A New Quadruples E-Core Transformer To Minimize Output Ripple Current

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Abstract

A new quadruples E-transformer made of ferrite is proposed in this paper. In order to control magnetic flux (ψ) in the ferrite with coil in the primary and secondary core transformer, wire coil should be twisted 50° with tiny air gap, resulting in higher efficiency. However, it should be suitable to heavy system loads. Otherwise, it will influence the duty cycle, and it will create ripple current for about 10 percents. The fixed air gap should be evaluated with respect to magneto motive (mmf), as one of their electromagnetic field sources in the system. In addition, the adjusted magnetic flux (ψ) also can be controlled by inserting air gaps, and the magnetic flux can be justified by varying the width of gap.

In this experiment six air gaps are inserted in the quadruples E-transformer. The coil is composed by a ring wire gauge in which each ring wire gauge has radius r is 0.0004 m give the ripple current 0.036%. So The New quadruples E-transformer help greatly to make system more stable.

Keywords: Boost converter, E type ferrite, geometry, air gap, gyrator-capacitor, low ripple current.

1. Introduction

Nowadays, a lot of industry activities such as electroplating and chemical processing require a good electrical system which has low ripple current since that ripple current could causes losses and disturb the output of the process. The ripple current from an electrical system usually treated as a noise and it has to be limited e.g. in chemical processing, the permitted ripple current is 3% but basically the smaller noise, the better system. Experiment hypothesis later on sees that ripple current could be reduced significantly by using the gyrator-capacitor [1] and twisting the winding of conductors [2].

The equivalent electric circuit approached from the modification is resulting new quadruples E transformation as total capacitor [3], where magnetic networks using the ferrite core. The ferrite become parasitic capacitor or inductor which simultaneous to counter the variable loads. It becomes simultaneous switching noise [4]. The properties of ferrite are lumped so there are no losses [5]. Also the air gap is generating magnetic flux [6]. Actually, interposed air can be utilized as a controller of input and output mmf and even some more technologies applied could be controlled the automatic system.

This paper proposed Cuk converter Slobodan with transformer four E type core, six air gap and twisted winding as new quadruples E core transformer to minimize the output ripple current.

2. Quadruples E-transformer design

2.1. The Model quadruples core E Type with six air gap and a couple winding

This paper is using a new quadruples E transformation modeled as the total capacitance approach and magnetic source as gyrator.

Gyror is a coil that analyze through approach on magnetic circuit to electric circuit [1], which the core have been applied to the coils system. Gyror must be paired to each other, so that it can make an optimal result that creates the electromagnetic coupling like the ideal transformer ones [2].

Gyror must be applied in boost converter Cuk Slobodan and put it in second core magnetic E type [3] as a universal in load resistance as seen in Figure 1, and it will get the percentage of output ripple current about 0.036 %.

Gyror in Cuk Converter can reduced the ripple less than 3%. With parallel RLC load, the ripple could make it up to only 0.036%. The magnetic core type must be at quadruples range as seen in Figure 1.

![Figure 1. Modification boost Converter and quadruples E Type with six air gap.](image-url)

The Cuk converter in Figure 1 is still loaded by resistance (R). Modification boosts Converter with second E Type with four air gap about 0.036%. If the RLC load, the ripple current becomes more than 3 %. It must be redesign with quadruples E-transformer with six air gap [3].
2.2. New approaching parameter in electric quadruples E-core transformer

The proposed geometry of quadruples E-transformer is shown in Figure 2.a. The structure geometry core of quadruples E-type is ferromagnetic which is composed as shown in the Figure 2. Air gaps are in structure between quadruples of E-type. The dimension is adjusted to obtain the best performance.

Based on Figure 1, the Cuk Converter could be analyzed by using a boost converter with 9 volt input [4]. The air gap cross-section at each base is 1 mm. The geometry of Figure 2.a. is provided in table 1.

![Figure 2. Geometry and coil winding on ferritecore transformer.](image)

(a) Transformer with air gap.

(b) Geometry of E core Type with 6 air gaps.

The calculation results of all Part of geometry in Figure 2.b. [3], like reluctance and permeance. The core and air gaps can be derived by magnetic material approach into the electric network [3], reluctance [6], capacitance and permeance [3]. The geometry of Figure 1 and the reluctance calculation (7) are provided in table 1.

Table 1. Reluctance and Permeance from a part 1 transformer.

<table>
<thead>
<tr>
<th>Part of Geometry E type</th>
<th>Long Race (cm)</th>
<th>Cross-section area (cm²)</th>
<th>Reluctance (AT/Wb)</th>
<th>Permeance (H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Foot Core I,</td>
<td>1</td>
<td>0.18</td>
<td>0.442 10⁻⁴</td>
<td>2.262 10⁻⁵</td>
</tr>
<tr>
<td>Part II, Core</td>
<td>0.6</td>
<td>0.18</td>
<td>0.365 10⁻⁴</td>
<td>3.773 10⁻⁵</td>
</tr>
<tr>
<td>Middle foot core III</td>
<td>1</td>
<td>0.36</td>
<td>0.221 10⁻⁴</td>
<td>4.524 10⁻⁵</td>
</tr>
</tbody>
</table>

Table 2. Assess Reluctance and Permeance of air gap 1 up to six.

<table>
<thead>
<tr>
<th>Air Gap1 (mm)</th>
<th>Cross section area (cm²)</th>
<th>Reluctance (AT/Wb)</th>
<th>Permeance (H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.18</td>
<td>0.00442 10⁹</td>
<td>226.24</td>
</tr>
<tr>
<td>0.2</td>
<td>0.18</td>
<td>0.00884 10⁹</td>
<td>113.10⁻⁹</td>
</tr>
<tr>
<td>0.3</td>
<td>0.18</td>
<td>0.0132 10⁹</td>
<td>75.75 10⁻⁹</td>
</tr>
<tr>
<td>0.5</td>
<td>0.18</td>
<td>0.0221 10⁹</td>
<td>45.24 10⁻⁹</td>
</tr>
<tr>
<td>0.6</td>
<td>0.18</td>
<td>0.0265 10⁹</td>
<td>37.73 10⁻⁹</td>
</tr>
</tbody>
</table>

Variable total capacitance and variable air gap could be showed in figure 3.
3. A new quadruples E-core transformer as gyrator-capacitor in Cuk Slobodan Converter.

3.1. Magneto motive force as Gyrator

The windings are evaluated as three conductors or two connected polar tide approach of electric network and magnetic network [3]. The voltage and the current equations (1 and 2) represent the interaction between electric field and magnetic field which can be seen on Figure 4. It is a quadruples-port polar electric network with hybrid parameter [5].

Based on Figure 2a, the primary voltage winding $V_1^p$ depend on the current on secondary is obtained by equation 1, and vise versa the voltage winding of secondary which $V_2^s$ depend on the current input of source is approached by magnetic circuit to electric circuit [1].

\[ V_1^p = r_1 \cdot i_2 \]  \hspace{1cm} (1)
 \[ V_2^s = r_2 \cdot i_1 \]

Voltage Control Current Source (VCCS) where $1/r$ is gyrator, desribed as equation 3 below:

\[ I_1 = g \cdot V_2 \] \hspace{1cm} and \hspace{1cm} (2)
\[ I_2 = g \cdot V_1 \]

Where:

- $V_1^p$ = input Voltage (V)
- $V_2^s$ = output Voltage (V)
- $r$ = the resistance of Gyrator (Ohm)
- $g$ = gyrator (mho)
- $f$ = frequency (Hz)
- $L$ = Inductance (Henry)

The implementation of modified equation is [1]:

\[ g = \frac{1}{r} \] \hspace{1cm} (3)

All parameters are calculated using Psim-val simulation. By substituting equation (1) and (2) into equation (3), the output ripple current in Cuk converter Figure1. is obtained by the equation 4.

\[ \Delta I_2 = \frac{V_2(1-k)}{fL_2} = \frac{V_2}{fL_2} \] \hspace{1cm} (4)

The VCCS and the CCVS configuration can be seen, respectively, on Figure 4a for Gyrator at primary side and Figure 4b. For air gap core coil Gyrator at secondary side.

3.2. Gyrator - Capacitor model could Reduce output ripple current of Cuk Converter.

From the Table 1 and table 2, the total capacitance and gyrator model in Figure 4 a and b. could be integrated, like shown in Figure 5.

Figure 4.(a) Gyrator model of transformer in primary and (b) Gyrator model si
de of secondary of the transformer.

Figure 5. The Gyrator - Capacitor model.
Gyrator-Capacitor model Figure 5. could be integrated with boost converter Cuk Slobodan in Figure 1. because four E core type and six air gap was modifie with the model of gyrator-capasitor. It can be seen as Figure 6.

Figure 6. Quadruple E-transformer in Cuk Converter Slobodan

4. Simulation and experiment.
4.1. Simulation

The experiment uses 1 – 6 mm variable air gaps in the permanent magnetic cores, which results in the best performance at 4 mm, constructed by 3 coil windings and twisted at 50o. By designing the load, we could find that the gyrator resistance will stabilize the load changing. Also, through the simulation it could be seen that the smaller gyrator resistance, the smaller magnetic resistance and capacitance.

We find the resistance of gyrator from the total approach of capacitance of ferrite material and air gap. RG at Table 1 and 2. For RG = 0. 2 Ohm and the output current ripple about 2 % in Figure 8.a. for full load.

for RG = 0. 0128 Ohm, result in the output ripple 1. 6 %. This is the same as Figure 8.b. that the resistance gyrator is about 0.098 ohm.

![Figure 7. The output ripples current before modification.](image)

Later on, it found that the total gyrator resistance must be suitable to material, air gap and coil winding. With that kind of total gyrator resistance, the ripple could be be reduced into 0.036 % (as long as the load is normal).

![Figure 8. The graph of Current Gyrator IG and current hybrid IH respect to time for](image)

RG = 0.0128 Ohm,
(a) The output ripple current more than 2 % with RLC load and double E-transformer.
(b) The output ripple current 0.36 % With RLC load and quadruples E-Transformer (Pspice simulation).

On Figure 8.b, the output current ripple is 0.36% for gyrator-capacitor. After calculating the twisted winding, it produces smaller ripple and makes the system more stable, like Figure 8.b. The efficiency is 99.8%.

4.2. Experiment

The experiment on Figure 9 could be seen both with and without air gap. The first time experiment held with air gap.

![Figure 9. Block Diagram experiment of Quadruple E-transformer in Cuk Converter Slobodan.](image)

The output voltage increasing until 21 Volt on RLC load. The air gap is about 0.4 mm with output ripple 0.36%. see Figure 10a.

The second experiment then was the one without air gap condition. The output ripple current turned into less than 1% but the output voltage is 12 Volt (Fig. 10b).
the less output of ripple current, where shown at the calculation of the capacitance parameter approach from the geometry of magnetic core. In the other hand, experiment shows that the voltage is increasing when it loaded by RLC loads, both for with and without air gap. Air gap could be increase the voltage about 18.5 Volt (see Figure 10.a and 10.b.), if the air gap of Quadruple E core transformer in Cuk Converter Slobodan load condition about 0.4mm on RLC load. (in experiment), in PSpice simulation the air gap could be increase the voltage about four Volt. The optimal air gap about 0.4 mm, duty cycle 60 on RLC load. The output ripples current about 0.36%. on RC, RL load condition the ripple more than 1 %. The experiment could increase the voltage higher then simulation on RLC load.

In the simulation and experiment, almost show the same output ripple current.

6. Conclusion

By making the air gap equal to 4 mm in the six air gaps, the best output performance is achieved. The modeled of quadruples E-type ferrite is given by coil winding radius of wire $r = 4. 10^{-4}$ m, at metal strain before twisting. The output ripple current is 1.8 %, and after twisted is 1.6 %. For radius coil $r = 8.10^{-4}$ m at metal strain before twisted, the output ripple current is 1.6 %, and after twisting the output ripple current is 1.4 %. For radius $r = 16. 10^{-4}$ m at metal strain before twisted, we obtain the ripples are 1.4%, and after twisting became 1.2 %.

The total impedance consists of air gap, geometry of materials, permeability, and twisted, could be reduce the ripple current about 0.036%.

The prototype could be applied to any system, it was done and tested.

7. References