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An Efficient Control Implementation for Inverter Based Harmony Search Algorithm

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ABSTRACT

This research implements a PI controller based on harmony search (HS) optimization algorithm for voltage source inverter to improve the output performance under step load change conditions. The HS algorithm aims to handle the trial and error procedure used in finding the PI parameters and then apply the proposed control algorithm via the eZdsp TMS320F28355 board to link the inverter prototype with the Matlab Simulink. The mean absolute error (MAE) is used as an optimization problem to minimize the output voltage error for the developed controller (PI-HS) as compared to the PI controller based particale swarm optimization algorithm (PI-PSO). Based on the experimental results obtained, it is noted that the proposed controller (PI-HS) provides a good dynamic performance, robustness, constant voltage amplitude, and fast response in terms of overshoot, transient, and steady-state.

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1. INTRODUCTION

The topic of the voltage source inverter is playing an important role nowadays in research area to generate an AC output for different applications [1]-[5]. An inverter device is required to convert a DC to an AC source because of the most applications are connected to the AC loads [6]-[9]. So, the main important feature of the inverter design is its controller improvement. In addition, the controller ability is to provide a good dynamic performance, keep a constant output voltage waveform and frequency regardless of different loads are connected [10]-[11].

Therefore, there are a lot of various control algorithms have been carried out in the literature to solve the voltage control problems. The author in [12] has implemented a PI controller with a PWM algorithm for the PV inverter system using eZdsp F2812 board to keep the voltage waveform as a sinusoidal. Similarly, the researchers in [13] have also proposed a conventional controller of proportional-integral design to control the boost converter for the inverter system in order to get a good performance. In a related research, a field programmable gate array (FPGA) has been used in the PV inverter systems to develop the control algorithm described in [14]-[15] but it considered a time consuming task because it needs a wide knowledge in software programming. For a real time hardware setup, the reference [16] has used the platform of dSPACE DS1104 control unit to implement the PI controller of three-phase PV inverter system for a good dynamic performance. Also, same control unit has been used in [17] to enable the user to develop the control algorithm by employing the available features of Matlab/Simulink tools with the library blocksets in order to link the simulated model directly into the dSPACE controller.

However, the tuning of PI parameters is very essential for good control algorithm. Therefore, many optimization techniques of artificial intelligence have been applied to achieve the desired performance. For example, an optimal strategy of PI controller with a DC voltage regulation source was suggested in [18] for the photovoltaic grid-connected. In addition, an optimal PI controller has been proposed in [19] utilizing genetic algorithm (GA) to control the photovoltaic system performance especially the output voltage. Yet, harmony search (HS) optimization algorithm has not been applied in the inverter applications to tune the PI coefficients. In this research, the PI controller based HS algorithm is utilized to enhance the performance of the voltage source inverter. The inverter prototype and the control algorithm are modeled using the environment of MATLAB (Simulink/Code). After that, the control algorithm of the inverter prototype is experimentally implemented in the eZdsp F28335 board to validate the effectiveness of the proposed controller under different load conditions.

2. DESCRIPTION OF VOLTAGE SOURCE INVERTER

Figure 1 describes the voltage source inverter considered in this research, which includes both power and control stages. The power stage consists of a DC voltage source (V_{dc}), full bridge configuration with IGBTs switches followed by an appropriate LC filter circuit which filters out the frequency switching f_s of the bridge circuit as well as improve the voltage waveform linked to the loads, and two resistive loads. The control stage consists of DSP board, proposed controller, and bipolar SPWM method. The output voltage of the inverter (V_{Load}) can be sensed at the terminal of two different loads ($R1, R2$) by using a voltage feedback sensor and it can be represented as;

$$V_{load} = V \sin \omega t \tag{1}$$

Where V is the peak voltage and ω is the fundamental frequency of the inverter output. However, the generated error between the reference and the measured voltages as shown in equation (2) is then sent to the proposed controller which includes the harmony search algorithm based PI approach. Next, a comparison between $V_{control}$ and $V_{carrier}$ is done to derive the inverter by generating $S_1$and S_2 signals in order to obtain the desired output. All these steps are implemented using the TMS320F28335 board. The mean absolute error (MAE) is applied an optimization problem as in equation (3) to minimize the output error of the voltage source inverter [20].

$$e = V_{ref\ rms} - V_{Load\ rms} \tag{2}$$

$$\text{MAE (minimization)} = \frac{1}{L}\sum_{p=1}^{L}|e| \tag{3}$$

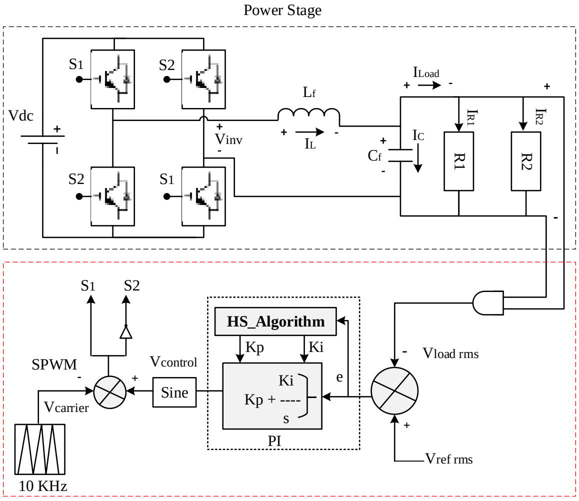

Figure 1. Voltage source inverter with proposed controller

3. HS IMPLEMENTATION TO FIND PI PARAMETERS

Harmony search (HS) is a well-known meta-heuristic optimization algorithm inspired by the modern natural phenomena, which was proposed by [21],[22]. In this research an optimum PI voltage controller using HS algorithm to optimize k_p and k_i coefficients is proposed to control the output voltage drop and keep the system is at a desired performance with a fast dynamic response. The HS algorithm has been widely utilized in different studies to solve a lot of optimization problems related to the applications of engineering felids such as design of steel structure, heat exchanger design, robotics, telecommunications, and so on [23] but it has not been used to solve the voltage control problems for the inverter applications under different load conditions. In brief, the optimization process for the proposed control algorithm is described in the pseudo code below;

Control flow of PI based Harmony Search Algorithm: pseudo code

Start program:

Definition of $input\ vector\ formula = Z(k), k_n \in \boldsymbol{K_n};\ (n = 1,2, \ldots \ldots .. M)$;
Definition of HMS, HMCR, PAR, and MaxI;
Definition the upper and lower boundaries of the decision parameters (k_p,k_i);
Harmony memory (HM) initialization;
$\boldsymbol{for}\ i \le MaxI$, if satisfied $\boldsymbol{do}$
  $\boldsymbol{for}\ j \le number\ of$ decision parameters, if satisfied $\boldsymbol{do}$
    $\boldsymbol{if}$ HMCR $> r_1$, if satisfied $\boldsymbol{do}$
      Choose a decision parameter from the HM;
      $k' = [k_p^1 \quad \ldots \quad k_p^{HMS}\ or\ k_i^1 \quad \ldots \quad k_i^{HMS}]$;
      $\boldsymbol{if}$ PAR $> r_2$, if satisfied $\boldsymbol{do}$
        Adjust the decision parameter by;
        $k'_{new} = (k'_{\text{selected}} + rand)$;
      $\boldsymbol{end}$
    $\boldsymbol{else}$
      Choose a new random decision parameter by;
      $k' = rand * [(upper - lower) + lower]$;
    $\boldsymbol{end}$
  $\boldsymbol{end\ for\ j}$

$\boldsymbol{if}$ the fitness value $f(k')$ of the new solution vector $<$
  the worst fitness value stored in the HM, $\boldsymbol{do}$
  Accept the new solution vector and replaced by the old one,
  then added it to the HM;
  $\boldsymbol{end}$
$\boldsymbol{end\ for\ i}$
Return back the best solution found ($latest\ k_p$,k_i);

4. IMPLEMENTATION CONTROL ALGORITHM USING eZdsp F28335

In recent decades, Texas Instrument such as the C2000 family of eZdsp TMS320F2833x is becoming very essential board for the high switching algorithms in different control applications for voltage source inverters [24]. In this research, the Harvard architecture of eZdsp TMS320F28335 board is used due to its features as compared with the previous models like TMS320F2812 board. In this algorithm, the feedback voltage is initially measured using a voltage sensor which called LEM LV25-P (716029). This sensor decreases the value of the measured voltage to eZdspF28335 board's range which is from 0 to 3 volt and then fed to the analog digital converter (ADC) channels for the sampling process. The reference sinewave voltage and the measured feedback voltage are saved in the ADC input channels (ADCCHSELSEQ1.bit.CONV00) and (ADCCHSELSEQ1.bit.CONV01) respectively. The digital equation of the proposed PI intelligent controller can be derived from the analog controller equation shown in equation (4) as follows;

$$V_{control}(z) = k_p\ e(z) + \frac{k_i}{1-z^{-1}}\ e(z) \quad (4)$$

This derivation can be applied to regulate the inverter output voltage by reducing the steady-state error in order to keep the voltage error $e(z)$ at minimum value. For more explanation, the code of the proposed control algorithm is presented so far in Figure 2 which is experimentally implemented and tested on the designed prototype inverter illustrated in Figure 1.

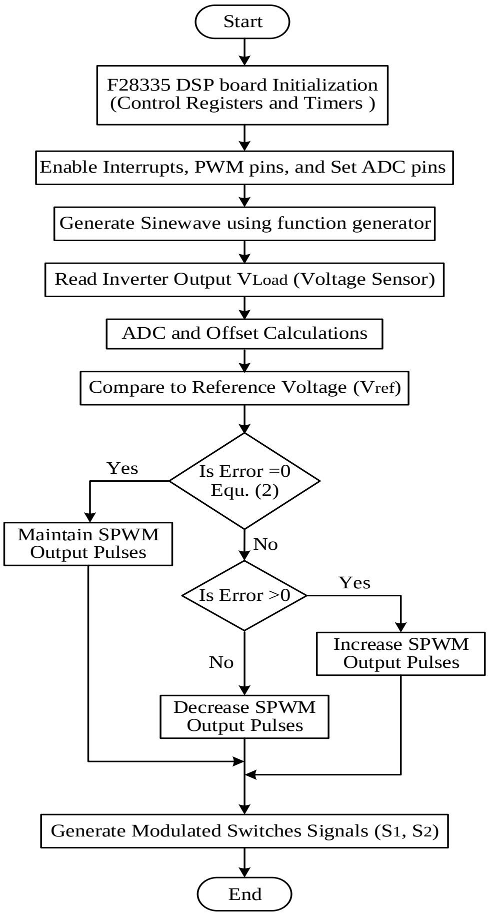

Figure 2. Proposed Control algorithm flowchart

5. HARDWARE SETUP OF INVERTER

The complete hardware setup of the voltage source inverter is described in Figure 3. The details of the proposed inverter parameters, voltage sensor, and switches status of SPWM to obtain the AC output voltage across the load are shown in Table 1. A F28335 unit board and the Code Composer Studio (CCS) environment have been used to implement the proposed controller and monitor the system performance. Furthermore, a get driver circuit has been used to electrically isolate the control and power circuits through opto-coupler devices.

Figure 3. Hardware setup of voltage source inverter

Table 1. Proposed prototype details

Inverter Parameters	Values
Input DC voltage, V_{dc}	75 V
Filter inductance, L	5 mH SMP made
Filter capacitance, C	15 $\mu F \pm$ 10% , 440 AC, 50 Hz
Resistive loads, R_1 and R_2	(100, 200) Ω, DDR 300W
Inductive load, RL	$100 + j15.7\ \Omega$
Switching frequency, f_s	10 KHz
IGBTs (G4PC50UD-326P)	Thresholds; 15 V, 50 mA, 2.5 μs dead time
Voltage Sensor	Details
LV25-P (Voltage Sensor)	0 → 25 mA, 12 → 15 V
Potentiometer (4885293)	500Ω ±25% , 1/5W
LM285LP-1-2 (Shunt Voltage)	1.235V, 1%, 3-Pin TO-92
NMH0515DC(DC-DC Converter)	Vin 4.5 →5.5 Vdc, Vout ±15Vdc
Switches Status of SPWM	Output Voltage (V_{Load})
S_1 is on and S_2 is off	Positive V_{dc}
S_2 is on and S_1 is off	Negative V_{dc}

6. RESULT AND DISSCUSSION

In this section, the hardware model of the proposed voltage source inverter shown in Figure 1 has been implemented to evaluate the effectiveness of the optimum voltage controller using PI based harmony search algorithm (PI-HS). To evaluate the system performance based on resistive loads (R_1,R_2), it has been focused on the output voltage and current waveforms for the inverter output through the experimental and simulation results. Figure 4 shows the simulation results of the output voltage and current waveforms which validated by the experimental results, both of them are in same phase (unity power factor). This is to indicate that the relationship's efficiency between the voltage and the current is high and both of them are sinusoidal with 50 Hz, resistive load is 100 Ω (R_1), voltage value is 50.72V rms (peak value is 50.72*$\sqrt{2}$), and current value is 0.55A rms (peak value is scaled, 0.55*$\sqrt{2}$).

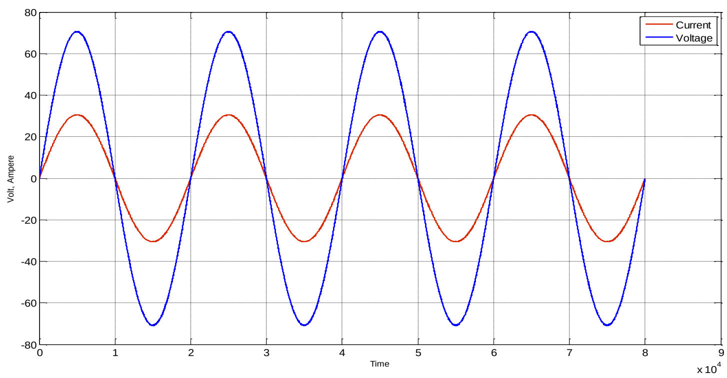

Figure 4a. Simulation output waveforms with resistive load R_1

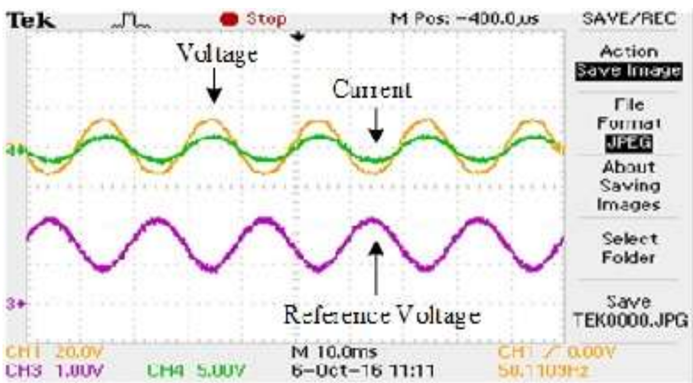

Figure 4b. Experimental output waveforms with resistive load R_1

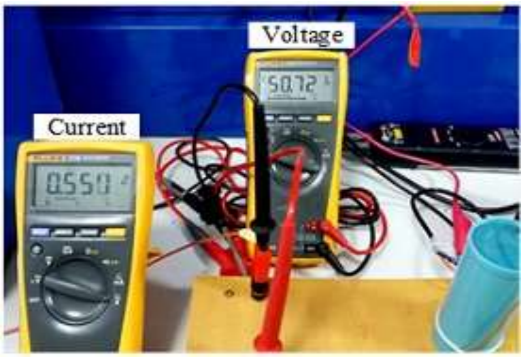

Figure 4c. Experimental output values in rms with resistive load R_1

For more analysis to see the drop voltage behavior on the inverter output without a controller, another resistive load R_2 (200 Ω) is added to the system. The simulation output responses of the voltage and current are shown in Figure 5a, 5b which validated by the experimental output responses. It is clear that the peak value of the output current is increased from 0.55*$\sqrt{2}$ to 0.737*$\sqrt{2}$ (peak value is scaled). From Figure 5c, when R_2 is added to the system, it is shown that the output voltage is dropped from 50.72V rms into 46.63V rms while the output current is increased from o.557A rms to 0.737A rms. On the other hand, the voltage and current waveforms are still in the sinusoidal form with unity power factor.

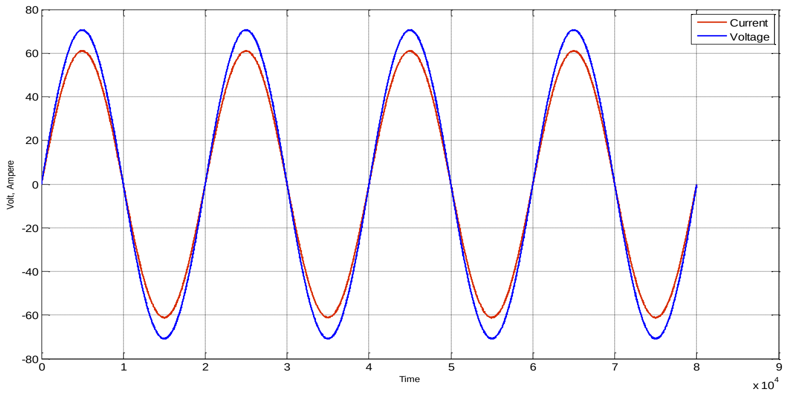

Figure 5a. Simulation output waveforms with resistive loads (R_1+R_2)

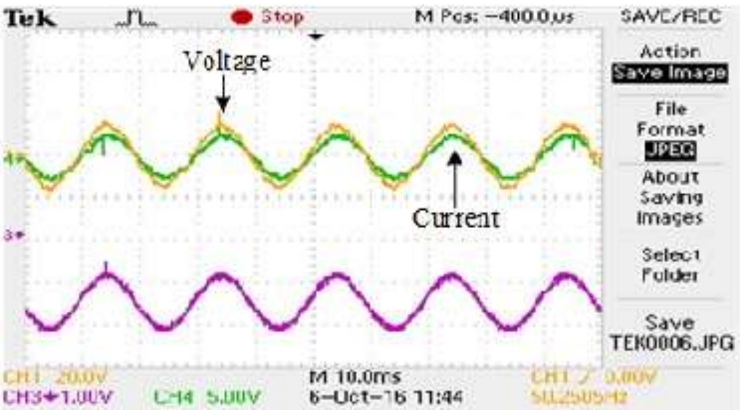

Figure 5b. Experimental output waveforms with resistive loads (R_1+R_2)

Figure 5c. Experimental output values in rms with resistive loads (R_1+R_2)

To solve the problem shown in Figure 5c, the proposed controller is used. Figure 6 shows the voltage value in rms form is fixed at 50.31V while the current value in rms form is 0.782A. This is to confirm that the proposed controller for regulating the voltage amplitude based on the reference voltage is succeeded under different loads. Meanwhile, the proposed control algorithm for the voltage sourve inverter is sufficiently robust and stable under different loads.

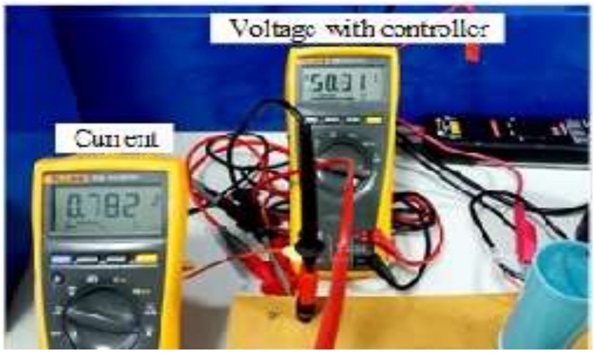

Figure 6 Experimental output values in rms with resistive loads (R_1+R_2)

To validate the efficiency and the robustness of the proposed HS-PI controller, a transient operation has been occurred to the system by step change in R_2 (deceased the load value) through the on/off switch. This changing in the R_2 load will lead to disturb the voltage and current waveforms but the voltage value must be regulated by the proposed controller depending on the error value. When the load is decreased from 600W to 300W (means R_2 is disconnected) at t is equal to $0.04\ s$. Figure 7a shows the simulation results which are validated by the experimental results as shown in Figure 7b. Based on decreasing the load, the output voltage will be increased. Therefore, the error will be calculated and then sent to the controller to choose the optimal values of K_p and K_i in order to control and keep the output voltage as close as to the reference voltage at 50Vrms. Furthermore, it is noted that from Figure 7, there is no effect of overshoot or oscillation on the output voltage waveform at the time of $0.04\ s$. This result means that the proposed control algorithm is highly efficient according to the voltage reference.

For the optimal system performance, Figure 8 displays the convergence characteristics of the developed controller (PI-HS) as compared to the convergence characteristics obtained by using PSO algorithm based PI (PI-PSO). In both optimization algorithms, same parameters are used like number of iterations, population size, dimension of problem, and the objective function in equation (3). Based on Figure 8, it is clear that the convergence of the proposed PI-HS is faster than PI-PSO. In other words, the obtained response of the overall inverter system is better and robustness under different loads conditions.

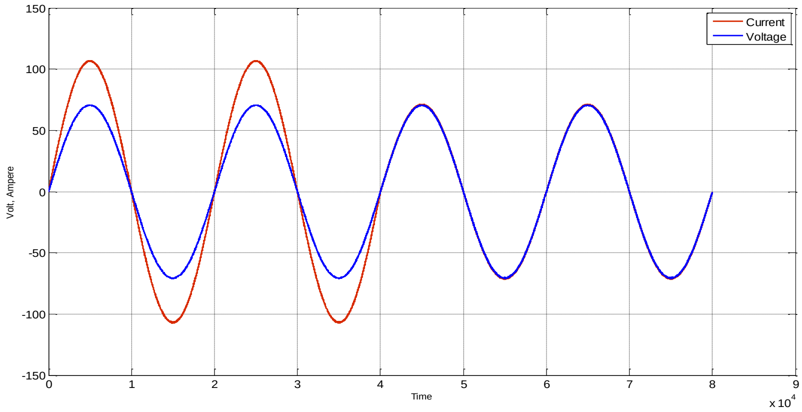

Figure 7a. Simulation output waveforms with step load change (R_2 disconnected)

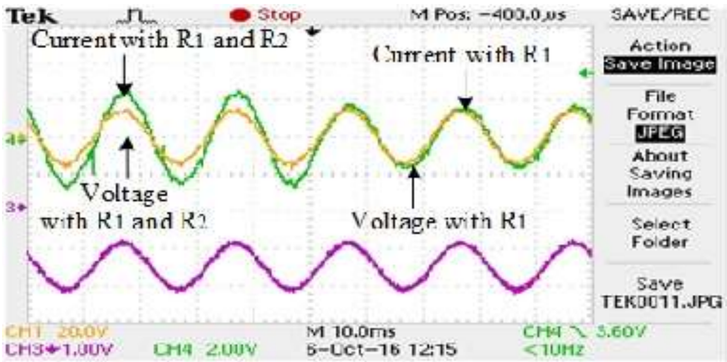

Figure 7b. Experimental output waveforms with step load change (R_2 disconnected)

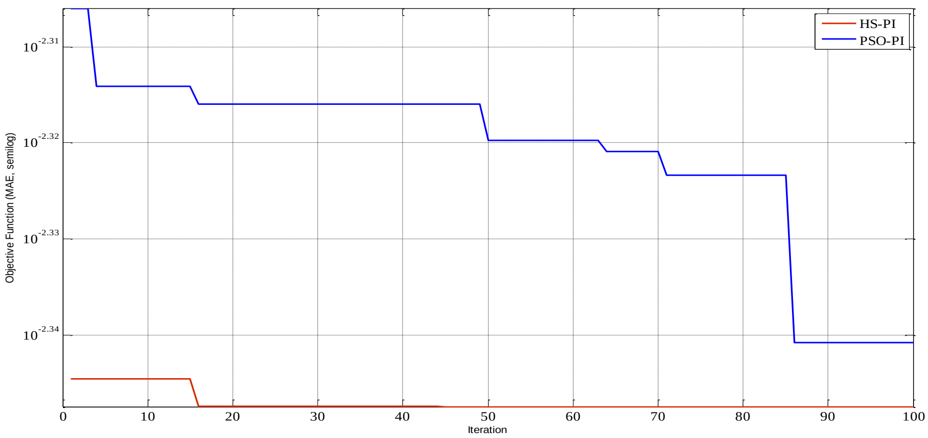

Figure 8. Objective function performances based on HS-PI and PSO-PI

Furthermore, based on a statistical evaluation, a Wilcoxon test was conducted with P-value equal to 0.05 to verify whether the obtained results by using HS-PI and PI-PSO algorithms are statistically significant. Based on the generated report, the ratio of the p-value for both PI-HS versus PI-PSO is less than 0.05 (p-value <0.05). This is to indicate that the tested iterations which done by HS-PI is statistically better than PSO-PI. In addition, the box plot based on PI-HS and PI-PSO over 50 runs is described in Figure 9 to demonstrate the effectiveness of the obtained solutions distribution by both algorithms. It is shown that the results of solutions distribution which generated by PI-HS is better than PI-PSO and the error value of the objective function (MAE) is 0.00034 for the developed controller (PI-HS) as compared to 0.0016 of the PSO-PI controller.

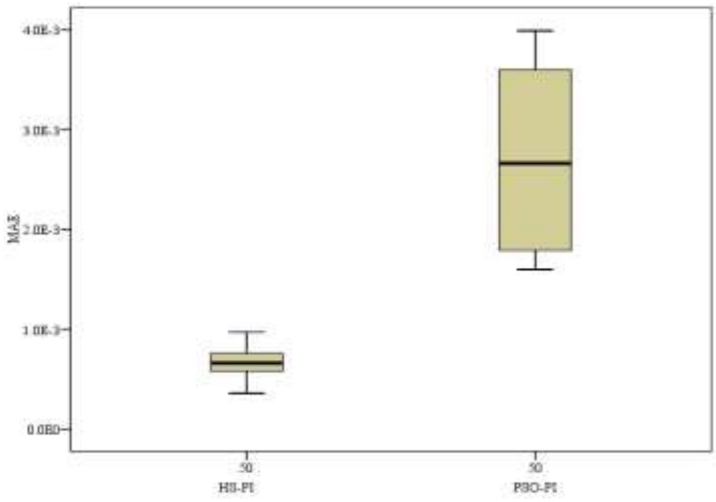

Figure 9. Box plot of solutions distribution based on HS-PI and PSO-PI

7. CONCLUSION

In this research, a PI controller for voltage source inverter based on harmony search (HS) algorithm has been developed and implemented. The procedure of trial and error in finding PI parameters has been avoided by using HS algorithm. The proposed controller has been modeled using Matlab environment and linked by the prototype inverter using eZdsp TMS320F28335 control unit. The mean absolute error (MAE) value of the proposed controller PI-HS is 0.00034 as compared to 0.0016 of the PI-PSO algorithm. Experimental results has been done under different loads to validate the proposed controller. The results showed that the proposed controller offers an efficient response in terms of output voltage and current waveforms. Meanwhile, there is no negative effects or overshoot in the output waveforms.

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Dr. Muhamad Bin Mansor received his Bachelor of Electrical Engineering (Hons) from Universiti Teknologi Malaysia, Master of Electrical Engineering Degrees in Electrical Power from Universiti Tenaga Nasional, Malaysia, and Ph.D in Power Electronics from University of Malaya, Malaysia in 2000, 2006 and 2012 respectively. He is currently a senior lecturer in the department of Electrical Power, Universiti Tenaga Nasional (UNITEN), Malaysia. His research interests are Power Electronics (Voltage Sags Compensator, solar, electric vehicle), Occupational Safety and Health, Power Quality, EMF studies, Statistical Pattern Recognition and Finite Element Analysis using Electrostatic Method. He is actively supervising Ph.D and Master candidates, undergraduate students and also interns under the Global Exchange Mobility Program.