Design of a single phase series-parallel current injection resonant converter with wireless power transmission

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Abstract: This paper proposes a new circuit topology of single phase AC to DC Series-Parallel Current Injection Resonant Converter (SPCIRC) with wireless power transmission function. Thus, characteristics are accomplished such as shaping the current waveforms of the sinusoidal line with improved power factor resulting in small total harmonic distortion (THD). This is implemented by employing the resonant conversion technique, involving two active soft switches that generate high frequency currents. The circuit operation is explained and the analysis of the converter is presented. The full detailed circuit simulation is then carried out to ascertain the workability of the converter and its ability to operate with wireless power transmission. As a result, a low input current THD of 3.52% was obtained with 130V output DC voltage when supplied by 240V AC input voltage. The efficiency of the proposed SPCIRC is calculated as 87.5%. The current injection topology's main operation is described in detail.

Keywords: AC-DC converter, Resonant converter, Current injection resonant converter, Wireless power transmission (WPT), Series-parallel resonant converter.

1. Introduction

Three-phase AC-DC current injection technique resonant converter circuit topology named as Current Injection Series Resonant Converter (CISRC), was firstly introduced in [1] The design of the circuit construction began with a series circuit configuration. The topology engaged in injecting the high frequency currents into a three-phase bridge rectifier resulting in the input rectifier voltage being modulated at high frequency. The circuit only requires two active switches using MOSFET providing continuous, sinusoidal supply current and in-phase with the supply voltage waveforms contributing to a high power factor[1]. More studies on small signal analysis and closed loop control of the AC-DC three-phase current injection series resonant converter were subsequently carried out[2]. The research study focused on improving the transient characteristics and to control or regulate the output voltage. Other work has shown that the autotransformer can be removed with the inclusion of a simple high-frequency transformer by using the full-bridge setup of the series current resonant injection, which lowers the weight of the converter [3], [4]. However, there was no experimental verification reported for the circuit topology. Furthermore, the use of series circuit setup has a restriction to control the output voltage under circumstances of light or zero load. This was due to the load current for series circuit configuration that varied in proportion to the resonant current. In order to be consistent with the accessibility of power electronics as an enabling technology, it would be extremely desirable to develop an alternative topology for the CISRC outcomes with the solution to eliminate their disadvantages while providing performance enhancement. A three-phase AC-DC current injection hybrid resonant converter based on a steady state assessment of the three-phase AC-DC CIHRC was
subsequently created as mentioned in [5]–[7].

2. Three-Phase AC-DC Current Injection Converter

A. Three-Phase AC-DC Current Injection Converter

A review of the theory behind the operation of the Current Injection Series Resonant Converter (CISRC) as shown in Figure 1 is presented [1]–[7]. In the previous work, the technique was proposed in AC-DC three-phase system which offers high-power-factor operation [5]–[7].

Figure 1. Current Injection Series Resonant Converter for Three-phase System

A high quality input supply current is obtained by the current injection Pulse Width Modulation (PWM) technique. This is achieved by the self-injected high frequency sinusoidal resonant current to the midpoint of the diode converter. The resonant current is produced by the DC-DC series loaded resonant circuit. The interaction between input current and the inject high frequency resonant current results in PWM voltage at the mid-point of the diode converter. The basic circuit of a converter employs the technique is as shown in Figure 1. The abovementioned work is attempted to apply in a single-phase application.

3. Proposed Half-Bridge Single-Phase AC-DC Series-parallel Current Injection Resonant Converter (SPCIRC)

Figure 2 shows the circuit configuration of SPCIRC. It consists of a single-phase AC supply with input/supply inductor Ls connected to a single-phase diode rectifier. The diode rectifier is then connected to a high frequency series-parallel loaded resonant DC-DC converter consists of resonant tanks element, Lp, Cp1, Cs, Cp2 a high frequency autotransformer, which feeds DC load R. This circuit comprises a combination of two different stages of frequency. The first stage consist of the input supplyfrequency for the rectifier and the second stage consist of high frequency at the resonant tank, which is maintained in constant oscillation close to natural frequency \( f_0 \). The pair of MOSFETS operates with fixed 50% duty ratio at high frequency slightly above the natural frequency \( f_0 \), driving a high-frequency current and resulting in lossless zero voltage condition [2]. In order to obtain a high-power-factor input current, a high frequency transformer may be easily incorporated into the resonant circuit to provide output isolation.
Figure 2. Circuit Configuration of Proposed SPCIRC

Figure 3. Simulation of SPCIRC using Matlab/SIMULINK

4. Principle of Operation of Proposed SPCIRC with WPT

There are two components involved for WPT function in the proposed SPCIRC as shown in Figure 2; a) transmitter, and b) receiver. In this research, the application of current injection technique is adapted in mitigating the distorted supply current waveform while improving the power factor. The integration of the transmitter and receiver coils in the proposed single-phase AC to DC SPCIRC could intensify the ability of the converter to wirelessly supply the power source to the load. First, the single phase diode bridge rectifier transformed the single phase supply voltage from AC to DC. Instead of converting AC supply to DC voltage form, it also helps to mitigate the distorted supply current waveform and improving its power factor. The DC voltage was then transformed into a high frequency AC voltage. An autotransformer which consists of a resonant current, $I_{res}$, and a switching leg voltage, $V_{DC-DC}$ is connected to the transmitter coil and the $I_{res}$ is injected to the input of the diode rectifier. The high frequency resonant current flows through a transmitter coil producing the alternating magnetic fields. The receiver coil was purposed to capture the oscillating magnetic field, which in turn produces or induces an electrical current. Then, the AC voltage is rectified to the DC voltage form. A DC capacitor was connected in between the rectifier and the load to lower the output voltage ripple. The input supply sinusoidal modulating current $I_s$ is assumed sinusoidal and through a proper design, the supply current is able to sustain the sinusoidal current waveform. Both currents are injected into the midpoint of the diode rectifier producing PWM voltage. At the midpoints of the
diode rectifier, when the summation of input supply sinusoidal modulating current $I_s$, and the high frequency sinusoidal resonant carrier current $I_{res2}$is greater than zero, the upper diodes (D1 and D3) of the rectifier conduct. However, whenever the summation is lower than zero, the lower diodes (D2 and D4) conduct. Figure 2. Two conditions are observed to conduct the diode rectifier at both midpoints:

At $V_A$

$I_s + I_{res2} > 0 \Rightarrow$ Diode D$_1$ conducts

$I_s + I_{res2} < 0 \Rightarrow$ Diode D$_3$ conducts

whilst at $V_B$

$-I_s + I_{res2} > 0 \Rightarrow$ Diode D$_2$ conducts

$-I_s + I_{res2} < 0 \Rightarrow$ Diode D$_4$ conducts

5. Result and Discussion

This section represents the simulation results of the figure 3 proposed for SPCIRC. AC single phase supply of 240Vrms, 339Vp at 50Hz is used in simulation as shown in Figure 4. The simulation work on the suggested SPCIRC is performed using 20kHz of switching frequency, $f_s$. The input current is measured as 4.541A(rms) by Matlab/SIMULINK. Figure 5 indicates the input current waveform, $I_s$ in the simulation procedure and the resonant current $I_{res}$ injected to the rectifier. Then, Figure 6 shows an input current of 6.417A (peak) and its THD of 3.52%, obtained in the simulation work. Figure 7 shows the output current measured from the simulation at 7.5A (DC) while Figure 8 shows the output voltage of 130Vdc.

Figure 4. Input Voltage and Input Current (10 times higher than actual result) of proposed SPCIRC

Figure 5. Input Current, $I_s$ and resonant current, $I_{res}$ of proposed SPCIRC
Figure 6. Input Current & THD (Simulation)

Figure 7. Output Current

Figure 8. Output Voltage
Furthermore, the output power measured from the simulation is 955.1W while the input power is 1090W. From the calculation of the efficiency as shown in Table 1 it shows that the efficiency of the proposed SPCIRC is 87.5%.

6. Conclusion

The proposed SPCIRC functioning with WPT function has been demonstrated. The result of the suggested SPCIRC shows that it could achieve small harmonic content of supply current and high efficiency. The total harmonic distortions acquired are in accordance with IEEE Standards 519-1192 and 1159-1995 requiring the THD to be below 5%. The proposed SPCIRC is proven has good behavior to perform as wireless power transmission interface.

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