Performance Analysis of Full bridge, Boost Half Bridge and Half Bridge Topologies for Application in Phase Shift Converters

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Abstract—In this paper, performances of three topologies of bidirectional ports applicable to phase shift converters are compared. The proposed topologies include full bridge, half bridge and boost-half bridge that are commonly used as bi-directional port in various topologies of DC converters. The proposed analyses based on several indicators and characteristics of the topologies including reliability factor, switching loss, current ripple, cost, size, efficiency, range of power flow versus phase shift angle and control complexity. A phase shift converter based on proposed topologies was simulated using P-SIM. The analysis shows that considering all effective factors, full bridge topology provides better characteristics compared with others and can be selected for a phase shift converter. Also in some applications other topologies still remain a favorite choice.

Keywords—Bi-directional Port, Boost Half, Full Bridge, Phase shift, Converter

I. INTRODUCTION

Renewable energy systems have found extreme interest for research and development recently. According to intermittent nature of renewable energy sources using energy storage devices is almost inevitable [1]. These energy storage devices should be charged and discharged to store additional produced energy and deliver it to the loads on demands [2]. So far many topologies of DC converter are suggested for renewable energy systems [3]-[8]. Although in case of using storage device a bidirectional DC-DC converter should be used as a link between energy storage and renewable source. Phase shift converters are one of the best candidates for these applications as they are able to provide a controllable bi-directional power flow among the source, storage and loads[9],[10]. The simplest form of a phase shift converter included two bi-directional ports which is called dual active bridge (DAB) converter. This topology can be extended to triple active bridge (TAB) and even multi-active bridge (MAB). In general three topologies of full bridge (FB), half bridge (HB) and boost half bridge (BHB) have been used as interface port in phase shift converters [11]-[14]. Figure (1-45) shows the structure of three bidirectional switching topologies suitable for a phase shift converter. Selection of appropriate port based on performance of the above mentioned topologies needs an accurate analysis and comparison of their features. In the following sections some important features of these topologies are compared and they are classified considering all characteristics and their importance.

II. PERFORMANCE ANALYSIS

The main characteristics of three topologies effective in assessment included the cost, size of the circuit, efficiency, power flow range, reliability, switching loss current ripple and control complexity. These features are calculated and simulated for an assumed 4kW bi-directional port. The first selected feature is overall cost of topologies as is discussed in the following section.

A. Cost

The cost of topologies was calculated on base of number of main components and their average price in market. The main components included switching device, Diode, Capacitor, inductor and transformer. Table (2-5) shows the average price of the main components.

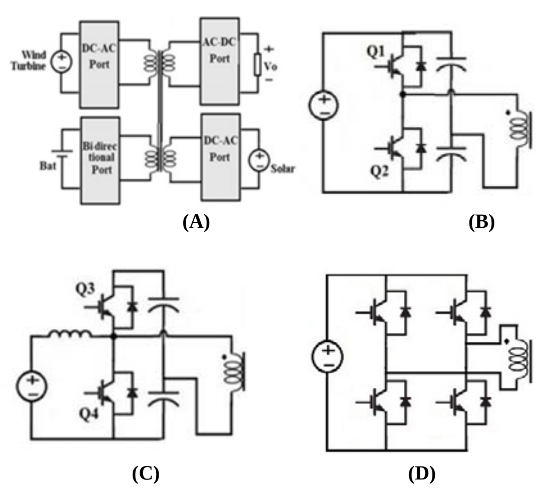


Figure (1)- (A)-Structure of four ports phase shift converter-(B) Half-bridge port (C)-Boost-Half-Bridge port (D)-Full bridge port

The total cost of the topologies are calculated for the ports with power ranges from 1-5kW according to the tabulated average prices for the main components, and are shown in figure(2). As can be seen in this figure the total cost for BHB topology is the highest and for FB topology is the lowest for all ranges of rated power. Based on this, the normalized cost factors for FB, HB and BHB topologies can be estimated as 1, 0.86 and 0.61 respectively where the higher value of cost factor allocated to the less cost.

B. Size

The area occupied by each topology is considered as one of evaluation factors. It is calculated on base of the average size of included components according to below equation.

$$V = 1.2(\sum_{i=1}^{n} A_i).h_{\max} \qquad (1)$$

In this equation A_i is the seated area of components on PCB and h_{max} is the height of the highest component. A 20% additional area is considered as spare area among the components. Table (4) shows the estimated size of each topology for different ranges off rated power. It can be seen that the estimated size of full bridge topology is less than others as it included no capacitors and inductors. While the half bridge topology needs two capacitors and in boost half bridge an inductor should be added to the capacitors.

C. Efficiency

Power transfer efficiency shows the efficiency of power transferred between the converter ports for a range of phase shift angle. The efficiency factor was defined as relative transferred power (P_{12}) to the input power (P_1) for each topology. It can be calculated according to (2).

$$\eta_{PT} = 100.\frac{P_{12}}{P_1} \qquad (2)$$

A DAB converter was simulated using P-SIM as shown in figure (3) to measure this parameter. The simulation results are shown in figure (4). It can be seed that at the lower phase shift angle the efficiency of power transfer decreases in all types of topologies and the highest efficiency can be achieved around the phase shift angles of 30-60 degrees. As is illustrated in figure the efficiency for both half and full bridge topologies is better than boost half bridge especially in lower value of phase shift angles. This factor was estimated as 1, 1 and 0.8 for FB, HB and BHB topologies respectively.

Table(1)- The average price for capacitor (1200uF / 200 V, -40- +105 C , +/-20%)

	Nichicon	Panasonic Electronic Corporation	Chemi-Con	Average price
Price (for 100 pcs)	6 $	4.8 $	8.5 $	6.43 $

Table(2)- IGBT switch (300V/70A) are shown in below tables.

	IXYS IXGH85N30	International Rectifiers IRGB4086	Fairchild Semiconductor FGA70N30	Average price
Price (for 100	3.91 $	5.8 $	4.3 $	4.67 $

	Pulse Electronic Corporation	Bourns Industrial Company	Average price
Price (for 100 pcs)	7.5 $	4.5 $	6 $

Table (3)- the average price for inductor (90 uH , 10 A, Toroidal Ferrite core

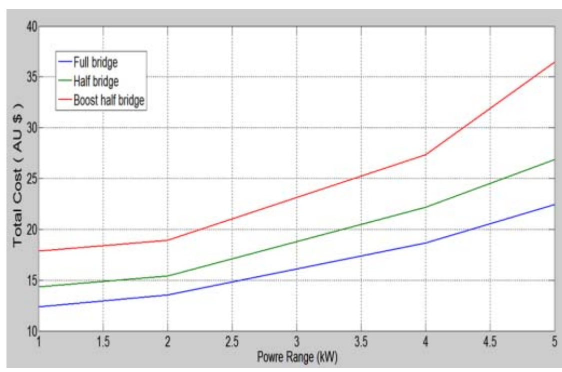


Figure (2)- Comparison of total cost for FB, HB and BHB topologies

Table (4)- Estimated size of FB, HB and BHF topologies

Power range / Topology	1 KW	2 KW	4 KW	5 KW
Full Bridge	112 cm3	144 cm3	144 cm3	150 cm3
Half Bridge	146 cm3	146 cm3	156 cm3	164 cm3
Boost Half bridge	180 cm3	180 cm3	216 cm3	224 cm3

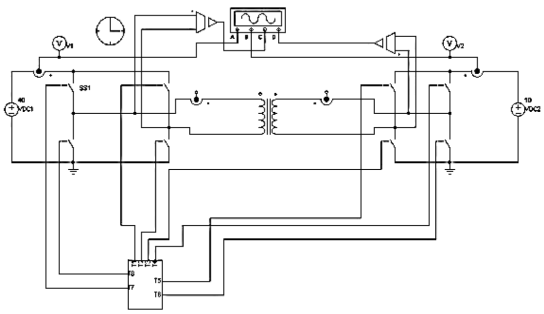


Figure (3)- Simulated circuit of DAB converter

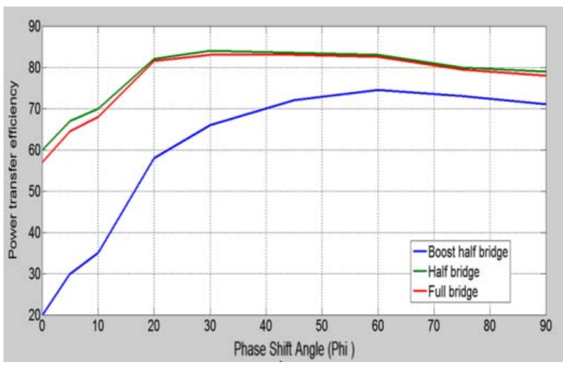


Figure (4)-The power transfer efficiency versus phase shift angle

D. Switching power loss

The last parameter that is used as an indicator to compare the three topologies is switching power loss which can be used by measuring the voltage and current on switching device. To do this stage the simulated circuit of two phase ports phase shift converter using real switching device was used. The results show that the switching power loss for boost half bridge is higher than two other topologies especially in lower phase shift angles. As the phase shift angle increases the power loss on switching device decreases. It is shown that the best range of phase shift angle which provides lower switching power loss changes from 30 to 60 degrees.

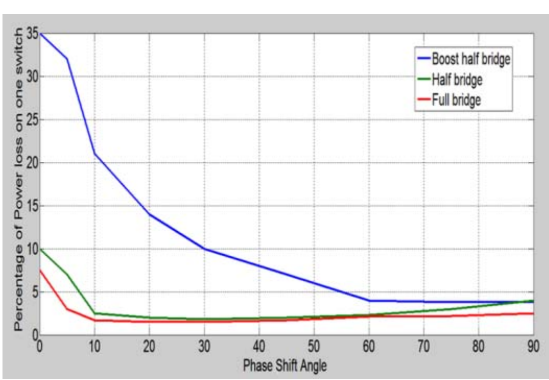


Figure (5)- Comparison of switching power loss between three topologies

Switching power loss factor was defined as ratio of loss in one switch to input power. It was measured for all topologies in same conditions for simulated circuit using PSIM software. The lowest loss was measured in FB and the highest in BHB topologies.

E. Reliability

The reliability of switching topologies can be an important factor especially for converters with off-grid applications [15]-[18]. The two main factors related to reliability are failure rate and life time of topology. Failure rate is defined by the number of failures during a specific test time of components. The failure rate is used to calculate the mean time between failures (MTBF). On the other hand the life time (LT) is an expected average time maintaining required performance before the wear-out failure. Figure (6) shows the relation between failure rate and life time of components.

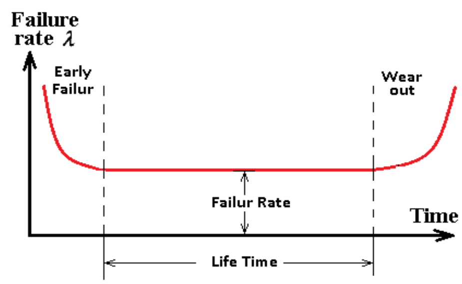


Figure (6)- The relation between failure rate and life time for components of a circuit

In general the reliability assessment of converter depends on reliability of each main block of converter and the reliability of each block depends on failure rate of its included components. To evaluate the reliability of each topology, two factors should be calculated. The factors are MTBF and LT of topology. The MTBF for a port is defined as inverse of its failure rate and can be defined as shown in (3).

$$MTBF = \frac{1}{\lambda_s} \tag{3}$$

In this equation λ_s can be calculated by summation of failure rates of all included components as is shown below.

$$\lambda_s = \sum_{j=1}^{m} \lambda_j \tag{4}$$

Where λ_j is the component failure rate per million hours. The failure rate of components can be defined for a period of one million hours according to the military hand book of MIL-HDBK-217 and can be calculated using (5).

$$\lambda_j = \lambda_b . \prod_{k=1}^{n} \pi_i \qquad (5)$$

in this equation λ_b is the base failure rate of component and π_i factors are some modification factors which modify the base failure rate according to the environmental and operational conditions which affects the reliability of the component. The life time of each topology is equal to the minimum life time of its included components as is shown below.

$$LT = Min(LT_{IGBT},\ LT_{Capacitor},\ LT_{Inductor}) \qquad (6)$$

Based on this information the failure rate and life time of main components of three topologies in temperature (70 C^o) are calculated as shown in below table. The reliability factor as an indicator for comparison of three topologies can be defined as a function of normalized MTBF and LT as shown in (7).

$$R.F = \frac{MTBF}{MTBF(\max)} \times \frac{LT}{LT(\max)} \qquad (7)$$

In the above equation the MTBF(max) and LT(max) are the maximum value of this parameters among the three topologies. The results of reliability comparison are shown in table (6). According to these results the FB topology provides the best reliability as there is no capacitor in this topology.

Table (5)- value of failure rate and life time for three main components of topologies

Component	IGBT	Capacitor	Inductor
Failure Rate (/1000000 hour)	0.241	1.071	0.012
Life Time (hours)	458,000	125,000	2,153,000

Table (6)- comparison of reliability factor for three topologies

Topology / Parameter	Full Bridge	Half Bridge	Boost Half Bridge
MTBF	1,037,344	381,097	379,362
Life Time (LT)	458000	125000	125000
Reliability Factor (R.F)	1.00	0.74	0.62

Table (7)- Complexity factors of three topologies

Complexity Element / Topology	Number of Switching Devices	Number of Driving Signals	Number of required voltage balance circuits	Complexity Factor
Full Bridge	4	2	1	1
Half Bridge	2	2	2	0.85
Boost Half Bridge	2	2	2	0.85

F. Control complexity

To compare the complexity of three topologies, some indicators such as number of switching device, number of driving signals and the voltage balance circuits are considered. The reason that the number of switching device is considered as a complex indicator is that each switching device means a gate drive signal and driving circuits increase the complexity of converter. The complexity factors of three topologies are compared in table (7). According to this criterion number of isolated drive signals, switching devices and voltage balance circuits are considered as effective complexity factors.

G. Power flow range versus Phase shift angle

The next parameter that selected as effective factor for quality assessment of topologies is the range of power transfer between the ports versus the change in phase shift angle. The topology that provides a higher range of power flow capabilities for the same range of phase shift angle achieves the most points. To do the comparison the simulated circuit was used and the ideal switches were replaced with real transistors. The result of simulation is shown in figure (6). As is illustrated, the FB and BHB topologies provide the wider range of power flow compared with HF. It can be seen that the BHB provides slightly better capability compared with FB topology.

H. Current ripple

The next parameter that is considered for comparison of topologies is ripple of current drawn from the input source by each topology. The simulated DAB circuit was used to measure this parameter. The harmonic spectrum of each input current was measured as shown in figure (7) A, B and C.

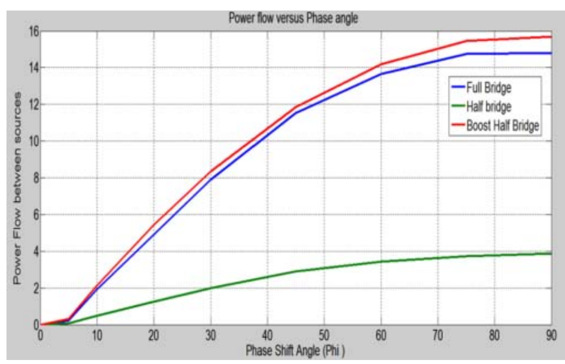
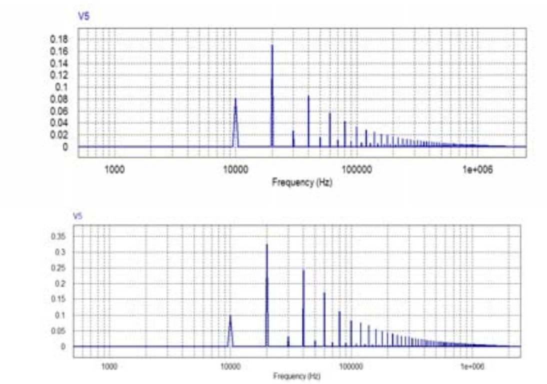
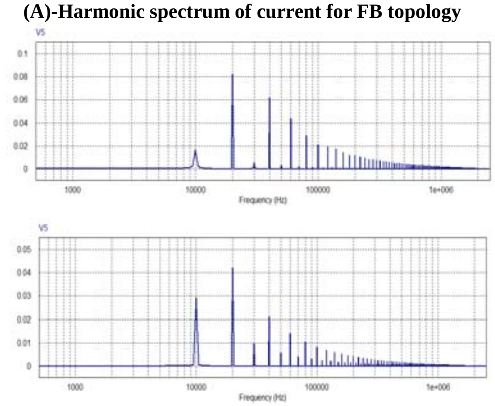


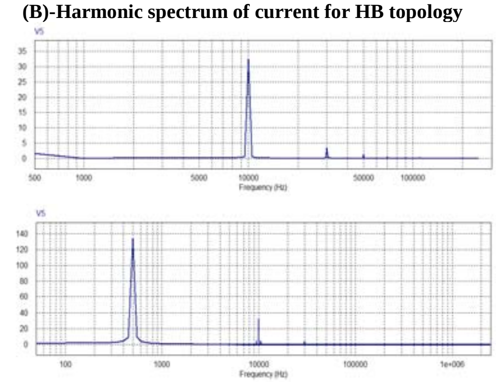
Figure (6)- Comparison of power flow capability versus phase shift angle for three topologies



(A)-Harmonic spectrum of current for FB topology



(B)-Harmonic spectrum of current for HB topology



(C)-Harmonic spectrum of current for BHB topology

Figure (7)-Harmonic spectrum of current for HB,FB and BHB topologies for phase shift angle of (30)

The current ripple was measured using equation (8) as an indicator for comparing the ripple current among the three topologies.

$$R(ripple)\% = 100.\sqrt{\frac{I_{rms}^2}{I_{av}^2} - 1} \qquad (8)$$

Based on this equation the values of current ripple for three topologies are calculated for different phase shift angles. As can be seen in the figure (8), the value of current ripple in all three topologies decreased as the phase shift angle is increased. It is also clear that the value of current ripple for BHB topology is more than others for all entire range of phase shift angle while it changes similarly for full and half bridge topologies.

III. FINAL EVALUATION

To do the final assessment of three topologies, the extracted factors should be normalized firstly and then add up them using some weighting factors. The normalization equation is based on the difference between maximum and minimum of that parameter as is shown below [19].

$$X_i(norm) = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \quad , \quad 0 \le X_i(norm) \le 1 \quad (9)$$

The weighting factor for each parameter should be adjusted according to the importance of it and the summation of all weighting factors should be equal to one.

$$\sum_{i=1}^{n} \delta_i = 1 \qquad (10)$$

Where (δ_i) is weighting factor and $X_i(norm)$ is normalized parameter. The final evaluation factor (K) for each of three topologies can be calculated by summation of all effective factors multiplied by their weighting factor as shown in (11).

$$K = \sum_{i=1}^{n} [\delta_i . X_i(norm)] \qquad (11)$$

Table (8) shows the normalized selected parameters of three topologies as indicators to help us to compare their performance. Table (9) shows the selected weighting factors for evaluation of quality of three topologies. The final results are shown in table (10). As can be seen the evaluation factor for FB, HB and BHB topologies are 0.987, 0.677 and 0.561 respectively. This means that the full bridge topology can be selected as the best choice for phase shift converter with off-grid application.

III. CONCLUSION

An analysis was carried out on main features of three commonly used bidirectional ports named as FB, HB and BHB. The analysis contrasted several characteristics of the topologies including size, cost, reliability, efficiency, range of power flow, switching loss and complexity. Finally an evaluation factor (K) calculated for each of FB, HB and BHB topologies considering all effective factors and their importance. This factor showed that FB topology provides the best characteristics while HB stands on middle and the BHB obtains the least evaluation factor. According to this the best choice of bidirectional port for phase shift converter with power range of 4Kw is FB. It is considerable that for different scenarios depending on the weighting factors the result can be different.

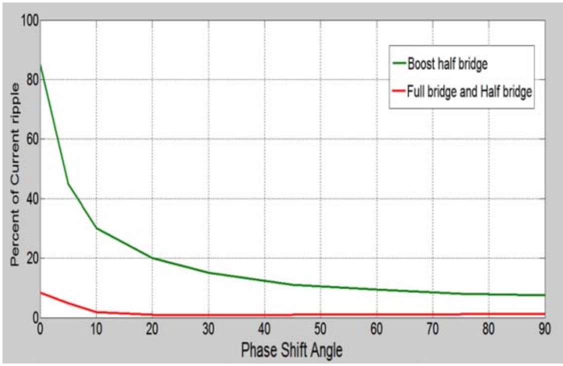


Figure (8) – Comparison of ripple current for all three topologies

Table (8) – Normalized parameters of three topologies

Topologies / Evaluation Parameters	Full Bridge	Half Bridge	Boost Half Bridge
Cost	1	0.86	0.61
Size	1	0.91	0.67
Reliability	1	0.32	0.31
Control Complexity	1	0.85	0.85
Current ripple	0.98	1	0.1
Switching Power Loss	1	0.5	0.14
Power Transfer Range	0.9	0.4	1
Power Transfer Efficiency	1	1	0.8

Table (9) – weighting factors for evaluation

Evaluation Parameter	Cost	Reliability	Efficiency	Switching loss
Weighting Factor	0.27	0.23	0.10	0.08

Evaluating Parameter	Current ripple	Size	Control complexity	Power transfer versus phase shift
Weighting Factor	0.05	0.1	0.05	0.12

Table (2-17)- the final results of evaluation of three topologies

Topology	Full Bridge	Half Bridge	Boost Half bridge
Result	0.987	0.677	0.561

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