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A PARTICLE SWARM OPTIMIZATION APPROACH FOR FINDING OPTIMAL CONTROLLER PARAMETERS OF PLUG-IN HYBRID ELECTRIC VEHICLE IN AN ISOLATED SMALL POWER SYSTEM

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Abstract. *Integration of wind and solar energy sources into a small power system may make a frequency deviation problem because of irregular power generation from such energy sources. To alleviate the frequency deviation, a plug-in hybrid electric vehicle (PHEV) can be applied. However, improper PHEV charging power control may not be able to compensate the real power unbalance in the small power system and may result in the frequency control effect deterioration. This paper concentrates on an application of a particle swarm optimization (PSO) for finding the optimal PHEV controller parameters considering proper PHEV charging power control by minimizing an integral absolute error (IAE) value of the real power unbalance deviation and minimizing an IAE value of the frequency deviation for frequency control in an isolated small power system. The PHEV controller structure is a proportional-integral (PI). Simulation studies show the effectiveness and superiority of the proposed PI controllers of PHEV.*

Keywords: Particle swarm optimization, Frequency control, Isolated small power system, Plug-in hybrid electric vehicle

1. **Introduction.** In rural areas, wind and solar energy sources called as renewable energy sources have been widely installed with isolated small power systems owing to clean energy and low price [1]. However, fluctuating power generation from renewable energy sources may lead to a severe problem of the frequency deviation in the isolated small power system [2,3].

In order to damp the frequency deviation, plug-in hybrid electric vehicles (PHEVs), which have been vastly utilized in transportation due providing fuel cost reduction, can be applied as controllable loads for compensating the real power unbalance in the isolated small power system [4,5]. However, inappropriate control of the PHEV charging power may not be able to compensate the real power unbalance in the isolated small power system and also may cause the deterioration of frequency control effect [6].

In [7], the proportional-integral (PI) controllers of PHEV are able to damp pleasingly the frequency deviation in the isolated small power system. However, there is still another requirement to minimize the frequency deviation. In order to minimize the frequency deviation in the power system, many optimization methods, such as simulated annealing (SA), genetic algorithm (GA), and particle swarm optimization (PSO), have been employed to search the optimal controller parameters [8-10]. Generally, the GA method is faster than the SA technique because the GA has parallel search methods, which emulate natural genetic operations [11]. However, the GA has a degraded performance if the function to be optimized is epistatic where the parameters to be optimized are greatly correlated [12]. The GA algorithm still has the demerit of the premature convergence.

The PSO is a heuristic search method first introduced by Kennedy and Eberhart in 1995 [13]. The PSO is a population based optimization tool for computational method that optimizes a problem by iteratively trying to improve a candidate solution [14]. The particles are evaluated using a fitness function to see how close they are to the optimal solution [15]. Moreover, the PSO can generate effectively high-quality solutions within shorter computation time and also has more stable convergence characteristics than other stochastic techniques [16]. In addition, [17] has successfully shown a PSO method for an optimum design of PI controller for damping the frequency deviation in a hybrid renewable energy system. The PSO can be well used. Accordingly, the PSO approach is applied to finding the optimal controller parameters in this paper.

This paper focuses on an application of a PSO for searching the optimal PHEV controller parameters considering the appropriate PHEV charging power control by minimizing an IAE value of the real power unbalance deviation and minimizing an IAE value of the frequency deviation for controlling the frequency in an isolated small power system. Simulation results demonstrate that the proposed PI controllers of PHEV can capably compensate the real power unbalance in the isolated small power system and also can damp greatly the frequency deviation in comparison with the conventional PI controllers of PHEV in [7].

This paper is organized as follows. First, the system is described in Section 2. Next, Section 3 shows methodology. Subsequently, Section 4 shows experiments and results. Finally, conclusion is given in Section 5.

2. The System.

2.1. The isolated small power system.

Figure 1(a) shows an isolated small power system with a wind farm [7]. In Figure 1(a), it consists of a 20 MW diesel generator, a 6 MW wind farm, a 17 MW load, and a 5 MW PHEV. Figure 1(b) shows the linearized model of the studied isolated small power system.

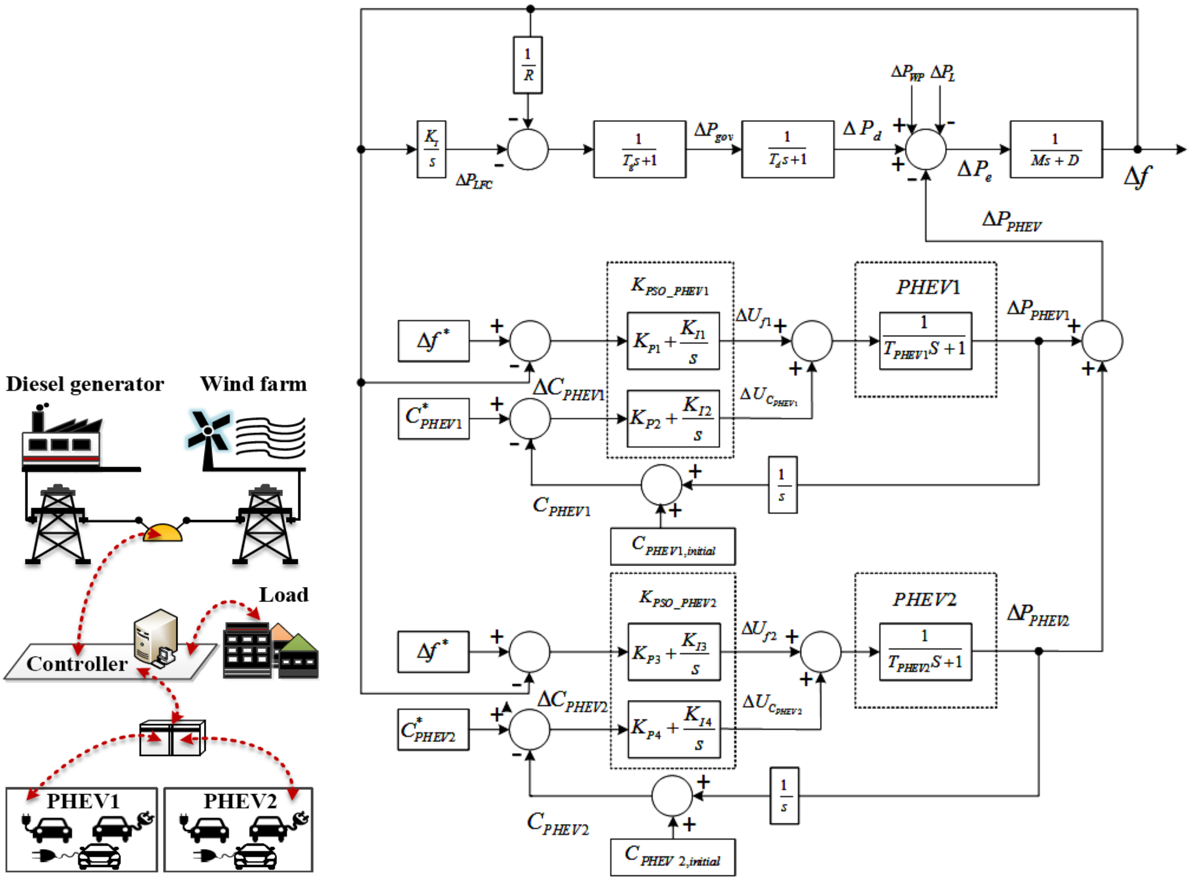
2.2. The linearized system parameters.

In Figure 1(b), the proposed PI controllers of PHEV are (1) and (2) as follows:

$$K_{PSO\_PHEV1}(s) = K_{P1} + \frac{K_{I1}}{s},\ K_{P2} + \frac{K_{I2}}{s} \tag{1}$$

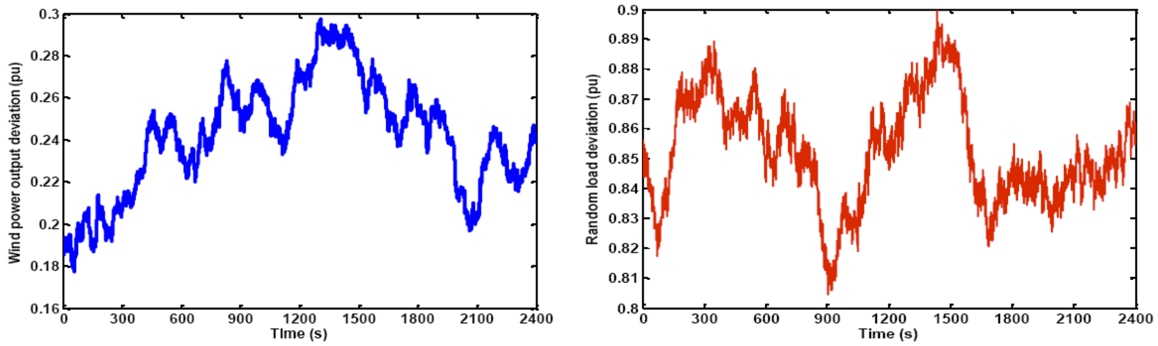
$$K_{PSO\_PHEV2}(s) = K_{P3} + \frac{K_{I3}}{s},\ K_{P4} + \frac{K_{I4}}{s} \tag{2}$$

where K_{PSO_PHEV1} and K_{PSO_PHEV2} are the proposed PI controllers of PHEV1 and PHEV2. The K_{P1} and K_{I1} are the PI controller parameters of the frequency deviation of PHEV1. The K_{P2} and K_{I2} are the PI controller parameters of the charging rate deviation of PHEV1. The K_{P3} and K_{I3} are the PI controller parameters of the frequency deviation of PHEV2. The K_{P4} and K_{I4} are the PI controller parameters of the charging rate deviation of PHEV2. The T_g and T_d are the time constants of governor and diesel generator. The ΔP_e is the real power unbalance deviation. The Δf is the frequency deviation. The ΔP_{PHEV1} and ΔP_{PHEV2} are the charging power deviations of PHEV1 and PHEV2. The



(a) (b)

FIGURE 1. An overview system: (a) the isolated small power system and (b) the linearized model of the isolated small power system



(a) (b)

FIGURE 2. Simulated graphs in 2400 seconds: (a) the wind power output deviation and (b) the random load deviation

ΔP_{PHEV} is the PHEV charging power deviation. The ΔC_{PHEV1} and ΔC_{PHEV2} are the charging rate deviations of PHEV1 and PHEV2. The details of the linearized system parameters are provided in [7].

In the simulation, the isolated small power system is operated under the wind power output deviation in Figure 2(a) and the random load deviation in Figure 2(b).

3. **Methodology.** The PSO was invented by Eberhart and Kennedy [13]. The PSO algorithm is comprised of a collection of particles that move around the search space influenced by their own best past location and the best past location of the whole swarm or a close neighbor [18]. The PSO algorithm is represented as follows.

Step 1. Initialize a population of the particles with random position ($\vec{p_i}$) and velocity ($\vec{v_i}$)

$$\vec{p_i} = \vec{p}_1, \vec{p}_2, \ldots, \vec{p_i} \tag{3}$$

$$\vec{v_i} = \vec{v}_1, \vec{v}_2, \ldots, \vec{v_i} \tag{4}$$

Step 2. Evaluate the fitness function of each particle

$$f(\vec{p_i}) = f(\vec{p}_1), f(\vec{p}_2), \ldots, f(\vec{p_i}) \tag{5}$$

Step 3. Update individual best position of the particle (*pbest*)

$$pbest = f(\vec{p_i}) \tag{6}$$

Step 4. Update the global best fitness (*gbest*)

$$gbest = \min f(\vec{p_i}) \tag{7}$$

Step 5. Modify the particle velocity based on the *pbest* and *gbest*

$$v_{i+1} = w \cdot v_i + c_1 \cdot rand_1 \cdot (pbest - x_i) + c_2 \cdot rand_2 \cdot (gbest - x_i) \tag{8}$$

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} iter \tag{9}$$

where c_1 and c_2 are the acceleration constants of the cognitive component and the social component. The $rand_1$ and $rand_2$ are the random numbers of range $(0, 1)$. The w is the inertia weight factor. The $w_{\min}$ and $w_{\max}$ are the minimum and maximum inertia weight factors. The $iter$ and $iter_{\max}$ are the iteration count and maximum iteration.

Step 6. Update the particle position

$$\vec{p_i}(t) = \vec{p_i}(t-1) + \vec{v_i}(t) \tag{10}$$

Step 7. Go to Step 2 or stop the process, when the maximum number of iterations is arrived.

4. **Experiments and Results.** The proposed PI controllers of PHEV used in the simulation study are called as "PSO-PHEV". The PSO-PHEV can be obtained by minimizing an IAE value of the real power unbalance deviation and minimizing an IAE value of the frequency deviation under the wind power output deviation and the random load deviation in Figure 2 as the following equation.

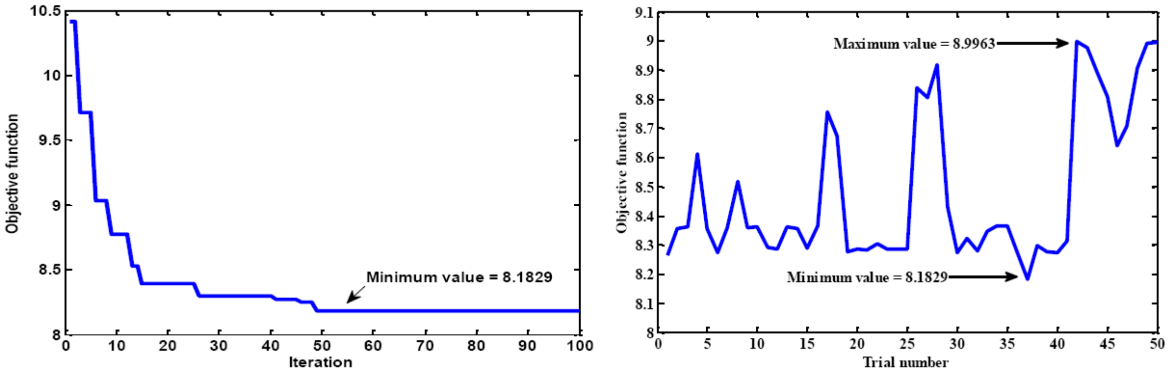
$$Minimize \quad \int_0^\infty |\Delta P_e(t)| dt + \int_0^\infty |\Delta f(t)| dt \tag{11}$$

In the optimization process, the PSO parameters are set as $K_{P1-4} \in [0.0001\ 5.0000]$, $K_{I1-4} \in [0.0001\ 5.0000]$, PSO sizes = 50, maximum iterations = 100, $c_1 = 2$, $c_2 = 2$, $w_{\min} = 0.4$ and $w_{\max} = 0.9$. The PI controller parameters of PHEV are optimized automatically by PSO. The convergence curve of the objective function is demonstrated in Figure 3(a). Note that we performed 50 trials for finding the optimal PI controller parameters of PHEV in order to obtain the minimum objective function value as shown in Figure 3(b).

As seen in Figure 3(b), the minimum objective function value is 8.1829 at 37 trial numbers. As a result, the proposed PI controllers of PHEV (PSO-PHEV) are

$$K_{PSO\_PHEV1}(s) = 1.0027 + \frac{0.0062}{s}, 2.9879 + \frac{1.9067}{s} \tag{12}$$

$$K_{PSO\_PHEV2}(s) = 0.0229 + \frac{0.0142}{s}, 2.8298 + \frac{1.1256}{s} \tag{13}$$



(a) (b)

Figure 3. Results of the convergence curve and 50 trials: (a) typical objective function versus iteration and (b) the statistical values of the objective function

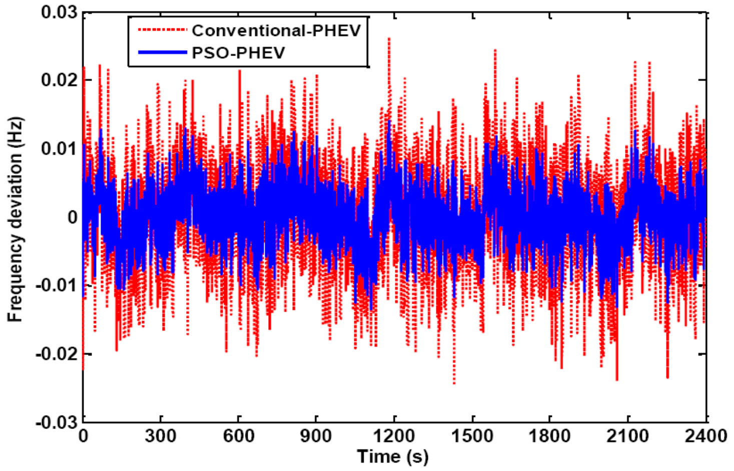


Figure 4. Frequency deviation

In the simulation study, the proposed PSO-PHEV is compared with the conventional PI controllers of PHEV called as "Conventional-PHEV" in [7].

Figure 4 shows the frequency deviation in the isolated small power system. The red graph dotted line is the Conventional-PHEV. The blue graph is the PSO-PHEV. The proposed PSO-PHEV can suppress greatly the frequency deviation when compared with the Conventional-PHEV. Here, the IAE value of frequency deviation in the case of the Conventional-PHEV is 12.2220. Also, the IAE value of frequency deviation in the case of the PSO-PHEV is 6.4868. The IAE value of frequency deviation of the proposed PSO-PHEV is much lower than the IAE value of frequency deviation of the Conventional-PHEV. This illustrates that the PSO is able to effectively find the minimum IAE value of frequency deviation.

5. **Conclusions.** Finding the optimal PI controller parameters of PHEV considering the proper PHEV charging power control by PSO for controlling the frequency in the isolated small power system has been presented. It has been represented that the proposed PSO-PHEV can efficiently compensate the real power unbalance in the isolated small power system and also can capably damp the frequency deviation in comparison with the conventional PI controllers of PHEV. In the next work, we will develop the PI controller design procedure of PHEV by considering the charging rate deviation control of PHEV in order to achieve the desired charging rate level of PHEV.

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