



# **Comparison of an Efficient Buck Converter Configuration for the DC Power Distribution Of Future Green Data Centers**

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**ABSTRACT:** The internet and the demand for online connectivity are fuelling the energy consumption in Data Centers. According to DataCenterDynamics 2012 Global Census, the power requirements grew by 63% globally to 38GW, up from 24GW in 2011. The census estimated a further rise of 17% to 43GW in 2013. It is important that this growing demand for energy is met by the power supply from renewable energy sources. The Power Supply Distribution System for Future Data Centers is shifting towards DC Architecture from existing AC architecture. In this paper, 380V DC is considered as the transmission voltage and 48 V DC as the distribution voltage inside the Data Centers. An efficient 380V to 48V DC-DC buck converter with less switching and thermal losses can reduce the cooling requirements of the Data Center. In this direction a suitable configuration is selected by comparing Two- Stage, Half-Bridge, Push-Pull and Full-Bridge buck converters based on efficiency and power loss analysis.

**KEYWORDS:** Buck Converter, Full-Bridge, Push-Pull, Two-Stage, Half-Bridge, Isolated, DC distribution, Data Center

## **I. INTRODUCTION**

The Data Centers depend on AC power supply distribution from mains utility power supply which is highly inefficient. Uptime institute conducted a research among 500 data centers and found that the average Power Usage Efficiency (PUE) is 1.8 which means 1.8kW is required to power a 1kW server and 800W is consumed by the facility loads & cooling systems. So the reduction in thermal losses will result in less cooling requirements and therefore less energy consumption. With the penetration of renewable energy sources in the distribution networks, the paradigm is shifting towards DC distribution for Data Centers. The renewable energy sources such as solar and wind can be effectively used in this case since they can directly provide DC power supply. This reduces the use of rectifiers, the problem of harmonics and there is no need to interface the renewable sources to the AC grid. DC transmission is also gaining popularity and 380 V is established as the globally compatible DC distribution voltage. The 380 V supply can be obtained from the renewable energy sources by installing solar panels and wind turbines on the rooftop of the Data Center. Although majority of the servers today operate on 12 V DC distribution, 48 V DC servers are being manufactured and they could become the norm in future. The 48 V supply can also run other facility loads in the Data Center like cooling fans and lighting. Keeping these advances in mind, 380V is considered as the distribution voltage and 48 V as the distribution voltage within the servers for the Data Centers in this paper. This leads to the requirement of an efficient 380 V to 48V DC-DC buck converter to achieve this conversion. The converter can be inside the server or outside (i.e. adapter). If the converter is in the form of an adapter outside the server, then the server size can be reduced and the floor efficiency of the Data Center can be improved significantly. An efficient converter with less switching/thermal losses can also reduce the cooling requirements of the Data Center. In this direction, four existing configurations of the DC-DC buck converter have been compared to decide a suitable converter for this application based on efficiency and reliability.

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The Simulink models of the Two-Stage, Half-Bridge, Push-Pull and Full-Bridge are presented in Section II. The output voltage equations are also given in each sub-section; these can be used for obtaining the duty cycle of the switches.  $V_{in}$  refers to the input voltage,  $V_{out}$  – output voltage,  $D$  – duty cycle,  $N_s$  – number of turns on transformer secondary and  $N_p$  – number of turns on transformer primary. Section III presents the analysis and observations of the simulation results. Based on the efficiency and power loss curves, Full-Bridge is selected as the most suitable configuration and its simulation results are presented. Also a table of comparison of the four configurations is given. Section IV presents the conclusion and future scope.

## II. BUCK CONVERTER MODELS

### A. Two-Stage Converter

The Two-Stage converter is a non-isolated converter that achieves the required conversion in two stage buck operations. It has four active switches and can provide gain up to 8. The main drawback is that it does not provide isolation between the source and the load. This can be considered for applications where protection/isolation is not required. The Simulink model of the Two-Stage converter is shown in Fig. 1 which is indicative of the topology. The output voltage is given by Eq. 1.

$$V_{out} = 0.5V_{in}D \quad (1)$$

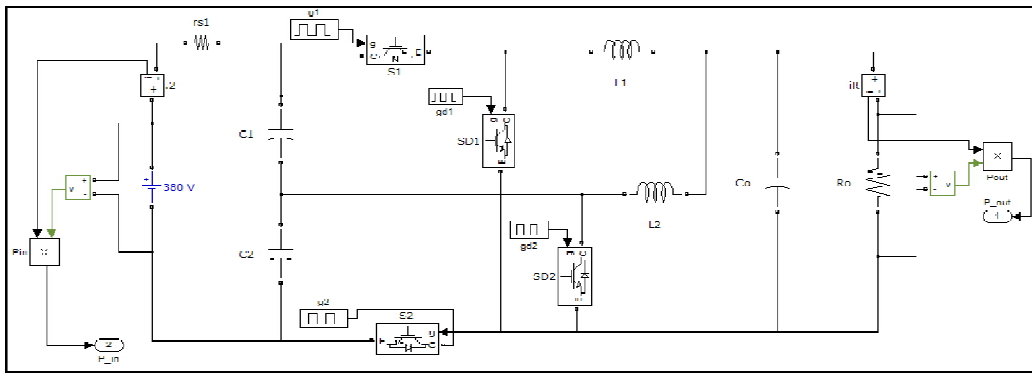


Fig. 1 Simulink Model of Two-Stage Buck Converter

### B. Half-Bridge Converter

The voltage stress on the active switches in the Half-Bridge is less than that of Full-Bridge and Push-Pull configurations. The voltage appearing across the transformer primary winding is one half of the input voltage. It has two active switches but it also contains two extra capacitors.

$$V_{out} = 0.5V_{in}D (N_s/N_p) \quad (2)$$

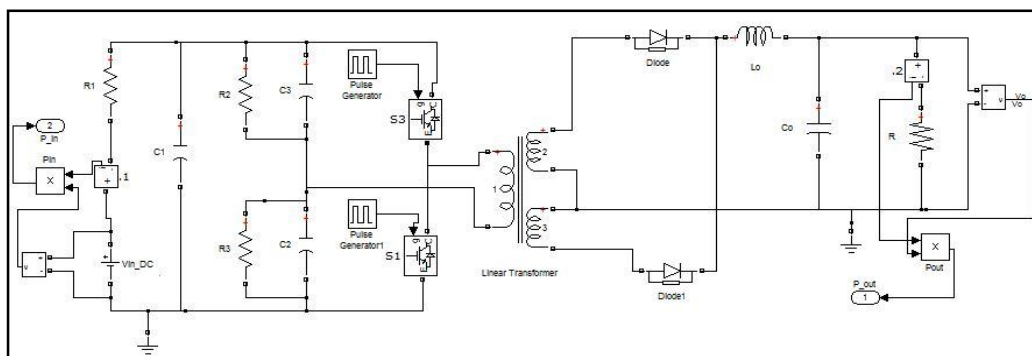


Fig. 2 Simulink Model of Half-Bridge Buck Converter

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### C. Push-Pull Converter

The Push pull has a center-tap on the primary of the transformer which imposes a voltage of more than twice the input voltage on the two switches. Push-Pull topology faces problems of transformer flux imbalance if the transistors and the transformer windings are not perfectly matched. The secondary rectification side can be either a center-tapped full wave rectifier or a bridge rectifier. The output voltage equation is given in Eq. 3.

$$V_{out} = 2V_{in}D (N_s/N_p) \quad (3)$$

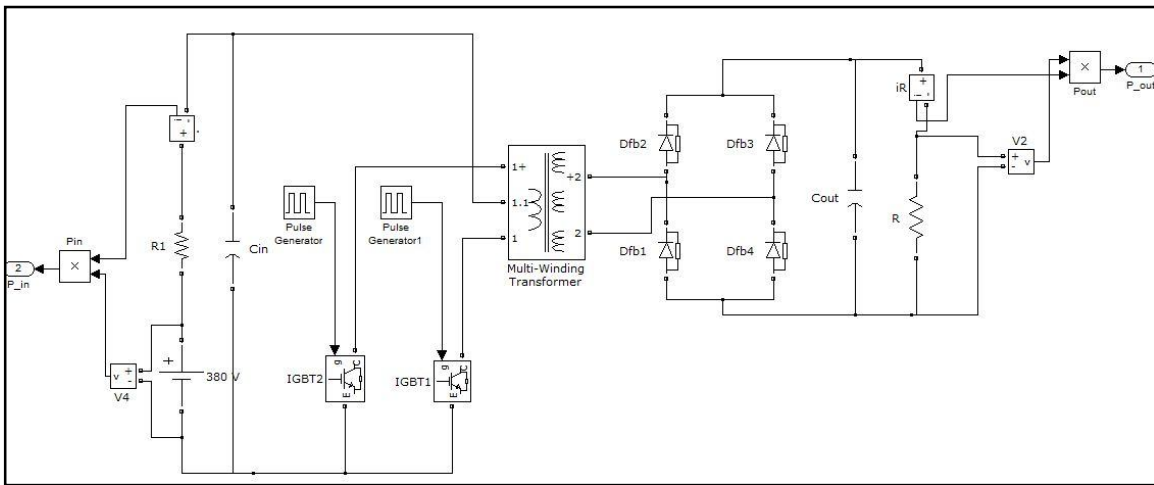


Fig. 3 Simulink Model of Push-Pull Buck Converter

### D. Full-Bridge Converter

The Full-Bridge has four active switches and the voltage stress across the switches does not exceed the input voltage. Similar to Half-Bridge and Push-Pull, the Full-Bridge topology also suffers from transformer saturation problems. The duty cycle is obtained by using Eq. 4.

$$V_{out} = V_{in}D (N_s/N_p) \quad (4)$$

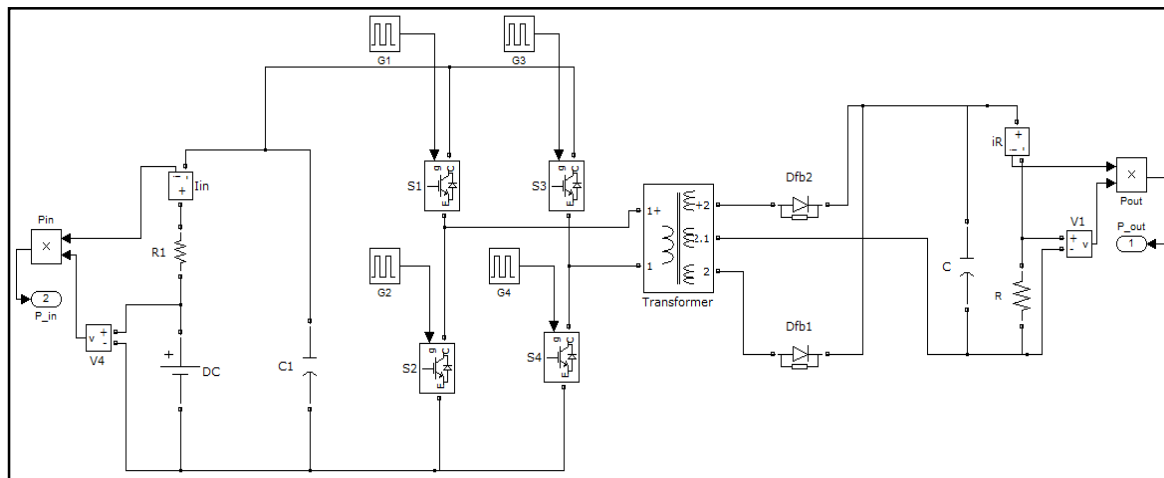


Fig. 4 Simulink Model of Full-Bridge Buck Converter

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### III. ANALYSIS AND OBSERVATIONS

The efficiency is calculated as the ratio of the output power to the input power. The efficiency curves for the four configurations from 40 % loading to full load are plotted in Fig. 5. The full load power is 2 kW. IGBT switches are considered as the switching frequency is set at 20 kHz. The input voltage is fixed at 380 V and the output required is 48 V. All the passive component values are kept same wherever possible, to maintain uniformity. The analysis is done on the steady-state characteristics.

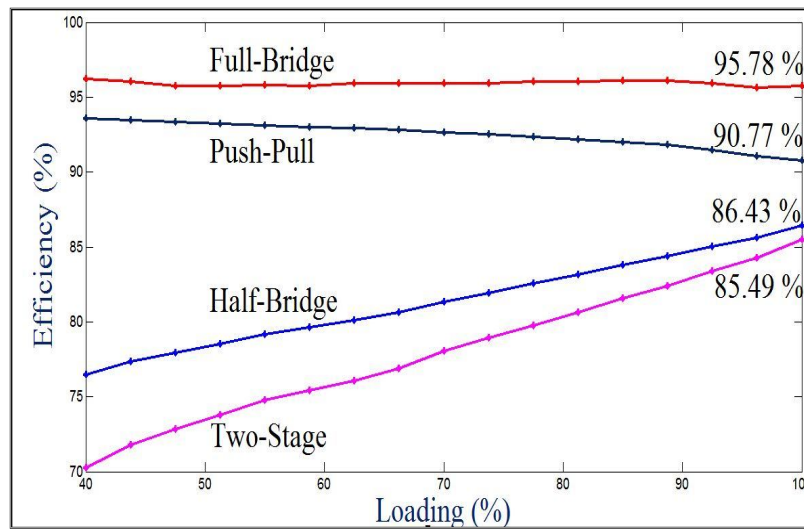


Fig. 5 Efficiency curves for a2kW system (40%-100% loading)

The power loss is calculated as the difference between input power and the output power. The full load power loss for the considered configurations is shown in Fig 6.

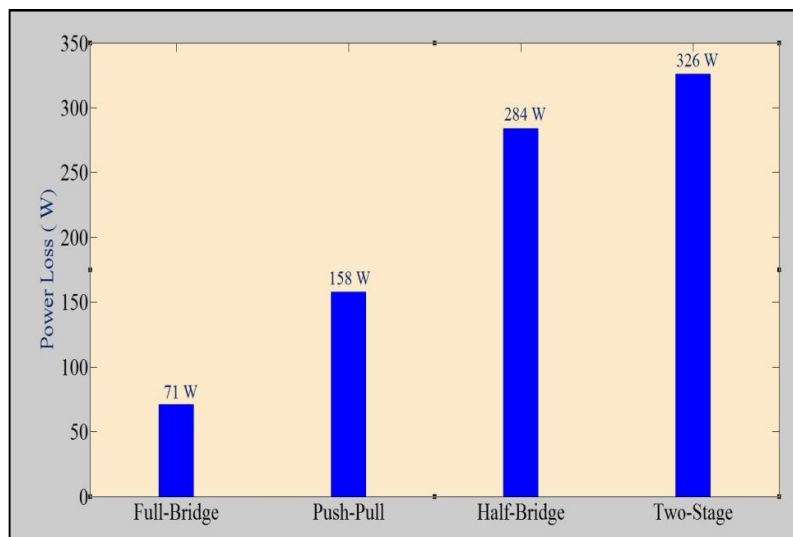


Fig 6. Full load Power Lossfor 2kW system



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From Figs. 5 and 6, it can be observed the Full-Bridge converter provides the highest efficiency than the other three configurations. Moreover, the efficiency does not vary much from 40% loading to full load unlike the other topologies. This is very important for Data Center applications where the load on the servers keeps varying throughout the day. Full-Bridge converter has the least power loss of 71 W for a full load power of 2 kW.

The best configuration for a particular application depends on many factors like power level, size, cost etc. Table I provides a comparison of various factors for the configurations which will help in the selection of the converter.

Parameter	Configuration			
	Half-Bridge	Push-Pull	Full-Bridge	Two-Stage
No. of Active Switches	2	2	4	4
Duty cycle	~0.50	~0.50	~0.50	~0.25
Voltage stress across the active switches	$\geq 190$ V	$\geq 760$ V	380 V	380 V
Transformer primary winding	One primary winding	Center tap in primary winding	One primary winding	NA
Transformer turns ratio ( $N_p/N_s$ )	2	8	4	NA
Full load Efficiency (for 2kW system)	86.43%	90.77%	95.78%	85.49%
Full load Power Loss (for 2kW system)	284 W	158 W	71 W	326 W

Table. I

The use of four switches in Full-Bridge is justified for high power and high input applications as the voltage stress across the switches does not exceed input voltage. Current mode control is recommended to mitigate the transformer saturation problems in the case of Full-Bridge and Push-Pull topologies.

Considering these factors, the Full-Bridge Converter is selected for an efficient Data Center DC distribution system. Simulation results of the output voltage, output current and the input current of the Full-Bridge converter are shown in Fig. 7. The input voltage is 380 V and the load resistance  $R = 2$  ohm.

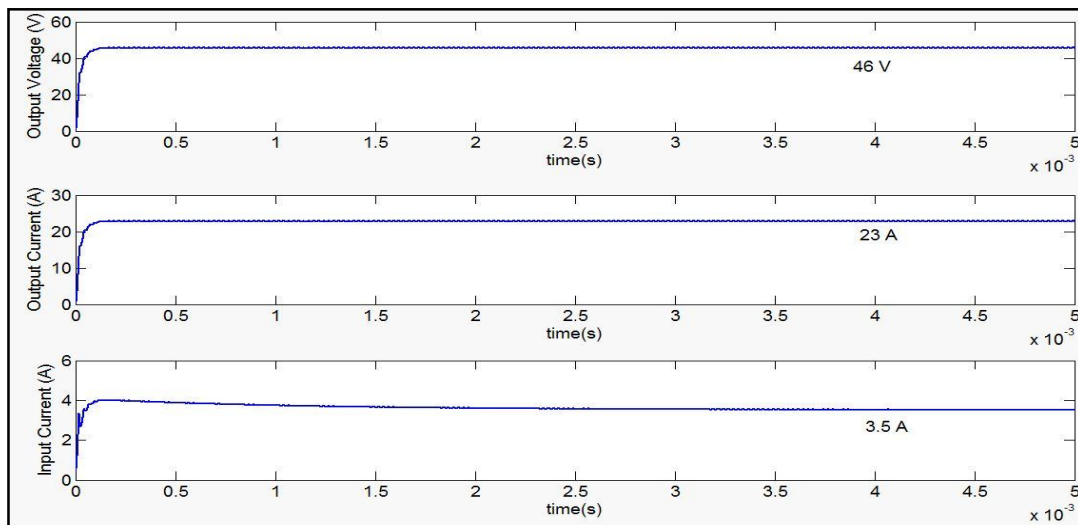


Fig. 7 Output voltage, Output Current and Input Current of Full-Bridge Configuration



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## IV. CONCLUSION

The 380 V DC transmission and 48 V DC distribution architecture was considered for the Data Centers. To achieve the 380 V to 48 V DC-DC buck conversion, four configurations namely Two-Stage, Half-Bridge, Push-Pull and Full-Bridge were analyzed and compared. The Full Bridge is found to be the most efficient configuration for the considered power level of 2 kW. The future work is directed towards implementing phase-shift controlled Full Bridge converter with ZVS (zero voltage switching) to reduce the thermal losses by which the overall efficiency can be improved.

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