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Z- Source Inverter Based On Sample Boost Optimized With Particle Swarm Optimization (PSO) Algorithm

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In this paper, a new approach based on the particle swarm optimization (PSO) algorithm is proposed to tune the parameters of the Sample Boost control method for the Z- Source Inverter (ZSI). The purpose of utilizing PSO technique is to minimize Total Harmonic Distortion (THD) output voltage of ZSI. The design problem of the Sample Boost control method is converted to an optimization problem with the time-domain-based objective function which is solved by a PSO technique which has a strong ability to nd the most optimistic result. The MATLAB/SIMULINK was used to verify the effectiveness of proposed control method. The simulations results prove that the Sample Boost optimized PSO algorithm has excellent ability in minimize THD output voltage toward Sample Boost.

Keywords:Z-source Inverter (ZSI); Sample Boost Control; Particle Swarm Optimization (PSO); Total Harmonic Distortion (THD)

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I Introduction

The voltage-source inverter (VSI) and current-source inverters (CSI) are two types of traditional power inverter topologies. Both inverter topologies have some limitations and theoretical barriers [1], [2]. The most important limitations of these topologies are:
- VSI and CSI act as a buck and boost inverter respectively for dc-to-ac power conversion.
- Electromagnetic interference (EMI) noise problem. In VSI both switches in a leg cannot be switched on and in CSI cannot be switched off simultaneously [3].

To overcome the limitations of conventional inverters, a new type of inverters (Z-source inverter) has been introduced by F.Z. Peng in 2003 [3]. The Z-source inverter is a new topology in power conversion, which has unique features that can conquer the limitations of VSI and CSI [3]. The Z-source inverter has the unique buck-boost capability which can ideally generate an output voltage range from zero to infinity regardless of the input voltage. This will be achieved by using a switching state that is not permitted in the VSI which is called the shoot-through state. This is the state when both upper and lower switches of a phase leg are turned on. However, Z-source also has its own shortages, such as the X-network capacitor voltage stress is very high and huge inrush current exists at Z-source inverter startup. While these problems are being conquered using the new topology proposed in the recent research article [4]. By setting a proper shoot-through duty cycle [5-10], ZSI could produce any desired output ac voltage, even greater than the input DC source voltage, which could not be achieved with conventional VSI. Pulse width-modulation (PWM) control for the Z- source inverter has to be modied to utilize the shoot-through states for voltage boost. There are various methods can be used to control Z-source inverter [5-10]. One of these methods is "sample boost". It is one of the simplest and most common boost control methods for Z-Source Inverter. Contrary to other methods, it is very simple and doesn't have the complexity of previous ones. Also it provides tremendous boost ability for Z-Source Inverter. Despite of benefits, this control method is not optimized. In this paper, PSO technique is used for optimal tuning of this control method in order to minimize the THD output voltage. PSO is a novel population based meta-heuristic, which utilizes the swarm intelligence generated by the cooperation and competition between the particle in a swarm and has emerged as the useful tool for engineering optimization. Unlike the other heuristic techniques, it has a exible and well-balanced mechanism to enhance the global and local exploration abilities. This algorithm has also been found to be robust in solving problems featuring non-linearity, on-differentiability and high-dimensionality [11], [12]. Simulation results with MATLAB verify the effectiveness of the proposed PSO based controller.

II CONSIDERATION Z-SOURCE INVERTER

A Traditional Z-Source Inverter

Fig. 1 shows the Z-source inverter topology which is composed of four main blocks: dc voltage source, Z- source network, inverter network, and AC load [3]. The DC source can be either a voltage source or a current source. The Z-source network consists of two identical inductors and L1 and L2 two identical

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capacitors C1 and C2 connected in X shape [3]. The inverter network can be single-phase or three-phase; the focus here is the three phase. The end block is an AC load, which can be connected to the load (i.e., motor), or to another converter [3]. The diode is responsible for preventing discharging the capacitor through the dc-input voltage [13]. The Z-source inverter has an additional shoot-through zero state, which is forbidden in voltage-source inverter. When the input voltage is high enough to produce the desired output voltage, the shoot-through zero state is not used and the Z-source inverter performs the buck conversion the same way as the voltage-source inverter. When the input voltage is low, the shoot-through zero state is used to boost the voltage; therefore, the Z-source inverter performs as a buckboost inverter [5-7].

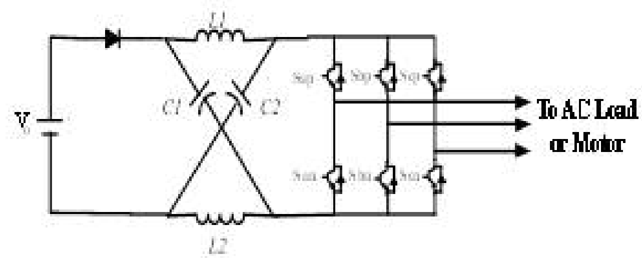

Figure 1: Traditional Z-source inverter

B Improved Z-Source Inverter

The improved Z-source inverter is shown in Fig. 2 [4]. The elements which are used are exactly the same as the previous one. The difference is that the positions of the inverter bridge and diode are exchanged and their connection directions are inversed [4]. The voltage polarity of Z-source capacitors in the proposed topology remains the same as the input voltage polarity; therefore, to get the same voltage boost, the capacitor voltage stress can be reduced to a signicant extent [4].

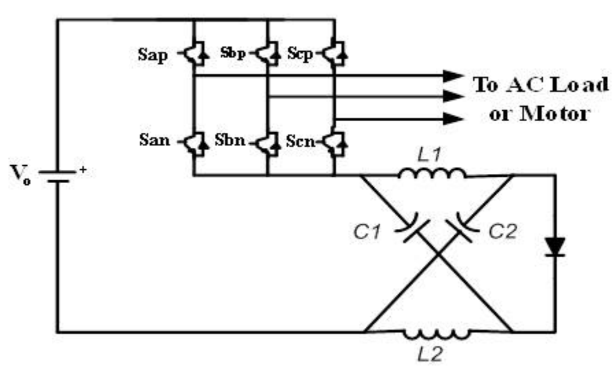

Figure 2: Improved Z-source inverter

In addition, as can be observed in Fig. 2, the topology has inherent inrush-current limitation ability compared to the previous one, because there is no current path at startup [4].

III SAMPLE BOOST CONTROL BASED PSO ALGORITHM

Pulse width-modulation (PWM) control for the Z-source inverter has to be modied to utilize the shoot-through states for voltage boost. There are various methods that can be used to control the Z-source inverter [5-10]. In this paper, a new control method for Z-source inverter is presented. This control method is Sample Boost that optimized by the PSO algorithm to achieve the minimum THD output voltage. So, firstly the Sample Boost control method should be described. In the next section, the PSO algorithm with the aim of utilizing in this control method will be explained.

A Sample Boost Control Method

In [5], a Sample Boost control method was used to control the shoot-through duty ratio. Fig. 3 illustrates the Sample Boost control method that employs a straight line (V_P) equal to or greater than the peak value of the three phase references to introduce the shoot-through duty ratio in a traditional sinusoidal PWM. Here if the triangular carrier signal is greater than V_P or smaller than V_N, the Z-source inverter is in shoot-through state. The Z-source inverter maintains the six active states unchanged as in the traditional carrier based PWM control. For this Sample Boost control method, the obtainable shoot-through duty ratio decreases with the increase of the modulation index (M). The maximum shoot-through duty ratio of the Sample Boost control methods limited to $1 - M$, thus reaching zero at a modulation index of one. The Sample Boost method is desirable for applications requiring a voltage gain of two to three.

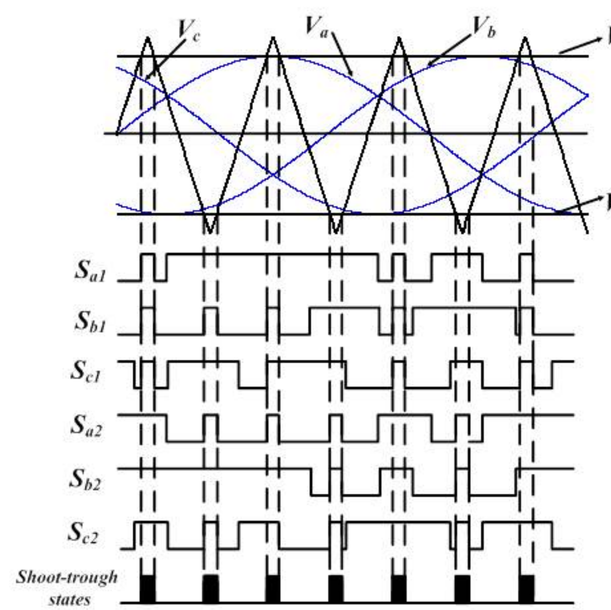

Figure 3: Simple boosting PWM generation waveforms of the ZSI

Considering the description of sample boost control method given in the previous section, it can be said that frequency of the carrier signal and shoot-through are two parameters that have a significant effect on ZSI output voltage waveform. On the other hand, duty cycle of shoot-through is $1 - M$. Therefore, modulation index M can be used to adjust the shoot-through duty cycle. In this paper, the PSO algorithm is used to optimize sample boost method for minimizing THD of output voltage. Modulation index (M) and carrier wave frequency (f_s) are optimization parameters used in this algorithm.

B PSO Algorithm

PSO which is first developed by Dr. Kennedy and Dr. Eberhart in 1995 is a population based stochastic optimization method. It is inspired by social behavior of bird flocking or fish schooling [15]. It usually is implemented to improve the speed of the convergence and also to detect the global optimum value of the objective function. It can be utilized to solve many same problems as other kinds of algorithms such as Genetic Algorithm (GA). In comparison with GA, the PSO is easy to implement, needs fewer adjustable parameters, is suitable for the nature of the problem, and is easy for coding [11], [12], [16]. So, with consideration of these merits toward other methods, the researchers are convinced to use this method widely. The PSO is launched with some initial random particles and searches for the optimal point with updating the generations.

In PSO algorithm, some simple entities which are named as particles are located in the search space of the problem or function. Each particle, at its current position, calculates the objective function and then determines its movement through the search space. The movement can be done by aggregating some facets of the history of each particles current and the best positions by other particles or more members of the swarm with some random perturbations. When all the particles have been moved, the next iteration will be happened. At last, the swarm as a hole, just like school of fish which collectively searching for food, is likely to move toward an optimum of the objective function [15], [16].

In the PSO technique, by dynamically regulating the velocity of each particle according to its own movement and the movement of the other particles, the trajectory of each individual in the search space is altered. The velocity vector and the position of a particle in the D-dimensional search space can be expressed as:

$$V_i = (V_{i1}, V_{i2}, ...V_{id}),\ X_i = (X_{i1}, X_{i2}, ...X_{id})$$

respectively. Consider a predefined objective function by the user; the best objective function obtained by particle at time ($pbest$), can be expressed as:

$$P_i = (P_{i1}, P_{i2}, ...P_{id})$$

. Furthermore, the overall best value of the objective function obtained by the particles at time ($gbest$) is calculated through the algorithm. By using the following equations, the new velocity and new position of each particle can be achieved [16], [17]:

$$\begin{aligned} V_{id}(t) &= w \times V_{id}(t-1) + c_1 r_1 (p_{id}(t-1) \\ &-X_{id}(t-1)) + c_2 r_2 \times (p_{gd}(t-1) - X_{id}(t-1)) \end{aligned} \quad (1)$$

$$X_{id}(t) = X_{id}(t-1) + cV_{id}(t) \quad (2)$$

where, $p_i d$and $p_g d$ are $pbest$ and $gbest$ respectively. c_1 and c_2 are positive constants which are responsible for alternation of the particle velocity toward $pbest$ and $gbest$. r_1 and r_2 are two random constants between 0 and 1. In order to balance the local and global searches and also to decrease the number of iterations, the w, or inertia weight is defined. The definition of inertia weight is expressed as [17]:

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter\_\max} iteration \quad (3)$$

Where, $iter_{max}$ is the maximum number of iterations and $iteration$ is the current number of iteration. The new inertia weight is updated through equation 3, where, ω_{max} and ω_{min} are initial and final weights. The flowchart of the proposed PSO algorithm for constant maximum boost control method is shown in Fig. 4.

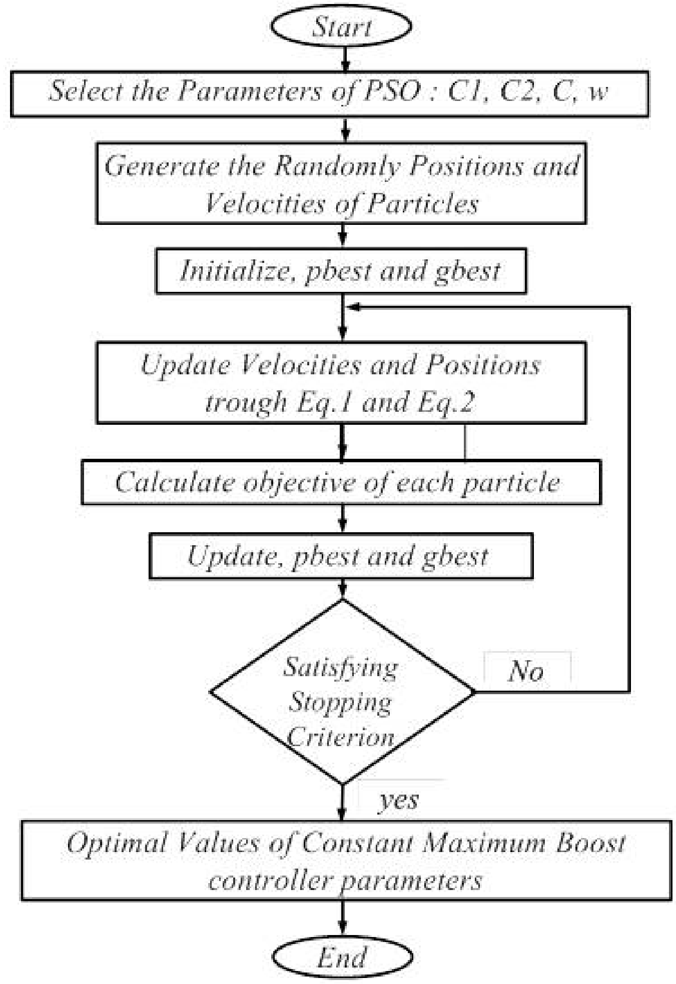

Figure 4: Flowchart of the PSO algorithm

In this paper, the PSO algorithm is selected to tune parameters M and frequency of carrier signal (f_s) in sample boost control method. It is so clear that because of the importance of minimizing the THD of output voltage for increasing the output quality in the ZSI inverter, the objective function presents below:

$$J = \int_0^{t_{sim}} t.|THD|.dt \tag{4}$$

Where, t_sim is the simulation time. The main aim of optimization is to minimize the objective function due to constrain:

$$M^{\min} \leq M \leq M^{\max} \tag{5}$$

$$f_s{}^{min} \leq f_s \leq f_s{}^{max} \tag{6}$$

The PSO algorithm searches for the optimal values of parameters above in range of: [0.5, 0.9] for M and [1000, 3000] Hz for f_s. With implementing the time domain simulation model of the sample system on simulation period, the objective function is computed and after reaching to specified criterion, the optimal parameters of the controller will be achieved. The parameters yielded from PSO algorithm are $M = 0.821996$ and $f_s = 2500$.

IV SIMULATION RESULTS AND DISCUSSION

In order to better assess the capability of the designed PSO based Sample Boost method control toward Sample Boost control method, time-based simulation of the proposed system is utilized. Simulations were conducted with the conguration shown in Fig. 5. The simulation parameters are:
1) DC power source: V_{dc} = 200V
2) Z-source network: $L_1 = L_2 = 0.5mH$, $C_1 = C_2 = 1mF$;
3) Output filters: $L_f = 500e^{-6}H$, $C_f = 15e^{-6}F$;
4) Load: three-phase resistance load R_L = 15Ω/phase

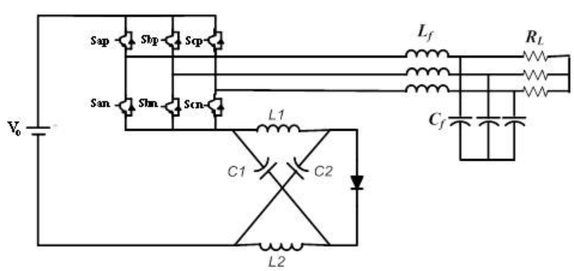

Figure 5: System configuration

The simulation results with the modulation index (M=0.8) and frequency of carrier signal (f_s=2500 Hz) arbitrary is shown in Fig. 6 and Fig. 7 for Sample Boost control method. Fig. 6 and Fig. 7 show the output voltage and THD of output voltage respectively. The THD value is 6.81
Operation of PSO algorithm is shown in Fig. 8. In this figure, the minimum cost versus iteration is plotted. The min cost is the minimum objective function in each iteration.
The simulation results with the modulation index (M = 0.821996) and frequency of carrier signal (f_s =2500 Hz) that optimized by PSO algorithm is shown in Fig. 9. From the simulation waveform of Fig. 9, it is clear that the output voltage

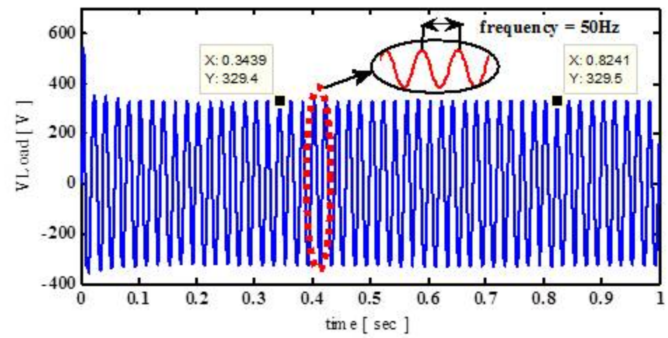

Figure 6: Output voltage of Z- Source Inverter based Sample Boost Control

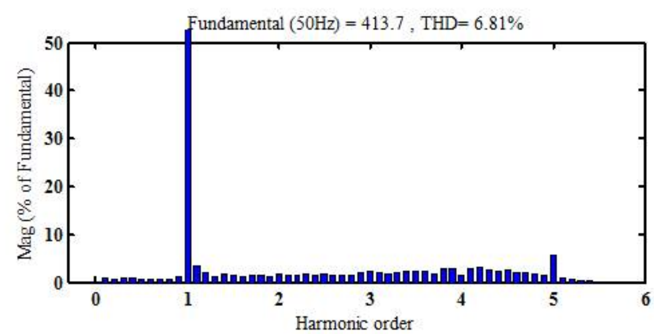

Figure 7: FFT analysis of Z- Source Inverter based Sample Boost Control

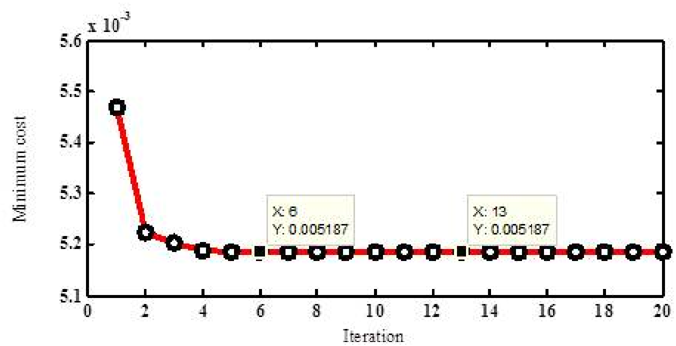

Figure 8: Operation of PSO algorithm

is boosted and the output line-to-line is 197.56 Vrms or 279.4 Vpeak.
This circuit is simulated in MATLAB and the harmonics are obtained using FFT analysis. Fig. 10 shows the harmonics represent in the output voltage. The THD value is 3.35 percent. This value of THD shows better performance of the PSO algorithm that the Modulation Index and frequency of carrier signal parameter are optimized.

V CONCLUSION

In this paper, tuning of Sample Boost control method parameters is studied for the ZSI by means of PSO algorithm. The shoot trough and frequency of carrier signal parameters

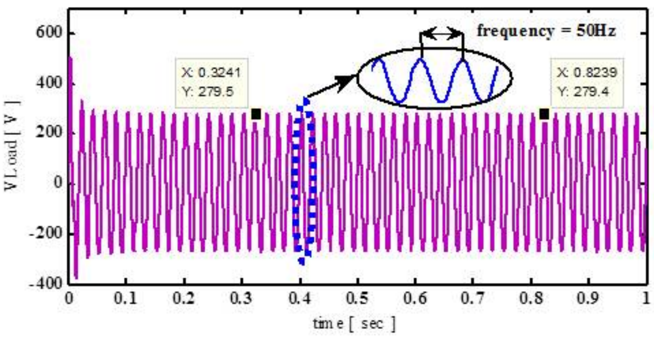

Figure 9: Output voltage of Z- Source Inverter based Sample Boost Control optimized with PSO algorithm.

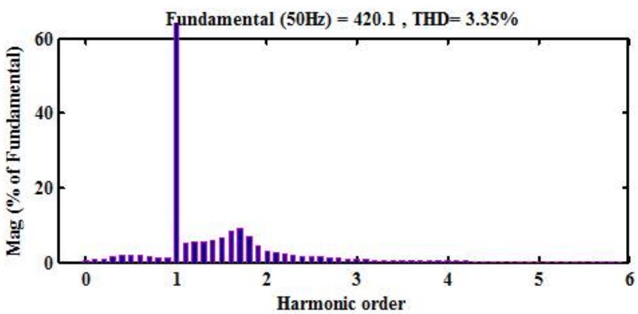

Figure 10: FFT analysis of Z- Source Inverter based Sample Boost Control optimized with PSO algorithm.

in this control method have an important role. On the other hand, the shoot trough parameter is equal 1-M. Thus, the shoot trough parameter can be controlled by adjusting the modulation index (M) parameter. The modulation index and frequency of carrier signal parameters in this control method is optimized through PSO algorithm by minimizing the objective function of the algorithm. Simulation results verified that the Sample Boost Control optimized with PSO algorithm operates fine. consequently, the Sample Boost control method optimized with PSO algorithm is a good candidate in minimizing the THD output voltage.

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