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Convergence Parameter Analysis for Different Metaheuristic Methods Control Constant Estimation and it's Tradeoff Inference

R. Sagayaraj *, S. Thangavel **
* Department of Electrical and Electronics Engineering, Pavai College of Technology, Namakkal, India
** Department of Electrical & Electronics Engineering, K.S.Rangasamy College of Technology, Tiruchengode, India

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ABSTRACT

This paper is an extension of our previous work, which discussed the difficulty in implementing different methods of resistance emulation techniques on the hardware due to its control constant estimation delay. In order to get rid of the delay this paper attempts to include the meta-heuristic methods for the control constants of the controller. To achieve the minimum Total Harmonic Disturbance (THD) in the AC side of the converter modern meta-heuristic methods are compared with the traditional methods. The convergence parameters, which are primary for the earlier estimation of the control constants, are compared with the measured parameters, tabulated and tradeoff inference is done among the methods. This kind of implementation does not need the mathematical model of the system under study for finding the control constants. The parameters considered for estimation are population size, maximum number of epochs, and global best solution of the control constants, best THD value and execution time. Matlab^{TM} /Simulink based simulation is optimized with the M-file based optimization techniques like Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Cuckoo Search Algorithm, Gravity Search Algorithm, Harmony Search Algorithm and Bat Algorithm.

Corresponding Author:

R. Sagayaraj,
Departement of Electrical and Electronics Engineering,
Pavai College of Technology,
Pachal, Namakkal 637 018, Tamil Nadu, India.
Email: rsrajeee@yahoo.co.in

1. INTRODUCTION

Modern computers, communication and electronic systems get their "Life Blood" from power electronics, which aids all energy harveting systems [1]. Energy harvesting has become a very important field in electrical engineering as every small amount of energy developed can be tapped for use in its own magnitude. Apart form the applications of Power Electonics in energy harvesting systems, electric motors motion control, reducing the noise generationin in motors; it plays a vital role in improving the motor steady state and dynamic characteristics [2]. Power Factor Correction (PFC) is a prime factor that would increase the power loss, which must be introduced in almost all the industrial drive unit. Resistance emulation is one such energy harvesting method used for renewable energy resources like the wind energy system. Even though there are low power devices that are developed in wireless sensor network nodes, the need of high-density power is a need in the field even today. The Maximum Power Point Tracking (MPPT) algorithm for the wind generator based converter is applied using the resistance emulation technique. The boost converter, which would act as an MPPT controlled converter [3]. The resistance emulation method deals with the three phase rectifier, where a switched resistance emulation method is introduced with two capacitors and three resistors are used for shaping the input current at the AC side similar to that of the voltage [4]. The resistance emulation technique for harmonic elimination does't senses the input voltage and the load current [5]. A scalar system model with the PI controller has been introduced to develop a single-phase shunt active filter. A higher power factor operation of a three phase rectifier implementation is possible on a DSP TMS320F240F from Texas Instruments was possible and the control algorithm has been given response within $40\mu\sec$.

To overcome the excessive overshoot and damping a universal method was used [6]. The method called Karim's method, which used the PI controller for the outer loop and the PD controller for the inner loop in order to achieve the above said criterions. Also it is it is difficult for the PID controller to respect well to changes in the operating point, and they exhibit poor performance when the system is subjected to large load variations [7]. A simple PSO (SPSO) was used to reject the effect of external disturbance and assure the output. The PI-PD parameter estimation was done by solving the SPSO problems. The power factor correction stage is built using the boost converter topology, which has the advantages of grounded transistor, small input inductor, simplicity and high efficiency (95%) [8]. The controller used for the PFC is usually a PI controller [8] and for every controller the mathematical modeling of the circuit and the controller constant estimation must be done before hand, which is time consuming and trivial process. The resistance emulation technique for the three-phase induction motor drive system is taken and implemented using the technique of introducing three single-phase inverter and the passive power factor correction circuit elements [9].

This paper attempts to develop a controller constant estimation using different optimization technique. The proposed implementation is developed using a DSP processor could get a response that is of micro seconds range the optimization technique can be added in the estimation of the control constants in the PI controller of the resistance emulation technique. Different traditional and the modern optimization are taken for analyzing which would be computationally and economically effective. The optimization techniques used for the comparative analysis are Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Cuckoo Search Algorithm, Gravity Search Algorithm, Harmony Search Algorithm and Bat Algorithm. The parameters considered for estimation are population size, maximum number of epochs, and global best solution of the control constants, best THD value and execution time. The parameters considered are those, which help to know whether this technique can be implemented on the hardware.

This Paper is organized as follows. A brief about resistance emulation method fills Section-II; Different optimization techniques are introduced in Section-III. Section-IV delivers the idea about proposed system under analysis. Section-V deals with the results and discussion on the work carried out. Conclusion and the Reference follow in the last Section.

2. RESISTANCE EMULATION METHOD

The idea behind resistance emulation is that the circuit after the bridge rectifier in the AC-DC converter circuit would absorb only pure sinusoidal current, which is proportional to the AC supply voltage. This idea was previously implemented using the passive components. The resistance emulation technique boils down to shaping the input current, supply being of constant voltage. The Average Current Mode (ACM) method is a successful method implemented for emulating resistance by the use of power electronic devices. The boost converters are usually used for PFC in many Switched Mode Power Supply (SMPS) applications and the same has been taken up in this paper [1].

The boost converters are natural harmonic reduction devices, as the capacitor in their load side would eliminate the second order harmonics in the supply side, hence it is inferred that only the odd harmonics are to be taken up seriously and the PWM techniques are developed towards reducing or eliminating the odd harmonics. The PWM control in this algorithm is aided by the use of a PI controller whose control constants are to be predetermined in order to attain the lowest THD. This paper attempts to determine these parameters on the run, which means that the control constants are determined when the system is ON can be taken as a road that this can be implemented on the DSP boards [5]. The optimization algorithm considers THD as the objective function, which must be minimized, and the constraints are taken as the control constant's limits. This novel method of determining the control constants will have a good accuracy level as compared to the traditional methods.

3. OPTIMIZATION TECHNIQUES

The traditional optimization techniques like the gradient descent method and quasi newton method would work only on the differentiable functions. But the bio-inspired techniques used in this paper are not dependent on the function even if it is differentiable or not. The original intention researching on bird flock movement was to graphically simulate the graceful and unpredictable choreography of a bird flock which when analyzed turned out to be an optimizer called Particle Swarm Optimization (PSO) [10]. The PSO method starts with the initialization of the population within the solution space created. Objective function for the initial population is created and the pbest, gbest values are determined [10]. With this as the initial solution set the iteration will go on, where the new population set is generated using the velocity function as defined below,

$$v_{id} = v_{id} + c_1 * rand() * (p_{id} - x_{id}) + c_2 * rand() * (p_{gd} - x_{id})$$
$$x_{id} = x_{id} + v_{id} \quad (1)$$

Where, x_{id} is the current value and the next value of the ith population, c_1 and c_2 are the constants, p_{id} is the neighboring best value, p_{gd} is the global best value. For the new set of population generated using equation (2) the objective function is recalculated until the optimization condition is reached.

Genetic algorithm is one of the earliest evolutionary algorithms (EA), which used the concept of natural selection for the optimization problem solutions. For initialization many solutions are taken and those solutions are called the initial population. The initial populations are spread out in the whole range of possible solutions. The selection process succeeds the initialization process, where the fitter solution are taken from the initialized values by means of finding the fittest solution of the objective function or randomly selecting from the initial population. The genetic operators of mutation and crossover are applied on these selected solution values. These values are considered as the parent and the children are found by combining these selected parent solutions. Then new parents are selected for every child and the above process of mutation and crossover continues until a desired number of solutions are obtained. The solutions are again checked for fitness on the objective function. The termination of the algorithm occurs if the number of iteration is reached or the objective function is either minimized or maximized [11]. Cuckoo Search Algorithm (CSA) is also a population based met heuristic method with two sub operations, first one being the direct search based on the Levy flights and a random search based on the probability of the host bird to find out whether it is an alien egg [12]. This is based on the fact that Cuckoo would use the nest of different birds to develop its offspring from the period of laying eggs. The algorithm is dependent on how does cuckoo strategize to grow its offspring from the hatching stage in the host bird's nest.

The steps involved in the CSA method is as defined in the following,

As in every optimization algorithm here the initial population is the number of host nest, which in our problem is the population of control constants inside its limits. The nest with higher quality level will go to the next generation. The probability level of the host bird to find whether there is an alien egg is measured. If the probability is above a desired limit then the host bird would either throw the alien egg outside the nest or it would migrate from that nest to build a new nest. When the nest is abandoned the nest goes out of the solution space. In order to replace the new nest instead of the removed one, as the number of the nest must be constant, the Levy Flight's algorithm is used to move to a new solution point, which would become the new nest added in the next generation [12]. Gravity Search algorithm is developed on the basis of law of gravity and mass interactions. The interaction between the agents, which are objects having their performance measured by their masses, are carried out using the force of gravity between them. The four parameters that define the GSA are position, inertial mass, active gravitational mass, and passive gravitational mass. The position of the mass would determine the solution of the objective function, where as the gravitational and the inertial masses are determined using a fitness function. The movement of the masses, which is the new solution point, is controlled by the use of the gravitational and the inertial masses. The heaviest mass is the solution in the search space [13]. Harmony search algorithm is another optimization algorithm, which is derived from the concept of finding the best harmony created from the musicians. The best harmony created is the best solution, while each musician is the decision variable, the play they create is the generated value; a note in the play is the value for finding the best harmony [14]. BAT algorithm is a bio-inspired algorithm, which derives the echolocation behavior of the microbats for varying pulse rates of loudness and emission. By using these entire discussed algorithms the optimization of the THD in the boost converter is carried out with the estimation of the control constants in the PI controller used in the converter.

4. BOOST CONVERTER DESIGN

Boost converter based PFC has been a trend, as it has the inherent design, that would eliminate the second order harmonics in the supply side. The reduction of harmonics and the voltage ripple is taken care by the ACM method. This circuit is obtained by combining the uncontrolled rectifier with the boost converter topology which is then connected to the Voltage Source inverter (VSI) with the three phase induction motor as given in the Figure 1.

The Induction motor is made to work without any control technique, thus running at its rated speed. The specification of the induction motor considered for the research study is 5.4 HP, 400V, 1430 rpm, 50 Hz, 4 poles one [1]. As the motor is a 400 V three phase induction motor, in order to limit the starting current, we should have used the starter in order to get rid of the starting current dynamics, but the inductor in the boost converter would serve the purpose of the smooth starting of the induction motor, hence starter can be avoided. The schematic of the converter with the induction motor is as given in Figure 1.

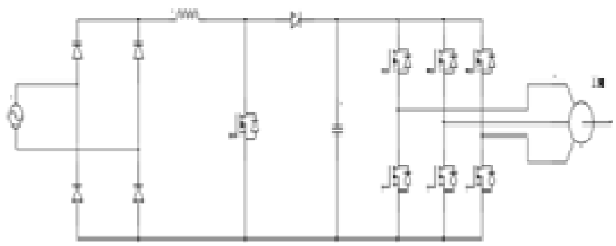
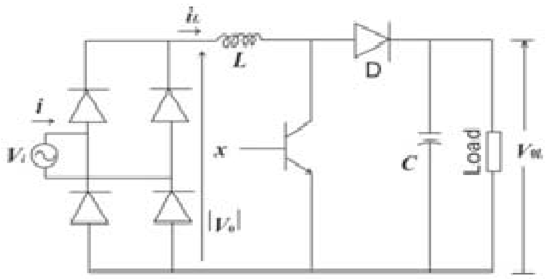


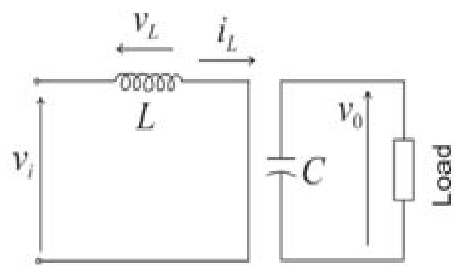
Figure 1. 1-ϕ Boost Rectifier with he 3-ϕ
Electric Drive System

The boost converter is designed for the following design criteria. When the transistor switches ON, the equation of the current $i_L(t)$ is given by the following equation (3) as

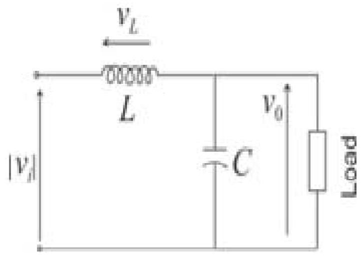
$$\frac{di_L}{dt} = \frac{V_L}{L} = \frac{|v_S|}{L} \qquad (2)$$



(a)



(b)



(c)

Figure 2. Single-Phase Boost Rectifier for the Electric Drive System: (A) Power Circuit and Equivalent Circuit for Transistor T in (B) On-State and (C) Off-State

Due to the fact that $|v_s| > 0$, the ON state of transistor T always produces an increase in the inductance current i_L. The design parameters for the design of the boost rectifier is given in equation (3) as

$$C_0 = \frac{2\,P_0\,t_{hld}}{V_{0_{\min}}^2 - V_{0L_{\min}}^2} = 8.5\,mF\ (approx) \tag{3}$$

where,
C_0 = Output capacitance,
P_0 = Output power of the converter 4 KW,
t_{hld} = Hold up time, normally 20 ms,
V_{0min} = Minimum value of the output regulated voltage (400 V DC),
V_{0Lmin} = Range of input voltage (230V AC).

The value of the boost inductor affects many other design parameters. Most of the current that flows through this inductor is at low frequency. This is particularly true at the lowest input voltage where the input current is the highest. Normally, the acceptable level of ripple current is between 10 and 20 %. For a switching frequency of 100 kHz, the following formula will produce acceptable results.

L_a = 3000 / Po mH
L_a = 300 / 250 = 1mH (approx.)

The capacitor that is designed from the boost converter configuration will eliminate the second harmonic in the first hand. The Fourier analysis tells that the amount of the second harmonics present is about 0.02 % whereas the third harmonic is about 63.93 %. Considerable attention is given towards suppressing the third and successive odd harmonics in our proposed system, which is one of the contributions of the research work [1].

5. PROPOSED WORK

As the extension of our previous work as in [1] this paper is meant to develop a tradeoff estimation of the different optimization algorithms defined in the above section. The algorithm is used to estimate the control constants in the PI controller used in the boost converter. The parameter for comparison for all these algorithms are as mentioned above and these results are tabulated and discussed in the next section.

The fitness function for the optimization technique is the Total Harmonic Distortion calculated from the Matlab[TM]/Simulink model which will be calculated by the use of the mathematical formula as given in the formulae

$$THD_F = \frac{\sqrt{V_2^2 + V_3^2 + \ldots . V_n^2}}{V_1^2} \tag{4}$$

The population is created for two control constants K_p and K_i and the optimization is carried out for the minimization of the THD as defined in equation (4).

6. RESULTS AND ANALYSIS

The parameters that are calculated for the performance measure are population size, maximum number of epochs, and global best solution of the control constants, best THD value and execution time.

The Simulink model for the above boost converter with the resistance emulation method was developed with the PI controller and the control constants of this controller are the values that are optimized by the use of different optimization techniques discussed above. The objective function for minimization is the THD calculation. The results obtained from different optimization technique as given below

7. ALGORITHM PARAMETERS

7.1. PARTICLE SWARM OPTIMISATION

Objective function: Mean (THD) in percent.
Number of variables = 4 (Kp1, Ki1, Kp2, Ki2).

Inertia weight = 0.9 – 0.4.
Acceleration constant1 = 2.
Acceleration constant2 = 2.
Range of variables = LB [0 0 0 0],
UP [0.1 7 2 3]
Global best solution: kp1=0.002421, ki1=1.785496,
kp2=2.000000, ki2=1.563399

7.2. GENETIC ALGORITHM
Objective function: Mean (THD) in percent.
Number of variables = 4 (Kp1, Ki1, Kp2, Ki2).
Number of mutation children (Gaussian) = 4.
Number of mutation children (random) = 4.
Number of elitism children = 2.
Range of variables = LB [0 0 0 0], UP [0.1 7 2 3]
Global best solution: kp1=0.010105, ki1=1.967732,
kp2=1.815011, ki2=0.333261

7.3. CUCKOO SEARCH ALGORITHM
Objective function: Mean (THD) in percent.
Population size =20.
Number of variables = 4 (Kp1, Ki1, Kp2, Ki2).
Probability of abandon (Pa) = 0.25.
Range of variables = LB [0 0 0 0], UP [0.1 7 2 3]
Maximum epochs = 100.
Global best solution: kp1=0.000000, ki1=1.766594,
kp2=2.000000, ki2=0.000000
Global best THD = 1.867032
Execution time =10254.02 sec.

7.4. GRAVITY SEARCH ALGORITHM:
Objective function: Mean (THD) in percent.
Population size =20.
Number of variables = 4 (Kp1, Ki1, Kp2, Ki2).
Initial Gravitational constant (G0) = 10.
Acceleration constant (alpha) = 10.
Epsilon = 0.0001.
Euclidean length of R (Rnorm) = 1.
Power of R (Rpower) = 1.
Percent of agents apply force (find_per) = 2.
Range of variables = LB [0 0 0 0], UP [0.1 7 2 3]
Maximum epochs = 50.
Global best solution: kp1=0.000090, ki1=1.939398,
kp2=2.000000, ki2=1.112169
Global best THD = 1.894284
Execution time = 9523.09 secs.

7.5. HARMONY SEARCH ALGORITHM
Objective function: Mean (THD) in percent.
Population size =20.
Number of variables = 4 (Kp1, Ki1, Kp2, Ki2).
Pitch Band width (bw) = 0.9.
Harmony Memory considering Rate (HMCR) = 0.95
Pitch Adjustment Rate (PAR) = 1
Range of variables = LB [0 0 0 0], UP [0.1 7 2 3]
Maximum epochs = 50.
Global best solution: kp1=0.000000, ki1=2.401094, kp2=2.000000,
ki2=0.260736
Global best THD = 1.963194

Execution time = 408.88secs

7.6. BAT ALGORITHM

Objective function: Mean (THD) in percent.
Population size =20.
Number of variables = 4 (Kp1, Ki1, Kp2, Ki2).
Pitch Band width (bw) = 0.9.
Loudness (A) = 0.9
Rate of pulse emission(r) = 0.1
Minimum frequency (Qmin) = 0
Maximum frequency (Qmax) = 2
Range of variables = LB [0 0 0 0], UP [0.1 7 2 3]
Maximum epochs = 50.
Global best solution: Kp1= 0.0061529, ki1= 6.9073
kp2= 2   ki2= 2.9943
Global best THD = 2.2826
Execution time =6253.17 secs.

7.7. CONVERGENCE GRAPH

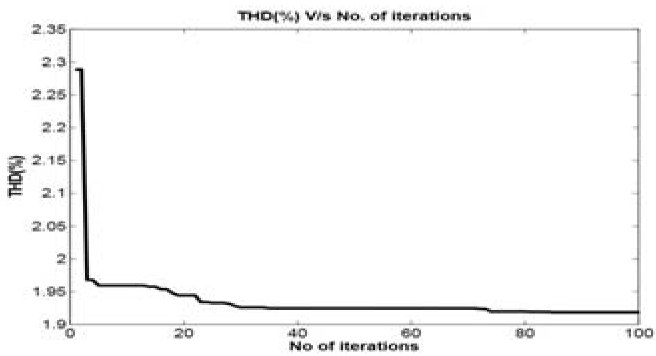


Figure 3. Particle Swarm Optimization THD vs No.of Iterations

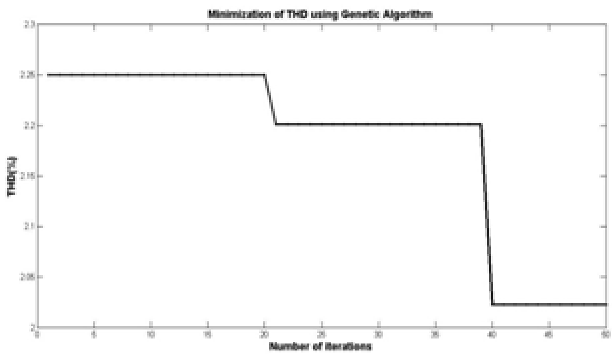


Figure 4. Genetic Algorithm THD vs No.of Iterations

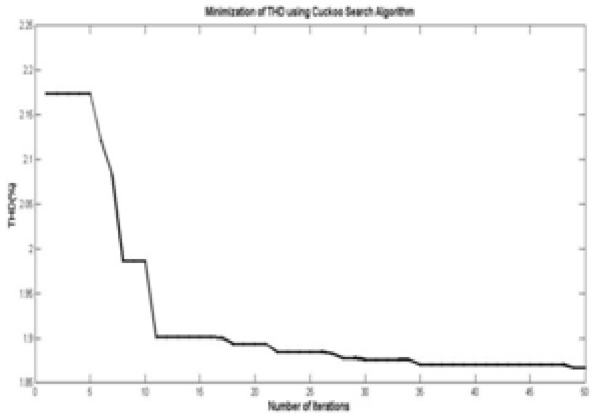


Figure 5. Cuckoo Search Algorithm

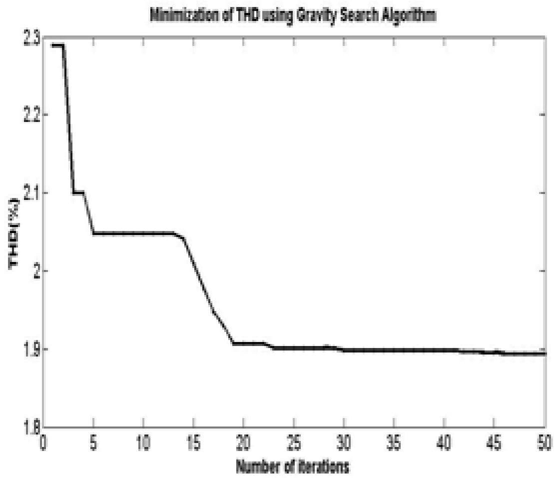


Figure 6. Gravity Search Algorithm

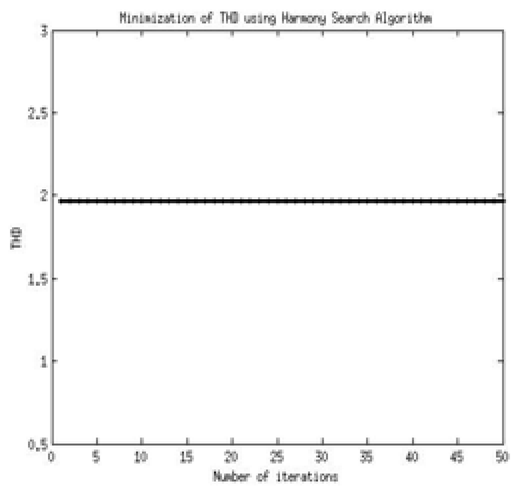


Figure 7. Harmony Search Algorithm

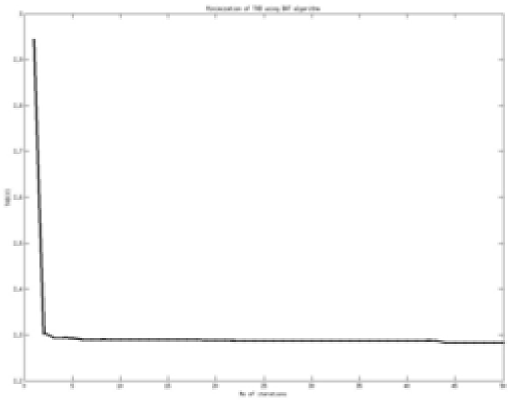


Figure 8. BAT algorithm

7.8. TRADEOFF ANALYSIS COMPARISION TABLE

Table 1. Comparison of THD values from Different Control Techniques

Control Technique	Global Best THD
Without ACM	63.93 %
With ACM	4.93 %
FLC	2.9 %
ANFIS	2.8 %
PSO	1.918916%
GA	2.022101%
CSA	1.867032%
GSA	1.894284%
HSA	1.963194%
BAT	2.2826%

Table 2. Comparison of Parameters from various Optimization Algorithms

Name	Population Size	Maximum Epochs	Execution Time in sec
PSO	10	100	25315.08
GA	20	50	20787.73
CSA	20	100	10254.02
GSA	20	50	9523.09
HSA	20	50	408.88
BAT	20	50	6253.17

The tradeoff inference is dependent on whether the algorithm can be implemented on a processor or the parameters like the population size and execution time which is dependent on the memory and the speed of the processor is taken care. Also the accuracy of THD minimization must be taken as it is the ultimate aim of the experiment.

CSA exhibits the optimal THD value and less execution time compared with other optimization algorithms. However PSO also provides best THD value but it takes more execution time and lesser population size.

GA takes lesser execution time compares with PSO, but its favorable THD value is greater than PSO algorithm. GSA gives better THD value compared with PSO and GA with lesser execution time.

BAT algorithm takes lesser execution time compared with PSO, GA and CSA, but its optimal THD value is poorer than other algorithms.

HSA algorithm provides optimum THD value with very less execution time compared with other algorithms, but CSA algorithm overrules all the other algorithms to obtain the best THD value.

8. CONCLUSION

The convergence graph shows that the lowest time taking algorithm for settling is the Harmonic Search Algorithm (HSA). CSA gives the lowest THD calculated among all the algorithms used. GSA has the second lowest THD optimized. The PSO used very lesser number of iteration compared to all the other algorithms. From the table 1 and 2, it is obvious that the PSO is the most memory efficient and the HSA is the most time efficient algorithm to be implemented on the control constant estimation for resistance emulation in a boost converter. CSA has proved itself to be a more accurate method in estimating the control constants.

Hence tt can be inferred that, the efficient algorithm to use in this optimization can be the HSA, which resulted in lowest THD value.

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BIOGRAPHIES OF AUTHORS

R. Sagayaraj received the B.E degree in Electrical and Electronics Engineering in 1996 and M.Tech. in Power Electronics & Drives in 2003. He is a part time research Scholar of Anna University, Chennai. Currently, he is working as Associate Professor in Electrical and Electronics Engineering department at Pavai College of Technology. He has published 2 papers in International Journals. His research interests include Intelligent Power Converters and Soft Computing. He is an ISTE Life member.

S. Thangavel received the B.E degree in Electrical and Electronics Engineering in 1993 and M.E. in Control and Instrumentation in 2002. He received his Ph.D degree in Electrical Engineering in 2008. He is currently working as Professor and Head of the department of Electrical and Electronics Engineering at K.S.Rangasamy College of Technology, Tiruchengode. His research interests include heuristic optimization and real-time control applications, hybrid intelligent controllers and so on. He has published 14 papers in International and 3 papers in National Journals. He is a reviewer for 6 international journals. He is an ISTE and IEEE member.