Augmented ASC Network for Photo Voltaic Applications

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ABSTRACT - This work uses a DC-DC converter that employs an Active Switched Capacitor (ASC) to provide high gain that makes it appropriate for the Photo Voltaic (PV) system. The transformer less converter with an ASC network consists of a capacitor and a diode that boosts voltage effectively. The well-liked converter operates effectively on both Continuous Conduction Mode (CCM) and Discontinuous Conduction Modes (DCM). The suggested topology of converter is easy to design, and it renders a less stress on auxiliary diode and capacitors. This preferred converter scheme is validated through MATLAB Simulink and the outcomes are confirmed using hardware prototype.

Keywords: Continuous Conduction Mode; high gain DC-DC converter; Active switched capacitor and Perturb and observe.

1. INTRODUCTION

Step up converters are the class of converters that lifts the voltage to high value. Photovoltaic (PV) panels and battery sources generate low voltage outputs which should be increased to high voltages for grid-tied and standalone applications [1]. High gain converters are essential for renewable energy applications like photo voltaic systems, fuel cells etc. [2]. In [3], boost converter designed with switched inductor configuration is described. In order to boost voltage gain, Active Switched Inductor (ASL) converters are combined with Active Switched Capacitor (ASC) and Voltage Lift (VL) boosting techniques. Currently, renewable energy has wide application due to the energy crisis. By using the ASC based converter circuit, a higher gain can be achieved with high efficacy and less stress on the switches [4]. By utilizing split inductors, boost converters achieve a voltage increase. The converter that has low energy consumption, lesser-voltage stresses on switches and less control complexity is normally preferred in many applications. The high gain voltage conversion feature is more attractive, and it is employed for harnessing energy from renewable energy sources like fuel cells, photo voltaic. Based on experiments, the suggested converter can meet the converter performance requirements with an efficiency of around 95.5% [12]. Normal boost converters never provide the sufficient gain hence the transformer less high gain converter is preferred in this scope. Here the single stage conversion with ASL and a passive SC network is accomplished which makes this topology more attractive for renewable applications [13]. As a result of high output voltage, it is crucial to reduce the voltage stress across each conducting diode and switch. Thus, for boosting the gain, quasi ASL configuration is proposed. In [14], numerous SL and SC circuits are compared, and the voltage gain is boosted. The proposed DC-DC converter offers high gain uses fuzzy logic controller for uplifting the voltage obtained from solar panel [15]. In this scope, a novel H-SLC (Hybrid Switched inductor and capacitor) network is analyzed and implemented to enhance the voltage gain with high efficiency [16]. In [17], a new step-up converter of n stage is presented that find its application in integrating low voltage from solar PV. An active coupled inductor comprises of two coupled inductors for a renewable energy system is proposed in [18]. A transformer less three switched capacitor network that attains high gain with lesser duty ratio is elaborated in [19]. The literature review reveals there is a need to introduce high gain converters that prevail.

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over the shortcomings like switching stress, high component count and high duty ratio. One such converter that overcomes the above said drawbacks is proposed in this paper.

2. MATERIALS AND METHODS

There is a constant rise in energy demand worldwide, and scientists are still searching for ways to address these needs by exploiting alternative sources of energy. In terms of alternate sources of energy, solar energy offers the most advantages since it is abundant and clean. The schematic representation of PV system is portrayed in Figure 1. The converter serves as an integrating platform for harvesting energy from renewable sources. Here the interface between solar and load is ASC based DC-DC converter. It is possible to utilize the energy acquired from the PV for a variety of applications. Because it offers high gain in voltage, the proposed system is ideal for grid-connected applications.

2.1 Active Switched Capacitor Based Exalted Convolution

The proposed converter topology has a conventional ASL converter. Along with the existing ASL network, a diode and a capacitor are included to ensure that the power switch is under low stress and therefore provides enhanced gain. The proposed converter circuit is presented in Figure 2.

![Figure 1: Schematic diagram of proffered system](image1)

![Figure 2: High gain converter with ASC](image2)

This active switched capacitor-based converter is made to increase the output of a solar PV system. The traditional ASL network contains inductors L1 and L2 and switches S1 and S2. Diode D1 and capacitor C1 share a common switch S1 in the existing circuit. Table 1 enlists the design specifications of the proposed converter.

| Criterions        | Value |
|-------------------|-------|
| Input voltage     | 48 V  |
| Output voltage    | 120 V |
| Inductor L1       | 200 μH|
| Inductor L2       | 720 μH|
| Capacitor C1      | 10 μF |
| Capacitor C2      | 100 μF|
| Resistor          | 144 Ω |
| Duty cycle        | 0.3   |
| Switching frequency | 50 kHz|

2.2 Proposed Power Converter Operation

There exist two operating modes. The converter is made to operate under CCM. It is taken that all the devices used in the converter are in ideal state. The current flow path under CCM of converter is picturized in Figures 3(a) and 3(b).

2.2.1 Mode 1

In this mode, switches S1 and S2 are turned ON so that inductors L1 and L2 are charged parallelly and capacitors C1 and C0 are being discharged. In this condition diodes D1 and D0 remains off due to reverse bias. Capacitor C0 is feeding the load and L2 is getting charged via load. Equation (1) and (2) reveals inductor voltages.

\[ V_{L1} = V_{in} \quad (1) \]
\[ V_{L2} = V_{in} + V_{c1} \quad (2) \]

![Figure 3(a): Mode I switches ON](image3)

![Figure 3(b): Mode II switches OFF](image4)
2.2.2 Mode 2
The diodes (D₁ and D₀) are ON, when switches S₁ and S₂ are OFF. The inductors L₁ and L₂ now deliver stored energy to charge the capacitor C₀. Meanwhile, capacitor C₁ is charged through inductor L₁. The inductor voltages are derived as in equations (3) and (4).

\[ V_{L1} = V_{c1} - V_{in} \]  \hspace{1cm} (3)

\[ V_{L2} = V_{o} - V_{c1} \]  \hspace{1cm} (4)

2.3 Converter Design Equation
Assume the converter is operated in CCM and the design equations are given in equations (5) to (10).

\[ \frac{V_o}{V_{in}} = \frac{1+D+D^2}{(1-D)^2} \]  \hspace{1cm} (5)

\[ L_1 = \frac{L_1 f_s}{D V_{in}} \]  \hspace{1cm} (6)

\[ L_2 = \frac{L_2 f_s}{(1-D) L_1 f_s} \]  \hspace{1cm} (7)

\[ C_1 = \frac{C_1 f_s}{(1-D) V_{c1} f_s} \]  \hspace{1cm} (8)

\[ C_0 = \frac{V_{c0} f_s}{D_0} \]  \hspace{1cm} (9)

\[ R = \frac{V_o^2}{P} \]  \hspace{1cm} (10)

2.4 Converter Switching Waveforms
The customary switching waveform in CCM mode is depicted in figure 4.

![Figure 4: Switching waveforms obtained under CCM mode for the proposed converter](image)

3. RESULTS AND VERIFICATION
Simulation outcomes of proposed DC-DC converter with Active Switched Capacitor obtained using MATLAB/SIMULINK and are presented below.

3.1 Open Loop Simulation Results of the Proposed Converter
The simulations are performed in open loop and the waveforms obtained from simulation are displayed in figure 5 and figure 6.

![Figure 5: Output voltage waveform for preferred converter](image)

3.2 Closed Loop Simulation Outcomes of the Proposed Converter with Solar MPPT Technique
The closed loop simulation of the proposed converter is then performed with solar MPPT and the results are analyzed. The specifications of the solar PV panel are mentioned in table 2.

| Parameters | Solar panel values |
|------------|--------------------|
| Sc         | 7.244 A            |
| Voc        | 44.816 V           |
| Im         | 6.925 A            |
|Vm          | 36.83 V            |

3.3 Closed Loop Analysis of the Converter with Solar MPPT Technique
3.3.1 Type 1: For 1000W/m² Irradiation and Temperature of 25°C
Table 3 summarizes the results of the converter for quick changes in load under 1000 W/m² of irradiation and 25°C of temperature. The voltage waveform attained is depicted in Figure 7 (a).

| Power (W) | Load Voltage (V₀) | Load Current (I₀) | Efficiency (%) | Resistive Load (Ω) |
|-----------|-------------------|-------------------|----------------|-------------------|
| 100       | 120               | 0.8334            | 90             | 144               |
| 75        | 120               | 0.625             | 88             | 192               |
| 50        | 120.1             | 0.4167            | 83             | 288               |
The Figure 7(b) interprets the output voltage waveform at standard temperature and irradiation level and Figure 7(c) portrays voltage waveform under load adjustments.

3.3.2 Type 2: For 850W/m² Irradiation and Temperature of 20°C

Table 4 displays the simulation outcomes achieved with 850 W/m² irradiation and 20 °C temperature for different loads. Figures 8(a) exhibits output voltage waveform obtained. The regulated output voltage for change in reference and change in load conditions are represented in figures 8(b) and 8(c).

| Power (W) | Resistive Load (Ω) | Load Current ($I_{out}$) | Load Voltage ($V_{out}$) | Efficiency (%) |
|-----------|--------------------|--------------------------|--------------------------|----------------|
| 100       | 144                | 0.8334                   | 120                      | 91             |
| 75        | 192                | 0.625                    | 120                      | 89             |
| 50        | 288                | 0.4168                   | 120.1                    | 83             |

3.4 Comparative Results of Proposed Converter

The analogies of various converter topologies are displayed in Table 9 to justify that the suggested converter exhibits the high gain.

Figure 9 portrays the representation of propounded converter’s performance with other topologies of the converters. The voltage gain obtained from suggested converter is high compared to other traditional converters.
3.5 Hardware Results
The real time implementation of proposed converter of 100 W power rating with 120V rated supply voltage is designed with the derived parameter values as shown in Table 5. Figure 10 shows the hardware arrangement of the proposed converter offering high gain. Figures 11 and 12 portrays the gating signal and output voltage observed with the prototype.

Figure 10: Hardware setup of the proposed converter

Table 5: Hardware specifications for the preferred converter

| Parameters       | Specifications       |
|------------------|----------------------|
| Duty cycle       | 0.65                 |
| Input Voltage    | 20V                  |
| Resistance (R)   | 144Ω                 |
| Power            | 100W                 |
| Output Voltage   | 200V                 |
| MOSFETs (S1, S2)| IRFP150              |
| Diodes           | FF306/3.0A, 800V      |
| Switching Frequency | 50kHz               |

The gate signal generation is done using TL294 IC to drive the MOSFET switches.

Figure 11: Gate Pulse Generation of the Preferred Converter
Figure 12: Output Voltage Waveform of the Preferred Converter

4. DISCUSSION
The suggested ASC converter is built and tested in MATLAB and the results are presented in Section 4.1 to 4.5. The open loop simulation results for various duty ratio are presented. The results show that when duty ratio varies there is a corresponding variation in output voltage. The closed loop simulation of the converter with solar MPPT technique is presented. The results verify that the converter maintains a constant voltage at the output under different solar irradiations and temperature. A 100 W, 120 V prototype is developed in the laboratory and its open loop results are presented in Section 4.6.

5. CONCLUSION
ASC-based converters with a higher gain are proposed here in order to harness energy from a PV panel. By operating the converter with optimal duty cycle, desired gain value of output voltage is obtained. This converter is compact as it has lesser number of elements. An illustration of the preferred converter's response to constant insolation level and temperature was presented. A Proportional Integral controller keeps a steady output voltage under load modifications. Perturb and Observation MPPT method is employed for acquiring maximum power from the solar PV panel. The efficacy achieved is 80-90% in simulation. With the MATLAB/Simulink platform the findings are substantiated. At rated condition the converter efficiency achieved with the experimental prototype is 85%. The proposed converter is suitable for use with renewable energy and all drive applications. The work can be further extended by implementing the proposed work with intelligent controllers.

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