# Dual Active Bridge DC-DC Converter using Both Full and Half Bridge Topologies to Achieve High Efficiency for Wide Load

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***Abstract*—This papar proposes which the Dual Active Bridge (DAB) converter changes between Full Bridge (FB) converter's operation and Half Bridge (HB) converter's operation on the secondary side of the high frequency transformer depending on the output power. With the HB converter operation's, the iron loss of the transformer becomes small because the secondary voltage of the transformer becomes half compared to the FB converter's operation. In addition, Zero Voltage Switching (ZVS) is achieved at the light load. Therefore, the proposed circuit can obtain the high efficiency for the wide load by the changing the HB and the FB converter's operation depending on the output power. In this paper, the changing point between the HB and the FB converter is derived using the loss calculation. The validity of the proposed circuit is verified by 800-W prototype. From the experimental results, it is confirmed that the proposed circuit has the two local maximum efficiencies which are 92.9% and 93.4% at the light load and the heavy load using the proposed circuit.**

***Keywords—Dual Active Bridge Converter; Zero Voltage Swtichng (ZV S);***

## I. INTRODUCTION

Recently, the high efficiency and the high power density bidirectional isolated DC/DC converters are increasingly desired in the application of power grid system that found in the smart grid system and electric vehicles. Therefore, the power conversion system requires the isolation and bidirectional operation. In order to achieve the bi-directional power transmission and the isolation, a bi-directional isolated DC-DC converter is used as power conversion systems [1-3]. A Dual Active Bridge (DAB) converter has been presented such as a bidirectional isolated DC-DC converter [4-5]. The DAB converter can achieve the bidirectional power conversion, isolation and high voltage boost up using active switches and a high frequency transformer. In addition, in order to reduce the switching loss, the DAB converter achieves Zero Voltage Switching (ZVS) during the dead time using an additional capacitance or a parasitic capacitance of the switching devices [5]. However, the ZVS cannot be achieved at the light load in the conventional DAB converter because the capacitor connected in parallel to the switching devices is not completely charged or discharged due to the small transformer current. Moreover, the conduction loss also increases due to the large circulating current [6]. In order to solve these problems, Pulse Width Modulation (PWM) is added to the phase shift control in order to extend the ZVS range and reduce the circulating current in [7-8]. However, it is not always possible to achieve the ZVS for all switches due to the error between the primary voltage and the secondary voltage including the turn ratio of the transformer. Besides, the efficiency is not discussed in terms of the high voltage boost up. In [9-10], the reactive power is suppressed by voltage compensation using an auxiliary transformer. However, the additional switching devices and the auxiliary transformer are required in order to reduce the circulating current. In addition, the iron loss is increased by the auxiliary transformer. In [11-12], the variable switching frequency control is introduced and a relay switch is connected to the transformer in order to change the leakage inductance depending on the output power. However, the variable switching frequency makes the design EMC filter difficult in the high power application. In [13], a FB converter and a HB converter are combined using a bidirectional switch. The bidirectional switch can be on-state or off-state during the whole switching period when the input voltage is maximum or minimum. However, the bidirectional switch works based on the PWM switching while the input voltage is changed. Therefore, the switching loss occurs in the bidirectional switch although the ZVS is achieved on the main switches. In [14-16], a three-level DAB converter with a neutral-point-clamped topology has been proposed in order to improve the total harmonic distortion of the inductor current. However, the number of switching devices is increased.

This paper proposes a new isolated bidirectional DC-DC converter based on the DAB converter. The secondary side of the circuit topology is changed from the FB converter or the HB converter depending on the load conditions. The bidirectional switch without the PWM operation is used to select the circuit topology. By changing between the FB converter and the HB converter depending on the load, the proposed circuit can achieve the high efficiency for the wide load because the ZVS range is extended and the iron loss of the transformer is reduced at the light load. This paper is organized as follows; first, the configuration and the operations of the proposed circuit are explained. Second, the principle of the

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power loss reduction in the proposed circuit is described. Thirdly, the proposed calculation method that is used to evaluate the power loss is confirmed. Finally, the experimental results show the fundamental operation and the efficiency characteristics of the prototype circuit.

## II. PROPOSED DUAL ACTIVE BRIDGE CONVERTER

### *A. Circuit configulation*

Fig. 1 shows the configuration of the proposed isolated bidirectional DC-DC converter based on the DAB converter. The proposed converter consists of the DAB converter, a bidirectional switch $Sw_5$ and two capacitors $C_1$ and $C_2$. The capacitances of $C_1$ and $C_2$ are same. The proposed circuit can achieve the ZVS in the same manner with the conventional DAB converter when the switches are modulated at the high output power. The maximum rating voltage of the bidirectional switch is same to that of $C_1$ and $C_2$ which is half of other switches on the secondary side of the transformer. In addition, the bidirectional switch does not require the high speed switching because the PWM is not applied to $Sw_5$. Therefore, the bidirectional switch which has low on-resistance can be selected in order to reduce the conduction loss of $Sw_5$ when $Sw_5$ is on-state.

### *B. Output power for Full Bridge Mode and Half Bridge mode*

Fig. 2 shows the operation modes of the proposed circuit. The FB converter and the HB converter are combined on the secondary side of the transformer.

Fig. 2 (a) shows the operation mode when the secondary side of the transformer is operated as the FB converter. During this mode, $Sw_5$ is always off. Therefore, the power loss does not occur on $Sw_5$. The capacitors $C_1$ and $C_2$ work as a smooth capacitance to $E_2$.

When the secondary side of the transformer is operated as the FB converter, the transferred power to the secondary side $P_{DC\_FB}$ is expressed by (1) [17].

$$P_{DC\_FB} = \frac{nV_{1\_max}V_{2\_FB\_max}}{\omega L_l}\delta(1-\frac{\delta}{\pi}) = \frac{nV_{1\_max}V_{2\_FB\_max}}{2\pi f_{sw} L_l}\delta(1-\frac{\delta}{\pi}) \quad (1)$$

where $V_{1\_max}$ is the maximum value of the secondary voltage of the transformer, $V_{2\_FB\_max}$ is the maximum value of the secondary voltage of the transformer, $L_l$ is the sum of the leakage inductance and that of the additional inductor, $\delta$ is the phase difference between the primary voltage and the secondary voltage of the transformer, $n$ is the turn ratio of the transformer, $\omega$ is the switching angular frequency and $f_{sw}$ is the switching frequency.

When the primary side of the transformer is operated as the FB converter, $V_{2\_FB\_max}$ is $E_2$. Therefore, the higher power is transferred using the FB converter to the secondary side of the transformer. On the other hand, the ZVS cannot be achieved at the light load because the capacitors connected in parallel to the switches are not completely charged or discharged due to low current in the conventional dual active bridge converter. In addition, the iron loss becomes large due to high $E_2$. As a result, the efficiency is sharply decreased at the light load.

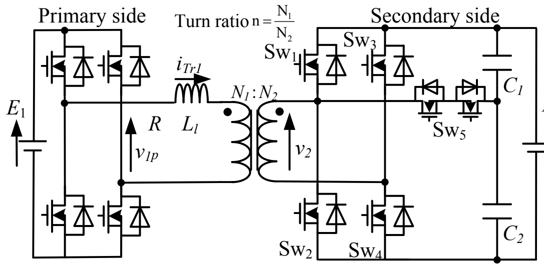
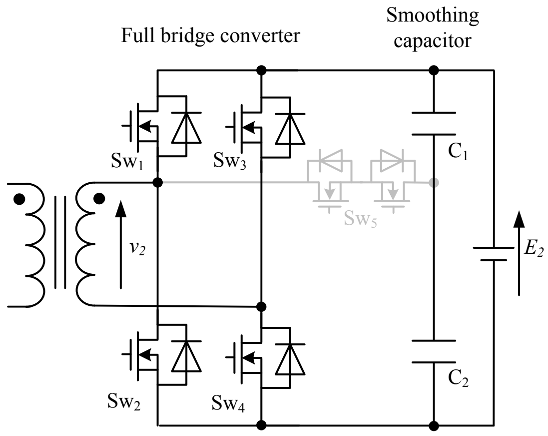
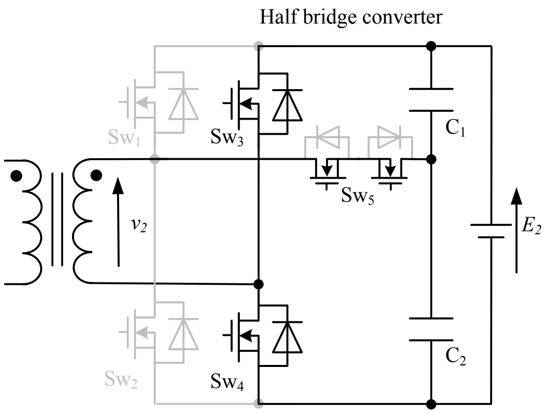



Fig. 1. . Configuration of proposed bidirectional DC-DC converter based on dual active bride converter ($E_1 < E_2$).




(a) FB converter operation. $C_1$ and $C_2$ work as smoothing capacitor to $E_2$.




(b) HB converter operation. $C_1$ and $C_2$ work as a part of HB converter operation.

Fig. 2. Operation mode of secondary side of transformer.

Fig. 2 (b) shows the operation mode when the secondary side of the transformer is operated as the HB converter. During this mode, $Sw_5$ is always on. Therefore, the power loss occurs on $Sw_5$. However, the conduction loss can be reduced due to low on-resistance because $Sw_5$ does not require the high switching speed. The capacitors $C_1$ and $C_2$ work as a part of the

HB converter. When the secondary side of the transformer is operated as the HB converter, the maximum value of the secondary voltage of the transformer $V_{2\_HB\_max}$ becomes $E_2/2$. When the secondary side of the transformer is operated as the HB converter, the output power to the secondary side $P_{DC\_HB}$ is expressed by (2).

$$P_{DC\_HB} = \frac{nV_{1\_max}V_{2\_HB\_max}}{\omega L_l}\delta(1-\frac{\delta}{\pi}) \quad (2)$$

From (2), it is understood that $P_{DC\_HB}$ is half of $P_{DC\_FB}$ when the FB converter's operation is selected. Moreover, the iron loss of the transformer is reduced because $V_{2\_HB\_max}$ becomes half of $E_2$. As a result, the lower power is transferred while the iron loss becomes lower compared with that of the FB converter.

In addition, the transformer current with the HB converter's operation becomes higher than the FB converter's operation. Therefore, the ZVS is achieved in the lower power region compared to the conventional DAB converter.

From above mentioned explanation, it is understood that the operation modes of the proposed circuit are changed according to the output power. In high output power region, the proposed circuit is operated as the conventional dual active bridge converter. In the low output power region, the proposed circuit is operated as a hybrid of the FB converter on the primary side of the transformer and the HB converter on the secondary side of the transformer. In the proposed method, It is required to derive the changing point between the HB converter and the FB converter from the converter loss

*C. ZVS range*

In order to achieve the ZVS for all switching devices in the FB converter's operation, the condition of the output power is presented by (3) [5].

$$\frac{nV_{1\_max}V_{2\_FB\_max}\pi}{4\omega L}\left\{\left|1-\left(\frac{nV_{1\_max}}{V_{2\_FB\_max}}\right)^2\right|\right\} \le P_{DC\_FB} \le \frac{nV_{1\_max}V_{2\_FB\_max}\pi}{4\omega L} \quad (3)$$

From (3), the lower limit of the output power to achieve the ZVS increases due to the ratio of the primary and the secondary voltage including the turn ratio of the transformer $nV_{1\_max}/V_{2\_FB\_max}$ .

On the other hands, the condition of the output power is presented by (4) in order to achieve the ZVS in the HB converter's operation.

$$\frac{n\pi V_{1\_max}V_{2\_HB\_max}}{4\omega L}\left\{\left|1-\left(\frac{nV_{1\_max}}{V_{2\_HB\_max}}\right)^2\right|\right\} \le P_{DC\_HB} \le \frac{nV_{1\_max}V_{2\_HB\_max}\pi}{4\omega L} \quad (4)$$

From (4), The ZVS range at the HB converter's operation is wider than the FB converter's operation at light load when $nV_{1\_max}/V_{2\_HB\_max}$ is close to 1

## III. Design Procedure of Maximum Efficiency Point for Two Modes

The power loss of the proposed circuit consists of the switching loss, the conductions loss of MOSFETs, the copper loss, the iron loss. Other power losses are not considered for simplification. Those power losses are divided into three kinds of a power loss. First, the switching loss is a power loss which is proportional to current. Next, the conduction loss of MOSFETs and the copper loss are a power loss which is proportional to the square of current. In the end, the iron loss is a power loss which is not related to current. Therefore, the total power loss $P_{loss}$ considering a single converter is expressed by (5)

$$P_{loss} = K_2P_{out}^{\ 2} + K_1P_{out} + K_0 \quad (5)$$

where $K_2$ is the constant coefficient for the power loss which is proportional to the square of current, $K_1$ is the constant coefficient for the power loss which is proportional to current and $K_0$ is the power loss which is not related to current.

In addition, the efficiency is expressed by (6) using (5).

$$\eta = \frac{P_{out}}{P_{out}+P_{loss}} = \frac{P_{out}}{K_2P_{out}^{\ 2}+(1+K_1)P_{out}+K_0} \quad (6)$$

By differentiating (6) with respect to $P_{out}$, the condition of the output power which achieves the maximum efficiency $P_{\eta max}$, is expressed by (7).

$$K_2P_{\eta\max}^{\ 2} = K_0 \quad (7)$$

From (7), $P_{\eta max}$ is determined the relationship between $K_0$ and $K_2$. Eq. (7) is re-expressed by (8)

$$P_{\eta\max} = \sqrt{\frac{K_0}{K_2}} \quad (8)$$

Fig. 3(a) shows the relationship among above three kinds of power loss and the efficiency in the case of a single converter. In the case of the general DAB converters, $K_1$ is zero at the higher output power due to ZVS. Therefore, $P_{\eta max}$ can be designed by adjusting relationship among the conduction loss of MOSFETs, the copper loss and the iron loss while the region which achieves the ZVS is independently designed.

Fig. 3(b) shows the efficiency characteristics considering the proposed circuit. The proposed circuit has two local maximum efficiencies at the light load and the heavy load because the HB converter's or the FB converter's operation is selected depending on the output power. Therefore, the efficiency is higher compared with the conventional DAB converter by changing two circuits on the secondary side of the transformer at $P_{sw\_HB\text{-}FB}$. In the proposed circuit, the efficiency can be improved for wide load variation by designing the ZVS range and adjusting the ratio among the conduction loss, the copper loss and the iron loss of the transformer. Therefore, it is necessary to calculate the each loss.

## IV. EXPLESSION FOR POWER LOSS

This section explains the power loss expression of the proposed circuit. The switching loss is ideally zero, because the switching devices can achieve the ZVS. The power loss of the proposed circuit consists of the conduction loss and the constant loss. The conduction loss is generated in the on-resistance of MOSFET, the wire resistance of the transformer. The constant loss is generated within the iron loss of the transformer and the no load loss.

### A. MOSFET Loss in primary and secondary inverter

The power loss of the MOSFET consists of the conduction loss. In the secondary voltage side inverter of Fig. 1, the conduction loss of the secondary voltage side MOSFET $P_{condloss\_pr}$ can be obtained by (7) using the on-resistance of the secondary side MOSFET $R_{on\_pr}$. Thus, the power loss per secondary MOSFET $P_{condloss\_se}$ can be obtained by (5), (6) using the on-resistance of the secondary side MOSFET

$$P_{condloss\_pr} = R_{on\_pr} I_L^{\,2} \tag{5}$$

$$P_{condloss\_se} = R_{on\_se} (N I_L)^2 \tag{6}$$

In the HB converter's operaiton, it should be noted that the conduction loss does not occur at two switches $S_{w1}$, $S_{w2}$ because the two switches are always off. However, the inductor current is double compared to the FB converter's operation at same load.

### B. Transformer loss

The power loss of the transformer consists of the iron loss and the copper loss. The iron loss occurs because of the flux change in the core. The copper loss occurs in the winding resistance of transformer. At first, when the square wave is inputted to the transformer, the flux density $B_{ac}$ is obtained by (7).

$$B_{ac} = \frac{V_{2\_FB\_\max} \cdot t_{on}}{2 N_2 A_c} \tag{7}$$

where $N_2$ is the secondary wire turns, $A_c$[m$^2$] is the effective cross-section of the core. Therefore, the iron loss of the transformer $P_{trans\_fe}$ is obtained by (14) using the characteristics of the flux density - core loss value $P_{cv}$[W/m$^3$] and the effective volume of the core $V_e$[m$^3$].

$$P_{trans\_fe} = P_{cv} V_e \tag{8}$$

In the half bridge mode, the iron loss is decreased by decrement of the flux density.

The copper loss of the transformer is obtained from the winding resistance with the skin effect. The primary winding copper loss $P_{copper\_pr}$ in the main circuit is obtained by (9) using the primary winding resistance of the main circuit with skin effect $R_{wire\_pr}$. The secondary winding copper loss $P_{copper\_se}$ in the main circuit is obtained by (10) using the primary winding resistance of the main circuit with skin effect $R_{wire\_se}$.

$$P_{copper\_pr} = R_{wire\_pr} I_L^{\,2} \tag{9}$$

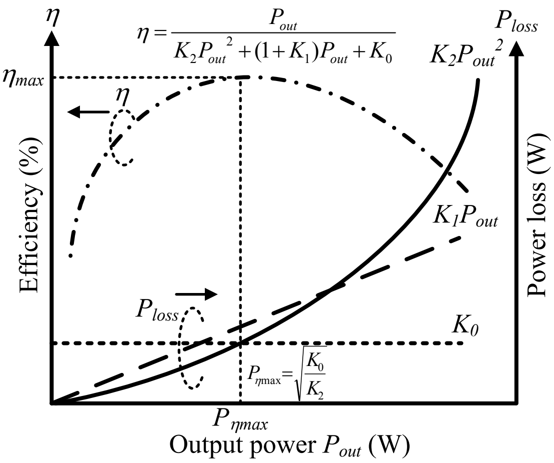
$$P_{copper\_se} = R_{wire\_se} (N I_L)^2 \tag{10}$$

### C. Additional inductor loss

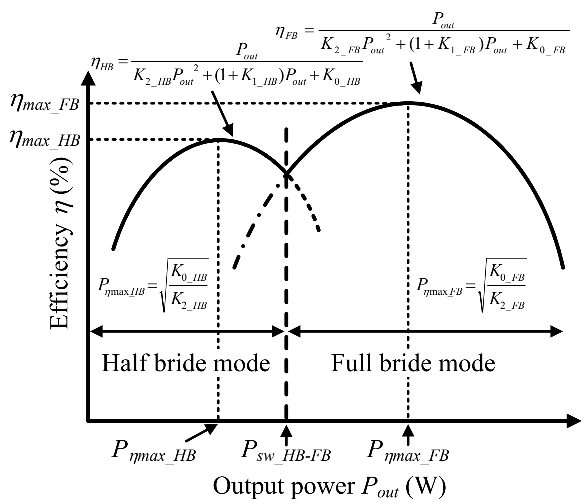
The power loss of the additional inductor consists of the copper loss and the iron loss. In order to neglect the saturation of the flux in the core, the air coil is used. Thus, the copper loss occurs only in the additional inductor. The copper loss of the additional inductor is obtained by similarly to (10).

## V. EFFICIENCY ESTIMATION BY LOSS CALCULATION

The proposed circuit in Fig. 1 is investigated using the loss calculation. The circuit parameters are shown in Table 1. It should be noted that the primary side wire resistance is larger than the secondary side because the additional inductor is series connected to the primary side of the transformer. The rating power is 800 W. The primary voltage has 36 V to 60 V and the secondary voltage has a fluctuation of 340 V to 380V. In the primary side inverter, IRFP4568 (IR co.) of MOSFET is




(a) Single converter.




(b) Proposed converter ($\eta_{max\_HB} < \eta_{max\_FB}$).

Fig. 3 Efficiency curve.

selected. On the other hands, STB45N65M5 (ST co.) of MOSFET is selected in the secondary side.

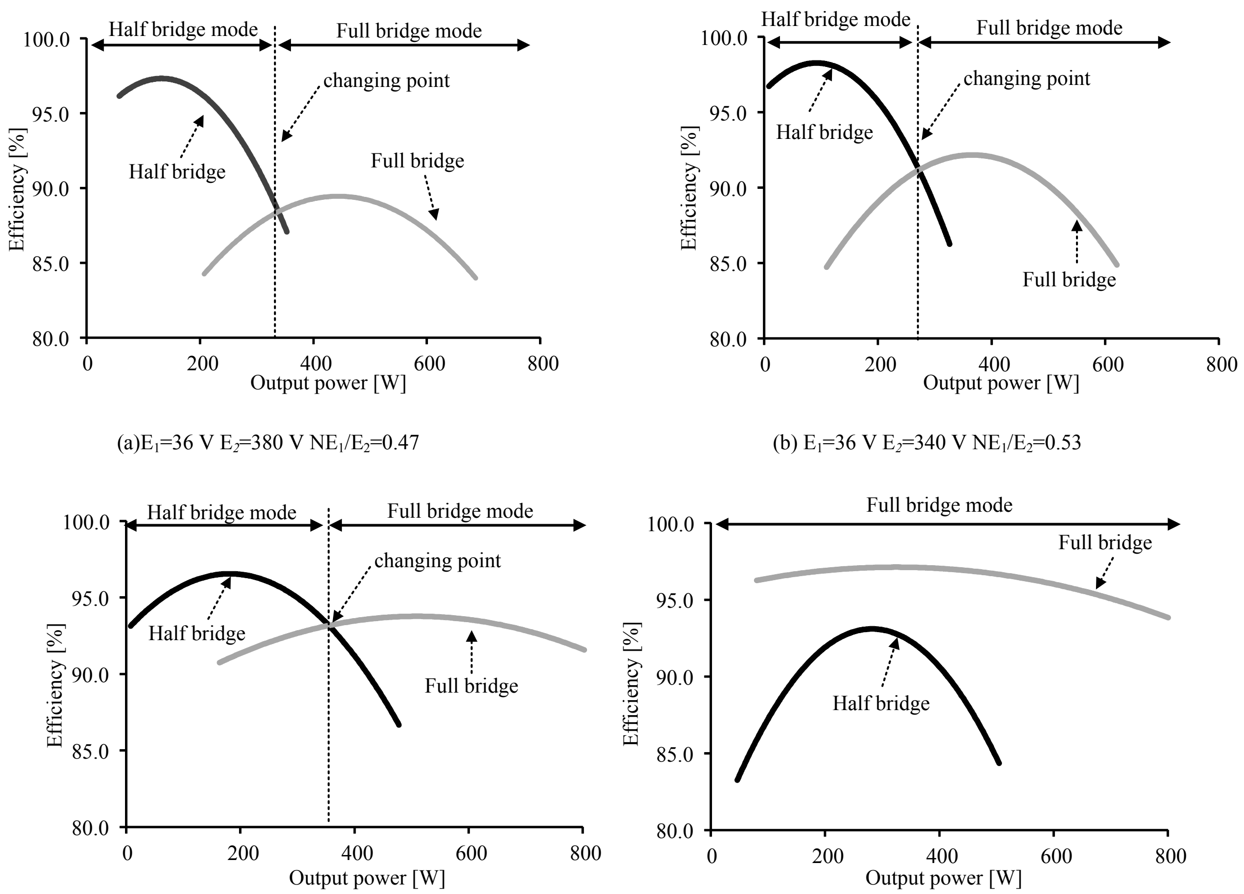
Fig. 4 shows the loss calculation results against the output power at the fluctuation of the primary and the secondary voltage. From the results, the maximum efficiency of over 95% is achieved against the voltage fluctuation. From Fig. 4, the changing point between the HB converter's and the FB converter's operation is decided by the primary/the secondary side voltage including the turn ratio of the transformer.

Fig.4 (a) shows the efficiency against the output power when $E_2$ is 380 V, $E_1$ is 32 V. the efficiency of the HB converter‘s operation is much higher than the FB converter's operation at the light load. This is because the iron loss is decreased compared to the FB converter's operation. However, the efficiency at the FB converter's operation is low. This is cause that the reactive current is large due to the error between the primary voltage and the secondary voltage including the turn ratio of the transformer. Moreover, the ZVS range is narrow from (3). Thus, the switching loss occurs at the light load.

For the same reasons, the efficiency of the FB converter's operation becomes low at close to $nE_1/E_2$=0.5 (In Fig.4 (b) and (c)). On the other hand, In Fig. 4 (d), the efficiency of the FB converter's operation is increased when the ratio of the primary and the secondary inverter voltage including the turn ratio is close to 1.

TABLE I. SPECIFICATION PARAMETERS OF THE POWER LOSS CALCULATION FOR PROPOSED CIRCUIT

| Parameter | Symbol | Value | Unit |
|---|---|---|---|
| Primary voltage | $E_1$ | 36 to 60 | V |
| Secondary voltage | $E_2$ | 340 to 380 | V |
| Switching frequency | $f_{sw}$ | 32 | kHz |
| Additional Inductor | $L_l$ | 15 | μH |
| Rated power | $P_{rated}$ | 800 | W |
| On resistance of primary switching devices | $R_{on\_pr}$ | 0.25 | mΩ |
| On resistance of secondary switching devices | $R_{on\_se}$ | 11 | mΩ |
| primaryside wire resistance | $R_{wire\_pr}$ | 150 | mΩ |
| Turn ratio of transformer | $n$ | 5 | |
| primaryside wire resistance | $R_{wire\_se}$ | 170 | mΩ |




(a)$E_1$=36 V $E_2$=380 V $NE_1/E_2$=0.47

(b) $E_1$=36 V $E_2$=340 V $NE_1/E_2$=0.53

(c) $E_1$=48 V $E_2$=380 V $NE_1/E_2$=0.63

(d) $E_1$=60 V $E_2$=340 V $NE_1/E_2$=0.88

Fig. 4 Calculation results of proposed circuit.

## VI. Experimental results

### A. Operation waveforms of the proposed circuit

Fig. 5 shows the experimental waveforms of a prototype circuit. Table 1 shows the experimental conditions. From the results, it is confirmed that $V_{2\_HB\_max}$ is $E_2/2$ = 190 V (In Fig. 5(a)) while $V_{2\_FB\_max}$ is $E_2$ = 380 V (In Fig. 5(b)). From Fig. 5(a) and Fig. 5(b), the primary current of the transformer is larger than the HB converter's operation because the secondary voltage of the transformer is different.

### B. Efficiency of each mode

Fig. 6 (a) shows the measurement efficiency against the output power when the secondary terminal voltage $E_2$ is 340 V. From the results, the local maximum efficiencies of 92.9% and 93.4% are achieved. At below $P_{\eta max\_FB}$, the efficiency at the FB converter's operation is decreased because the iron loss of the transformer is large compared with the total loss. Therefore, the secondary side of the transformer is operated as the HB converter in order to output the lower power and reduce the iron loss of the transformer. At the HB converter's operation, another local maximum efficiency exists because the constant coefficients for the power loss are different from that of the FB converter's operation. Therefore, it is confirmed that the proposed circuit improves the efficiency at the light load. On the other hand, the efficiency is decreased at the output power of more than $P_{\eta max\_FB}$. This is because the conduction losses of MOSFETs on the secondary side and the copper loss on the secondary side of the transformer are dominant in the total power loss.

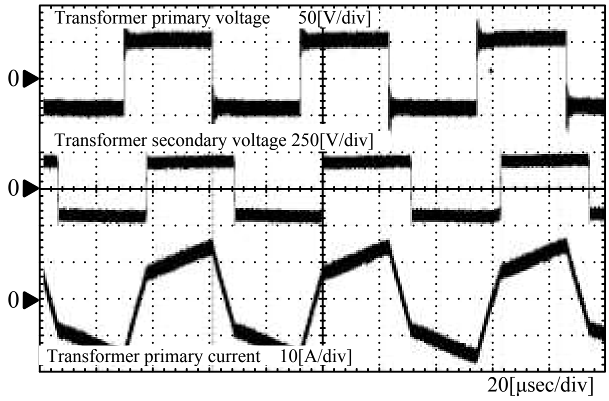
Fig. 6 (b) shows the measurement efficiency against the output power when the secondary voltage $E_2$ is 380 V. From the results, the local maximum efficiencies of 93.8% and 92.4% are achieved. The maximum efficiency at the FB mode in Fig. 6 (b) is lower than that of Fig. 6 (a). This is because the iron loss in Fig. 5 (b) becomes large compared with that in Fig. 5 (a) due to higher secondary terminal voltage. At the output power of more than 650 W, the efficiency in Fig. 6 (b) is higher than that in Fig. 6 (a) because the conduction loss of MOSFETs and the copper loss the transformer are reduced due to the low inductor current. At the HB converter's operation, the high efficiency is achieved compared with Fig. 6 (a).

The changing point which the FB converter and the HB converter are switched $P_{sw\_HB\text{-}FB}$, is not same between Fig. 6(a) and (b). This is because the minimum current which achieves the ZVS is different from the two conditions. When the secondary terminal voltage $E_2$ is high, the current of the primary side and the secondary side are lower than that when $E_2$ is low. Therefore, the ZVS range is extended when the FB converter is operated on the secondary side of the transformer. As a result, the changing point between the FB converter and the HB converter are higher output power in Fig. 6 (b).

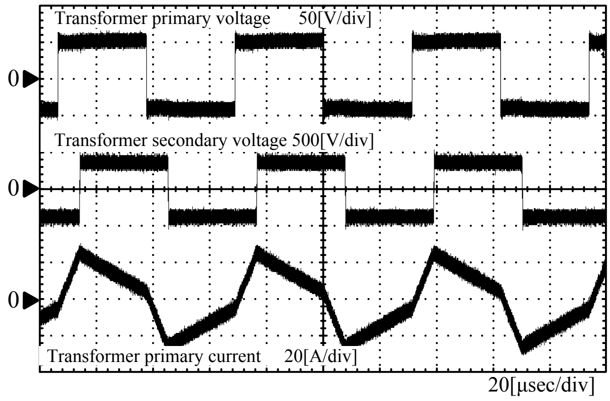
The output power which achieves the maximum efficiency at the FB converter $P_{\eta maxFB}$, is also different. This is because that the iron loss of the transformer is larger and the conduction loss is lower due to $E_2$ is high. Therefore, $K_{0\_FB}$ is large and $K_{2\_FB}$ is lower. As a result, the higher $E_2$ becomes, $P_{\eta maxFB}$ moves toward. On the other hand, the output power which achieves the maximum efficiency $P_{\eta maxHB}$ is almost same at the

TABLE II. Experimental conditions

| Parameter | Symbol | Value | Unit |
|---|---|---|---|
| Primary terminal voltage | $E_1$ | 48 | V |
| Secondary terminal voltage | $E_2$(Fig. 7(a)) | 340 | V |
| | $E_2$(Fig. 6, 7(b)) | 380 | V |
| Turn ratio | $n$ | 5 | |
| Switching frequency | $f_{sw}$ | 32 | kHz |
| Phase shift angle | $\delta$ | π/4 | rad |
| Additional inductor | $L_l$ | 15 | μH |




(a) HB converter's operation.




(b) FB converter's operation.

Fig. 5 Experimental waveforms of prototype circuit ($E_2$ is 380 V)

HB converter's operation. This is because the iron loss, the conduction loss of MOSFETs and the copper loss are not different much because $E_2$ is low.

### C. Loss analysis of alternation point

In order to evaluate the power loss at changing point which the HB and the FB converter's operation, the loss measures and analysis each part was implemented under the experimental conditions as shown in Table 1.

Fig.7 shows the loss analysis of the DAB converter with the FB converter and the HB converter. This is case that the secondary side voltage is changed while the primary voltage is constant. Fig.7(a) shows the loss analysis results at the condition of $E_1$=48 V,$E_2$=340 V. Fig.7(b) illustrates the analysis results with the HB converter's operation and the FB converter's operation when the primary side voltage $E_1$ is 48 V, the secondary voltage $E_2$ is 380 V. From the loss analysis, the iron loss of the transformer at the HB converter's operation is decreased compared to the FB converter's operation. In addition, the switching loss is reduced by achievement of the ZVS. However, the copper loss and the conduction loss are increased because the transformer current is large in the case of the same output power compared to the FB converter's operation. Moreover, the copper loss of the primary side transformer is predominant. It account for over 50% of the total loss. This is causes that the wire resistance of the additional inductor is large. Therefore, in order to achieve the higher efficiency, it is necessary to optimize the transformer and the additional inductor design.

## VII. CONCLUSION

This paper proposed isolated bidirectional DC-DC converter based on the DAB converter combining the FB converter and the HB converter on the secondary side of the transformer. The proposed converter changes the FB converter's operation and the HB converter's operation depending on the output power in order to extend the ZVS range and reduce the iron loss.

In order to derive the changing point of the FB converter and the HB converter, the loss calculation of the proposed circuit are investigated and evaluated in term of losses. From the results, it is clarified that the relationship among the primary, the secondary side voltage and the changing point of the FB converter's operation and the HB converter's operation. The validity of the loss calculation was confirmed the theoretically with the maximum efficiency of over 95%.

Finally, the principle of the proposed circuit is experimentally confirmed. It is confirmed that the two local maximum efficiencies are achieved by changing point between the two circuits. From the experimental results, the maximum efficiency of 93.8% at 280W is obtained. From the loss analysis results, the relationship between the switching point and the each part loss.

In future work, the converter efficiency will be improved by the optimizing design of the transformer and the additional inductor.

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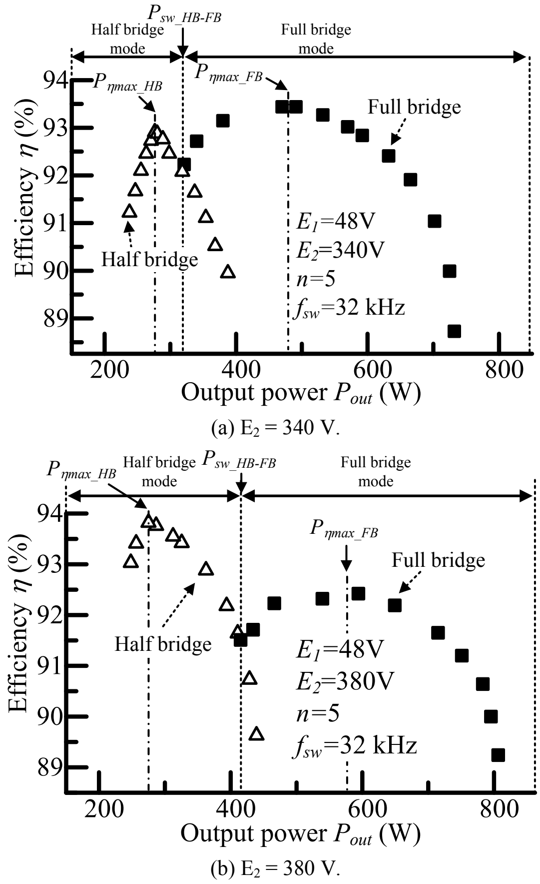


Fig. 6 Measured efficiency of prototype circuit.

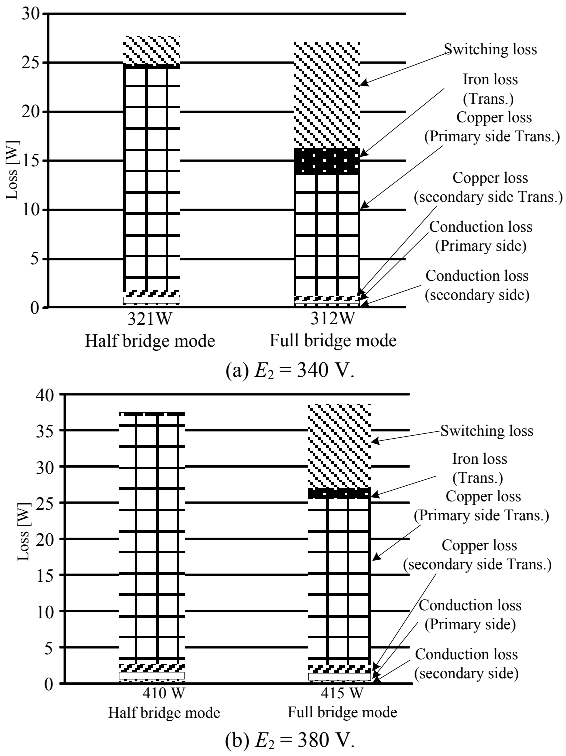


Fig. 7 Loss analysis of DAB converter with FB converter and HB converter at changing point

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