# Speed Controller Design using Hybrid Differential Evolution Algorithm-Particle Swarm Optimization for PSMS

Muhammad Aldo Setiawan[1], Herlambang Setiadi[2], Rodik Wahyu Indrawan[3], Rizki Putra Prastio[4]

[1,2,3,4] *Faculty of Advanced Technology and Multidiscipline, Universitas Airlangga, Surabaya, Indonesia*

***Abstract*—The use of engines that motorized the world based on fossil fuel sources has led to many problems, such as air pollution, energy security, global warming, and climate change. To prevent further damage reducing the application of fossil fuel as a source of the motor is crucial. Hence, utilizing an electric motor could be the solution to reduce the application of motors based on fossil fuel. Among the number of electric motors, permanent magnet synchronous motor (PSMS) is becoming more popular due to their efficiency. However, the challenge here is how to design the controller of PSMS, especially the speed controller. Hence, this paper proposed a design of a speed controller of PSMS using a PI controller. The hybrid differential evolution algorithm-particle swarm optimization (DEA-PSO) is used to optimize the PI controller for better performance. From the simulation result, it is found that the proposed method can enhance the performance of PSMS.**

***Keywords*—Hybrid DEA-PSO, Load torque, PI controller, PSMS, Speed response, Transportation services.**

## I. Introduction

The exploitation of fossil fuel engines for motoring the world causes oil depletion globally. This condition has a significant impact on the security and sustainability of energy all over the world. Another major issue of using fossil fuels for motoring the transportation and industrial sector is air pollution which can lead to global warming and climate change. To reduce air pollution and prevent global warming, utilizing electric motors in the transportation and industrial sector is crucial. Among numerous types of electric motors, permanent magnet synchronous motors (PSMS) are becoming popular in the industrial sector due to size, weighting ratio, and high torque. PSMS has advantages in terms of efficiency due to zero rotor losses, the no-load current is lower than the nominal speed, and the performance of the decoupling control is much less sensitive to the motor parameter [1, 2].

One of the most important parts of operating PSMS is the controller. One of the most common control methods in industrial applications, especially in the drive system, is PI controller. The PI controller as PSMS drive system controller has been made in a practical scenario, despite finding the best parameter for PI controller needs considerable effort. Even PI controller parameters that have been well set by the operator potentially perform poorly due to the complexity of designing and finding the parameter itself. Hence, it is necessary to use appropriate design and optimization methods, such as the metaheuristic algorithm approach to design and find the best PI controller parameter.

The application of metaheuristic algorithms in engineering problems has been studied deeply over the past few decades. It is well known that the metaheuristic algorithm has shown good performance in finding the best value for the complex problem. Numerous metaheuristic algorithms are applied to optimization problems, such as genetic algorithm artificial bee colony, particle swarm optimization, artificial immune system, ant colony optimization, differential evolution algorithm, bat algorithm, flower pollination algorithm, and firefly algorithm [3-12]. The application of a differential evolution algorithm for designing a power system stabilizer is reported in [3]. It is found that developing a power system stabilizer (PSS) using differential evolution algorithm can make the PSS robust againt different operating conditions. The research effort in [4] applied an artificial immune system clonal selection algorithm to find the optimal linear quadratic regulator matrix—application of firefly algorithm for dynamic stability enhancement of power system as reported in [5]. The application of the differential evolution algorithm for finding the best battery energy storage in the system controller is reported in [6]. The research effort in [7] shows that ant colony optimization can also find the best value of a redox flow batteries controller. The optimization research for battery energy storage for microgrids in [8] also shows that particle swarm optimization gives optimal solutions for sizing the battery energy storage size. The application of an artificial bee colony for sizing and placing the distribution

***Corresponding Author:***
Muhammad Aldo Setiawan
Faculty of Advanced Technology and Multidiscipline
Universitas Airlangga,
Campus C UNAIR Gedung Kuliah Bersama, Mulyorejo, Surabaya, Indonesia
m.aldo.setiawan@ftmm.unair.ac.id

generator in the distribution system is reported in [9]. The bat algorithm is also showing promising results for tuning the parameter of PID-PSS, as investigated in [10]. The flower pollination algorithm is showing promising results for optimizing over the current relay, as reported in [11]. The research effort in [12], shows that the genetic algorithm is providing optimal results for sizing the distributed generation. Among them, particle swarm optimization (PSO) and differential evolution algorithm (DEA) are becoming more favorable due to simple modeling, fast calculation, and higher robustness than other algorithms [13, 14]. Even though PSO and DEA have advantages, they also have a handicap in terms of convergence in local optimal too quickly in PSO and some DEA mutation problems [15, 16]. Hence, it is necessary to design a hybrid algorithm between DEA and PSO to handle the handicap of the booth.

Thus, this research novelty is designing PI controller of PSMS drive system controller using hybrid DEA-PSO to enhance the speed response of PSMS. The rest of this paper is organized as follows: Section II briefly explains about PSMS mathematical model, PI controller, and hybrid DEA-PSO. The result and analysis are described in section III. Section IV highlights the conclusions and future research directions.

## II. Fundamental Theory

### A. PSMS Mathematical Model

A permanent magnet synchronous motor (PSMS) consists of three-phase stator windings and a permanent magnet mounted on the rotor surface or embedded in the rotor (PSMS interior). PSMS is highly influenced by current-controlled pulsed width modulation (PWM). The current component of the motor is divided into two ($I_d$, $I_q$), which is the component of flux and torque in the rotor based on the d-q axis. The mathematical representation of PSMS is described in (1)-(5) [2, 17-19].

$$T_e = \frac{3}{2}\frac{P}{2}\left[\lambda_m i_q + \left(L_d - L_q\right) i_d i_q\right] \quad (1)$$

$$\frac{d(i_d)}{dt}\frac{v_d - r_s i_d + \omega_r L_q i_q}{L_d} \quad (2)$$

$$\frac{d(i_q)}{dt}\frac{v_q - r_s i_q + \omega_r (L_d i_d + \lambda_m)}{L_q} \quad (3)$$

$$\frac{d(\omega_m)}{dt}\frac{T_e - T_L - B\omega_m}{J} \quad (4)$$

$$\omega_r = \frac{P}{2}\omega_m \quad (5)$$

Several parameters corresponding to electric torque ($T_e$), load torque ($T_L$), number of the pole ($P$), and magnetic flux ($\lambda_m$) are considered. Here, $i_d$ and $i_q$ represent stator current in the d and q axis, respectively. Other parameters are inductance in d axis ($L_d$), inductance in q axis ($L_q$), stator voltage in d axis ($v_d$), stator voltage in q axis ($v_q$), the moment of inertia ($J$), and friction ($B$). In contrast, $r_s$ and $\omega_r$ are stator resistance per phase and electric rotor speed, respectively [2, 17-19].

### B. PI Controller

The workspace of the automatic controller is indicated by the area that has been set. The set point is the expected output value of the plant. The error detector adds up the setpoint value with the actual output value so that the final finding is an error or deviation value. The amplifier comprises the PI constant value, which will be used to alter the response of the plant. The actuator is an additional device to set the plant. The plant is the equipment that will be arranged by utilizing feedback passed in the previous sections. Sensors are used to convert the analog value into digital values to compare sensor output with setpoint values. This section will briefly explain the PI controller [20-22].

The application of a proportional controller changes the system response to be faster in achieving steady-state value and minimizing the error value. The proportional controller operates by multiplying the proportional gain value with an error value. The value of the proportional constants has certain limits and cannot be entered randomly. If the proportional constant is too high, the system response will not reach the steady-state condition. If the proportional constant is too low, a system response will be generated in a steady-state condition, which is different from the setpoint value. As a result, the error value will become very large. Fig. 1 illustrates the block diagram of the proportional controller [20-22].

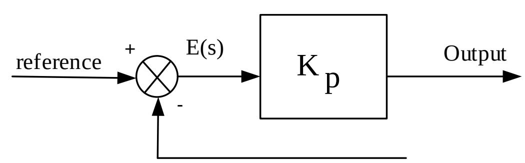


Figure 1. Block diagram of proportional controller [21, 22]

The purpose of the integral controller is to reduce errors on the system with the principle of integration. It also operates to speed up time in eliminating offsets or reaching steady-state conditions. The integral controller works by multiplying the value of gain with the integral of the error. The integral controller ensures the error value of the system is zero or very small. However, this can not happen if the system only used proportional controllers due to the different ways of operation to enhance the system response. Fig. 2 shows the block diagram of the integral controller [20-22].

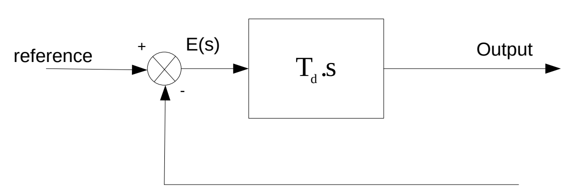


Figure 2. Block diagram of integral controller [21, 22]

Proportional plus integral plus or more frequently written as PI controller combines the three controllers (proportional, integral). This combination will remove the weaknesses of each controller. Hence, the purpose of PI controller is to speed up the system response and eliminate offsets of the system response. Fig. 3 shows the block diagram of PI controller [20-22].

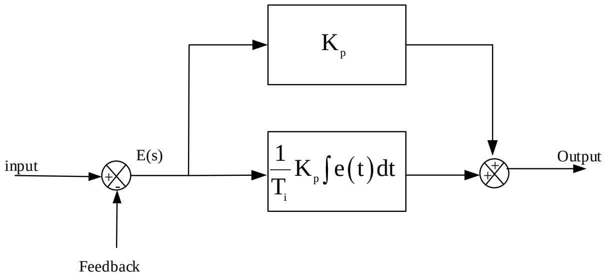


Figure 3. Block diagram of PI controller [21, 22]

## III. Method

### A. Hybrid DEA-PSO

Hybrid DEA-PSO is an optimization method consisting of a combination of two algorithms, DEA and PSO. The basic program of DEA-PSO uses an algorithm from PSO and the selection process in DEA to increase convergence speed. Technically this process can minimize the search function space. When piloted on PSO, birds or particles can be led directly into the solution space.

The initial process of the DEA-PSO algorithm begins with the initialization of the PSO parameter, which includes the number of particles, the upper search limit, the lower search limit, and several other PSO parameters. Then each particle is propagated in a randomly assigned solution space. Randomly dispersed particles begin to move their movement based on information from the particles with the best position. The fitness function of each particle is evaluated, where the best value of the movement of each particle ($P_{best}$) and the best value of the swarm ($G_{best}$) can be obtained. Given the best value of the swarm, a second iteration process will take place with an additional role of DEA. In the second and subsequent iterations, DEA first selects some of the best particles before the particles in the swarm continue the searching process of the solution.

DEA performs the process of particle selection by involving mutation, recombination, and evaluation steps. After passing through the DEA process, the particle will accumulate more or focus on the smaller search space to speed up the discovery of the best solution. Furthermore, the particles on the swarm perform the same procedure as the PSO algorithm in general. When viewed from the process, DEA-PSO does not have the possibility of a broader solution than PSO due to the narrowing of the solution search area. But with the constriction of this solution area, the best solution will be achieved more quickly [23-25]. Fig. 4 shows the flowchart of DE-PSO algorithms.

### B. Procedure for Designing the Controller

This section explained the procedure of tuning the speed controller parameter of PSMS thoroughly. The minimum error of PSMS speed time domain response is used as the objective function. The Objective function can be described using (6).

$$E = \sum \int_0^{t1} t|\Delta\omega(t,X)|dt \quad (6)$$

In (6), $\Delta\omega(t,X)$ is PSMS speed response. $X$ consists of PI controller parameters, while $t1$ is the time frame of the simulation. The objective function is used to minimize the value of $E$ subject to the minimum and maximum value of an individual parameter of the PI controller.

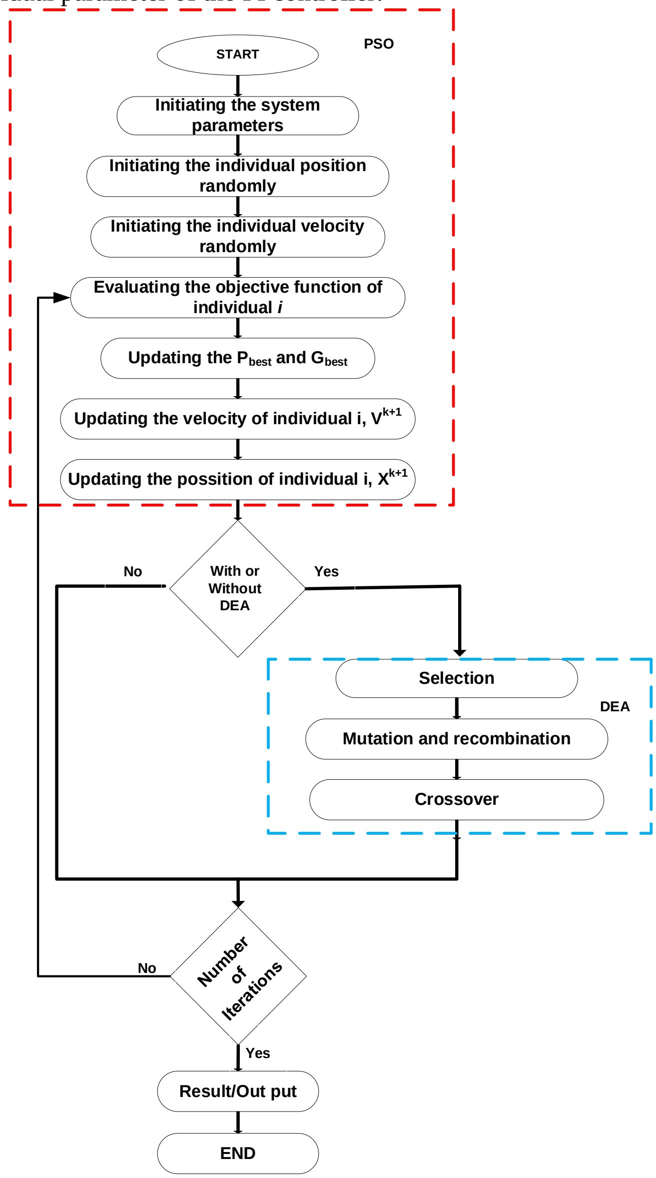


Figure 4. DE-PSO Flowchart

Furthermore, the number of iterations and the number of particles are 50. The procedure of designing a PI controller using hybrid DE-PSO can be described as the following steps:

Step 1: Linearize the system around the chosen operating point.
Step 2: Add the PI controller to PSMS speed controller
Step 3: The hybrid DE-PSO starts to simulate in this step (the step of hybrid DE-PSO can be seen in Fig. 4).
Step 4: Print the results (DIPSS parameter).

Fig. 5 shows the block diagram of the optimization scheme, while Fig 6 illustrates convergence curves of the fitness function during an iteration of hybrid DEA-PSO. It is shown that after 50 iterations, the hybrid DEA-PSO found its convergence value. The optimum PID parameter values obtained through the iteration are shown in Table 1.

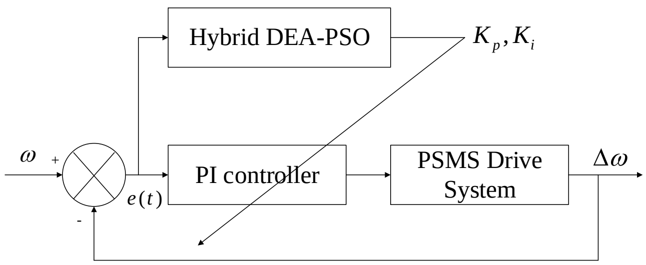


Figure 5. Block diagram of the optimization method

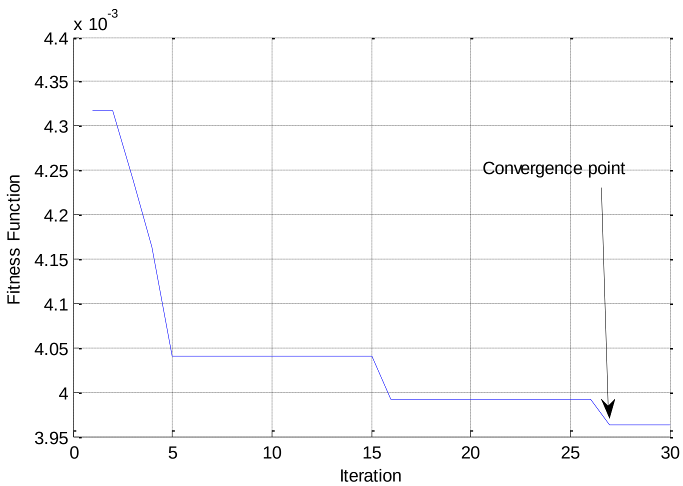


Figure 6. Convergence graph of hybrid DEA-PSO

Table 1. Optimum parameters values obtained using hybrid DEA-PSO

| Variable | Value |
|---|---|
| Kp | 1.35 |
| Ki | 48 |

## IV. Results and Discussion

In this section, the result and analysis of the proposed method are presented. There were two cases study; the first one analyzed the speed of PSMS due to speed reference variation. The second one analyzed the impact of load torque variation on PSMS speed response. The PI controller was used as the PMSM speed controller. The hybrid DEA-PSO was used to optimize the parameter of PI controller, which is the gain constant (*Kp*) and integral constant (*Ki*). The case studies were carried on in MATLAB/SIMULINK environment.

### A. Speed Reference Variation

In this section, speed variation was considered to analyze the effectiveness of the proposed method. The first-speed reference was 1250 rpm, and the second-speed reference was 1650 rpm. Fig. 7 shows the PSMS speed response die to speed reference variation. It was monitored that system without a controller has a lower overshoot and faster settling time than the system with PI controller. However, the final value of the system without a controller is not the same and is less than the speed reference (1250 and 1650). The value obtained was unacceptable for designing the motor drive system. After PI controller was installed in the system, the final value of the PSMS speed response was the same as the speed reference. However, the overshoot and the settling time were still higher. Hence designing PI controller based on hybrid DEA-PSO was crucial. From the Fig. 7, it was monitored that the proposed method (PI controller tune by hybrid DEA-PSO) shows the best response indicated by small overshoot, fastest settling time, and precise final value. Tables 2 and 3 illustrate the overshoot and settling time of the PSMS speed response.

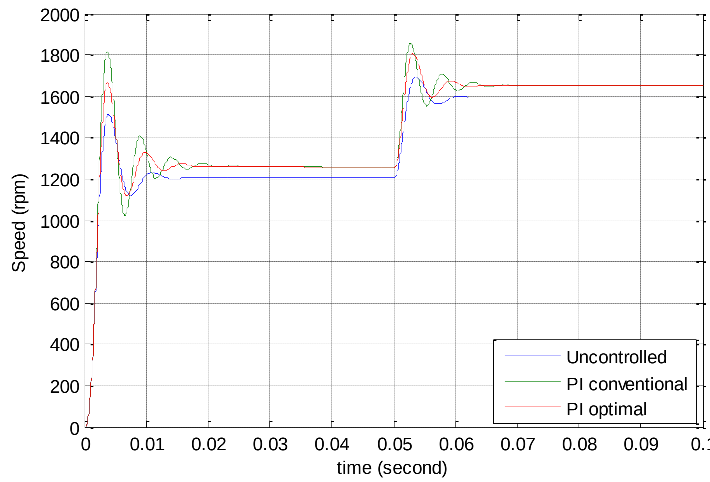


Figure 7. PSMS speed response

Table 2. Overshoot and settling time of PSMS speed response 1250 rpm

| Variable | Uncontrolled | PI controller | PID DEA-PSO |
|---|---|---|---|
| Overshoot (rpm) | 306 | 557 | 409 |
| Settling time (sec) | 0.03027 | 0.04164 | 0.02061 |
| Final value (rpm) | 1206 | 1250 | 1250 |

Table 3. Overshoot and settling time of PSMS speed response 1650 rpm

| Variable | Uncontrolled | PI controller | PID DEA-PSO |
|---|---|---|---|
| Overshoot (rpm) | 104 | 205 | 155 |
| Settling time (sec) | 0.0202 | 0.0299 | 0.017 |
| Final value (rpm) | 1591 | 1650 | 1650 |

### B. Torque Variation

For the second case study, the load torque was considered to investigate the impact of load torque fluctuation on PSMS speed response and analyze the proposed method's effectiveness. The load torque was 1.2 N/m. Fig. 8 depicts the PSMS speed response due to load torque variation. It was noticeable that the overshoot of all of the cases increased due to external load torque. It was monitored that the best response was the system with the proposed method (PI controller based on hybrid DEA-PSO) indicated by small overshoot, fastest settling time, and precise final value. Table 4 shows the overshoot and settling time of the PSMS speed response.

Table 4. Overshoot and settling time of PSMS speed response with external load torque

| Variable | Uncontrolled | PI controller | PID DEA-PSO |
|---|---|---|---|
| Overshoot (rpm) | 361 | 746 | 505 |
| Settling time (sec) | 0.02 | 0.042 | 0.02 |
| Final value (rpm) | 1571 | 1650 | 1650 |

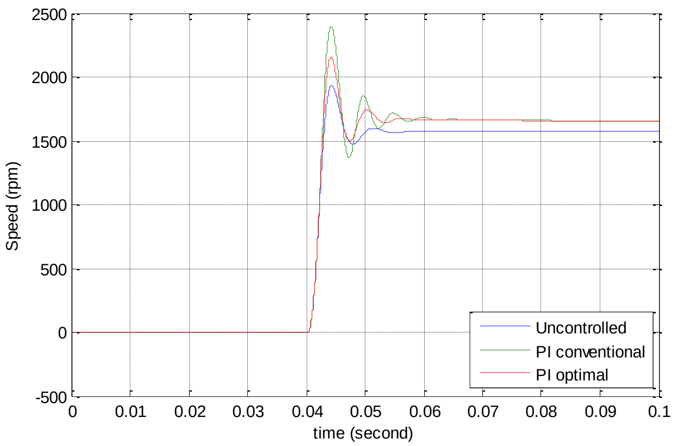


Figure 8. PSMS speed response due to external load torque

## V. Conclusion

This paper proposed the optimal speed control design on a permanent magnet synchronous motor (PSMS) using hybrid differential evolution and particle swarm optimization (DEA-PSO). From the case studies,

- It is monitored that PI controller has played an important role in terms of bringing the PSMS speed to the reference speed.
- It is also found that the PSMS cannot reach the speed reference without PI controller.
- It is noticeable that the proposed method has given the best performance, indicated by a slight overshoot and the fastest settling time.

Further research is required to utilize another algorithm to design and tune the PI controller of the PSMS drive system. Moreover, designing the controller using another method, such as fuzzy logic control, artificial neural network, and model predictive control, can be considered.

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**Muhammad Aldo Setiawan, S,Si., M.Sc(Eng)**, Born in Depok, Indonesia at 14th of July 1992. After graduating from the Robotics & Mechatronics master's degree program at the University of Leeds, He continues his career as a lecturer in Robotics and AI undergraduate program at Airlangga University, Indonesia.

He continues with his research in motor control which started from the previous research on developing a DC Motor characteristics Identification system that focuses on knowing all the parameters needed for controlling the DC motor. His research interest currently focuses on aerial robots, mobile robots, and robotics locomotion.

**Herlambang Setiadi** is lecturer at Faculty of Advanced Technology and Multidiscipline Universitas Airlangga. He received a bachelor degree from Institut Teknologi Sepuluh Nopember (Surabaya, Indonesoa) majors in Power system Engineering in 2014. Then, master degree from Liverpool John Moores University (Liverpool, United Kingdom), majors in Electrical Power and Control Engineering in 2015. Furthermore, he received a Doctoral degree from The University of Queensland. His research interests power system dynamic and control, renewable energy integration and metaheuristic algorithm. He can be contacted at email: h.setiadi@ftmm.unair.ac.id.

**Rodik Wahyu Indrawan** is lecturer at Faculty of Advanced Technology and Multidiscipline Universitas Airlangga..His research interest is robotic, mechatronic and control system.

**Rizki Putra Prastio** is lecturer at Faculty of Advanced Technology and Multidiscipline Universitas Airlangga..His research interest is biomedical imaging, machine learning, image processing, signal processing and computer vision.