = \frac{-K_{p1}T_{p1}K_{FC}K_{p2}}{2H_\omega}\left(\Delta P_w + \Delta P_m - \Delta P_{load}\right)$$
$$-K_{p1}T_{p1}K_{FC}K_{p2}\omega_2 + K_{p1}\Delta x_2 - \Delta x_3$$

$$\frac{d\Delta x_4}{dt} = \frac{1}{T_{p2}}\left(\Delta x_3 - \Delta x_4\right)$$

$$\frac{d\Delta P_m}{dt} = K_{P3}K_{PC}\Delta x_4 - P_m$$

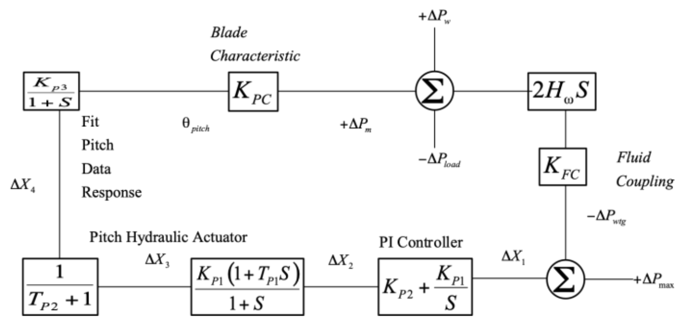


Figure. 2 Dynamic model of wind power systems.

## III.Method

*A.Particle Swarm Optimization*

Particle Swarm Optimization (PSO) was first introduced by Kennedy and Eberhart in 1995 [8]. This Algorithm is inspired by the behaviors of birds for finding a food. Particles can be represented as birds living socially in PSO, where each particle is depending on each other. Particle and swarm are representing the individual birds and bird population. The optimal value of the algorithm can be presented as the best source of food. In the process of finding a food, there are two essential things, which are particle speed and particle position. The particle speed and particle position can be presented as (10) and (11). Furthermore, the complete mathematical representation of the PSO algorithm can be found in [9, 10].

$$v_i^{k+1} = v_i + c_1 r_1\left(P_{best} - x_i^k\right) + c_1 r_1\left(G_{best} - x_i^k\right)$$

$$x_i^{k+1} = x_i + v_i^{k+1}$$

In (10) and (11), $k_i$ is particle position and $v_i$ corresponds to the velocity of the particle, $P_{best}$ and $G_{best}$ are the best position of the particle and the best $P_{best}$ in the population. $C_1$ and $C_2$ are learning factors. $r_1$ and $r_2$ are random values from 0 to 1. However, PSO has disadvantages in term of tending to convergence in local optima [9, 10].

*B.Differential Evolution Algorithm*

Differential evolution (DE) is a population-based search method that used the recurrence cycle of recombination and

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selection for finding the optimal value. This algorithm was first introduced by Storn and Prince in 1997 [11]. This algorithm has five important steps for generating optimal solution: initialization, mutation, recombination, crossover, and selection [12, 13].

In the initialization process, a random value in certain region is set as the initial value. This initial value has a boundary which is upper and lower limit (this limit is based on the parameter that will be optimized. The mathematical representation of initialization process can be captured in (12) [12, 13].

$$x_{j,i,g} = rand_j(0,1) \times (b_{j,u} - b_{j,l}) + b_{j,l}$$

Where, $b_{j,u}$ and $b_{j,l}$ are upper and lower limit of vector $j$. While $x_{j,i,g}$ is a vector value of $I$ on $j$ parameter and $g$ generation. $rand_j(0,1)$ is a random value between 0 and 1. After this procedure, mutation and recombination are performed. The mathematical representation of recombination is described in (13). Where $v_{i,g}$ and $F$ are the mutant vector and a real number with ranges 0 to 1 respectively. While $x_{rl,g}$, $x_{r2,g}$ and $x_{r0}$ are a chosen random vector [12, 13].

$$v_{i,g} = x_{ro} + F \times (x_{rl,g} - x_{r2,g})$$

The next step of DE process is crossover, this process can be described in (14). The limit of *Cr*'s crossover probability value is 0 to 1 and *Cr* is the value set by the user to control the division of the duplicated parameter values from the mutant. $rand_j$ is a random value that will determine whether the vector needs to be passed through a crossover process or not. If the value of the $rand_j$ vector (0, 1) is less than *Cr*, then the value of the vector to be duplicated in the trial vector is the mutant vector. If the process goes the opposite and the $rand_j$ value is over *Cr* then the vector value to be duplicated in the trial vector is the initial vector [12, 13].

$$u_{i,g} = u_{j,i,g} = \begin{cases} u_{j,i,g} \, if \, (rand_j(0,1) < Cr) \\ x_{j,i,g} \end{cases}$$

The last step is the selection. In this process the vector that will be used for the next iteration is determined. Once a new population is selected the DE process is repeated from mutation process. It should be noted that DE is also has a handicap in term of slowing down the convergence when the algorithm enters the global region [12, 13].

### *C.Hybrid DEA-PSO*

Basically, this algorithm is combination of DE and PSO technique. The basic program of this algorithm is PSO as PSO that has lest computational effort compared to the DE. To overcome the drawback of PSO, the DE process is included in this algorithm. So, this algorithm will overcome both of PSO and DE drawback [14]. Fig. 3 shows the flowchart of HDESPSO.

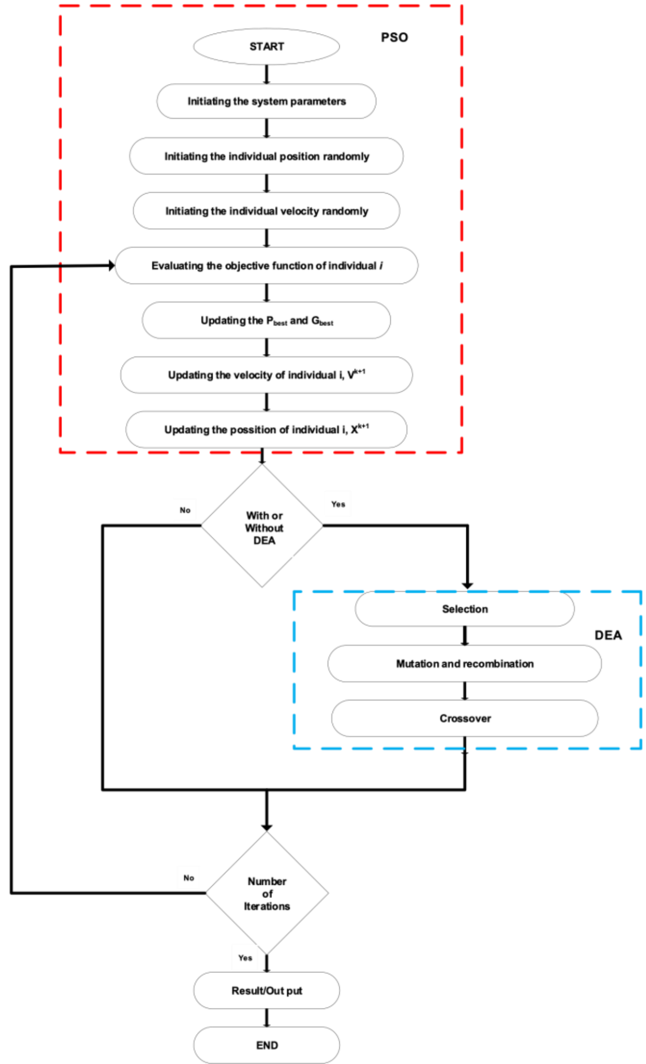


Figure 3. DE-PSO Flowchart

### *D.Procedure for Designing the Controller*

The controller of wind power system is PI controller. The PI controller will control the blade pitch angle of wind turbine. The input of the PI controller itself is the feedback signal of wind power system frequency response. The purpose of this research is to stabilize the frequency response as good as possible. Hence, the objective function of all three algorithm can be determined using (15) [15].

$$E = \sum \int_0^{t1} t \left| \Delta\omega(t, X) \right| dt$$

*Δω(t,X)* is the oscillatory condition of a generator's rotor speed. *X* consists of PI parameters while *t1* is the time frame of the simulation. The purpose of this objective function is to reduce the error of frequency response. By setting the PI controller based on the minimum error deviation, the frequency response of wind power system can enhance. Furthermore, all the simulation are performed in MATLAB/SIMULINK environment.

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## IV. RESULTS AND DISCUSSION

In this section, the comparison performance of PSO, DE and HDEPSO for enhancing frequency stability performance of wind power system is thoroughly investigated. Three case studies are considered to investigate which is the best algorithm for these problems. The first case study is comparison of execution time between PSO, DE and HDEPSO. The second case study is focused on the comparison of dynamic response of wind power system frequency performance. The last case study is comparison of dynamic performance under specific indices

### *A. Case study 1*

This case study focused on execution time comparison. In all of the algorithm, iteration is set at 50 iterations. Moreover, the number of particles for all the simulation are set at 50. The upper and lower limit are also set at the same value. Fig. 4 shows the execution time comparison for all three algorithms.

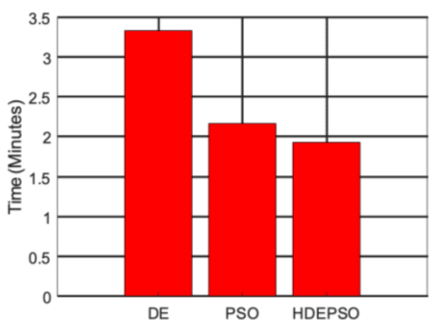


Figure. 4 Execution time comparison.

As shown in Fig. 4, the fastest execution time is HDEPSO. While the slowest execution time is DE. Hence, the simulation and ref [12] are agreeing each other.

### *B. Case Study 2*

In the second case study, the comparison of wind power system dynamic response is performance. The dynamic response of wind power system can be investigated by using time domain simulation. The time domain simulation can be carried out by giving a wind speed variation on the system. Fig. 5 illustrates the frequency performance comparison of system with PSO, DE and HDEPSO.

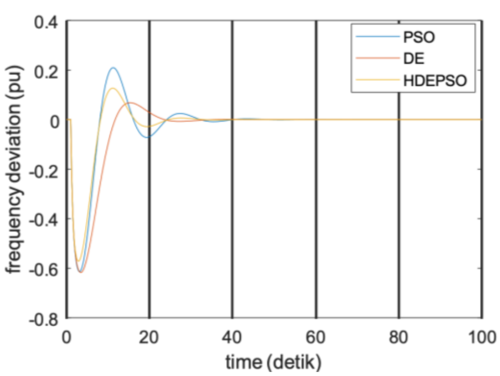


Figure. 5 Frequency response.

From Fig. 5, it is noticeable that the best dynamic frequency response is provided by system with HDEPSO. This can be seen by the smallest overshoot and fastest settling time compared to the other scenarios. Furthermore, Table 1 shows the detailed features on Fig. 5.

**Table 1.** Detailed features of Fig. 5.

| Index | Overshoot | Settling Time |
|---|---|---|
| PSO | -0.6137 | 54.17 |
| DE | -0.6176 | 46.67 |
| HDEPSO | -0.5715 | 34.15 |

## V. CONCLUSION

This paper investigates the performance of DE, PSO and HDEPSO for designing PI controller of wind power systems. From the simulation results, it is found that designing PI controller based on HDEPSO, the frequency performance of wind power system can be enhanced. It is noticeable that by combining DE and PSO the drawback of both algorithms can be overcome.

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