Solar Energy based low cost Converter for Rural Houses Electrification

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Abstract. A Rectified Sinusoidal based Pulse generation method for a DC – DC converter is proposed in this discussion. To exhibit this, the methodology is applied to a Self-Lift topology based SEPIC converter. In this paper a two stage grid connected system is used. In stage I the said converter is used for boosting and DC rectification. This converter is considered, can provide the required voltage from a renewable source. The DC rectification is done by using the RSPWM technique. Stage II uses an inverter which inverts the DC rectified signal to produce AC signal. The usage of the bulky transformers are avoided by using the proposed modulation technique. The notable advantages of the RSPWM technique are: (i) the switches of the inverter are functioned at low frequency (50Hz), (ii) harmonic content of the output waveform is reduced because of RSPWM, (iii) decrease of the filter size and (iv) inverter switches life time are increased as complicated control techniques are avoided. These features are validated through simulations.

1. Introduction

Conventional power generation methodologies using the fossil fuel sources are depleted every day and in future might get exhausted. In this view, renewable energy sources which are non exhaustible are getting popular [1]; in particular the solar energy based power generation is the widely popular one. The solar system produces relatively low voltage as an output and it requires very high gain step up converters for integrating it with the grid. There are two stages of a solar grid connected system [2]. In stage I a DC – DC conversion is done and in stage II DC – AC conversion is done. The required high gain is brought in either at stage I, stage II or in both the stages. If the required gain is not attained in both the stages then transformers are used. Hence the solar based grid connected systems are generally categorized as transformer and transformerless
systems. The transformerless systems are further classified into high gain converters which include (i) DC – DC converters [3] and (ii) DC – AC converters [4]. The DC – DC converters which have a high gain are further categorized [5], [6]as converters with additional components, and the components are
(A): coupled inductor
(B): switched capacitors
(C): inductor and switched capacitors
(D): coupled inductor and switched capacitors
(E): Interleaved boost converters
In this proposed work self-lift SEPIC converter is used which comes under the category of converters with Inductor and Switched Capacitor. The output of the DC – DC converter is modulated to follow a rectified sine waveform [12]. In this paper the converter output is modulated to follow as DC Rectified Output voltage. The output of the converter is modulated by applying Rectified Sinusoidal PWM (RSPWM) technique based pulse generation technique.

2. High Gain DC – DC Converter

The self-lift SEPIC converter [13] is shown in Figure 1. The circuit is designed as explained below. The designed values of various components are shown in Table 1. Using these values, the self-lift SEPIC converter fed by solar energy source is simulated in MATLAB for its operation as shown in Figure 2.

The input to the converter (V_s) is 48V DC and the voltage (V_o) and the current (I_o) at the output side is 230V DC and 2.3A DC for a 100Ω resistive load.
By substituting the input and output voltages the gain (K) value is calculated using the formula
\[ 1-K = \frac{V_s}{V_o}, \]
then \( K = 0.7913. \)
The converter switching frequency is 50KHZ.
\[ I_s = 11.02083A, \] by \( V_s I_s = V_o I_o \)
It is assumed that 5% is the ripple content in the output current.
As a result \( \Delta I_s = 5\% \) of \( I_s = 0.55A. \)
Then, \( L = \frac{K \times V_s}{f_{sw} \times \Delta I_s} = 0.001379H. \)
pretentious 5% of disturbance in the voltage at the output side, then 5% of \( V_s \) is the \( \Delta V_c \) value that is 2.4V.
Then \( C = \frac{I_o}{f_{sw} \times \Delta V_c} = 1.9167 \times 10^{-5} F. \)
Similarly value of \( C_1 \) is obtained as \( 1.9167 \times 10^{-5} F \) using \( C_1 = \frac{I_o}{f_{sw} \times \Delta V_{c1}}, \)
where \( \Delta V_{c1} \) is 5% of \( V_s. \)
The value of \( C_2 \) is calculated using the formula \( C_2 = \frac{I_o K}{f_{sw} \times \Delta V_{c1}}, \)
On substitution the value is \( 3.165 \times 10^{-6} F. \)
The expression of \( L_0 \) is given by \( L_0 = \frac{V_o K}{8 \times f_{sw} \times \Delta I_o \times C_2}\). On substitutions, \( L_0 = 0.025H. \)
\( C_0 \) is calculated using \( C_0 = \frac{I_o K}{64 \times f_{sw} \times L_0 C_2 \Delta V_0}, \) which gives \( C_0 = 0.25 \times 10^{-9} F. \)
Table 1: Design values of self-lift SEPIC converter

| Components | Values          |
|------------|----------------|
| $V_s$      | 48V            |
| $V_o$      | 230V           |
| $L$        | 0.001379H      |
| $L_1$      | 0.001379H      |
| $L_{0i}$   | 0.025H         |
| $C$        | 1.9167x10^{-5}$F |
| $C_{0i}$   | 0.25x10^{-9}$F |
| $C_1$      | 1.9167x10^{-6}$F |
| $C_2$      | 3.165x10^{-6}$F |
| $R$        | 100Ω           |

2.1 PWM based self-lift SEPIC converter with inverter:

The converter steps up the input voltage of 48 V from the solar panel to an output voltage of 230 V. For a load of 100 Ω, the converter voltage at input and output side then output current obtained are revealed in Figure 3, Figure 4 and Figure 5 respectively.

The converter DC output voltage of 230 V is inverted, to give an AC voltage of 230 V (Figure 6) and 2.3 A (Figure 7). The Total Harmonic Distortion (THD) value in the waveform is 53.09% (figure 8).
3. Proposed Methodology

The block diagram of the proposed work is shown in the Figure 9. This includes majorly the self-lift SEPIC converter for grid based applications. In this diagram a PV Module is used as an input.
for the self-lift SEPIC converter. The converter is triggered by a Rectified Sinusoidal Pulse Width Modulation (RSPWM), which produces an output as ‘Negative Cycle Converted’ DC rectified output voltage. This output, is given as an input to the inverter. The inverter converts the ‘Negative Cycle Converted’ DC Rectified Output voltage to a sinusoidal AC voltage and feeds it to the grid. The proposed RSPWM procedure is same as that of Sinusoidal Pulse Width Modulation (SPWM), but there is a difference in operation. The SPWM is used in inverters; instead, RSPWM is used in DC – DC converters. In the case of SPWM method a sinusoidal modulating signal, which is the desired fundamental component of the inverter, is related with a high frequency triangular carrier waveform to produce the pulsating signal; whereas in RSPWM the desired fundamental component is a rectified sine waveform, which is related with a high frequency triangular carrier waveform to produce the pulsating signal.

In SPWM technique, the DC voltage is converted to an AC voltage using conventional SPWM method and a step up transformer is used to step up the AC sine voltage to the magnitude of mains AC, for possible grid connected applications. In the Rectified SPWM method the amplitude of the DC voltage is controlled to look like a rectified sinusoidal voltage. The step up characteristic is established with duty cycle control and the modulation in the amplitude is achieved by dynamically changing the duty cycle at a high frequency to match the rectified sinusoidal voltage.

3.1 Rectified SPWM based self-lift SEPIC converter:
The RSPWM technique based self-lift SEPIC converter is shown in the figure 10. This is done in order to get a rectified sine waveform as the output of the DC – DC converter. By applying the RSPWM technique modelled to the self-lift SEPIC converter the output voltage obtained as shown in the figure 11. The output voltage waveform is a rectified waveform. If this voltage is connected to an inverter operating at a low frequency (say 50Hz) a sinusoidal waveform can be obtained.
3.2 Rectified SPWM based self-lift SEPIC converter with inverter:

Figure 12 shows applying the RSPWM technique to the self-lift SEPIC converter with inverter. The output voltage and output current are obtained are shown in the figure 13 and figure 14 respectively. The circuit shown in Figure 11 is used along with an H bridge inverter. The converter output voltage is connected to an inverter circuit to obtain a sinusoidal waveform. The $V_{\text{max}}$ of the $V_{\text{ac}}$ is 230 V, whereas the load current is 2.3 A for a load of 100 Ω.

Figure 12 RSPWM Technique based self-lift SEPIC converter with inverter

Figure 13 Output voltage of RSPWM Technique based self-lift SEPIC converter with inverter
3.3 Solar Power fed RSPWM based self-lift SEPIC converter with inverter:

Figure 15 represents the PV system with RSPWM technique based self-lift SEPIC converter along with inverter implemented in the MATLAB / Simulink. Figure 16 and figure 17 show the output voltage and output current representation of this full fledged system. The value of $V_o$ is 220 V and $I_o$ is 2.2 A.
FFT is done on the output voltage waveform obtained using RSPWM technique based solar powered self-lift SEPIC converter – inverter system. The THD of the waveform is 13.75% as shown in figure 18. FFT analysis is done to the output voltage waveform using normal pulse given to the solar power self-lift converter – inverter system. The Total Harmonic Distortion (THD) of the waveform is 53.09% as shown in figure 8. Both these THD values are obtained without filter. The evaluated values are tabulated in Table 2.

Table 2: Comparison of THD values of the above circuits.

| SI. No | Circuit                                           | Voltage Value | Voltage THD% | Current Value | Current THD% |
|--------|---------------------------------------------------|----------------|--------------|---------------|--------------|
| 1.     | PV Panel connected to the Self-Lift SEPIC Converter with Inverter | 230            | 53.09        | 2.3           | 53.09        |
| 2.     | PV Panel connected to the RSPWM Technique based Self-Lift SEPIC Converter with Inverter | 230            | 13.75        | 2.3           | 13.75        |

The solar panel produces 48V DC voltage, which is boosted to 230V DC by the self-lift SEPIC. This boosted DC voltage is transformed to output sine wave voltage 230V AC with an inverter. The closed loop control of RSPWM triggered self-lift SEPIC converter with inverter as shown in Figure 19. In this technique, the output of the converter (V_{actual}) is taken and compared with the required rectified sinusoidal waveform (V_{Ref}) and fed to the comparator. The output of the comparator is compared with the saw tooth waveform to generate the gate pulse for the switch. Based on the error signal the switch’s gate pulse is varied to get the required rectified sinusoidal voltage waveform.

The output voltage and its THD values are shown in figure 20 and figure 21 respectively are the simulation results of the closed loop self-lift SEPIC converter using the design values for a output voltage of 320V. For this voltage waveform the obtained THD value is 2.49% without any filter.
4. CONCLUSION
This paper proposes a transformer less single stage DC-DC converter for a grid connected system. A RSPWM based Self-lift SEPIC converter is modelled to produce a ‘negative-cycle-converted’ DC rectified output voltage as output which is verified. This methodology reduces the switching stress of the four switches of the inverter. Hence the life time of the inverter is improved. The Self-lift SEPIC converter switch is operated at high frequency; the inverter switches are operated at low frequency. Therefore the control circuit required for the overall network is very small. The error rectification process is easier in these types of control circuitry. The advantage of the proposed RSPWM based converter is reduction of the filter size connected to the inverter side. Hence cost can be reduced and stresses on the inverter switches are reduced. As the inverter is operated at a low frequency the noise from the inverter also gets reduced. Hence, this model proves to be safer, as only one switch is operated at higher frequency, when compared to the conventional circuit model where four switches of the inverter are operated at high frequency.

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