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Cuckoo Search Algorithm Study for Voltage Source Inverter Harmonic Reduction

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ABSTRACT- This research examines the issues with harmonics in a voltage source inverter (VSI) and proposes the cuckoo search optimization (CSO) algorithm for reducing THD value. This algorithm has been employed to estimate the optimum values of the PI constants. Utilizing the traditional PI controller attached VSI, the tuned values of PI constants determined by the CSO algorithm are employed to reduce harmonics. The Simulink tool of the MATLAB program and the hardware configuration employing the PIC microcontroller were used to carry out the experimental verifications. The estimated THD values for both the software and the hardware results demonstrate that the THD values are significantly lower than the requirements set out by the IEEE standard.

KEYWORDS- Voltage Source Inverter, PI controller, cuckoo search optimization algorithm, Total harmonic distortion, PI controller, PIC microcontroller.

I. INTRODUCTION

A voltage source inverter (VSI) is a power electronic converter in the nonlinear category of load in which harmonics as a function of power frequency are produced during the process of inversion. Inverters are widely used in various commercial and industrial applications such as power conversion, transmission, utilization, traction, etc. Voltage Source Inverters, which are fed from a d.c. source of small internal impedance The sine wave inverters are preferred compared to other shapes for high-quality power, increased operating speeds of inductive loads, reduced noise during machine operation ,etc. Various modulation techniques are employed in inverters for obtaining low-distorted sine waves.

Power supply inverters that require pure sinusoidal voltage with the required magnitude, frequency, and low total harmonic distortion (THD)[1-5]. Sensing and quantifying the waveform's departure from the sinusoidal shape is required before attempting to devise control techniques to minimize distortion. On the measurement of harmonics in steady and non-stationary conditions, the technical literature is replete with helpful papers. To reduce the harmonic content in power inverters, many methods including PWM approach, soft computing techniques, switching angles, Hopfield neural networks, LC filter, interphase transformers, and harmonic injection techniques are used.[6-11] The single phase full bridge inverter has issues such harmonic torques, interferences, oscillations, heating, etc. because of the presence of harmonics.

In this study, total harmonic reduction in single phase inverters is achieved using the cuckoo search optimization algorithm (CSOA), which is based on the parasitic behaviour of the cuckoo bird and levy flights. Pure sinusoidal output with good voltage regulation and quick dynamic response are provided by the suggested Cuckoo search optimization algorithm (CSOA).

II. VOLTAGE SOURCE FULL BRIDGE INVERTER STATE SPACE MODEL

The switching scheme determines the frequency of the output ac waveform. The output voltage amplitude is controlled by varying the amplitude of the source voltage. The steady-state inverter operation can be explained by assuming two circuit modes with a control variable u € {0, 1}. The mathematical model for the voltage-controlled single-phase full bridge inverter based on bipolar voltage switching with SPWM is presented. It is assumed that all components are ideal. The alternating voltage is produced when switches SA and SD are closed for half the switching period while SB and SC are open. In the second half-period, SA and SD are open while SB and SC are closed. The control variable 'u' is defined as,

$$u(\theta) = \begin{cases} 0, -\alpha < \theta < \alpha \\ 1, \alpha < \theta < \pi - \alpha \end{cases} \quad (1)$$

If switches S_A and S_D are on, then u =1. If switches S_B and S_C are on, then u = 0.where u is a control variable.

A. Topology (1)

When switches S_A and S_D are on, then u =1 and the system can generate a positive half sine wave. Figure 1 shows its equivalent circuit for Linear R-Load. [2]

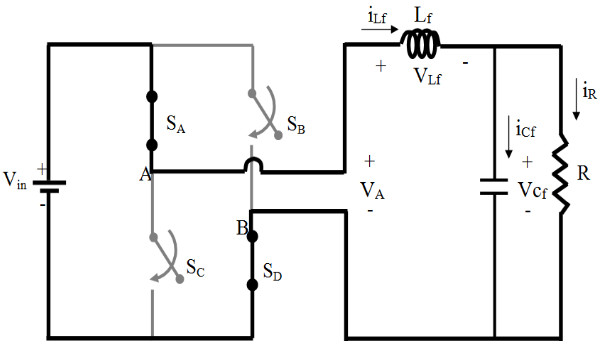

Figure 1: Circuit Mode of VSI When S_A and S_D Are ON

According to the circuit topology, the state-space equation can be written as follows.
Applying KVL,

$$V_{in} = L_f \frac{di_{Lf}(t)}{dt} + v_{cf}(t)$$

$$\frac{di_{Lf}(t)}{dt} = \frac{V_{in} - v_{cf}(t)}{L_f} \tag{2}$$

Also,

$$i_{Lf}(t) = i_{cf}(t) + i_R(t)$$

$$i_{Lf}(t) = C_f \frac{dv_{Cf}(t)}{dt} + \frac{v_{cf}(t)}{R}$$

$$\frac{dv_{Cf}(t)}{dt} = \frac{i_{Lf}(t)}{C_f} - \frac{v_{cf}(t)}{RC_f} \tag{3}$$

B. Topology (2)

S_B and S_C are on, then *u* =0 and the system can generate a negative half sine wave. Figure 2 shows its equivalent circuit for R-Load. [2]

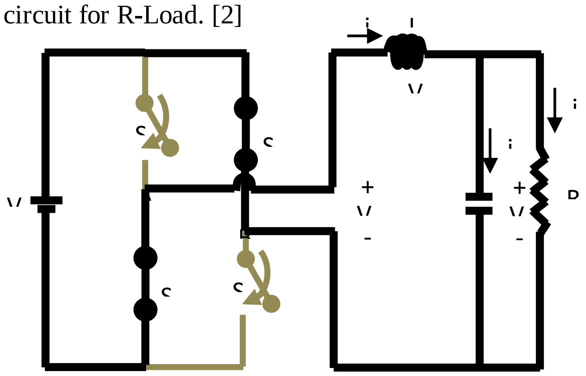

Figure 2: Circuit Mode of VSI When S_B and S_C Are ON

According to the circuit topology, the state-space equation can be written as follows.
Applying KVL,

$$-V_{in} = L_f \frac{di_{Lf}(t)}{dt} + v_{cf}(t)$$

$$\frac{di_{Lf}(t)}{dt} = \frac{-V_{in} - v_{cf}(t)}{L_f} \tag{4}$$

Applying KCL,

$$\frac{dv_{Cf}(t)}{dt} = \frac{i_{Lf}(t)}{C_f} - \frac{v_{cf}(t)}{RC_f} \tag{5}$$

Equations (2) to (5) are merged with controlled variable u∈ {0, 1} into following state space Equation (6):

$$\begin{bmatrix} \frac{di_{Lf}(t)}{dt} \\ \frac{dv_{cf}(t)}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L_f} \\ \frac{1}{C_f} & -\frac{1}{RC_f} \end{bmatrix} \begin{bmatrix} i_{Lf}(t) \\ v_{cf}(t) \end{bmatrix} + \begin{bmatrix} \frac{V_{in}}{L_f} \\ 0 \end{bmatrix} (2u-1) \tag{6}$$

III. CUCKOO SEARCH OPTIMIZATION ALGORITHM (CSOA)

A population-based optimization method called CSOA is influenced by the cuckoo bird's parasitic behaviour, in which the female lays her eggs in other birds' nests. In the CS method, a group of nests with a single egg in each are dispersed at random over the search space, where the eggs stand in for potential solutions. Levy Flights, a search pattern, is employed and is thought to be more effective than random walks or Brownian movements. The breed behaviour of a few cuckoo species is briefly reviewed to better explain the CSOA. The CSOA was motivated by the cuckoo species' obligate brood parasitism, in which they lay their eggs in the host birds' nests. Some cuckoo species have evolved to the point where female parasitic cuckoos can mimic the hues and patterns of the eggs of a select few host species. This improves the eggs' reproductively by lowering the possibility of abandonment.

It's important to note that several host birds directly battle trespassing cuckoos. In this scenario, the host birds will either discard the eggs or simply abandon their nests and establish new ones elsewhere if they realize the eggs are not their own. Cuckoo parasites frequently select nests where the host bird has recently laid its own eggs. Typically, the cuckoo eggs hatch a little bit before their host eggs. When the first cuckoo chick hatches, his first instinctive move is to drive the host eggs out of the nest by throwing them out blindly. By doing this, the cuckoo chick receives a larger portion of the food provided by its host bird. Additionally, research demonstrates that a cuckoo chick can replicate the host chicks' calls to get greater feeding opportunities. Such breeding behaviour can be modelled by the CSOA and used to solve various optimization issues. In general, animals' foraging routes offer a random walk since the next step depends on both the present location/state and the transition probability to the next place. The CS took the following three rules from cuckoo bird breeding behaviour:

- At a time, each cuckoo lay an egg. Unplanned nests received the eggs.
- The nest that produces eggs (solutions) of a high calibre would be used in subsequent cycles.
- The number of prospective hosts was predetermined, and there was a probability P [0, 1] that the cuckoo eggs would be detected.

A. *Controller Tuning With Pi Using Cuckoo Search Al gorithm*

The Cuckoo search optimization algorithm was inspired b y the cuckoo bird. The unique breeding and egg-laying patterns of this bird serve as the foundation for our optimization approach. Eggs and adult cuckoos were employed in this modelling. Eggs are laid by adult cuckoos in the habitat of other birds. If they are not removed by the host birds and are not removed by friends, those eggs develop into a full cuckoo. The migration of cuckoo groups and environmental requirements should bring them together and direct them to the ideal location for recombination and breeding. This is the optimal location, where goal functions reach their global maximum [12][13][14][15].

Yang and Deb created Cuckoo optimization in 2009 with inspiration from nature. Rajabioun created Cuckoo Optimization Algorithm in 2011. The parameters of the candidate components will be assessed in the fitness function. The algorithm starts with a primary population of birds and they have some eggs to lay in certain host birds' habitats, and then it goes through the following phases to search for the best answer. Some of these eggs develop into adult birds that resemble the host bird's eggs more and other eggs are found and destroyed by host birds. The more eggs that remains and hatches in that location, the more profit is made there. Therefore, COA will optimize the duration in which there are still more eggs. There is a "distance" from each cuckoo's preferred habitat [16] [17] [18] [19] [20].

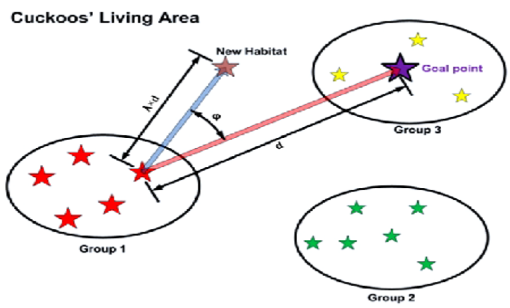

Figure 3: Migration of a Sample Cuckoo to its Intended Environment

Following is a flowchart of the suggested algorithm and a summary of the cuckoo optimization algorithm (COA).

B. *Algorithm*

1. Constructing cuckoo habitats using a random solution to the objective function;
2. Distributing eggs to each cuckoo;
3. ELR determination for each cuckoo;
4. Permit cuckoos to lay their eggs in the corresponding ELR;
5. discarded any eggs that the host birds had found;
6. Permit eggs to hatch and chicks to grow;
7. Evaluate each adult cuckoo's environment;
8. Remove cuckoos from the worst areas and restrict as many as possible in the environment;
9. Assemble cuckoos, find the ideal location, and choose the goal;
10. Allow the new cuckoo population to move toward the desired location;
11. If the stop condition is met, stop. Go to 2 if not.

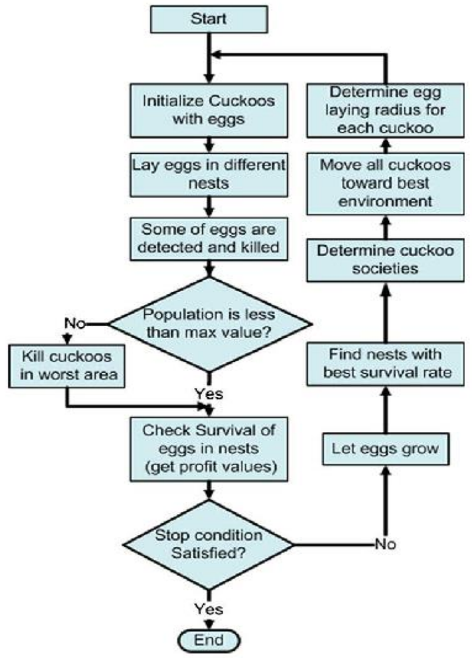

Figure 4: Flowchart for Cuckoo Search Algorithm

IV. MATLAB SIMULATION

Table 1: Simulation Specifications of VSI

Parameters	Values	Units
Input DC Voltage, V_{in}	15	V
Load Resistance,R_0	50	Ω
Load Inductance, L_o	100	MH
Load Capacitance, Co	470	if
Filter Inductance, L_f	2	mh
Filter Capacitance, C_f	500	µF
Reference Signal	Sine wave	-
Reference Voltage, V_{ref}	5	V
Frequency	50	Hz
CSOA-PI Algorithm	K_p=17.2,K_i=8.32	-
Switching frequency, f_s	7.69	KHz
Load waveform	Sine wave	-

To simulate using the SIMULINK model, the MATLAB/SIMULINK program is used. In order to determine the characteristic impedance and other constants, the MATLAB simulation depends on the selection of parameters like resistance, inductance capacitance, and other values.

In the above table 1 provides the specifications for the VSI simulation parameters in MATLAB that were utilized to reduce the harmonic magnitudes.

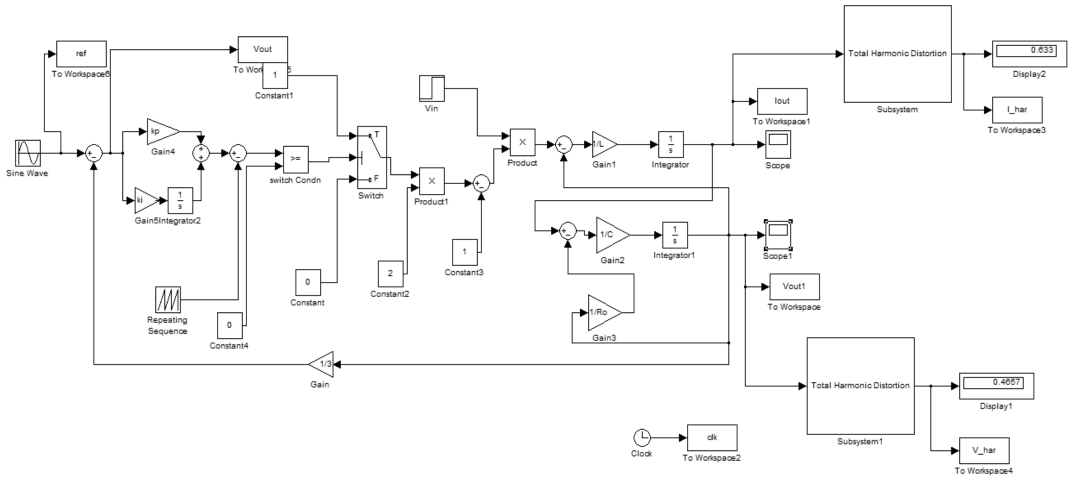

Figure 5: Simulink Block Diagram of PI Controller

Based on CSOA technique Figure 5 depicts the Simulink block diagram of a UPS Inverter with PI Controller.

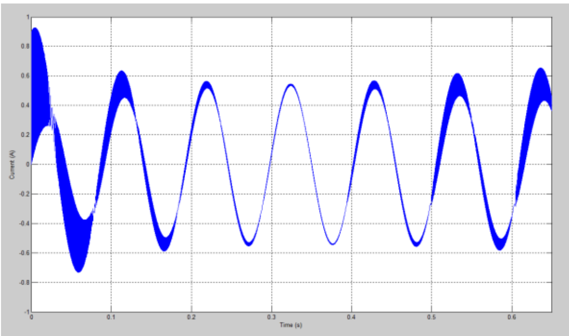

Figure 6: Current Output Waveform Using CSOA Technique

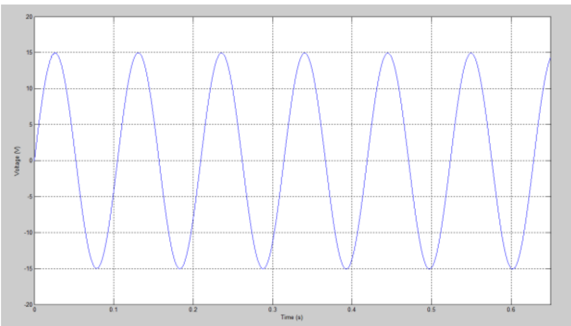

Figure 7: Voltage Output Waveform using CSOA Technique

Response time is accelerated and steady state error is eliminated by combining proportional and integral terms. The full bridge Power Inverter uses the optimum values of Kp=17.2 and Ki= 8.32. The Simulink blocks are used to estimate the Voltage and Current Harmonics Percentage THD Values. Plotted are the response curves for the single phase inverter's voltage and current harmonics. Figures 6 and 7 display the simulink output voltage waveforms corresponding to the CSOA algorithm.

Using CSOA, the output voltage magnitude is maintained without overshoots. For CSO algorithms, the output current waveform overshoots. In the case of the CSO algorithm, the controller performs well, reduces overshoots, and stabilizes the waveform with less distortion.

V. EXPERIMENTAL VERIFICATION

Figure 8: Hardware Setup

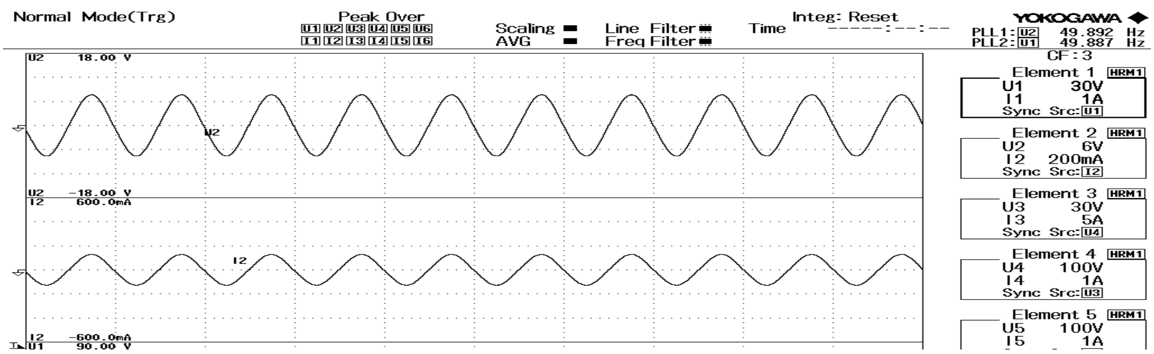

Figure 9: Hardware Results Using CSO Techniques (a) Voltage Across Load (b) Current Across Load

Figure 8 displays the hardware setup's block diagram. The processor, DAC, ADC, display, and other sections make up the Micro-4011 trainer. The PIC microcontroller (PIC30F4011) generates a PWM wave, which is sent to a driver circuit for use in turning on and off the power device by providing the appropriate gate signals. A miniature 4MHZ Quartz Oscillator is used as the resonator. It is an electronic oscillator circuit that uses mechanical resonance of a vibrating crystal of Piezoelectric material to create an electrical signal with a very Precise frequency charge.PIC is used to generate pulse width modulation (PWM) wave by comparing sine wave and oscillatory wave. It has 40 total pins, 33 of which are divided into five Ports, while the other pins are multiplexed with an alternative function for the device's peripheral features.

General intent I/O pins are among the most basic peripherals. They make it possible for the PIC microcontroller to see and manage other gadgets. Enhanced Flash Program memory, Data EEPROM memory, Self-reprogrammable under software control, Power-on reset (POR), Power-up reset (PUR), Oscillator start-up, etc. are only a few of the unique features of PIC microcontrollers. The output voltage and current waveforms from the Inverter module is shown in Figs.9 (a) and Fig.9 (b) [21-23].

Table 2: Comparative Performance

Operating condition	Algorithm	Total Harmonic Voltage Distortion (%THD v)	Total Harmonic Current Distortion (%THD I)
R-Load	SIMULATION USING CSOA-PI	0.785	1.425
	EXPERIMENT USING CSOA-PI	1.21	1.75

VI. CONCLUSION

In this paper, the Cuckoo search Optimization Algorithm (CSOA) is applied in voltage controlled single phase full-bridge inverter for harmonic reduction. The Simulation results and Experimental verification shows that the harmonics are reduced considerably in CSOA for R-Load as per IEEE standard 549-1992.This work improves the efficiency of the inverter as well as power factor. The simulation and Experimental results presented above shows that the converter works well under steady and dynamic conditions of the inverter under Line and Load variations.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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