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Z-SOURCE INVERTER BASED ON CONSTANT MAXIMUM BOOST OPTIMIZED WITH PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

A. Lak [1] **D. Nazarpour** [1] **S.H. Hosseini** [2]

1. Department of Electrical Engineering, Urmia University, Urmia, Iran
akbar.lak@urmia.ac.ir, d.nazarpour@urmia.ac.ir
2. Department of Electrical and Computer Engineering, Tabriz University, Tabriz, Iran, hosseini@tabrizu.ac.ir

Abstract- In this paper, a new approach based on the particle swarm optimization (PSO) algorithm is proposed to tune the parameters of the Constant Maximum Boost control method for the Z-Source Inverter (ZSI). The purpose of utilizing PSO technique is to minimize Total Harmonic Duration (*THD*) output voltage of ZSI. The design problem of the Constant Maximum 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 find the most optimistic result. The Matlab/Simulink was used to verify the effectiveness of proposed control method. The simulations results prove that the Constant Maximum Boost optimized PSO algorithm has excellent ability in minimize *THD* output voltage toward Constant Maximum Boost.

Keywords: Z-Source Inverter (ZSI), Particle Swarm Optimization (PSO), Total Harmonic Distortion (*THD*).

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:

1- VSI and CSI act as a buck and boost inverter respectively for dc-to-ac power conversion.

2- 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 or ZSI) has been introduced by F.Z. Peng in 2003 [3]. The Z-source inverter (ZSI) 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 (ZSI) 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 [10-13], 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 modified to utilize the shoot-through states for voltage boost.

There are various methods can be used to control Z-source inverter [5-10]. In [5], a simple boosting method was used to control the shoot-through duty ratio. Using the simple boosting method, the voltage stress across the switches is quite high, which will restrict the obtainable voltage gain because of the limitation of device voltage ratings [9].The maximum boosting strategy explained in [9] as an alternative to the simple boosting method. The maximum boosting method can achieve the minimum voltage stress across the switches. However, it has the drawbacks of low- frequency ripples on the Z-source network, which is shown in [10]. Another boosting method proposed to achieve maximum possible voltage boost/gain while maintaining a constant boost viewed from the Z-source network and producing no low-frequency ripples associated with the output frequency is explained in [10].

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 flexible 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, non-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

Figure 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 L_1 and L_2 and two identical capacitors C_1 and C_2 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 buck-boost inverter [5-7].

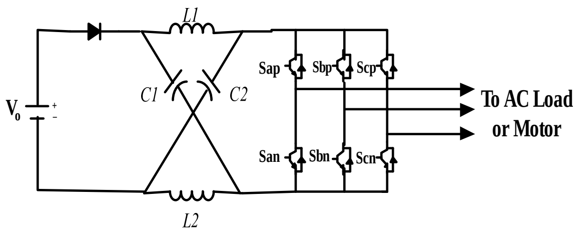

Figure 1. Traditional Z-source inverter

B. Improved Z-Source Inverter

The improved Z-source inverter is shown in Figure 2 [10]. 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 [10]. 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 significant extent [10].

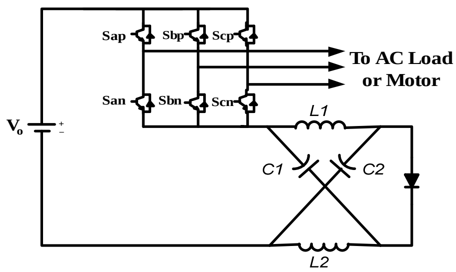

Figure 2. Improved Z-source inverter

In addition, as can be observed in Figure 2, the topology has inherent inrush-current limitation ability compared to the previous one, because there is no current path at startup [5].

III. MAXIMUM CONSTANT BOOST CONTROL BASED PSO ALGORITHM

Pulse width-modulation (PWM) control for the Z-source inverter has to be modified to utilize the shoot-through states for voltage boost. There are various methods that can be used to control the Z-source inverter [5-11]. In this paper, a new control method for Z-source inverter is presented. This control method is Maximum Constant Boost that optimized by the PSO algorithm to achieve the minimum *THD* output voltage. So, firstly the Maximum Constant 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. Maximum Constant Boost Control

This control method achieves maximum boost while maintaining a constant shoot-through duty ratio throughout; thus it results in no line frequency current ripple through the inductors. The PWM control map of maximum constant boost control is shown in Figure 3. By using this method, the inverter can buck and boost the voltage from zero to any desired value smoothly within the limit of the device voltage [9, 10].

Figure 3 shows the sketch map of the constant boosting method proposed in [10], which achieves the maximum voltage gain while always keeping the shoot-through duty ratio constant. There are five modulation curves in this control method: three reference signals (V_a, V_b and V_c), and two shoot-through envelope signals (V_p and V_N). When the carrier triangle wave is higher than the upper shoot-through envelope V_p or lower than the bottom shoot-through envelope V_N, the inverter is turned to a shoot-through zero state. Otherwise, it operates in the traditional PWM mode.

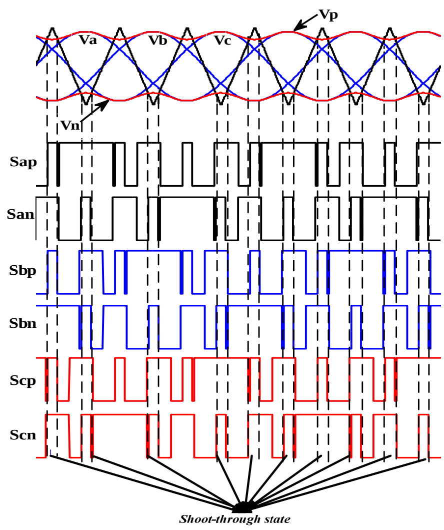

Figure 3. Constant boosting PWM generation waveforms of the Z-source inverter

For the first half-period, $[0, \pi/3]$ in Figure 3, the upper and lower envelope curves can be expressed by Equations (1) and (2), respectively.

$$V_{P1} = \sqrt{3}M + \sin(\theta - \frac{2\pi}{3})M \quad \text{for } 0 < \theta < \frac{\pi}{3} \quad (1)$$

$$V_{N1} = \sin(\theta - \frac{2\pi}{3})M \quad \text{for } 0 < \theta < \frac{\pi}{3} \quad (2)$$

For the 2nd half-period $[\pi/3, 2\pi/3]$, envelope curves are expressed by Equations (3) and (4).

$$V_{P2} = \sin(\theta)M \quad \text{for } \frac{\pi}{3} < \theta < \frac{2\pi}{3} \quad (3)$$

$$V_{N2} = \sin(\theta)M - \sqrt{3}M \quad \text{for } \frac{\pi}{3} < \theta < \frac{2\pi}{3} \quad (4)$$

The voltage stress for the constant boosting method was derived in [10] as

$$V_S = BV_g = (\sqrt{3}G - 1)V_g \quad (5)$$

As can be seen from Figure 4, the constant boosting method has a much lower voltage stress across the devices than the simple boosting method, while having a slightly higher voltage stress than the maximum boosting method. The ideal voltage-stress ratio is one. The constant boosting method is highly desirable for applications which require a voltage gain of two to three. Also the constant boosting method requires the minimum inductance and capacitance because inductor current and capacitor voltage contain no low- frequency ripples associated with output voltage, thus reducing cost, volume, and weight of Z-source network [10].

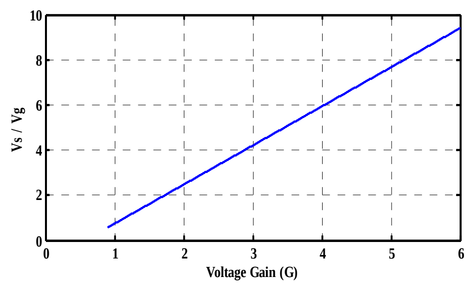

Figure 4. Switch voltage stress versus voltage gain in constant boosting method

The explanation that was given to this control method can be concluded that the shoot trough parameter in this control method has 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. Optimization of the Maximum Constant Boost Control method algorithm for optimization of the *M* parameter is proposed.

B. PSO Algorithm

PSO which is first developed by Kennedy and 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 particle's 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 ith particle in the D-dimensional search space can be expressed as: $V_i = (V_{i1}, V_{i2}, \ldots V_{id})$, $X_i = (X_{i1}, X_{i2}, \ldots X_{id})$ respectively.

Consider a predefined objective function by the user; the best objective function obtained by ith particle at time ($pbest$), can be expressed as: $P_i = (P_{i1}, P_{i2}, \ldots P_{id})$. 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]:

$$V_{id}(t) = w \times V_{id}(t-1) + c_1 r_1 (p_{id}(t-1) - X_{id}(t-1)) + \\ + c_2 r_2 \times (p_{gd}(t-1) - X_{id}(t-1)) \quad (6)$$

$$X_{id}(t) = X_{id}(t-1) + cV_{id}(t) \quad (7)$$

where, p_{id} and p_{gd} are $pbest$ and $gbest$, respectively. The c_1 and c_2 are positive constants which are responsible for alternation of the particle velocity toward $pbest$ and $gbest$. The 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]:

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter\_\max} iteration \quad (8)$$

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, $w_{\max}$ and $w_{\min}$ are initial and final weights. The flowchart of the proposed PSO algorithm for constant maximum boost control method is shown in Figure 5.

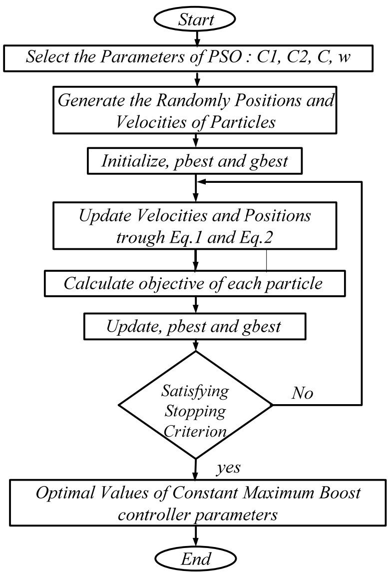

Figure 5. Flowchart of the PSO algorithm

In this paper, the PSO algorithm is selected to tune parameter M in constant maximum 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:

$$J = \int_{0}^{t_{sim}} t.|THD|.dt \tag{9}$$

where, t_{sim} is the simulation time. The main aim of optimization is to minimize the objective function due to constrain:

$$M^{\min} \le M \le M^{\max} \tag{10}$$

The PSO algorithm searches for the optimal values of parameters above in range of: $[0.001-0.99]$ for M. 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 M parameter is yielded from PSO algorithm is included as 0.879781.

IV. SIMULATION RESULTS AND DISCUSSION

In order to better assess the capability of the designed PSO based constant maximum boost method control toward constant maximum boost control method, time-based simulation of the proposed system is utilized. The simulation parameters are:

1) DC power source: $V_{dc} = 250$ V
2) Z-source network: $L_1 = L_2 = 500$ μH, $C_1 = C_2 = 1000$ μF
3) Output filters: $L_f = 500$ μH, $C_f = 15$ μF
4) Switching frequency: 10 KHz
5) Load: three-phase resistance load $R_L = 15$ Ω/phase

The simulation results with the modulation arbitrary are shown in Figures 6 and 7 for constant maximum boost control method. Figure 6 and Figure 7 show the output voltage and *THD* of output voltage respectively. The *THD* value is 7.18%.

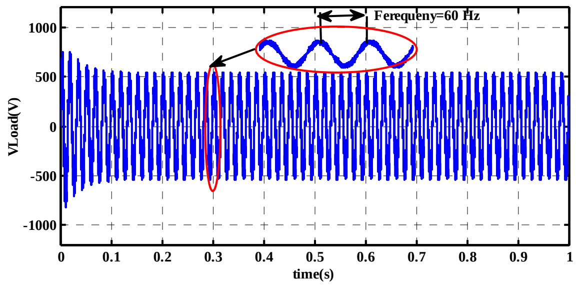

Figure 6. The output voltage of Z-source inverter based maximum constant boost control

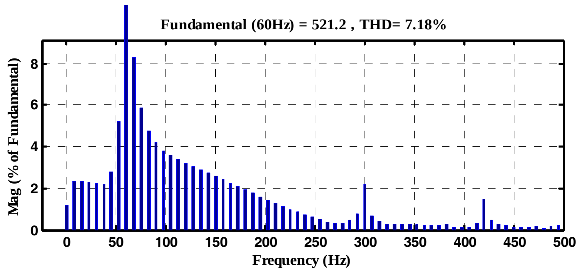

Figure 7. The FFT analysis of Z-source inverter based maximum constant boost control

The simulation results with the modulation index *M*=0.879781 that optimized by PSO algorithm is shown in Figure 8. From the simulation waveform of Figure 8, it is clear that the output voltage is boosted and the output line-to-line is 237.3 V_{rms} or 335.6 V_{peak}.

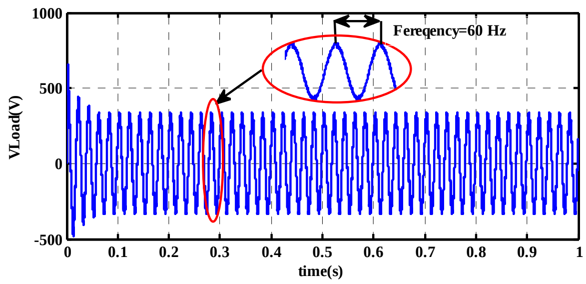

Figure 8. The output voltage of Z- Source Inverter based Maximum Constant Boost Control optimized with PSO algorithm

This circuit is simulated in Matlab and the harmonics are obtained using FFT analysis. Figure 9 shows the harmonics represent in the output. The *THD* value is 4.10%. This value of *THD* shows better performance of the PSO algorithm that the Modulation Index (M) parameter is optimized.

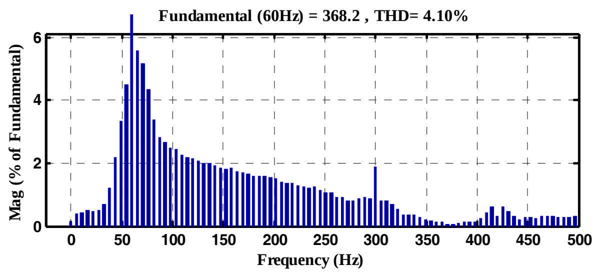

Figure 9. The FFT analysis of Z-source inverter based maximum constant boost control optimized with PSO algorithm

V. CONCLUSIONS

In this paper, tuning of constant maximum boost control method parameter is studied for the ZSI by means of PSO algorithm. The shoot trough parameter in this control method has 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 *M* parameter this control method is optimized through PSO algorithm by minimizing the objective function of the algorithm. Simulation results verified that the Maximum Constant Boost Control optimized with PSO algorithm operates fine. Hence, can be said the Maximum Constant Boost control method optimized with PSO algorithm is a good candidate in minimize the THD output voltage.

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BIOGRAPHIES

Akbar Lak was born in Khoy, Iran in 1988. He received the B.Sc. degree from Allameh Mohaddes Noori University (Noor, Iran). Currently, he is studying his M.Sc. on Electrical Engineering in Urmia University (Urmia, Iran). His research interests are in the area of advanced power electronics, Z-source inverter, power system dynamics, and flexible AC transmission systems (FACTS).

Daryoush Nazarpour was born in Urmia, Iran in1958. He received his B.Sc. degree from Iran University of Science and Technology, Tehran, Iran in 1982 and the M.Sc. degree from Faculty of Engineering, University of Tabriz, Tabriz, Iran in 1988. He received the Ph.D. degree from Tabriz University, in 2005 in Electrical Power Engineering. He is now an Assistant Professor in Urmia University, Iran. His research interests include power electronics, and flexible AC transmission system (FACTS).

Seyed Hossein Hosseini was born in Marand, Iran in 1953. He received the M.Sc. degree from Faculty of Engineering, University of Tabriz, Tabriz, Iran in 1976 and the Ph.D. degree from INPL, France, in 1981 all in Electrical Engineering. In 1982, he joined University of Tabriz, Iran, as an Assistant Professor in Department of Electrical Engineering. From 1990 to 1995 he was an Associate Professor and since 1995 he has been a Professor in the same university. He was also been visiting professor in the Universities of Queensland, Australia and Western Ontario, Canada in (1990-1991) and (1996-1997), respectively. He has published more than 160 papers in the national and international conferences and more than 40 papers in the national and international journals. His research interests include power electronics, reactive power control, harmonics and power quality compensation systems.