Normalization Design of Inductances in Triple Active Bridge Converter for Household Renewable Energy System

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This paper proposes a normalization design for series inductances in a triple active bridge (TAB) converter. The voltage variations and inductances are normalized based on percentage, and the complicated relationships between the elements of the TAB converter are clarified. The limitation of inductances corresponding to the different voltage variations is specified. The inductances are designed by considering the operation range of the phase shift angles. Based on this, the proposed method allows the inductances in TAB converter to be designed for various applications. A prototype converter rated at 200 V and 500 W is implemented to verify the proposed method. The experimental results show that the converter can operate under the rated power, indicating that the proposed method can be applied for designing of a TAB converter.

Keywords: triple active bridge converter, inductance design, normalization, household renewable energy system

1. Introduction

In recent years, electric vehicles (EV) and renewable energy systems have rapidly developed (1) (2). A rooftop photovoltaic (PV) system is a type of renewable energy method used in households and is becoming widespread globally. A PV system can charge an EV directly, reducing pollutant emissions (3). In comparison to an AC grid, a DC grid has many advantages such as a lower cost and higher efficiency (4)–(6). A DC grid has shown promise for future applications. The high capacity battery of EV is a storage, and thus the impact of power from the vehicle to grid (V2G) has been discussed (7). The integration of EV and a PV system has become a promising approach toward a renewable household energy system.

A triple active bridge converter is one of the most promising circuit topologies for future electrical energy systems. It is flexible regarding power transmission and shows advantages in many different applications (8)–(17). It has been proposed for use in electric vehicle applications (8)–(10). A fuel and supercapacitor system using a TAB converter has also been discussed (11). A DC power distribution system used in a data center through a TAB converter shows the advantage of higher reliability (12)–(13). TAB converters have also been proposed as a power router of a DC micro-grid (14)–(15) and for use in a renewable energy system (16).

Figure 1 shows a future residential electrical system integrating a PV system with an EV using a TAB converter. It consists of a rooftop PV system, an EV with a storage battery, electric devices, and a DC grid. An additional storage battery can be used and shared with the EV. The system uses only one TAB converter to control the power transmission between elements.

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Figure 2 shows a TAB converter connecting an EV with a PV system. It includes a three-winding transformer, three series inductances, and three full bridge inverters. The series inductance of each port may consist of an external inductance...
connected in series to the leakage inductance. The series inductances in the TAB converter are critical elements. Small values result in a small phase shift operation area, which is critical in terms of control. The power transmission ability of the converter is decreased when increasing the inductance. However, the design of the series inductances in a TAB converter satisfying all operation modes has not yet been discussed in detail.

In addition, when the voltage of each port varies in terms of the operating voltage range, a different effect occurs regarding the transmission power ability of each port because of the different relationships between the power and voltage between ports. Therefore, the design of the inductances used in the TAB converter should be discussed in more detail. Moreover, the variation in battery voltage in an EV differs depending on the model and manufacturer. The voltage variation of the PV system also depends on each individual system. Thus, there is an advantage when applying a general method to the inductance design in a TAB converter for many different rated powers with different switching frequencies and voltage variations.

A normalization design method for the inductance in a TAB converter was proposed (17). The relationships between the inductances, phase shift, and DC voltage ranges of the TAB converter have been clarified. As an advantage of the proposed method, the phase shift operation point and behavior of the converter are evident at the design point and are the same for different rated powers and switching frequencies in different applications. However, it had done the calculation for the voltage variation in only a single port. It is needed to develop the calculation for the voltage variations in two ports with better accuracy.

This paper proposes a normalization design method for a TAB converter when considering the voltage variations in two ports. The limitation of inductance corresponding to different voltage variations is specified. The relationship between the inductance and a phase shift operation are clarified. The suitability of the inductances is then discussed. The developed method is shown to be helpful in designing a TAB converter for many different applications. Finally, a laboratory prototype circuit and the experiment results for a system rated at 200 V and 500 W are described.

2. Operation and Power Transmission of TAB Converter

2.1 TAB Converter and Operation Figure 2 shows the connection of the TAB converter to three main parts of the household renewable energy system. The rooftop PV is connected to the primary side. The secondary side connects to the DC grid and load. The EV is connected to the tertiary side of the TAB converter.

As shown in Fig. 2, n2 is the turn ratio of the secondary side in comparison to the primary side of the transformer. It is also similar to the tertiary side, which is shown as n3. The series inductances, L1, L2′, and L3′ include the external inductance and leakage inductance on each side. The phase leg midpoints voltages u1, u2′, and u3′ have the amplitudes V1, V2′, and V3′ respectively. The direction and amplitude of the power in each port are controlled by the phase shift between the gate signals of the ports. Thus, the gate signal of the primary port keeps the phase shift angle at zero whereas the phase shift angle of the gate signal on the secondary side, ϕ2, and the tertiary side, ϕ3, are changed.

2.2 Power Transmission of TAB Converter Figure 3(a) shows the equivalent circuit of the three-winding transformer (16). Figure 3(b) shows the Y-type equivalent circuit of the TAB converter where the inductances, voltages, and currents of the secondary side and tertiary side referred to the primary side. Therefore, u2 = u′2/n2, u3 = u′3/n3, i2 = i′2/n2, and i3 = i′3/n3. The primary-referred inductances L2, L3 are defined through the following equation.

\[
\begin{align*}
L_2 &= L'_2/n_2^2 \\
L_3 &= L'_3/n_3^2 \\
V_2 &= V'_2/n_2 \\
V_3 &= V'_3/n_3
\end{align*}
\]

The primary-referred inductances and voltages are then used for the power calculation. The power of each port is formulated in the equations below (16).

\[
P_1 = \frac{V_1 V_2 \varphi_2 (\pi - |\varphi_2|) L_1 + V_1 V_3 \varphi_3 (\pi - |\varphi_3|) L_2}{2\pi f (L_1 L_2 + L_2 L_3 + L_3 L_1)} \\
P_2 = \frac{V_2 V_1 (-\varphi_2) (\pi - |\varphi_2|) L_3}{2\pi f (L_1 L_2 + L_2 L_3 + L_3 L_1)} + \frac{V_2 V_3 (\varphi_2 - \varphi_3) (\pi - |\varphi_2 - \varphi_3|) L_4}{2\pi f (L_1 L_2 + L_2 L_3 + L_3 L_1)} \\
P_3 = \frac{V_3 V_1 (\varphi_3) (\pi - |\varphi_3|) L_2}{2\pi f (L_1 L_2 + L_2 L_3 + L_3 L_1)} + \frac{V_3 V_2 (\varphi_2 - \varphi_3) (\pi - |\varphi_2 - \varphi_3|) L_4}{2\pi f (L_1 L_2 + L_2 L_3 + L_3 L_1)}
\]

Where f denotes the switching frequency, and P1, P2, and P3 are the transmission power of the primary, secondary, and tertiary sides, respectively.

3. Proposed Design Method

3.1 Normalization Design Method The normalization method is proposed to design the inductances of the TAB converter. The inductance, voltages, and power of the converter are standardized based on the rated values. The voltage variations and power transmission are normalized in terms of percentage. The inductances are then calculated based on percentage of the rated equivalent inductance, which can be used to design the TAB converter for many different voltages and power ratings in other applications.

Figure 4 shows an equivalent circuit for a TAB converter.
Normalization Design of Inductances in TAB Converter (Van-Long Pham et al.)

Fig. 4. Simple equivalent circuit of TAB converter

It includes a source \( u_2 \) and inductance \( L_{eq} \), where \( L_{eq} \) is the rated equivalent inductance, which is represented as the total load of the converter. Voltage \( u_2 \) has the amplitude as \( V_2 \).

For \( Z_{eq} \) is rated equivalent impedance of the equivalent circuit Fig. 4, as \( Z_{eq} = 2\pi f L_{eq} \), it has the following.

\[
Z_{eq} = \frac{V_2^2}{P_r}, \quad \text{......................... (5)}
\]

where \( P_r \) is the rated power. Therefore, the relationships among the rated power, voltage, and rated equivalent inductance \( L_{eq} \) are shown in the following equation.

\[
L_{eq} = \frac{V_2^2}{2\pi f P_r}, \quad \text{......................... (6)}
\]

For the tertiary voltage, \( V_3 \) varies from the minimum voltage \( V_{3\text{min}} \) to the maximum voltage \( V_{3\text{max}} \), and has the relationship with the rated voltage through the following equation.

\[
V_{3\%} = 100 \frac{V_3}{V_2} \quad \text{[\%], \quad \text{......................... (7)}}
\]

where \( V_{3\%} \) is the voltage of the tertiary side in percentage, which is similar to that of the primary port.

\[
V_{1\%} = 100 \frac{V_1}{V_2} \quad \text{[\%], \quad \text{......................... (8)}}
\]

where \( V_{1\%} \) is the voltage of the primary side in percentage.

For the sake of simplicity of the calculation, the primary-referred inductances, \( L_1 \), \( L_2 \), or \( L_3 \), are simplified as the same. If the primary-referred inductances are different, the proposed method can be used. The detail explanation will be shown in section 4.1 and the appendix.

\[
L_1 = L_2 = L_3 = L \quad \text{......................... (9)}
\]

\[
L_{eq} = 100 \frac{L}{L_{eq}} \quad \text{[\%], \quad \text{......................... (10)}}
\]

where \( L_{eq} \) is the normalized inductance, which is a percentage of the primary-referred inductance to the rated equivalent inductance. The normalized inductance can be designed based on the voltage variations and phase shift of the operating area.

### 3.2 Design of Normalized Inductance in TAB Converter

This section describes the calculation of the normalized inductance when the voltages of the primary and tertiary ports vary. It is considered for the case \( V_2 \geq V_{1\text{min}} \geq V_{3\text{min}} \). Thus, \( P_1 = P_r \) and \( P_3 = -P_r \), where \( P_2 = 0 \) is the most critical operation point because the phase shift of the tertiary port \( \varphi_3 \) is at maximum.

This is discussed for the range of phase shift in \( \varphi_2 \) and \( \varphi_3 \) from zero to \( \pi/2 \). The powers change the direction within the range of phase shift from \(-\pi/2 \) to zero. First, it is necessary to satisfy the following equation for \( P_2 = 0 \).

\[
V_2 V_1 (-\varphi_2) (\pi - |\varphi_2|) + V_2 V_3 (\varphi_3 - \varphi_2) (\pi - |\varphi_3 - \varphi_2|) = 0 \quad \text{......................... (11)}
\]

or

\[
V_1 (\varphi_2) (\pi - |\varphi_2|) = V_3 (\varphi_3 - \varphi_2) (\pi - |\varphi_3 - \varphi_2|) \quad \text{..................... (12)}
\]

Using the sinusoidal and linear approximation, where \( 0 < \varphi_2 < \frac{\pi}{4} \) and \( 0 < \varphi_2 < \frac{\pi}{4} \), the following is derived.

\[
\varphi_2 (\pi - |\varphi_2|) \approx \frac{8}{\pi} \varphi_2 \quad \text{................. (13)}
\]

\[
(\varphi_3 - \varphi_2) (\pi - |\varphi_3 - \varphi_2|) \approx \frac{8}{\pi} (\varphi_3 - \varphi_2) \quad \text{................. (14)}
\]

From (12)–(14), the following can be approximated:

\[
V_1 \varphi_2 = V_3 (\varphi_3 - \varphi_2) \quad \text{................. (15)}
\]

or

\[
\varphi_2 = \frac{V_3}{V_1 + V_3} \varphi_3 \quad \text{................. (16)}
\]

This indicates that the voltage variation affects the relationship between \( \varphi_2 \) and \( \varphi_3 \). Applying the condition \( P_2 = 0 \) by (16) to the equation of power of the primary port \( P_1 \), the following equation is derived:

\[
P_1 = \frac{V_1 V_2 V_3 (\varphi_3 - \varphi_2) + V_1 V_3 (\pi - \varphi_3)}{6\pi f L} \quad \text{................. (17)}
\]

where \( P_1 \) is replaced by \( P_r \) as the transmission power. Then it has the following.

\[
P_r = \frac{V_1 V_2 V_3}{6\pi^2 f L} \left( \frac{V_3}{V_1 + V_3} \pi - \left( \frac{V_1}{V_1 + V_3} \right)^2 \varphi_3 - \left( \frac{V_3}{V_1 + V_3} \right) \varphi_3 \right) \quad \text{................. (18)}
\]

or

\[
P_r = \frac{V_1 V_2}{6\pi^2 f L} \varphi_3 \left( \frac{V_3}{V_1 + V_3} \pi - \left( \frac{V_1}{V_1 + V_3} \right)^2 + \left( \frac{V_3}{V_1 + V_3} \right) \varphi_3 \right) \quad \text{................. (19)}
\]

Using \( V_{1\%} \) and \( V_{3\%} \) for the above equation, it has the following.

\[
L = \frac{V_2^2}{100} \frac{V_{1\%}}{6\pi^2 f P_r} \varphi_3 \left( \frac{V_{3\%}}{V_{1\%} + V_{3\%} + V_{3\%}} \pi - \left( \frac{V_{3\%}}{V_{1\%} + V_{3\%}} \right)^2 + \left( \frac{V_{3\%}}{V_{1\%} + V_{3\%}} \right) \varphi_3 \right) \quad \text{................. (20)}
\]

or

\[
L = \frac{V_2^2}{100} \frac{V_{1\%} V_{3\%}}{6\pi^2 f P_r} \varphi_3 (A\pi - B\varphi_3) \quad \text{................. (21)}
\]

where \( A \) and \( B \) are calculated

\[
\begin{align*}
A &= \frac{1}{V_{1\%} + V_{3\%} + 100} \\
B &= \frac{V_{3\%}}{(V_{1\%} + V_{3\%}) + 100}
\end{align*}
\]

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From (6), (10), and (20)–(22), the relationship between the normalized inductance and phase shift of the tertiary port at the rated power \( P_r = P_t \) is shown in the following.

\[
L_{\text{cor}} = \frac{V_{1s} V_{3s}}{3\pi \varphi_3 (\lambda \pi - B \varphi_3)} \quad \text{[\%]} \quad \ldots \ldots \cdot (23)
\]

The solution to (23) shows the relationship between the normalized inductance, phase shift, and voltage variations. Figure 5 demonstrates the limitation of inductance \( L_{\text{inmax}} \) corresponding to different voltage variations according to (23), where the phase shift is at maximum as \( \varphi_3 = \pi/2 \). The voltages of the secondary and tertiary sides are varied from 70% to 120% depending on the application. This indicates that the limitation of the inductance is specified for different voltage variations.

According to (23), by determining the maximum phase shift operation, the inductance is designed directly depending on the voltage variations of the application. For an application in which the voltages of the three ports are the same, (23) is written simply as follows.

\[
L_{\text{cor}} = \frac{100}{12\pi} \varphi_3 (6\pi - 5\varphi_3) \quad \text{[\%]} \quad \ldots \ldots \cdot (24)
\]

It can also be applied to an application that has one voltage variation. For example, only the tertiary voltage has a variation, and thus the normalization is calculated as follows.

\[
L_{\text{cor}} = \frac{100}{3\pi} V_{3s} \varphi_3 (\lambda \pi - B \varphi_3) \quad \text{[\%]} \quad \ldots \ldots \cdot (25)
\]

### 3.3 Transmission Power at Designed Inductance with Voltage Variations

In the operation of the TAB converter, the transmission power \( P_t \) changes depending on the voltage variations and phase shift angles.

\[
P_{\text{cor}} = \frac{100}{P_t} \quad \text{[\%]} \quad \ldots \ldots \cdot (26)
\]

where \( P_{\text{cor}} \) is the normalized power, which is the percentage of the transmission and rated power. The relationship between inductance, voltage variations, and power is as follows:

\[
L_{\text{cor}} = \frac{100V_{1s} V_{3s}}{3\pi P_{\text{cor}}} \varphi_3 (\lambda \pi - B \varphi_3) \quad \text{[\%]} \quad \ldots \ldots \cdot (27)
\]

The transmission power can be viewed as depending on the voltage variations at the designed inductance through the following.

\[
P_{\text{cor}} = \frac{100V_{1s} V_{3s}}{3\pi L_{\text{cor}}} \varphi_3 (\lambda \pi - B \varphi_3) \quad \text{[\%]} \quad \ldots \ldots \cdot (28)
\]

### 4. Design of TAB Converter for Household Renewable Energy System

#### 4.1 Design Process

This section introduces the design process for inductances in a TAB converter using the normalization design method. Figure 6 shows a flowchart of the design process. It includes five main steps. The equations in each step are provided in detail.

First, the rated power and voltage ranges of the converter are listed. After that, the voltages and inductances of the secondary and tertiary sides are then referred to the primary side from the transformer turn ratio by (1), in step 1. Therefore, the proposed method can be applied if the turn ratios are different. The rated voltage is decided. Thus, equivalent inductance is calculated by (6). The voltage variations in percentage are shown as (7) and (8), as shown in step 2. By applying (22) and (23), the normalized inductance \( L_{\text{cor}} \) is shown in relation to the phase shift angle and voltage variation, as shown in step 3.

By selecting the design point for the rated phase shift operation range, \( L_{\text{cor}} \) is determined. The design is based on the most critical aspect of the operation, and thus it makes certain that the converter can operate in all working modes. The primary-referred inductance is calculated according to (9) and (10), in step 4. If the primary-referred inductances are different, \( L_2 \) and \( L_3 \) in step 4 is calculated by using the appendix. Based on the transformer turn ratio \( n_2 \) and \( n_3 \), the series inductances in the secondary and tertiary ports, \( L_2' \) and
Table 1. Parameters of TAB Converter for Household Renewable Energy System

<table>
<thead>
<tr>
<th>Elements</th>
<th>Symbol</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power</td>
<td>( P_r )</td>
<td>10 kW</td>
</tr>
<tr>
<td>Primary voltage</td>
<td>( V_1 )</td>
<td>340 V - 440 V</td>
</tr>
<tr>
<td>Secondary voltage</td>
<td>( V'_2 )</td>
<td>400 V</td>
</tr>
<tr>
<td>Tertiary voltage</td>
<td>( V'_3 )</td>
<td>340 V - 440 V</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>( f )</td>
<td>20 kHz - 100 kHz</td>
</tr>
</tbody>
</table>

Table 2. Primary-referred Parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Normalization</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_2 : n_3 )</td>
<td>1:1:1</td>
<td>N/A</td>
</tr>
<tr>
<td>( V_1 )</td>
<td>340 V - 440 V</td>
<td>85% - 110%</td>
</tr>
<tr>
<td>( V'_2 )</td>
<td>400 V</td>
<td>100%</td>
</tr>
<tr>
<td>( V'_3 )</td>
<td>340 V - 440 V</td>
<td>85% - 110%</td>
</tr>
</tbody>
</table>

\( L'_3 \) of the TAB converter are computed from (1), as shown in step 5.

### 4.2 Design of TAB Converter for a Household Renewable Energy System Rated at 400 V and 10 kW

The proposed design method is applied to the design of a TAB converter for a household renewable energy system rated at 400 V and 10 kW. The battery voltage, which connects to tertiary port, varies from 340 to 440 V. The voltage range of the PV is also from 340 to 440 V. Table 1 shows the circuit parameters. The switching frequency of the TAB converter is within the range of 20 to 100 kHz.

The primary-referred parameters are shown in Table 2. In this application, the turn ratio of the transformer can be designed as 1:1:1. Thus, the primary voltage, \( V_{1\%} \), varies from 85% to 110%. The voltage range of the tertiary side \( V_{3\%} \) is from 85% to 110%. The voltage of the secondary side is the same as the rated voltage.

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Figure 7 shows the relationship between normalized inductance and highest phase shift operation point when \( V_1 = 85\% \) and \( V'_3 = 85\% \).

\( L'_3 \) of the TAB converter are computed from (1), as shown in step 5.

\[ L'_3 = \frac{V'_1}{V'_3} \]

The relationship between normalized inductance and highest phase shift operation point when \( V_1 = 85\% \) and \( V'_3 = 85\% \) is shown in Fig. 7.

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The relationship between normalized inductance and highest phase shift operation point when \( V_1 = 85\% \) and \( V'_3 = 85\% \) is shown in Fig. 7.

If the practical implementation and operation have an error in each inductance, the proposed method is still can be used. For example, the datasheet of inductor shows that the inductance may have an error. In addition, it shows that the error of inductance is depended on the operating current. Therefore, the normalized inductance should be smaller than the limitation value, \( L_{\%_{\text{max}}} \). As in this application, normalized inductance is suggested equal or smaller than 30%, which allows the error is 18%, at the rated power and even higher error at lower power. 35.4% is smaller than \( L_{\%_{\text{max}}} \).

It indicates that the power is limited when the normalized inductance is over \( L_{\%_{\text{max}}} \). For example, the power is limited at 90% when \( L_{\%} = 40\% \), as shown in Fig. 8. When the inductance is 20%, the converter operates at the rated power with a phase shift smaller than \( \pi/6 \). However, that is the highest phase shift operation when the voltage is lowest. At the highest operating voltage, the phase shift is smaller.

Figure 9 shows the phase shift operation areas of the converter with the normalized inductance \( L_{\%} \) at 20% and 30%, respectively. The violet color shows the phase shift operation area of the converter, which is limited by the operation of rated power, \( P_1 = P_r, P_2 = -P_r, P_3 = -P_r \), and at \( P_1 = 0 \), respectively. It is discussing for at highest voltage because the phase shift operation area is the smallest, which is critical for the accuracy of the control. For \( L_{\%} = 20\% \), the operation area is small, as shown in Fig. 9(a). Depending on the operation mode, but the phase shift angle of one port is smaller than 11°, which is sensitive in control. Each degree affects 10% of the rated power. For \( L_{\%} = 30\% \), the phase shift angles of both two ports are higher 16° at the rated power, as shown in Fig. 9(b).

This indicates that the normalized inductance \( L_{\%} \) at 30% is a suitable point for this application. There is no issue
regarding the operation area of the TAB converter. Figure 10 shows the relationship between the transmission power and phase shift at an inductance of 30% for the voltage variation range. This shows that the phase shift operation of the tertiary port, $\varphi_3$, varies from $35^\circ$ to $62.8^\circ$ at the rated power.

After determining the normalized inductance, the inductance of each port is calculated for two switching frequency systems, as shown in Table 3. The switching frequency increases in inverse proportion to the inductance (5). As a result, the inductances reduce five-fold when increasing the switching frequency from 20 kHz to 100 kHz.

5. Implementation Prototype Circuit and Experiment Results

5.1 Implementation of Prototype Circuit  A small-scale system rated at 200 V and 500 W is implemented to verify the proposed design method (Fig. 11). The parameters of the prototype circuit are shown in Table 4. The voltage variations of the prototype circuit are the same as the 10 kW system shown in Table 2. Thus, $V_{1\%}$ and $V_{3\%}$ vary from 170 to 220 V. The normalized inductance is also designed at 30%. The primary-referred inductance is 38.2 $\mu$H for the switching frequency at 100 kHz.

Figure 12 shows the prototype transformer and external inductors. The external inductors use air cores. The measured inductances are shown in Table 5. Each series inductance includes each external inductance and the leakage inductance of the transformer on the same side.

5.2 Experiment Results  The experimental circuit was tested for most types of critical operations when the transmission power is between the primary and tertiary ports with no power in the secondary port. To confirm the phase shift operation range of the converter in comparison to the theoretical calculation, three states were applied during the experiments, namely, the lowest voltage, the highest voltage, and the rated voltage design.

Figure 13 shows the inductance currents $i_1$, $i_2^\prime$, and $i_3^\prime$ and voltages between the phase leg midpoint, $u_1$, $u_2^\prime$, and $u_3^\prime$ for each port when the voltages of the three ports are 100% of the rated power. The phase shift of the tertiary port is $42.7^\circ$, which is almost same the same the calculated value as $42.9^\circ$.

Figure 14 shows the experiment results for $V_1 = 85\%$ and $V_3 = 85\%$. The actual phase shift of the tertiary port is $62.3^\circ$, which is close to the calculated phase shift of $62.8^\circ$. Figure 15 shows the experiment results in for $V_1 = 110\%$ and $V_3 = 110\%$. The preliminary phase shift of the tertiary port is $35.4^\circ$, which is also close to the calculated phase shift of $35^\circ$.

Figure 16 shows a comparison between the experimental results and the theoretical calculations for the power of 40% to 100%. The three lines indicate the relationship between
power and phase shift of the three voltage conditions by calculating. The dotted points are the experimental results, which indicate that the calculated and experimental results are almost the same.

6. Conclusion

A normalization design for the inductances in the TAB converter was proposed. The complicated relationship between the power, phase shifts, switching frequency, voltage variations, and inductances were clarified. The inductances were effectively designed. A small-scale system rated at 200 V and 500 W was implemented to verify the proposed method. The experiment results confirm the theoretical calculations. The proposed method was shown to be useful in the design of a TAB converter for other future applications.

References

Appendix

1. Design of Inductances in TAB Converter if Primary-referred Inductances are Different

If the primary-referred inductances, $L_1$, $L_2$, and $L_3$, are different, $L_1 \neq L_2 \neq L_3$, the equation (16) is updated as the following.

$$\varphi_2 = \frac{V_1 L_1}{V_1 L_3 + V_3 L_1} \varphi_1 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 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