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Inverter Harmonic Elimination through Flower Pollination Enhanced Genetic Algorithm

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Abstract: This paper suggests an alternative method for selective harmonic elimination in a PWM inverter. Selective harmonic elimination together with output voltage control is perceived as an optimization task and solution is achieved using a modified Genetic Algorithm (GA). In the proposed modification, steps of traditional GA are tailored suitably by closely imitating flower pollination and subsequent seed production in plants. The concept is well documented and verified with computed and measured results.

Keywords: Harmonic elimination, inverter, Genetic Algorithm, Flower pollination

I. Introduction

The objective of dc/ac inverter is to produce a sinusoidal ac voltage with adjustable amplitude and frequency. Pulse Width Modulation (PWM) [1] technique presents the advantages of its extreme simplicity and its easy and direct hardware implementation. Selective harmonic elimination in PWM scheme comprises of positioning a finite number of voltage pulses at desired instances. Computation of optimal switching angles for a given demand voltage in the past comprised of off-line computation of switching instances either using numerical methods [2,3] or employing Walsh function approach [4].The calculation of these optimal switching angles is a complex and time-consuming operation requiring the solution of a set of nonlinear, transcendental, simultaneous equations. Genetic algorithms are also recently employed [5] for converter harmonic elimination, which is shown to be superior to the calculus based approach. Inverter harmonic elimination based on a colony of foraging ants is seen in [6]. The works in [7-8] indicate that inverter harmonic elimination problem possesses multiple sets of solutions.
While the problem of inverter harmonic elimination has been discussed elaborately in the past few decades, the recent publications [8-11] indicate that consistent efforts are being made for improved techniques towards harmonic elimination in PWM inverters. The contribution of this paper lies in the enhancement of standard Genetic Algorithm (GA) [12-14] through the biology of pollination in seed plants [15] and its application to selective harmonic elimination in PWM inverters. The enhanced GA is termed as Pollination enhanced Genetic Algorithm-PGA-in this work for brevity. The development of the algorithm is systematically explained and then applied to inverter harmonic elimination in a Pulse Width Modulated inverter. The computed results are very encouraging and validated through experimentation. Further, the new dispensation is compared with traditional Newton-Raphson method as well as Genetic Algorithm and the results are analyzed.

II. Problem Formulation

The output voltage of a typical symmetrically defined three-level, unipolar single-phase PWM inverter is shown in figure 1. Here, the switching angles are optimally chosen to eliminate selective harmonic components (preferably lower order ones) and to achieve desired voltage output.
For generality, the output voltage is assumed to have k pulses per half cycle, where k is an odd number such that there are 3, 5, 7, … pulses per half-cycle of output voltage waveform. The inverter connects the d.c.source voltage to the load at various switching angles, $\alpha_1, \alpha_3, \ldots\ldots\ldots\ldots\alpha_k$ and the load terminals are shorted at $\alpha_2, \alpha_4, \ldots\ldots\ldots\alpha_{k-1}$ per quarter cycle. The output voltage can be expressed using Fourier series as,

$$V_0 = a_0 + \sum_1^n A_n Cos(n\omega t) + \sum_1^n B_n \sin(n\omega t) \qquad (1)$$

where n = 1,2,3,4,5…
Referring to output voltage shown in figure 1, it is observed that even harmonics are absent due to symmetry of the wave. Further, the coefficients A_n and a_0 are zero. Thus the above equation reduces to,

$$V_0 = \sum_1^n B_n \sin(n\omega t), \qquad (2)$$

Where n=1,3,5,….
The value of B_n is computed as

$$B_n(\alpha_1, \alpha_2, \ldots\ldots\ldots\alpha_{k-1}, \alpha_k) = \frac{4V_{dc}}{n\pi}\left[\cos(n\omega t)\right]_{\alpha_1,\alpha_3,\ldots\alpha_k}^{\alpha_2,\alpha_4,\ldots\frac{\pi}{2}} \quad (3)$$

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The fundamental component is given by

$$B_1(\alpha_1,\alpha_2,\ldots\ldots\alpha_{k-1},\alpha_k)=\frac{4V_{dc}}{\pi}\left[\cos(\omega t)\right]_{\alpha_1,\alpha_3,\ldots\alpha_k}^{\alpha_2,\alpha_4,\ldots\ldots\frac{\pi}{2}} \quad (4)$$

The problem objective is to find the switching angles to make $B_1 = V_o^*$ and perform selective harmonic elimination where V_o^* is the reference output voltage. This is transformed as an optimization problem and is stated below: For k number of pulses per half cycle, let $F(\alpha)$ be the objective function; then mathematically we can write the problem as

Minimize

$$F(\alpha) = F(\alpha_1,\alpha_2,\alpha_3,\ldots.\alpha_{k-1},\alpha_k)=e_r+hc \quad (5)$$

subject to,

$$\alpha_1 \le \alpha_2 \le \alpha_3 \le \ldots\ldots\ldots\alpha_{k-1} \le \alpha_k \le \frac{\pi}{2}.$$

Where, $$e_r = \left|V_o^* - \frac{B_1}{\sqrt{2}}\right| \quad (6)$$

and

$$hc=|B_3|+|B_5|+|B_7|+------+|B_{2k-1}| \quad (7)$$

The proposed algorithm is devoted for maximization and therefore, a new function F is defined and is given below:

$$F = \frac{1}{1+F(\alpha)} \quad (8)$$

III. Inverter harmonic elimination using Flower pollination enhanced GA

A. *The biology of flower pollination* [15]

Pollination is an important step in the reproduction of seed plants. It is the process of transferring pollen grains (male gametes) to the plant carpel. The receptive part of the carpel is referred as stigma. The transferring process is performed in two ways: biotic pollination or abiotic pollination. In biotic pollination, pollinating agents are insects such as bees, beetles, flies, birds etc. The pollinating agents receive honey as a reward for pollination. Thus pollinating agents depend on the followers for honey as their food while flowers depend on pollinators for reproduction. In abiotic pollination, the pollination is performed either by air or wind. About 80% of plant pollination is biotic and only 20% is abiotic. Flowers which have evolved to attract flying insects have optimized their flowers to increase the chance of a insect visit. The insects carry pollen from flower to flower, thus pollinating the plants and assisting them to reproduce. In order to attract the flies, the flowers have attractive color, shape, size or fragrance or a combination of all these features. Also, the flowers are shaped differently from the display of leaves. Flowers have evolved bulls'-eye and nectar guide patterns in their floral configuration to attract a passing insect in to landing.

After pollination, seeds are developed. The quality of all seeds will not be alike in the sense that these seeds vary in their capacity to sprout and grow as a plant and produce flowers. A "good" seed will take root and will grow fast to produce good flowers. On the other hand, a "poor" seed even may not germinate or even if it sprouts, it will not develop as a healthy plant. The fertility of the land and climatic conditions also largely influence reproduction of plants from seeds. In other words, re-production of a seed plant can be perceived as "survival of fittest mechanism" influenced by pollination as well as climatic conditions. This helps to develop an optimization algorithm which is described in the next section.

B. *Development of Pollination Algorithm*

In this section, the essential ingredients of the proposed evolutionary algorithm which closely follows reproduction of seed plants are presented. Flowers are assumed to be the solutions and are randomly generated in the allowable search space. Each flower is represented in the binary form. Pollination is thought to be exchange of binary bits among two flowers and the resulting two binary structures are called seeds. The transformation of the seeds in to plants depends on fertility of soil where it is deposited as well as climatic conditions and hence each seed is made to associate with a probability, named as probability of fertility, and is indicated as P_f. It is assigned a suitable value between zero and one and is kept constant throughout the run of the program. The various steps of the pollination algorithm are outlined below:

Step 1: Generation of flowers

In this step, solutions in binary form are randomly generated as flowers. The number of flowers is termed as population size and is denoted as n.

Step 2: Evaluation of size of flower

Each flower is evaluated for its capacity in maximizing F given in equation (8). The size of each flower is made proportional to F value associated with it; that is, the flower which has the maximum value of F is assigned biggest size. Instead of size, it could be color or fragrance, but size of flower as indicator of attraction looks to be more lucid in schematic representation and hence such an option is adopted here.

For a population size of $n=4,$ the floral distribution is shown in figure 2(a). Here, flower f_1 is the biggest followed by f_2, f_3 and f_4.

Step 3: Pollination and seed formation

Insects such as bees are made to fly around the flower patches. It is assumed that the bee is influenced by the size of the flower and hence it lands at f_1 first and then travels in the order of flower size. This is shown in figure 2(b).

The pollinating agent causes pollination among the flowers in the following order:

f_1 and f_2, f_2 and f_3, f_3 and f_4. This is effected as exchange of binary bits and is shown in figure 2(c). It is important to mention that this process is exactly similar to "crossover" in standard GA.

The outputs of all flowers which are in binary form after pollination are stored as seeds. At the end of pollination with n number of flowers, there will be $2(n-1)$ seeds.

Step 4: Fertilization of seeds

The seeds are distributed either manually in the case of agricultural crops or with the help of wind or birds. Assuming that the seed distribution is by wind or birds, the seed may fall in a fertile soil or infertile ground. This helps to incorporate a probability term with each seed. A random number between zero and one is generated for each seed labeled as p_i and it is compared with Probability of fertility.

For $p_i \leq P_f$,

then at least one bit in the binary structure of the seed is toggled to opposite binary provided it enhances its ability in optimizing the objective function. This is exactly similar to mutation in GA.

Else seed retain its structure as such.

Step 5: Sprouting of seeds and flower formation

In this phase, out of $2(n-1)$ seeds, only best n seeds are selected and the remaining $n-2$ seeds are discarded. The selected seeds are allowed to sprout producing flowers.

Step 6: End if termination criterion is reached; else go to step 2.

IV. Results

The various steps of flower pollination algorithm developed in the last section are now employed to maximize equation (8). For completeness, standard GA and traditional Newton-Raphson methods are also used to minimize F. The convergence characteristics are plotted in figure 3. It appears that the new algorithm converges faster than the other two existing schemes and produces quality solution. To be precise, PGA takes 50 iterations to reach an objective function value of 0.04 while the convergence of GA is relatively slow since GA takes 150 iterations to reach the same objective function value. It is important to mention that PGA and GA methods are averaged for 20 trial runs while computing the convergence graph shown in figure 3. Further, for fairness of comparison, each trial is started with same population. The parameters employed in the two algorithms are shown in tables 1 and 2. The major hindrance associated with NR lies in the judicial choice of initial values; a good guess makes the algorithm to converge, while an erratic initial estimation causes divergence.

The output voltage harmonic spectra of the inverter are now computed using the switching angles obtained the algorithm and a typical case is shown in figure 4. It is evident that the algorithm successfully eliminates the desired harmonics while achieving reference output voltage. In order to validate the theoretical findings, a 100VA PWM inverter is fabricated in the laboratory and is used to power a resistive load. The measured harmonic content of the output voltage of the inverter is included in figure 4. The good correspondence between computed and measured results indicates the veracity of the findings.

V Conclusion

This paper has suggested an enhancement method for standard GA through flower pollination and reproduction mechanism in seed plants and its application to harmonic elimination in PWM inverters. The steps of the algorithm are simple, computationally inexpensive and the scheme provides confirmed convergence with random initial guess. Computed and measured results show the effectiveness of the approach.

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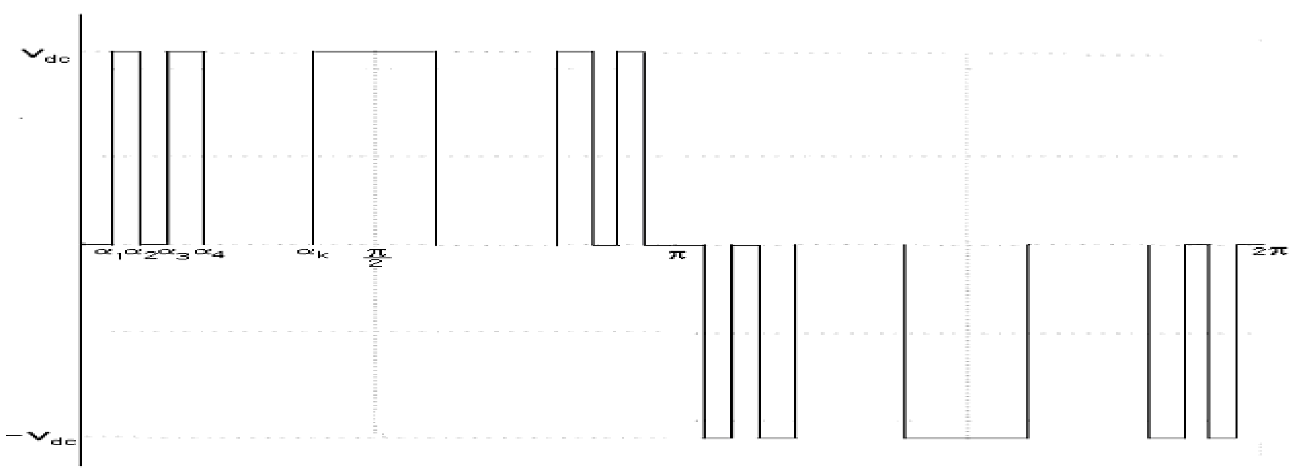


Figure 1. Output voltage of single-phase PWM inverter.

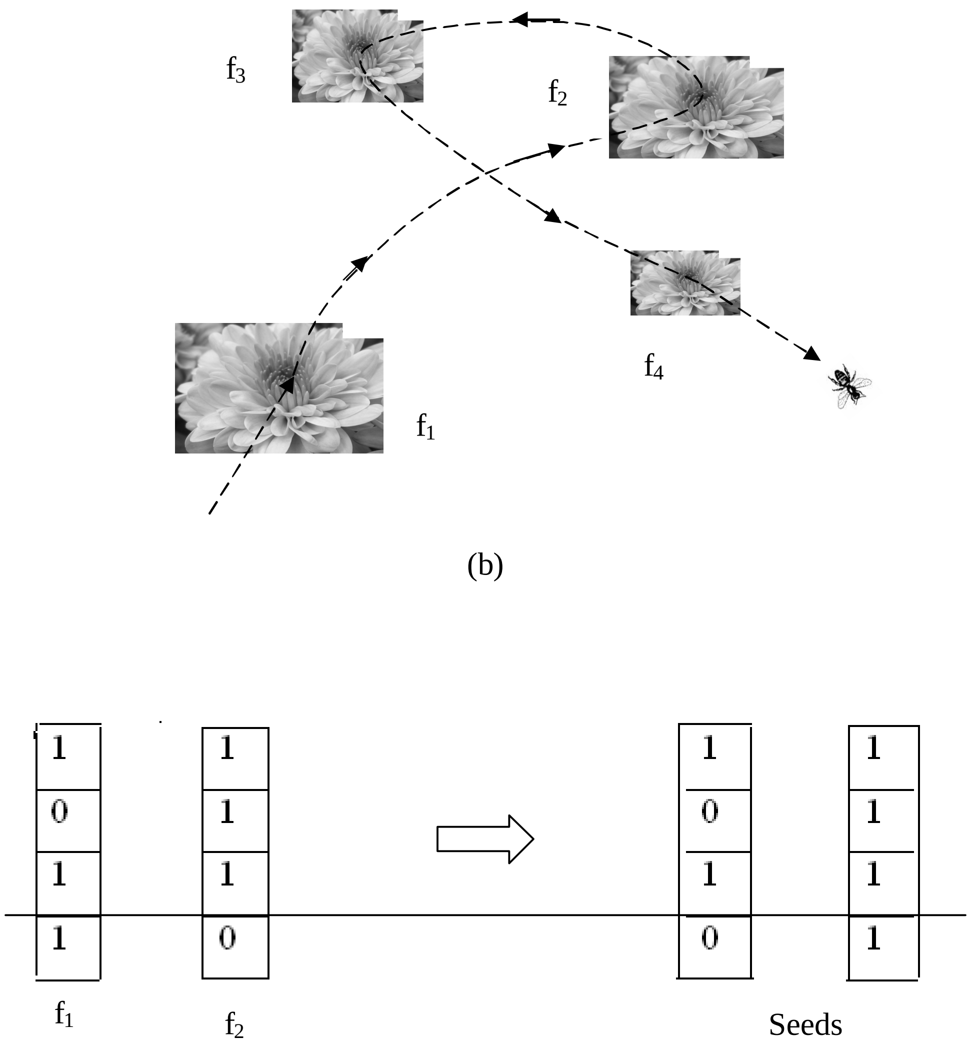
f_3

f_2

f_4

f_1

(a)



(c)

Figure 2. Operational steps of PGA. (a) Flowers as initial solutions. (b) Biotic pollination with a fly. (c) Pollination perceived as exchange of binary bits between flowers.

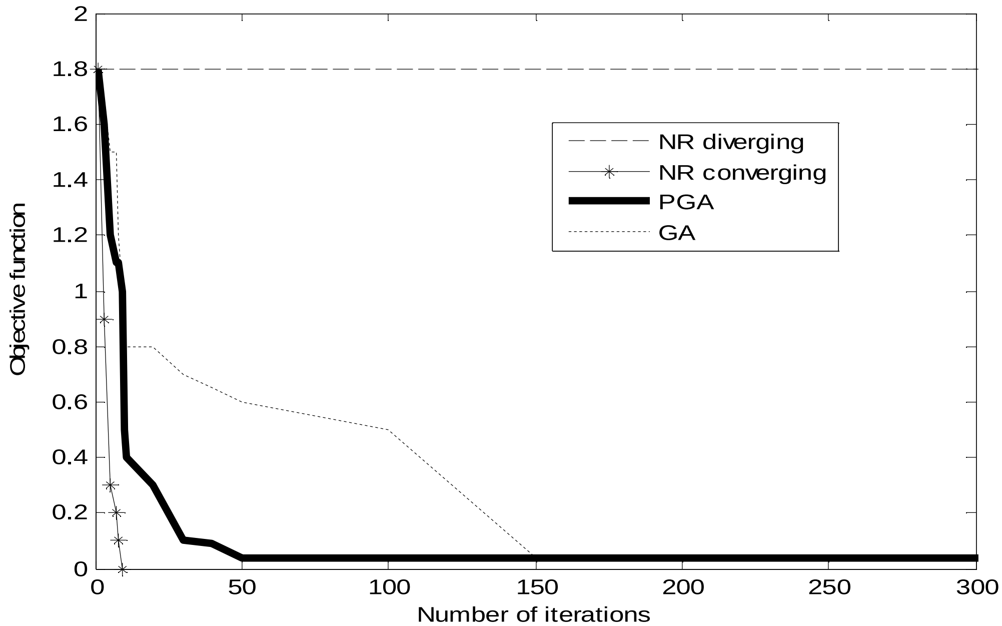


Figure 3. Convergence characteristics of PGA together with GA and NR.

Table1. Parameters of GA.

population size	10
Number of bits for one switching angle	8
Crossover probability	0.8
Mutation probability	0.06
Ending criterion	300 iterations

Table2. Parameters of PGA.

Population size	10
Number of bits for one switching angle	8
Fertilization Probability	0.8
Ending criterion	300 iterations

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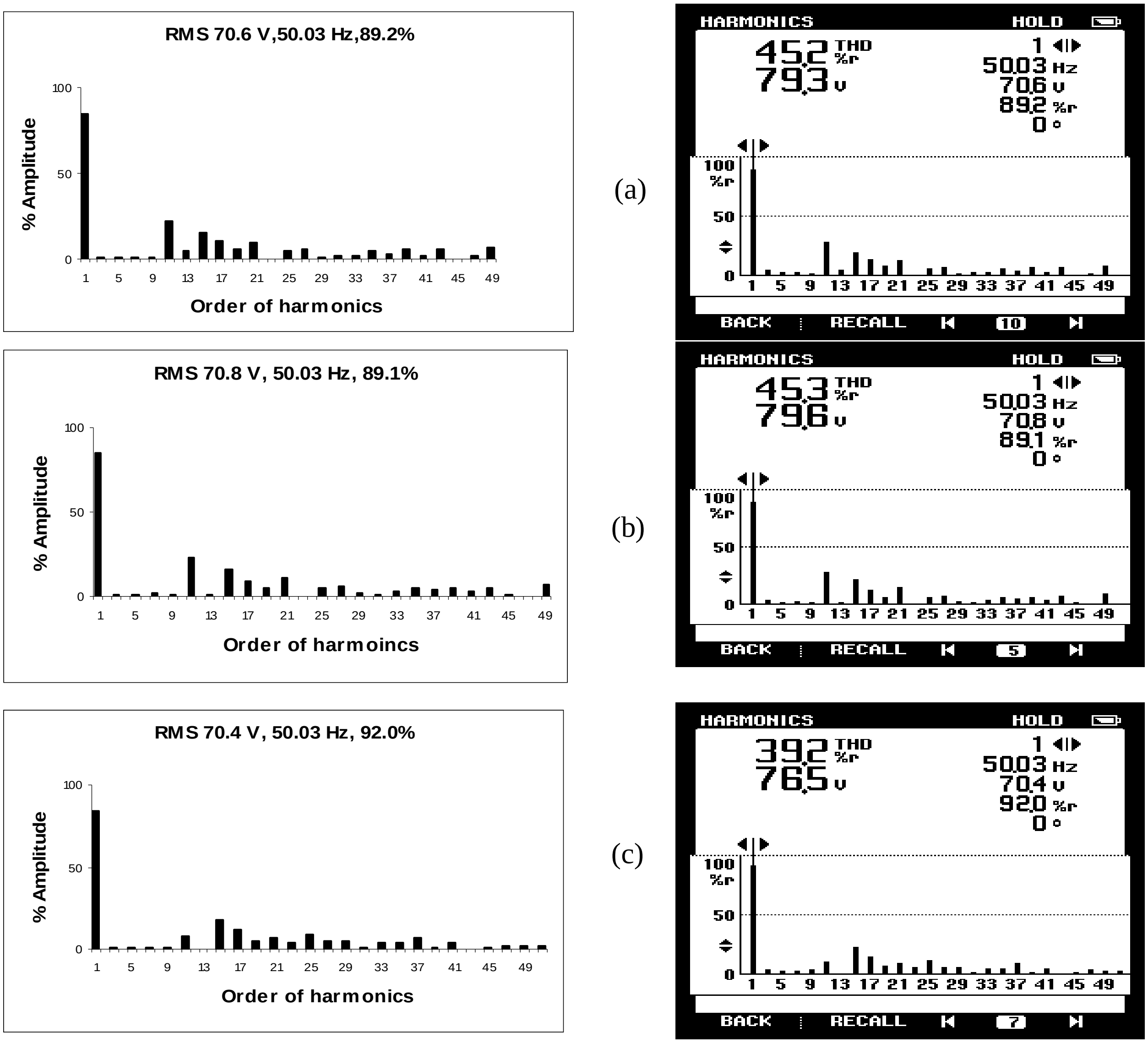

Computed Measured

Figure 4.Computed and measured harmonic spectra of PWM inverter for k=5 and V_o *=70Vwith V_{dc} = 100V, employing (a) PGA. (b) GA. (d) NR method.