ANN Switched Z-Source Inverter based PV Generation System under Partial Shading

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Abstract: Solar Energy Systems (SES) are grooming nowadays due to their own merits. The system consists of DC-AC converter network. In this paper, Z-Source inverter based SES has been proposed. In order to improve the efficiency of the system, Artificial Neural Network (ANN) based switching scheme is suggested to trigger the switches of the inverter circuit. The proposed scheme has been simulated using MATLAB/Simulink and the results have been presented. The results depict that the proposed scheme has reduced THD of 4.81%, compared to its conventional counterpart and can be used even under partial shadowing conditions of the SES.

Keywords: Z-Source Inverter, Multi-Level Inverters, THD, ANN, feedforward

I. INTRODUCTION

Photo Voltaic (PV) System based electrical power generation; called Solar Energy Systems (SES) has become popular nowadays, due to the revolution of green and clean energy. Solar energy is abundantly available. The system is noiseless and needs a little maintenance. The size of the system depends on the power capacity, which makes the system to be more robust and compact. Day by day, much advancement has been taking place in the solar energy conversion technologies. Efforts have been taken by researchers on the aspects of delivering the quality power generated from the solar energy system to the consumers. The main problem with the solar energy systems is the ways to increase the output voltage. Generally, a number of solar panels are being connected in series to increase the output voltage. The drawbacks of this method include low reliability and poor efficiency. The output voltage of the PV cell being DC is converted into AC through inverter and is fed to the consumer. The conversion of DC to AC is effected through inverters and in particular Multi-Level Inverters (MLI). In these MLI based SES modules, the output of the PV cell are modulated through DC-DC converters and then fed to the MLIs. Z-Source inverter is another type of inverter topology that doesn’t require DC-DC converter. The recent investigations are focusing on the development of new algorithms for DC-AC conversion, in order to improve the conversion efficiency. The conventional method is to step-up the AC output voltage through a step-up transformer. 3-Phase MLIs are also employed in the SES[1]. The problems associated with these conventional methods are electromagnetic interference, size, acoustic noise and high cost[2]. To overcome, these drawbacks, the Z-Source inverters have been suggested. [3-5]. These inverters employ less number of switches compared to the conventional inverters.

The model of the Z-source inverter has been developed and analyzed for its transient characteristics [6 & 7]. The proper switching of the switches in the z-source inverter yields better performance and efficiency [8 - 10]. In this paper, the Artificial Neural Network (ANN) based switching scheme for the Z-source inverter has been proposed for improving the performance of the SES. The proposed scheme has been simulated using MATLAB/Simulink. A comparative analysis has been made
between the conventional Pulse Width Modulated (PWM) Inverter and the proposed Z-Source Inverter scheme.

II. SES CONFIGURATION

Fig. 1. Conventional VSI based SES

Fig. 2. Z-Source Inverter based SES

Figures 1 and 2 depicts the system configuration of conventional and proposed Z-Source inverter based SES. The advantage of Z-Source topology is that it can either buck or boost the voltage/ current levels with a single circuit. This cannot be achieved through the PWM based Voltage Source Inverters (VSI). In this proposed system, the Z-source inverter acts as a boost converter and supplies sinusoidal voltage to the load.

It is generally known that the output voltage of PV array varies widely under different irradiance and environment temperature, the typical ratio of the maximum output voltage and the minimum is 2:1, and even bigger. Thus in order to get steady ac voltage, grid-connected PV system should have the ability to buck/boost voltage. What’s more, to enhance the efficiency of PV array, grid-connected PV system also should have the ability to make PV array output maximum power. A model-based control algorithm can be used to control a switching matrix that connects a solar adaptive bank to a fixed part of the PV array. Similarly, dynamic electrical array reconfiguration can be used to improve the PV energy production during partial shadowing conditions. A controllable switching matrix can also be used between the PV generator and the central inverter to allow electrical reconnection of the available PV modules so that the maximum energy efficiency can be achieved.
III. MATHEMATICAL MODEL OF Z-SOURCE INVERTER

Fig. 3 depicts the equivalent circuit model of Z-Source inverter under non-shoot through and shoot through state conditions. Assumptions made in the design are as follows:

L1 = L2 and C1 = C2. This results in a symmetrical Z-Source network, where the voltage across inductors and capacitors are as given in Equations 1 & 2.

\[ V_{c1} = V_{c2} = V_c \]  
\[ V_{l1} = V_{l2} = V_L \]  

During the shoot-through zero state for an interval (T0) during a switching cycle (TZ), \( V_L = V_C \), \( V_d = 2V_C \), \( V_0 = 0 \)

\[ VL = V0 - VC, V0 = VC - VL = 2VC - V_pv \]  

Now consider that the inverter bridge is in one of the eight non-shoot-through states for an interval of T1, during the switching cycle,

\[ TZ VL=V0 – VC, V0= VC – VL = 2VC – V_pv \]

Where \( V_pv \) is the output DC voltage of PV panel and \( TZ = T0+T1 \). The average voltage of the inductors over one switching period T should be zero in steady state.

From Equations 3 & 4, the voltages across inductors and capacitors are obtained as

\[ VL= [T0 VC + T1 (Vpv – VC)] / TZ =0 \]  
\[ VC / V_pv = T1/ (T1- T0) \]
The average DC link voltage is
\[ V_0 = \frac{T_1}{(T_1-T_0)} V_{pv} \]  \hspace{1cm} (7)

The peak DC-link voltage across the inverter bridge is expressed in Equation 4 can be rewritten as:
\[ V_0 = B \cdot V_{pv} \] \hspace{1cm} (8)

Where, \( B = \frac{T_Z}{(T_1-T_0)} = \frac{1}{(1-2T_0/T_Z)} \geq 1 \)

The DC-link voltage is the boost factor resulting from the shoot-through zero state. The output voltage from the inverter is represented by
\[ V_{ac} = \frac{M \cdot V_0}{2} \] \hspace{1cm} (9)

Here, \( M \) is the modulation index.

From Equations 8 & 9, the output of the inverter is expressed as
\[ V_{ac} = M \cdot B \cdot V_{pv} /2 \] \hspace{1cm} (10)

Equation 10, states that the output can be efficiently controlled by controlling the buck-boost factor \( M \cdot B \). Many efficient algorithms have been proposed to control the buck boost factor, which in turn determines the switching sequences of the switches in the Z-Source network.

IV. ANN BASED SWITCHING SCHEME

Feedforward Neural Network (FNN) is the simplest type of ANN where the information moves in only one direction, forward, form the input nodes, through the hidden nodes and to the output nodes. Loops or cycles are not present in this type of networks. Fig. 4 depicts the schematic of feedforward network.

![Feedforward NN](image)

Fig. 4 Feedforward NN

In this proposed Z-Source inverter the ANN method has been used to determine the buck-boost factor for switching the inverter switches. The output voltage of the system is measured and is compared with the reference voltage. The error is processed through the feedforward NN. The network in turn produces the necessary \( M \cdot B \) function which forms the gate pulses needed to trigger the switches.
V. SIMULATION RESULTS AND DISCUSSIONS

Fig. 5 Simulation Model of proposed Z-Source Inverter

Fig. 5 portrays the MATLAB/Simulink model of the proposed Z-Source Inverter model with the ANN switching scheme. The output of the inverter and its corresponding FFT analysis has been depicted in Figs. 6 & 7 respectively.

Fig. 6 Simulated output of Z-Source Inverter

Fig. 7 FFT analysis of Z-Source Inverter

Fundamental (50Hz) = 1.292, THD = 4.81%
The comparative analysis between the PWM VSI and proposed Z-Source inverter can be made from the figures 7 & 8. From the FFT analysis made it is evident that the proposed Z-Source inverter scheme results in reduced THD of 4.81% compared to its conventional counterpart.

VI. CONCLUSION

The Z-Source inverter topology with ANN based switching scheme has been modeled analyzed and simulated for the solar energy systems. The results and the corresponding FFT analysis show that the proposed ANN switched Z-Source Inverter based scheme has resulted in reduced THD. The output of the system has been observed to be more sinusoidal. The THD of the proposed scheme is 4.81%, whereas the conventional PWM scheme resulted in 6.17%. In this way, it is evident that the proposed inverter topology has an edge over the conventional scheme. Hence, it can be effectively used even when the SES is subjected to partially shadowing conditions.

REFERENCES


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