Neutral Point Type Buck Converter Circuit Application for Short Range Wireless Energy Transfer

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Abstract - Wireless energy transfer has been gaining interest due to its potential in wide range of foreseeable applications. As such, this paper explores the use of Neutral Point Type Buck converter to determine the circuit efficiency and capability for a finite range of wireless application. This objective is achieved in two parts; that is through Buck Chopper Converter circuit and Half-wave Rectification Chopper circuit. Magnetic Resonance Coupling is observed as the base principle in performing Wireless Energy Transfer to transmit power with high frequency across large air gap in this study. Results showed that maximum length obtained through the proposed approach has successfully performed an energy transfer of up to 14 centimetres. It was also shown that the hardware construction through the implementation of Neutral Point Type Buck converter was successful in producing desired output waveform and frequency required for wireless energy transfer.

Keywords - Wireless Energy Transfer, Neutral Point Type Buck Converter, Buck Chopper, Half-wave Rectification Chopper, Magnetic Resonance Coupling

I. INTRODUCTION

Neutral Point Type Buck Converter. A Buck Converter is a step down DC to DC converter, where the average DC output voltage is lower than the input voltage [1, 2]. This feat is achieved via two ideal switches and Metal Oxide Semiconductor Field Effect Transistor (MOSFET) that is manipulated through a switching technique. The prompted switching strategy is crucially applied to mitigate the risk of high switching frequency above 40 kHz.

Consequently, current study would attempt to address issues associated with the input current that would not be sinusoidal as well as ripple and harmonics presented within. This would conversely allow a reduction in current harmonics and inrush current resulted from filter capacitor impedance, installed to function as a short circuit. Thus active filter is used in the circuit to reduce these harmonics [2, 3].

Wireless Energy Transfer. Wireless Energy Transfer adopted an electromagnetic (EM) field of frequency that allows for energy to be sent from one place to another without the need for electrical conducting media [4] as shown in Figure 1. This process involves phenomenon known as Electromagnetic Induction [5]. The objective of this study is on power transfer over air gap based on coupled magnet coils in resonant circuits. The main issue identified from this application is the unintended magnetic coupling between inductor coils.

The Wireless Energy Transfer system must satisfy the requirement of high frequency and power to successfully achieve energy transfer to the targeted coil [5, 6]. Therefore, a switching strategy is applied to Neutral Point Type Buck Converter to meet this objective.

To satisfy the high frequency requirement of the application, a MOSFET was used as switching devices in low voltage and high current application. Electromagnetic resonator circuit constructed from combinations of inductors, capacitors and resistors.The circuit is constructed such that the energy would be stored in the capacitor while electric field produced will be dissipated by the resistor. The efficiency of the power transfer would depend on the displacement and load variation [7]. When two circuits are tuned to be resonant at the same frequency there can be highly efficient transfer of power which allows for an increase in displacement. Therefore
impedance matching is important to this circuit construction inherently to prevent mismatches which would cause reflected power. It is noted that the amount of power that can be transferred for an input voltage level would depend on the coupling coefficient and the characteristics of the load [8].

II. METHODOLOGY

There are several steps have been taken to realize the final Neutral Point Type Buck Converter circuit for Wireless Energy Transfer application. Initial investigation over the anticipated performances and characteristics of the proposed circuit was implemented through a simulation study using the PSIM software. However only the result of the hardware construction would be discuss in this current work. The Buck Converter was constructed such that it has a filter inductor on its output to provide a smooth continuous output current waveform to the load. The operation of the Neutral Point Buck Converter can thus be classified two modes which are positive and negative half cycle. Description over the circuit operation could be elaborated first in mode 1, during a positive half cycle at which he switching element S1 is turned ON and S2 is turned OFF. The current would start off by passing through diode D1 from supply voltage then flow to the switch S1 and through the inductor. The current from inductor L1 then flow to smoothing capacitor C2 and passes to D4 and back to negative supply voltage as shown in Figure 2 a). At the same time C2 is on charge condition. When S2 is ON, the capacitor C1 will be charge and C2 on discharge condition.

Next, mode 2 would be operational during negative half cycle, observed as the switching element S1 is OFF S2 is turned ON in Figure 2 b). The current flows from supply voltage to diode D3 and consequently travel through capacitor C1. The current flows from the inductor will pass through to diode D2 and returns to supply voltage while capacitor C1 is on charge condition. Finally, the switching element S1 and S2 are set to be 50% of duty cycle to accommodate power transfer to load. Connection of C1 and C2 are done in series which causes the load to be supplied with similar or equivalent to the input voltage. MOSFET (n-channel) is used as a power switching. Self-oscillation is used for this technique and is applied to the converter by varying the RT and CT of half bridge driver (IR2153) with 50% duty cycle for S1 and S2. This technique is found to be simpler and able to reduce the cost of the overall circuit.

Figure 2 The current flow during a) positive half cycle b) negative half cycle

III. RESULT AND DISCUSSION

Neutral Point Type Buck converter. The proposed Neutral Point Type Buck converter was constructed. The responses of the constructed circuit would be elaborated in Figure 3. As seen, the Neutral Point Type Buck converter was presented with an input current waveform that is not sinusoidal. This is found to be as a result from high total harmonic distortion within the supply voltage. An output voltage with substantial ripple is not suitable for the constructed circuit which requires an almost constant DC voltage [1]. Therefore, smoothing capacitor C3 or also known as filter capacitor is inserted at the load to reduce the ripple voltage [9].

It is worth to note that if the capacitor value is large enough, the resultant voltage would not have noticeable changes. Figure 4 would then elucidate the recorded circuit capacitor C1 and C2 voltages as well as the recorded voltage output of the converter on the oscilloscope. Finally Table 1 presented the average value of the obtained converter output for a given 12 Vac input voltage.
Figure 3 Result of Neutral Point Type Buck converter a) voltage input, b) current input, c) voltage output, d) current output

Figure 4 a) Voltage of capacitor C1 and C2 b) Output voltage of Neutral Point Type Buck converter

TABLE 1: HARDWARE CONSTRUCTION RESULTS

<table>
<thead>
<tr>
<th>Input voltage</th>
<th>12 Vac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output voltage</td>
<td>9.28 V</td>
</tr>
<tr>
<td>Output current</td>
<td>5.2 mA</td>
</tr>
<tr>
<td>Output Power</td>
<td>0.0048 W</td>
</tr>
</tbody>
</table>

Half-Bridge MOSFET driver. In order for the semiconductor switches to turn ON or OFF, a circuit driver is required due to the fact that a power semiconductor is unable to process a DC supply directly. Therefore, a half bridge driver circuit IR2153 was adopted to achieve the switching strategy previously mentioned. The resultant frequency value can be determined by calculating the formula below:

\[
\text{frequency, } f = \frac{1}{\frac{1.4 \times (RT + 750) \times CT}{RT}}
\]

(1)

where RT is the variable resistor and CT is the capacitor.

The resultant switching waveform output setup at 20 kHz with 50% of duty cycle. The value of RT can be adjusted through the variable resistor in order to obtain the desired frequency for Neutral Point Type Buck converter. Frequency above 20 kHz is preferred in this study due to the fact that it is outside the usable radio frequency range. Therefore, a fast switching requirement
where switching losses is small, has to be met to achieve the high frequency mentioned. It is highlighted that the switching power losses of power semiconductor are proportional to the switching frequency [1]. Wireless Energy Transfer. In order to achieve wireless energy transfer, the circuit must be able to create the maximum amount of flux to induce the greater voltage and current to transfer from primary to secondary coil [10]. Further, the magnetic resonant coupling must operate at resonance frequencies to transmit the power to the coils.

Table 2 would then elaborate on the resultant wireless energy transfer output for several distances with the maximum successfully transferred at 14 centimeters. It is observed that the value of the output voltage decreases as the length between the coils increases.

### TABLE 2: EXPERIMENTAL RESULTS

<table>
<thead>
<tr>
<th>Length (cm)</th>
<th>Output voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>0.85</td>
</tr>
<tr>
<td>6</td>
<td>0.82</td>
</tr>
<tr>
<td>8</td>
<td>0.76</td>
</tr>
<tr>
<td>10</td>
<td>0.72</td>
</tr>
<tr>
<td>12</td>
<td>0.66</td>
</tr>
<tr>
<td>14</td>
<td>0.64</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

A practical application of Neutral Point Type Buck converter circuit for wireless energy transfer has been successfully presented in this paper and was shown to be able to reduce the harmonics existed within the power supply. A maximum distance of 14 centimetres was achieved for a successful wireless energy transfer through the suggested circuit construction. Finally, the adopted switching strategy through a self-oscillating half bridge driver was deemed to achieve its purported target substantiated through the projection of desired output waveform and frequency.

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