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Basic Particle Swarm Optimizer and its Application in Power Electronics

Katsuma Ono†, Eiji Miyagawa† and Toshimichi Saito†

†EEE Dept., Hosei University, 3-7-2, Kajino-cho, Koganei-shi, Tokyo, Japan.
Email: { katsuma AT nonlinear.k., tsaito AT, age AT nonlinear.k. } hosei.ac.jp

Abstract—This paper studies an application of the particle swarm optimizer (PSO) to design of switching rule in DC/AC inverter. In the method particles correspond to switching angles of the inverter. The algorithm evolves to minimize a fitness corresponding to the total harmonic distortion of the inverters. The algorithm efficiency is considered through basic numerical simulation comparing with traditional methods.

1. Introduction

Particle swarm optimizer (PSO) is a population-based search algorithm inspired by dynamics of biotic communities such as birds within a flock and has been applied to a variety of optimization problems [1]-[3]. In the algorithm, particles are flown through the problem space and try to find optimum solution by communication with information of other particles. In order to improve the performance of search, a number of variants have been studied [4]-[7]. The PSO have several potential applications in practical problems: image classification, determination of RNA secondary structure, , mobiles sensor networks, digital filter design, blind source separation and so on [8]-[14].

This paper studies an application of the PSO to design DC/AC inverters. The inverters are very important circuits in power electronics and have been applied to ac machine drivers, uninterrupible power supply systems and so on. In order to realize efficient operation, design of switching rules is a key and a variety of design procedures are published [15] - [19].

However, the optimal design of the switching rules has not been established and is still in study objects. In our method particles correspond to switching angles of the inverter. The algorithm evolves to minimize a fitness corresponding the total harmonic distortion of the inverter output. The algorithm efficiency is considered through basic numerical simulation comparing with traditional methods.

2. Basic PSO

Let us begin with overview of the basic PSO algorithm. In the algorithm, particles correspond to objective variables and move through the problem hyperspace. The position of the i-th particle is denoted by a vector x_i. And its movement depends on the i-th particle velocity v_i. Each particle in the swarm moves to better position on the basis of the neighborhood position. The i-th particle is used to update P_{besti} particle is used to update P_{best} that is the personal best in the optimization process. The optimum value at each time is given by G_{best} that is the best of P_{besti} for all the particles.

Fig. 1 illustrates evolution of particles in an elemental problem to minimize the function $E(x, y) = x^2 + y^2$. The basic algorithm is summarized as the following:

Step1 Initialization

Let τ denote discrete time, N denote the number of particles and i denote particle index. Let $\tau = 0$. The number of particles N is initialized. The positions $\boldsymbol{x}_i(\tau)$, $i = 1, \cdots, N$, are located randomly in the x-y space. The personal best $\boldsymbol{P}_{besti}$ and the global best $\boldsymbol{G}_{best}$ are initialized.

Step 2 Let $E(x, y)$ denote the objective fitness function. The value of E is calculated for each particle.

Step 3 $\boldsymbol{P}_{besti}$ and $\boldsymbol{G}_{best}$ are updated on following:

If $\boldsymbol{P}_{besti} > E$ then $\boldsymbol{P}_{besti} = E$
If $\boldsymbol{G}_{best} > \boldsymbol{P}_{besti}$ then $\boldsymbol{G}_{best} = \boldsymbol{P}_{besti}$

Step 4 The velocity of each particle is defined by the following equation.

$$\boldsymbol{v}_i(\tau) = \boldsymbol{v}_i(\tau-1)+c_1 r_1(\boldsymbol{P}_{besti}-\boldsymbol{x}_i(\tau))+c_2 r_2(\boldsymbol{G}_{best}-\boldsymbol{x}_i(\tau)) \quad (1)$$

where c_1 and c_2 are positive coefficients and r_1 and r_2 are random numbers. Typically, the r_1 and r_2 given from uniform distribution in some range.

Step 5 Using the computed velocity, each particle position is updated by

$$\boldsymbol{x}_i(\tau) = \boldsymbol{x}_i(\tau - 1) + \boldsymbol{v}_i(\tau) \quad (2)$$

Let $\tau = \tau + 1$. Go to Step2, and repeat until $\tau = \tau_{max}$.
In Fig. 1, we can confirm that the particles movres to the origin that gives the optimal values of the fitness.

3. Basic DC/AC inverters

Here we overview operation of basic single phase inverters. Fig. 2 shows the single phase inverter that converts the DC input to AC-like output and applies it to the load. In DC/AC inverter, the traditional modulated method is Pluse Width Modulation(PWM) and Sin-Triangle Method (ST

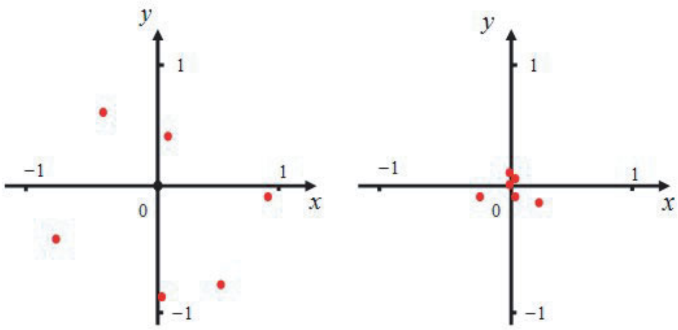

Figure 1: Movements of basic PSO

Method) is known as a typical of generating pluse in PWM. The principle of ST Method is shown in Fig. 3. The modulation wave $R(t)$ intersects with the triangle carrier wave $F(t)$. This switching rule is defined by

if $R(t) > F(t)$ and $R(t) > 0$ then
$\{S1, S4\}$ ON, $\{S2, S3\}$ OFF
if $R(t) < F(t)$ and $R(t) < 0$ then
$\{S1, S4\}$ ON, $\{S2, S3\}$ OFF

By these switching rules, the output of a single-phase DC/AC inverter is given as shown in Fig. 3.

In order to evaluate effects of the switching rule, we define the Total Harmonic distortion (THD). First, we assume that the output is odd-symmetric function with period T. Let k denote the number of switchings for quarter-cycle $0 \leq t < T/4$ and $\alpha \equiv \alpha_1, \cdots, \alpha_k$ denote the switching angles per the quarter-cycle. The output voltage can be expressed using Fourier series as

$$e = \sum_{n}^{\infty} B_n \sin(n\omega t) \qquad (3)$$

where $\omega = 2\pi/T$. The value of B_n is computed as

$$B_n = \frac{4E}{\pi}[\cos(n\omega t)]_{\alpha_1,\cdots,\alpha_k}^{\alpha_2,\cdots,\pi/2} \qquad (4)$$

B_1 is the fundamental component, and the others $(B_2, B_3, \cdots)$ are harmonic components. The THD is defines by

$$G(\alpha) = 1 - \frac{|B_1|^2}{\sum |B_n|^2} \qquad (5)$$

As G approaches 1, the output approaches pure sinusoidal waveform and we use the THD as the fitness function in PSO algorithm.

4. Algorithm

Here we propose an application of the basic PSO for finding the (semi-)optimal switching rules in the inverters. In the algorithm. the i-th particle position corresponds

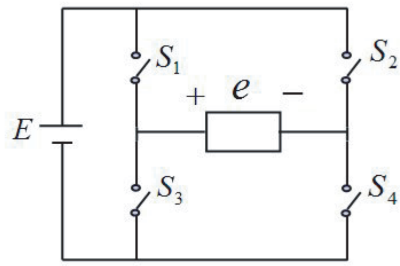

Figure 2: the circuit of a single-phase DC/AC inverter

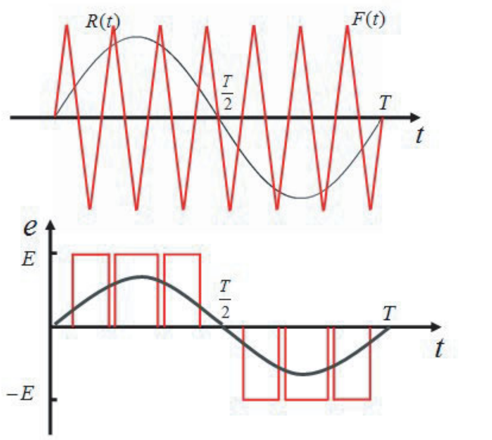

Figure 3: ST Method and the output of a single-phase DC/AC inverter

to a vector of the switching angles per the quarter-cycle: $x_i = (\alpha_1, \cdots, \alpha_k)$. The PSO evolves to minimize the THD $G(x_i)$ that is the fitness function.

Step 1 Initialization

Let $\tau = 0$. The number of particles N and the number of switching angles M is initialized. The switching angles α_k are given randomly in a range of $\{0, \cdots, \pi/2\}$. The positions $\boldsymbol{x}_i$, $i = 1, \cdots, N$, are located in a range in R^k. The personal best $\boldsymbol{P}_{besti}$, the global best $\boldsymbol{G}_{best}$ are initialized.

Step 2 Computation of objective function value.

The objective function value $G(x)$ of each particle position is computed by Equation (5).

Step 3 $\boldsymbol{P}_{besti}$ and $\boldsymbol{G}_{best}$ are updated as the following:

If $\boldsymbol{P}_{besti} > E(x_i)$ then $\boldsymbol{P}_{besti} = \boldsymbol{x}_i$
If $\boldsymbol{G}_{best} > \boldsymbol{P}_{besti}$ then $\boldsymbol{G}_{best} = \boldsymbol{P}_{besti}$

Step 4 Computation of velocity

The velocity of each particle is defined by the following equation.

$$\boldsymbol{v}_i(\tau) = \omega \boldsymbol{v}_i(\tau - 1) + c_1 r_1 (\boldsymbol{P}_{besti} - \boldsymbol{x}_i(\tau)) + c_2 r_2 (\boldsymbol{G}_{best} - \boldsymbol{x}_i(\tau)) \qquad (6)$$

where ω is the inertial term, r_1 and r_2 are random variables distributed uniformly in [0, 1]. c_1 and c_2 are positive coefficient.

The velocity v_k is limited by in [V_{max}, V_{min}] in order to avoid overflow of each particle.

if $v_k > V_{max}$ then $v_k = V_{0+}$
if $v_k < V_{min}$ then $v_k = V_{0-}$

where V_{0+} and V_{0-} are the limited velocity values.

Step 5 Update for each particle position

$$\boldsymbol{x}_i(\tau) = \boldsymbol{x}_i(\tau - 1) + \boldsymbol{v}_i(\tau) \tag{7}$$

Then each particle position α_k is limited in $[0, \pi/2]$:

if $\alpha_k > \pi/2$ then $\alpha_k = \alpha_{0+}$
if $\alpha_k < 0$ then $\alpha_k = \alpha_{0-}$

where $\alpha_{0+} = \alpha_{0+} = \alpha_{k-1} + (\alpha_{k+1} - \alpha_{k-1})/2$.
Let $\tau = \tau + 1$. Go to Step2, and repeat until $\tau = \tau_{max}$.

5. Experiments

In order to evaluate the algorithm efficiency, we have performed basic numerical experiments. The parameters are $N = 5$, $M = 11$ and $\omega = 0.8$. The inertial term $c_1 = 2$, $c_2 = 2$. Fig. 4 shows the process of THD minimizing by the proposed method. As τ increased, the value of THD is decreased by this algorithm. And Fig. 5 shows typical output voltage in the evolving process.

The output voltage wave form by ST Method is shown in Fig. 6. We confirm that the result in PSO algorithm is better than the result in ST Method.

6. Conclusions

An application of PSO to optimization of inverters' switching rule of the inverters is studied in this paper. In the algorithm, switching angles and THD correspond to particles positions and fitness function, respectively. Performing elemental numerical experiments, we have suggested that our algorithm has potential to improve the THD. Other future problems include improvement of the algorithm and comparison with other algorithms especially in viewpoints of swarm intelligence.

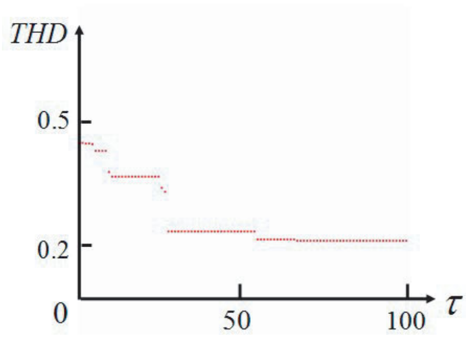

Figure 4: Processing of THD minimizing by the proposed method($N = 5$, $M = 11$)

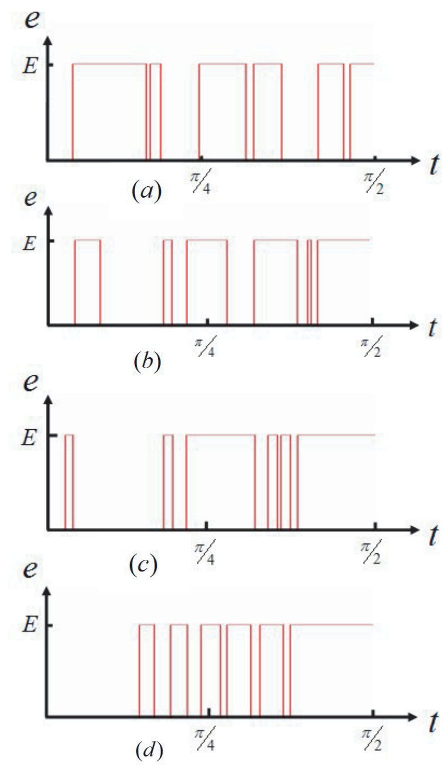

Figure 5: The output voltage of a single-phase DC/AC inverter($M = 11$, $N = 5$), (a): $t = 0$, THD = 0.465, (b): $t = 20$, THD = 0.383, (c): $t = 50$, THD = 0.251, (d): $t = 60$, THD = 0.228

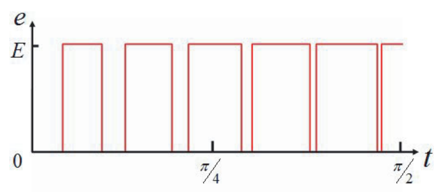

Figure 6: The output voltage of ST Method ($M = 11$, THD = 0.240)

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