THD minimization of ZVT-ZCT Quasi Resonant SEPIC Converter with proposed Harris Hawks Optimization Technique

Nisha C Rani
Department of Electrical and Electronics Engineering
The Oxford College Engineering
Bangaluru, India
nishashamin@gmail.com

N. Amuthan
Department of Electrical and Electronics Engineering
AMC Engineering College
Bangaluru, India
amuthannadar@gmail.com

Abstract—In this paper ZVT (Zero Voltage Transition)-ZCT (Zero Current Transition) based Quasi Resonant SEPIC (QRSEPIC) converter with a Voltage Source inverter (VSI) using optimization algorithm is proposed. The proposed converter uses solar energy as its input, which is a sustainable form of energy. In this paper special attention is paid to pulse width modulation (PWM) techniques, which aim to reduce the harmonic content. The harmonics are controlled due to the switching techniques. Rigorous work has been done for the reduction of harmonic content with various algorithms and optimization technique. This paper suggests optimization control technique to generate the PWM pulses, based on Harris Hawks Optimization algorithm to minimize the objective function. For this switching control of the proposed QRSEPIC converter, the system performance is improved, and Harmonic distortion is controlled. Further computation is done for the enhancement of efficiency. Simulation studies were carried out with MATLAB/Simulink for photovoltaic systems, and it was observed that the QRSEPIC with Harris Hawks algorithm gave better results compared to other optimization methods. The proposed method achieves an efficiency of 99.01 percentage and the reduction in THD to 0.832 percentage.

Keywords—HHO (Harris Hawks Optimization), PI controller, PV (Photovoltaic), Quasi Resonant SEPIC (QRSEPIC) converter, and Total Harmonic Distortion (THD).

I. INTRODUCTION

In the energy sector, one of the main concerns today is the increasing demand for electricity every day. However, the quantity and availability of conventional energy sources is not sufficient to cover current electricity consumption. In considering the future availability of conventional energy sources, it becomes very important to use renewable energy sources together with conventional energy generation system sources to meet energy demand [1]. To overcome the current energy crisis, a renewable method is to obtain energy from the incoming solar radiation, which is known as solar energy and is free to all people around the world [2]. Several advantages are there in the solar PV system, particularly low operating costs, virtually maintenance-free and environmental friendly [3], [4], [5], [35].

The circuit consists of two bidirectional booster converters which are activated in different ways by the load. The recommended Single Stage Inverter (SSI) for bidirectional boost converter is [6]. Sliding mode control is used to generate output of AC 127 Vrms at 60 Hz. SSI-based integrated inductor circuit was developed by [7]. Impedance network with integrated grid fed by DC power source like PV etc. connected in the 3 phase circuit front portion for complete the full cycle of the operation. The Maximum power extraction from the PV is used for Perturb and Observe (P & O) algorithm.

Another Single Stage Inverter (SSI) that uses tapped inductors to drive electric motors was developed by [8]. The circuit absorbs current continuously and supplies reduced voltage to capacitors. Simple gain control is a strategy used to control cycles. The process of the Sinusoidal Pulse Width Modulation (SPWM) is used to install solid state switches. SSI with high gain was developed by [9].

Single Stage Buck Boost Inverter (SSBBI) was recommended by [10]. Patel and Agarwal [11] came up with twice the power of SSI. The chain works well even in relatively shady conditions. A buck boost SSI to generate 230 V (rms) alternating current at 50 Hz to operate a network integrated system was developed by [12]. A new topology for a single-stage buck converter is recommended by [13], a modified circuit type recommended in [14]. This two-dimensional SSI was of course developed by [14].

A high gain SEPIC circuit combined with an inductor was developed by [15]. The SEPIC converter control techniques offers the gain is used for achieve the operating speed is high, so it attains the loss is low, the use of an integrated inductor brings maximum gain, the use of an integrated inductor as opposed to two separate inductors. This eliminates basic requirements and reduces space requirements. The Quasi buck boost Single-stage converter is used to reduce the harmonics and current overshoot problems because of the control of the Pulse Width Modulation [16], [22].

A circuit based on the concept of flyback converter was developed by [17], [28],[29], [30]. The Flyback converter components are the three diode, three switches, a transformer and a central branch secondary winding. Introduced a flyback converter based SSI [18]. The average life of electrolytic capacitors depends on the ambient temperature, so at high temperatures, especially in summer, the service life of such capacitors is reduced, leading to system failure and unreliable operation. Another flyback converter is proposed by SSI [19]. The flyback-based SSI...
was proposed by [20], [27] a modified design is proposed by [21-23].

The proposed ZVT-ZCT Quasi Resonance SEPIC (QRSEPIC) converter allows the main switch (IGBT) to turn off and turn on at zero current transition and zero voltage transition, respectively by introducing inductor capacitor (L-C) dynamics and creating a forced oscillation, thus switching device stress is reduced. Here the Voltage Source Inverter is controlled using the optimization techniques. The Optimization techniques is Harris Hawks Optimization [24], [31], [32], [33], [34], [36].

The first part of this document deals with the introduction. In the second part, a description of the ZCT-ZVT Quasi resonant SEPIC Converter block diagram is described. The third section briefly discusses the optimization Techniques. The Pulse Control of voltage source inverter Using optimization technique will be discussed in section four. In section five the results are discussed in MATLAB. The end of this document is the conclusion made in section six.

II. THE PROPOSED SYSTEM BLOCK DIAGRAM DESCRIPTION

Figure.1 displays proposed work block diagram. The PV is linked to the load via ZCT-ZVT QRSEPIC converter based VSI. From the PV Array the maximum voltage and current are monitored by the Optimized Supervised MPPT Controller. During quickly altering atmospheric conditions the Incremental conductance MPPT method gives best function and in extreme energy generation as a part of Incremental conductance with integral regulator (INC-IR) algorithm utilized of the photovoltaic system. The immediate conductance I/V for MPPT algorithm is used. In randomly created conditions this method was decided to work with more efficiency.

![Proposed SEPII converter Block Diagram](image1)

In this converters are designed to reduce the switching losses. To maintain the transient response is small, improve the system performance and efficiency. This article uses a PI controller with Harris Hawks Optimization (HHO) algorithm for a VSI (Voltage Source Inverter) to convert DC to AC voltage. PV System

The photovoltaic system has one major component, namely photovoltaic cells that generate energy. R, is the series resistance which is due to interference with the direction of movement of electrons from ‘n’ to ‘p’ stop and similar stability is for the current stop. The circuit diagram of the PV cell is shown in Figure 2.

![Circuit diagram of the Quasi Resonant SEPIII converter](image2)

If the saturation current across the diode is called \( I_s \), then the electron charge is called \( q \), the diode voltage is called \( V_d \), the Boltzmann constant is called \( k \) which is \( 1.38 \times 10^(-19) \) J/K and the bonding temperature is called \( T \) in Kelvin (K).

A. Modelling of SEPII Converter

The Proposed Quasi Resonant SEPII converter circuit diagram is shown in Figure 3. Switch \( M_1 \) is in the ON state Zero Voltage Switching is occurs and the the inductance current \( L_{r1} \) increases linearly and discharges the capacitor \( C_{IN} \) through the capacitor \( C \), the inductance \( L_{r2} \) and the ohmic load, so that the current through \( L_{r2} \) also increases linearly. \( M_1 \) is in the OFF state Zero Current Switching is occurs, the inductor current decreases linearly, capacitor \( C_{IN} \) is charged, and diode begins to conduct. Energy is transferred through capacitor \( C_{IN} \).

The proposed circuit consists of Quasi resonant uses the inductor is bulk and the capacitor is introduced to connect across the diode and Switch converters. This Quasi resonant is used in the SEPII converter reduces the switching losses and increase the efficiency of the converter. In this circuit the resonant capacitors and resonant inductors are namely as follows,

1. \( C_{r1} \) and \( L_{r1} \)
2. \( C_{r2} \) and \( L_{r2} \)

The SEPII converter open loop operation is done by using the pulse width Modulation (PWM) techniques and in the closed loop the MPPT controller is used to create the resonant [26].

III. OPTIMIZATION TECHNIQUE

The process of achieving the best possible result under given limits is known as optimization. In engineering field, the engineers have to take decisions. The ambition of all such decisions is either to minimize effort to maximize benefit. Optimization problems based on the equations involved and number of objective functions. The choice of suitable optimization methods depends on the type of Optimization problems. Nowadays various advanced optimization techniques are used to minimize the THD of a Voltage Source inverter. Open loop and closed loop operation is carried out in the Simulink. In closed loop PI Controller is used for VSI switching. For comparison the PI
tuned Optimization control technique is used. The proposed Harris Hawks optimization is used for comparison.

A. Harris Hawks Optimization

The outstanding and the most intelligent Harris hawk’s behavior is finding the prey for the hunting birds that establishes the power of following along, circling, taking out and trapping a potential animals (rabbit) in food groups. Here, the first population is considered to be the group of rabbits that have been planned (solution of performance) from a variety of indicators using seven kill or shock techniques. At first, the hawk leader tried to kill him the victim; if it fails to catch an animal due to the victim’s aggressive behavior and escape behavior, change strategies followed, became another team member (eagle in group) can beat the surviving victim and catch him. The advantage of this collaboration is that the birds were able to follow the rabbits identified by the confusion and weakness of the fleeing animals. At HHO, the competition between the contestants is the Harris Hawks and the best / international solution has been targeted [25].

IV. PULSE CONTROL OF VOLTAGE SOURCE INVERTER USING OPTIMIZATION TECHNIQUE

After The VSI converts Fixed DC voltage to AC voltage with variable magnitude and frequency. Figure 4 shows the Voltage source inverter schematic representation. Six Switches are composed the voltage source inverter. The Switches are $S_{m1}$ to $S_{m6}$. The inverter each leg middle is connected to each phases. The six switches are controlled by using the proper PWM switching. In this work the switching is done by the PI Controller. To avoid the DC short circuit each leg switches are connected at interchangeably.

![Voltage Source Inverter Schematic representation](image)

The step-by-step procedure of Harris hawks Optimization algorithm for switching pulse control of Voltage Source inverter is demonstrated below.

**Step 1: Initialization:** In the first Initialize the $K_p$ and $K_i$ gain parameters of the proportional and integral, the voltage command of inverter, duty cycle and the size of population is initialized as $V_{in}(t)$ and $D$.

**Step 2: Random Generation:** The initialized gain parameters of PI controllers are generated randomly.

**Step 3: Objective Function Evaluation:** The fitness or objective function is applied to each particles and the value of fitness was evaluated with the initial random population. Based on the following equation, the fitness function was calculated. The Integral Square Error (ISE) minimize the error.

**Step 4: Position Updation:** The position of moth is updated based on the fitness function.

**Step 5: Iteration:** The limit of iteration is tested, if the range of iteration is maximum then stop, else go back to step 2.

**Step 6: Termination:** In the last the fitness function is minimize using HHO and objective function minimization is changed as to the Fitness function = 1/ISE.

The Controller gain parameters are used for THD minimization.

$$K_i = \frac{K_p}{\tau_i}.$$  

The PI controller constraints are as follows,

$$0.5 \times K_i < 1$$  

$$1 < K_p < 3$$

Therefore, the HHO, the optimal gain parameters for the PI controllers are obtained. Then the optimal control pulses are generated based on the optimized gain parameters.

V. RESULTS AND DISCUSSION

This section reports simulation results and discusses soft switching of proposes quasi resonant SEPIC converter and switching control of voltage source inverter based renewable energy sources using the proposed strategy. In the Matrix Laboratory / Simulink platform, the proposed process is being implemented. The effect of the proposed strategies and existing strategies is analyzed. Existing strategies include base, PI controller and PI tuned Harris Hawks Optimization. Table 1 shows the simulation parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductor $L_{r1}=L_{r2}$</td>
<td>200μH</td>
</tr>
<tr>
<td>Capacitor $C_{s}=C_{r1}=C_{s}$</td>
<td>1 μF</td>
</tr>
<tr>
<td>Resistor, $R$</td>
<td>100Ω</td>
</tr>
<tr>
<td>Switch MOSFET</td>
<td>IRF840</td>
</tr>
<tr>
<td>Input voltage</td>
<td>300V, DC</td>
</tr>
</tbody>
</table>

Figure 5 is a present simulation of a PV based Quasi Resonant SEPIC converter. The PV based Quasi Resonant SEPIC converter was designed as a Simulink. This enables reducing the switching losses and also the minimization of THD. Figure 6 shows the subsystem model of the PV system. SEPIC converter operates the output voltage is greater than the input voltage. This is called boost operation. During boost operation, the instantaneous voltage level is 400 V. The PV based QRSEPIC is used for 0.5sec in the MATLAB / Simulink software. This converter also has the capability to provide improved power factor correction, low input current distortion and wide voltage range capability. By using this converter, THD can be minimized significantly while still maintaining high power efficiency. One of the main goals in designing this converter was to minimize the total harmonic distortion (THD) of the output voltage waveform. Various parameters and conditions were tested for their effects on THD, such as input voltage, switching frequency, load resistance and inductor value.

![Simulink model of the PV based Quasi Resonant SEPIC converter](image)
A. Photovoltaic System

The Solar Photovoltaic Panel is modelled on this paper according to the electrical features of the panels that provide information on the operating condition of the system. The input value of the irradiance is maintained at 1000W/m² and the reference temperature is at 25°C. Figure 7 and Figure 8 showing the voltage and current of the photovoltaic system. The total output voltage obtained is 300V. The total current generated by the PV system is 50A.

B. Converter Operation

The proposed converter ZVT-ZCT switching is compared with open loop, closed loop and the optimization techniques. The Open loop switching operation is shown in Figure 9 (a), Figure 9 (b) shows the ZVT-ZCT switching of using MPPT controller and Figure 9 (c) shows the MPPT controller based Incremental conductance with integral regulator techniques. From the switching techniques, the MPPT based Incremental conductance with integral regulator produces the switching loss is 3%. The open loop operation is used for pulse generator to produce the duty cycle. So, it has the switching loss is 45% and the closed loop operation the switching loss is 8%.

For SEPIC converter the working is the output voltage is less than or greater than or equal to the input voltage. Here the PV is used as the Input. The Input voltage is 300V. So, the converter changes this input to output is 400V.
C. Control Algorithm

The proposed converter switch is controlled by using the MPPT algorithm. The MPPT is used to generate the switching pulse of the SEPIC converter. Depending on the duty cycle the Quasi Resonant SEPIC converter output voltage is increased or decreased. This Quasi resonant reduces the switching losses. The output voltage is obtained by controlling the duty cycle of the converters. The values of the parameters selected for the optimization algorithm are given in Table 2. Thus, the parameters are used for the optimization algorithm to obtain the optimal values of the PI controller. This progresses to the maximum number of repetitions. In this way, the best particles are found by optimization technique, i.e., The best PI control parameters, obtained by minimizing the objective function. Table 3 shows the Kp and Ki parameter comparison. The grid side voltage and current comparison is shown in Figure 12.

TABLE II. PARAMETER VALUE SELECTED FOR ALGORITHM

<table>
<thead>
<tr>
<th>HHO PARAMETERS</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of values</td>
<td>30</td>
</tr>
<tr>
<td>Number of iteration</td>
<td>500</td>
</tr>
</tbody>
</table>

![Grid Side Current Comparison](image)

From Figure 12 the obtained THD is listed in the below Table 3 and Table 4. In this section THD minimization comparison is presented. Without using PI controller, the induced THD is 49.02%. By using PI controller, the THD is 40.12% only minimized. So, for better improvements HHO optimization is selected and reduced THD is only 0.832%. To compare the THD with the without using PI, PI, and HHO controlled Voltage Source inverter circuit, the proposed HHO is provided for 0.832% THD.

VI. CONCLUSION

This paper presents a new optimization control technique for a Voltage Source inverter based on ZVT-ZCT Quasi Resonant SEPIC converter. To generate the PWM pulses, the Harris Hawks Optimization Technique algorithm is used to minimize the objective function. The objective function that needs to be minimized is associated with THD. This work describes the Harris Hawks optimization technique incorporated with the pulse width modulation technique to produce better performance. Depending on the duty cycle the Quasi Resonant SEPIC converter output voltage is increased or decreased. This Quasi resonant reduces the switching losses. The proposed optimization technique minimizes the THD. Simulation studies were carried out with MATLAB/Simulink for photovoltaic systems, and it was observed that the inverter based HHO gave better results compared to other optimization techniques. Further computation is done to enhance the performance. The proposed method achieves the 99.01% of efficiency Compared to the existing switching techniques the proposed inverter with HHO reduces the THD by 0.832% for HHO. Therefore, by using resonant the switching losses are reduced, compared to the existing work the efficiency is improved and also improved the system performance.

VII. FUTURE WORK AND LIMITATION

In the future the work is extended to compare various other converters.

The limitation of the algorithm is low convergence speed, premature convergence, and ease of falling into a local optimum.

TABLE III. THD AND EFFICIENCY COMPARISON

<table>
<thead>
<tr>
<th>Control Technique</th>
<th>Kp</th>
<th>Ki</th>
<th>THD (%)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without using PI controller</td>
<td>-</td>
<td>-</td>
<td>49.02</td>
<td>75</td>
</tr>
<tr>
<td>With PI controller</td>
<td>2</td>
<td>0.76</td>
<td>40.12</td>
<td>87</td>
</tr>
<tr>
<td>HHO</td>
<td>1</td>
<td>0.65</td>
<td>0.832</td>
<td>99.01</td>
</tr>
</tbody>
</table>

TABLE IV. DIFFERENT TECHNIQUES FOR SWITCHING THD COMPARATIVE ANALYSIS

<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Reference</th>
<th>Switching technique</th>
<th>THD (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>[F. Chabni et al., 2018]</td>
<td>PSO based SHE-</td>
<td>4.46</td>
</tr>
</tbody>
</table>

REFERENCE


[16] Inverter SB., Khan AA., Member S., Cha H., Ahmed HF. "A highly reliable and high efficiency quasi. vol. 8993, no. c; 2016.


