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Power factor correction (PFC) converters feeding brushless DC motor drive

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Abstract

This paper presents a comprehensive study of power factor correction (PFC) converters for feeding brushless DC (BLDC) motor drive. This work explores various configurations of PFC converters which are classified into five different categories of non-isolated, bridgeless (BL) non-isolated, isolated, BL-isolated PFC converters and integrated and high quality rectifiersfor feeding BLDC motor drive. A comprehensive study of these PFC convertersis presented with focus on application potential, design and control aspects, components selection, cost of overall system, efficiency issues, power quality and the future trends. The proposed converters have been designed for achieving an improved power quality operation with low amount of total harmonic distortion (THD) of supply current at AC mains for a wide range of speed control at varying supply voltages.

*Keywords:*Brushless DC (BLDC)Motor, Discontinuous Conduction Mode (DCM), Power Factor Correction (PFC), Power Quality, Voltage Source Inverter (VSI).

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1. Introduction

In recent trends, energy efficiency has become an important aspect of an electrical drive system due to the scarcity of the energy resources. The selection of a motor for a particular drive application is a foremost taskand it depends on variety of parameters such as high efficiency, compact size and good performance over a wide range of speed control. Among numerous available motors such as induction motors, synchronous motor and many special motors; brushless DC (BLDC) motor emerges as a highly efficient motor in low and medium power applications [1, 2]. This motor posses many advantages such as compact size, high energy density, high efficiency, silent operation, highly rugged construction, low electro-magnetic interference (EMI) problems and requires very less maintenance [1, 2].

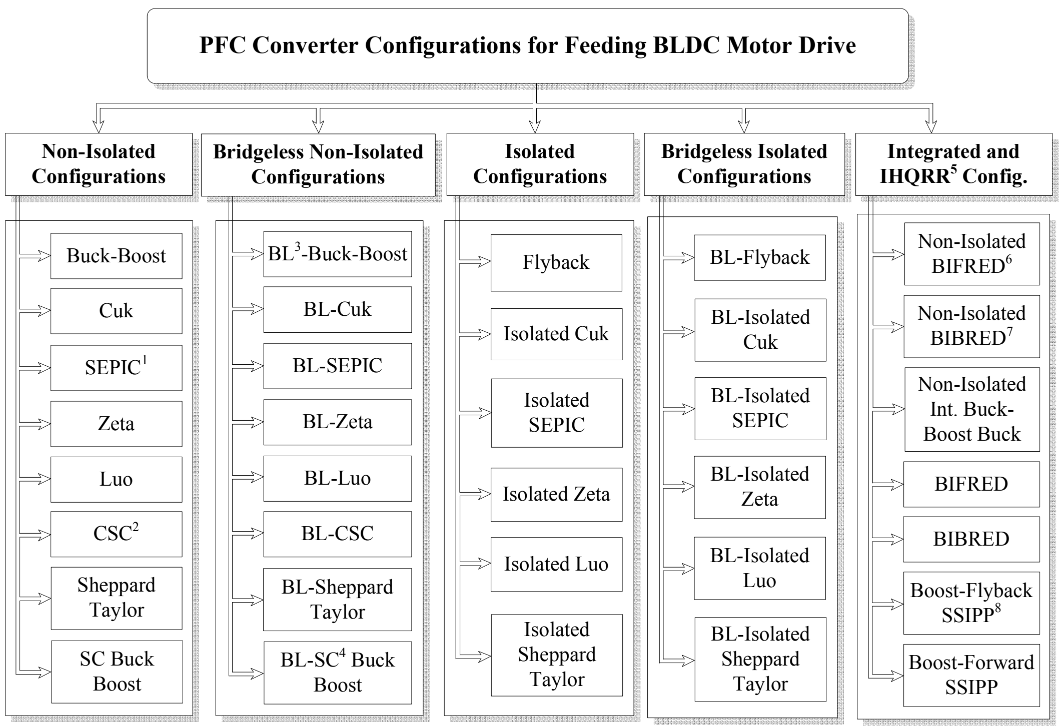
BLDC motor finds applications in variety of appliances used in domestic and household purposes, electrical vehicles and transportation, aerospace applications, medical equipments, medium power industrial tools, heating ventilation and air-conditioning (HVAC), precise motion control and industrial automation [1-4]. BLDC motor is a 3-phase synchronous motor with 3-phase concentrated windings on the stator and permanent magnets on the rotor [1]. It does not require any mechanical brushes and commutator assembly, rather an electronic commutation based on rotor position as sensed by Hall-Effect position sensors is used [2]. Therefore, the problems related to mechanical commutator and brushes assembly such as sparking, noise and EMI issues are eliminated in BLDC motor [1, 2].

A BLDC motor drive requires a 3-phase voltage source inverter (VSI) with constant DC link voltage for achieving an electronic commutation of BLDC motor [2]. An uncontrolled diode bridge rectifier (DBR) with high value of DC link capacitor fed from a single phase AC mains is used for maintaining the DC link voltage of the VSI for supplying the required energy to the BLDC motor. Such combination of DBR and DC link capacitor draws a peaky and highly distorted supply current from the AC mains which is rich in harmonics and has total harmonic distortion (THD) of supply current as high as 60-80% [5]. Such supply current results in very low factor of the order of 0.6-0.7 at the AC mains which is not acceptable under the limits of various international power quality standards such as IEC 61000-3-2 [6].

Hence, power factor correction (PFC) converters are used for achieving a unity power factor at AC mains [7-10]. Such converters draw a sinusoidal supply current in phase with the supply voltage while maintaining the DC link voltage at the reference value over a wide range of load variation and supply voltage fluctuations [7-10]. In this paper, a study various configurations of PFC converters feeding BLDC motor drive are presented as low cost solution for low power applications. An analysis, design and control of PFC converter are given for feeding BLDC motor drive with an emphasis of sensor reduction, simple control and overall efficiency improvement of complete BLDC motor drive.

2. State of Art

A boost PFC converter is a widely used configuration for improving the power quality at AC mains of BLDC motor drives [10]. However, this configuration uses a high frequency pulse width modulation (PWM) pulses for controlling the speed of BLDC motor. Therefore, it has high switching losses associated with the VSI and requires two costly current sensors for PWM based current control of BLDC motor [10]. In this work, the speed of BLDC motor is controlled by adjusting the DC link voltage of VSI [11].



[1] SEPIC -	Single Ended Primary Inductance Converter
[2] CSC -	Canonical Switching Cell
[3] BL -	Bridgeless
[4] SC -	Switched Capacitor
[5] IHQRR -	Integrated High Quality Rectifier/dc Regulator
[6] BIFRED -	Boost Integrated with Flyback Rectifier/Energy Storage/DC–DC Converter
[7] BIBRED -	Boost Integrated with a Buck Rectifier/Energy Storage/DC-DC Converter
[8] SSIPP-	Single Stage Isolated Power Factor Correction based Power Supplies

Figure 1. Classification of PFC converters for feeding BLDC motor drive.

This allows the operation of VSI in low frequency switching to achieve an electronic commutation of BLDC motor for reducing the switching losses in it. Moreover, a buck-boost PFC converter is used for this application due to its ability to control the DC-link voltage over a wide range at universal AC mains.

The operating mode of a PFC converter becomes an important issue as cost of system depends on the mode of operation. The PFC converter can be designed to operate in two modes of conduction i.e. continuous conduction mode (CCM) or discontinuous conduction mode (DCM) of operation [8]. In CCM, the current through the inductor or voltage across the capacitor remains continuous in a switching period but requires a complex current multiplier control for controlling the DC link voltage and power factor correction at AC mains. However, the voltage and current stress on PFC converter switch is low in this mode of operation and therefore, this mode is well suited for highpower applications [8]. However, in DCM mode of operation, the current through the inductor or voltage across the capacitor becomes discontinuous in a complete switching period. This mode requires a voltage follower approach, thereby, using a single voltage sensor for voltage control; an inherent power factor correction is achieved at the AC mains [8]. However, the PFC converter operating in DCM has higher voltage and current stress on the PFC converter switch andtherefore this mode is limited for low power applications. In view of these issues, the selection of any mode of operation is a trade-off between the extra cost associated with extra sensing and permitted stress on PFC converter switch.

These PFC converters can be classified into buck, boost or buck-boost category depending upon the output to input voltage transfer ratio. In PFC buck converter, the output voltage is always lower than the input voltage; therefore the voltage control range for feeding BLDC motor is very limited and it further reduces for a lower value of supply voltage of the order of 90 V [12]. Moreover, for a PFC boost converter, the output voltage is always higher than input voltage and becomes relatively much higher for high value of supply voltage of the order of 270V [13]. Therefore, the controls of BLDC motor fed by PFC buck or boost converter by controlling the DC link voltage is difficult at universal AC mains (90V – 270V). Hence, PFC buck-boost converters are better suited in such applications [14]. Therefore, in this work, PFC based buck-boost converters for feeding BLDC motor drive are investigated and classified as shown in figure 1. Numerous configurations of PFC buck-boost converters have been reported in the literature, selection of which depends on the power and voltage rating, application, number of components and requirement of galvanic isolation [14-21, 24-49].

3.Classifications of PFC Converter Configurations

The classification of proposed PFC buck-boost converters in five different categories are described as follows.

A. Non-Isolated PFC Converters

A non-isolated PFC buck-boost converter is widely used configuration for voltage control with unity power factor at AC mains [14]. Moreover, PFC Cuk, Single Ended Primary Inductance Converter (SEPIC), Zeta and Luo converters are also used in various applications requiring low current and voltage ripples in different components of PFC converter [15-18]. These converters also have good dynamic performance, high light load efficiency and good light load voltage regulation capability. A PFC based canonical switching cell (CSC) converter is also used as a modification of a PFC Cuk converter with single inductor and therefore has lower conduction losses in it [19]. In a similar way, two-switch configurations of non-isolated PFC buck-boost converters named Sheppard-Taylor converter [20] and switched-capacitor buck-boost converter [21] are also used invariably forpower factor correction at AC mains. PFC Sheppard-Taylor converter possesses an inherent capability to overcome control detuning problems i.e. inability of PFC converter to draw sinusoidal supply current at lower values of supply voltages. These non-isolated PFC converters are used for variable DC link voltage control of VSI feeding BLDC motor via VSI operating as an electronic commutator. The circuit configuration of one such converter belonging to non-isolated category i.e. PFC Cuk converter feeding BLDC motor drive is shown in figure 2.

B. Bridgeless Non-Isolated PFC Converters

Recently, bridgeless PFC converters have gained importance due to low conduction losses in the front-end converter by partial or complete elimination of DBR [22-31]. Bridgeless-buck and bridgeless-boost converters derived from their counter-parts i.e. PFC buck and PFC boost converters are presented in [22] and [23] respectively. These converters cannot be used for this application due to limited voltage transfer ratio i.e. <1 for bridgeless buck and >1 for bridgeless boost PFC converter. Hence a new configuration of a bridgeless buck-boost converter has been proposed in [24]. This configuration has very low components and thus exhibits highest efficiency of all configurations. Bridgeless configurations of PFC Cuk and SEPIC converters are also presented in [25] and [26] for improving the power quality at AC mains. These configurations of bridgeless non-isolated PFC converters are designed and developed for feeding BLDC motor drives. Moreover, some new bridgeless configurations of Zeta, Luo, CSC, Sheppard-Taylor, and switched-capacitor buck-boost PFC converters are also proposed for feeding BLDC motor drives with improved power quality at AC mains [27-31]. Figure 3 shows the circuit configuration of a bridgeless Cuk converter feeding BLDC motor drive operating at variable DC link voltage control.

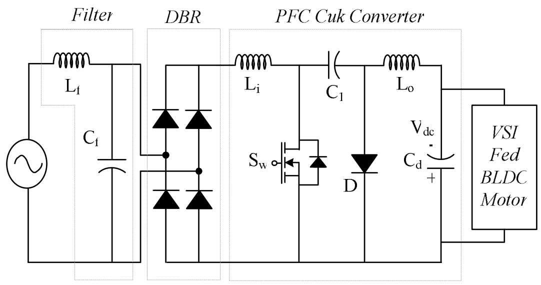


Figure 2. A PFC Cuk converter fed BLDC motor drive.

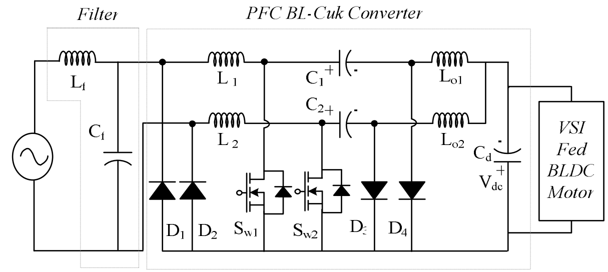


Figure 3. A PFC BL-Cuk converter fed BLDC motor drive.

C. Isolated PFC Converters

There are many household appliances such as refrigerators where galvanic isolation between the input and output side has to be provided due to safety reasons. To deal with such issues, isolated PFC converters are used for feeding the BLDC motor drives.Many such configurations of isolated PFC converters have been reported in the literature [32-37]. Configurations of PFC Flyback, Cuk, SEPIC and Zeta with high frequency isolation are presented in [32], [33], [34] and [35] respectively. In these configurations, PFC flyback converter has the minimum number of components but generally used in very low power applications due to stress on the PFC converter switch [32]. However, other PFC converters such as Cuk, SEPIC and Zeta converters find applications in much higher power rating as compared to PFC flyback converter [33-35]. Moreover, an isolated configuration of a PFC Sheppard-Taylor converter is also presented in [37] with a capability to overcome control detuning problems. These configurations with a newly developed isolated PFC Luo-converter are used for improving the power quality at AC mains of BLDC motor drives [36]. The proposed configuration is a low cost solution with minimal sensing requirements. Figure 4 shows a circuit configuration of a PFC isolated-Cuk converter fed BLDC motor drive.

D. Bridgeless Isolated PFC Converters

Bridgeless isolated PFC converters combine the advantages of bridgeless PFC converter with high frequency isolation [38-42]. Similar to non-isolated bridgeless PFC converters, these converters also offer low conduction losses in the front end. Bridgeless configurations of PFC flyback, isolated PFC Cuk, isolated PFC SEPIC and isolated PFC Zeta converters have been proposed in [38], [39], [40] and [41] respectively.In this work, some new configurations of bridgeless isolated-Luo and bridgeless isolated Sheppard-Taylor converter are also proposed [42]. Utilizing the twin benefits of bridgeless converter and high frequency isolation; these converters are used for feeding BLDC motor drive for improving the power quality at AC mains figure 5 shows circuit configuration of a bridgeless isolated-Cuk converter feeding BLDC motor drive.

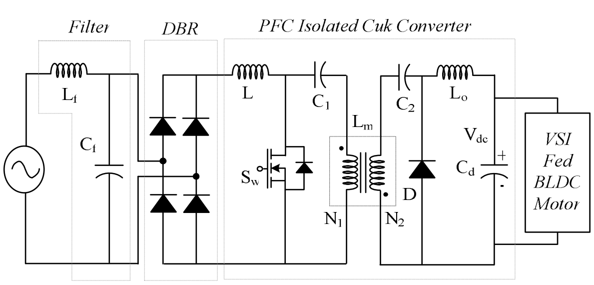


Figure 4. A PFC isolated Cuk converter fed BLDC motor drive.

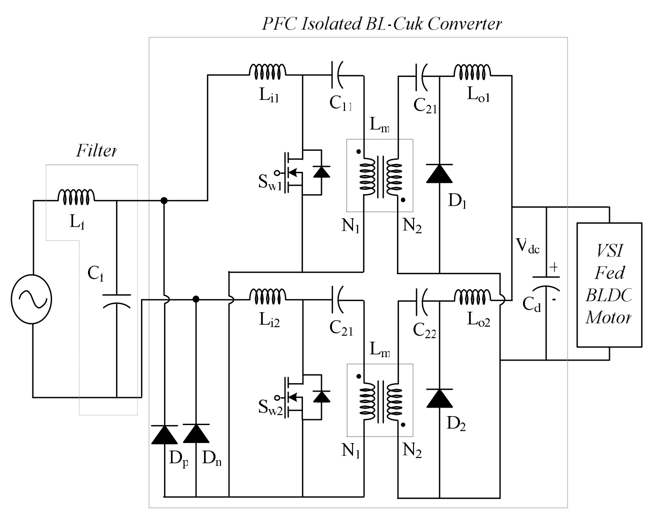


Figure 5. A PFC isolated BL-Cuk converter fed BLDC motor drive.

E. Integrated and High Quality Rectifiers

Integrated and high quality rectifiers (IHQRR) are used in applications which require a good dynamic response, high light load regulations capability and high light load efficiency but at the cost of high number of components [43-49]. The boost-integrated flyback rectifier energy-storage DC (BIFRED) converter [43] and the boost integrated buck rectifier energy-storage DC (BIBRED) converter [44] are the two configurations belonging to IHQRR. These are further classified into its non-isolated and isolated configurations [45, 46]. A non-isolated integrated buck-boost buck converter is also used which is a combination of buck-boost and a buck converter, which can provide a soft switching with extra one diode for reduced losses in the PFC converter switch [47]. Moreover, single-stage, single-switch integrated PFC based power a supply (SSIPP) is presented in [48, 49]. These converters are the combination of a boost PFC converter with an isolated DC-DC converter. Here, the boost converter is used for achieving the improved power quality at AC mains, whereas second DC-DC converter is used for regulation of DC link voltage. Utilizing the benefits of these converters, an application of these configurations for power quality improvement at AC mains for BLDC motor drives is also presented in this work.Two configurations of the non-isolated and isolated BIFRED converter are shown in figure 6 and 7 respectively for feeding BLDC motor drive.

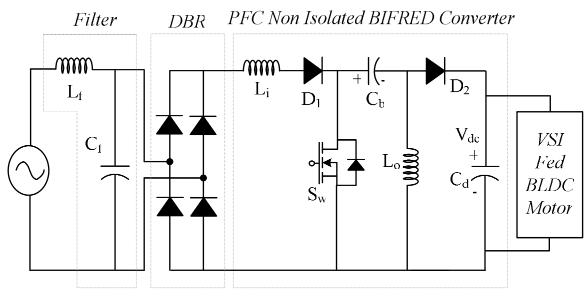


Figure 6. A PFC non-isolated BIFRED converter fed BLDC motor drive

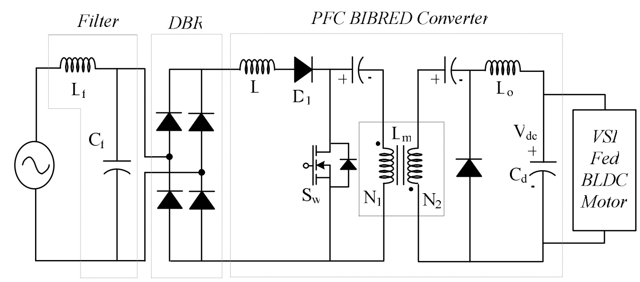


Figure 7. A PFC BIBRED converter fed BLDC motor drive.

4. Design Specifications and Selection Criteria of PFC Converters for Particular Applications

These PFC converters can be designed in CCM or DCM mode of operation depending upon the requirement [8]. For a low power application, PFC converter operating in DCM is preferred because of low amount of sensing. However, a CCM mode of operation is preferred in medium power applications where stress on the PFC converter switch and EMI issues become dominating as compared to the advantages achieved in DCM. There are numerous parameters which decide the design criteria and selection of a suitable PFC converter for the desired application such as,

1) Power rating of PFC converter
2) DC link voltage control range of PFC converter
3) Operation at universal AC mains
4) Requirement of high frequency isolation
5) Operating switching frequency
6) Desired power quality performance
7) Type of load on BLDC motor (fan, compressor, pump)
8) Cost of overall system
9) Desired efficiency of the drive
10) Conducted and emitted noise (EMI issues)
11) Size and weight of the overall system
12) Reliability issues
13) Environmental factors

These factors decide the proper selection of PFC converter for the desired application.

5. Comparative Study of PFC Converters Fed BLDC Motor Drives

Table-I shows the comparison of number of components of various configurations of PFC converters. This comparison includes total number of switches (S_w), low frequency diodes of the DBR (D_b), high frequency / fast recovery diodes (D_s), inductors (L), high frequency transformers (T), capacitors (C), total number of components (T_t) and total number of components conducting in a half line cycle of supply voltage (T_{tp}). As compared to the conventional non-isolated and isolated PFC converters, bridgeless PFC converters have higher number of total component count (T_t), but less number of components are conducting in a half line cycle of supply voltage (T_{tp}). This reduces the conduction losses in the bridgeless converters which lead to high overall efficiency of the system. Moreover, the average components conducting in a half line cycle of supply voltage in an integrated and high quality rectifier are high. This leads to lower efficiency in the integrated and high quality rectifier which can be acceptable at the cost of better dynamic performance and better power quality at light loads for certain application.

Table-II summarizes the key merits and limitation of all 35 configurations of the PFC converter as discussed in Section-III. As seen in this table, the selection of each PFC converter is a trade-off between various merits and demerits. Based on this evaluation a comparative analysis of five different categories of PFC converter is also presented as shown in Table-III. The non-isolated PFC converters have low number of components and simpler design, but suffer from efficiency issues at lower power levels. Whereas, the bridgeless non-isolated converters have an added advantage of lower conduction losses in the front-end converter due to partial elimination of DBR at the front-end. However, both of these categories do not provide galvanic isolation which becomes a critical issue in many household appliances. Hence, isolated and bridgeless isolated PFC converters are used in such applications. But these configurations suffer from efficiency issues due to losses in the high frequency transformers, hence the design of highly efficient transformer for these converters requires major attention. An another category of integrated and high quality rectifiers possess better dynamic performance, high quality regulated output, better light load efficiency and good light load regulation, but at the cost of high component count and relatively low overall efficiency of the system.

TABLE-I
COMPARISON OF NUMBER OF COMPONENTS IN VARIOUS CONFIGURATIONS OF PFC CONVERTER

PFC Converter	S_w	D_b	D_s	L	T	C	T_t	T_{tp}	*PFC Converter*	S	D_b	D_s	L	T	C	T_t	T_{tp}
Non-Isolated PFC Converters									***Bridgeless Non-Isolated PFC Converters***								
Buck-Boost	1	4	1	2	0	2	10	8	**BL- Buck-Boost**	2	0	4	3	0	2	11	7
Cuk	1	4	1	3	0	3	12	10	**BL-Cuk**	2	0	4	5	0	4	15	9
SEPIC	1	4	1	3	0	3	12	10	**BL-SEPIC**	2	0	4	5	0	4	15	9
Zeta	1	4	1	3	0	3	12	10	**BL-Zeta**	2	0	4	5	0	4	15	9
Luo	1	4	1	3	0	3	12	10	**BL-Luo**	2	0	4	5	0	4	15	9
CSC	1	4	1	2	0	3	11	9	**BL-CSC**	2	0	4	3	0	4	13	8
Sheppard Taylor	2	4	4	3	0	3	16	14	**BL-Sheppard Taylor**	4	0	10	5	0	4	23	13
SC-Buck-Boost	1	4	4	3	0	4	16	14	**BL-SC-Buck-Boost**	2	0	10	5	0	6	23	13
Isolated PFC Converters									***Bridgeless Isolated PFC Converters***								
Flyback	1	4	1	1	1	2	10	8	**BL-Flyback**	2	0	4	1	2	2	11	7
Isol. Cuk	1	4	1	3	1	4	14	12	**BL-Isol. Cuk**	2	0	4	5	2	6	19	11
Isol. SEPIC	1	4	1	2	1	3	12	10	**BL-Isol. SEPIC**	2	0	4	3	2	4	15	9
Isol. Zeta	1	4	1	2	1	3	12	10	**BL-Isol. Zeta**	2	0	4	3	2	4	15	9
Isol. Luo	1	4	1	2	1	3	12	10	**BL-Isol. Luo**	2	0	4	3	2	4	15	9
Isol. Sheppard Taylor	2	4	4	2	1	3	16	14	**BL-Isol. Sheppard Taylor**	4	0	10	3	2	4	23	13
Integrated Non-Isolated PFC Converters									***Integrated Isolated PFC Converters***								
Int. Buck Boost-Buck	1	4	3	3	0	3	14	12	**BIFRED**	1	4	2	2	1	3	13	11
Non Isol. BIFRED	1	4	2	3	0	3	13	11	**BIBRED**	1	4	2	3	1	4	15	13
Non Isol. NI BIBRED	1	4	3	4	0	3	15	13	**Boost Flyback SSIPP**	1	4	4	2	1	3	15	13
									Boost Forward SSIPP	1	4	5	3	1	3	17	15

S - Number of PFC converter switches
D_b- Number of diodes in a DBR (low cost power diodes)
D_s - Number of diodes in a PFC converter (high cost fast recovery diodes)
L - Number of inductors in a PFC converter and filter
T - Number of high frequency transformer (HFT)
C - Number of capacitors in a PFC converter and filter
T_t- Total number of components in a PFC converter and filter
T_{tp} - Total number of components conducting in half line cycle of supply voltage

6. Latest Developments and Future Trends

Recently, BLDC motor drives have gained wide attention of the manufacturers, designers and researchers due to various advantages over the conventionally used induction motor drives. The advancements in permanent magnet materials have enriched the possibility in design and development of a high energy density and a compact BLDC motor [50]. The introduction of latest software tools in motor design such as MagNet, Motor-Solve, SPEED etc [51-53] have led to accurate and efficient design of BLDC motors. Moreover, the increased use of DSP in power electronics and drive applications has enhanced the possibility of involving sophisticated algorithms for efficient control of BLDC motor drive. Many new sensorless control algorithms for elimination of rotor position sensors are also developed, which enhances the capability of BLDC motor in hazardous environments and reduce the cost on account of sensor reduction [54-55].

TABLE-II
COMPARISON OF ADVANTAGES AND DISADVANTAGES OF VARIOUS CONFIGURATIONS OF PFC CONVERTER

SN.	*PFC Converter*	*Merits*	*Limitations*
Non-Isolated PFC Converters and Bridgeless Non-Isolated PFC Converters			
1. 2.	**Buck-Boost BL-Buck-Boost**	Lowest Component Count, Simplest Design	EMI (Switch in Series)&Negative Output Voltage
3. 4.	**Cuk BL-Cuk**	Smooth Input and Output current, Low EMI Issues	Negative Output Voltage
5. 6.	**SEPIC BL-SEPIC**	Continuous Input Current, Positive Output Voltage	High component as compared to Buck-Boost / CSC
7. 8.	**Zeta BL-Zeta**	Very Good Dynamic Performance, Good Stability	EMI (Switch in Series)
9. 10.	**Luo BL-Luo**	Very Good Dynamic performance and stability	EMI (Switch in Series), Negative Output Voltage
11. 12.	**CSC BL-CSC**	Low Component Count	Negative Output Voltage
13. 14.	**Sheppard Taylor BL-Sheppard Taylor**	No Control Detuning Problems, High Power Factor	High Component Count, Negative Output Voltage
15. 16.	**SC-Buck-Boost BL-SC-Buck-Boost**	Light Load Regulation, Light Load Efficiency	High Component Count
Isolated PFC Converters and Bridgeless Isolated PFC Converters			
17. 18.	**Flyback BL-Flyback**	Lowest Component Count, Simple Design	EMI (Switch in Series), High Stress on Switch
19. 20.	**Isol. Cuk BL-Isol. Cuk**	Smooth Input and Output Current	Relatively Higher Component Count
21. 22.	**Isol. SEPIC BL-Isol. SEPIC**	Continuous Input Current	Critical Transformer Design in DCM
23. 24.	**Isol. Zeta BL-Isol. Zeta**	Very Good Dynamic performance, Good Stability	EMI Issues(Switch in Series)
25. 26.	**Isol. Luo BL-Isol. Luo**	Very Good Dynamic performance, Good Stability	EMI Issues (Switch in Series)
27. 28.	**Isol. Sheppard Taylor BL-Isol. Sheppard Taylor**	No Control Detuning Problems, High power Factor	Relatively Higher Component Count
Integrated and High Quality Rectifiers			
29.	**Non Isol. BIFRED**	Low Component Count, Good Power Factor Correction	EMI Issues (Input Inductor in DCM)
30.	**Non Isol. NI BIBRED**	Good Power Factor Correction, Light Load regulation	EMI Issues (Input Inductor in DCM)
31.	**Int. Buck Boost-Buck**	Soft Switching with One Extra Diode	Non-Isolated configuration
32.	**BIFRED**	Very Good Dynamic Performance, Good Stability	EMI Issues (Input Inductor in DCM)
33.	**BIBRED**	Very Good Dynamic performance, Good Stability	EMI Issues (Input Inductor in DCM)
34.	**Boost Flyback SSIPP**	Better Light Load Regulation and Light Load Efficiency	High Component Count, Relatively Low Efficiency
35.	**Boost Forward SSIPP**	Better Light Load Regulation and Light Load Efficiency	High Component Count, Relatively Low Efficiency

Moreover, rapid improvements in design of solid state switches have explored high speed and efficient switches in many low to medium power ranges [56-57]. Such switches have extended the operation of such converter at high switching frequency, reduced losses and miniaturized size of converter. Inclusion of improved design of converters and efficiency improvements on account of soft switching has also explored PFC converters to new heights.

TABLE-III
OVERALL COMPARISON OF VARIOUS CATEGORIES OF PFC CONVERTER CONFIGURATIONS

S.N	*Configurations*	*Advantages*	*Disadvantages*	*Potential Applications*
1.	**Non-Isolated PFC Converter**	Lowest Component Count Simpler design	PFC and efficiency issues at lower power levels	Fans, AC, Water-pumps
2.	**Bridgeless Non-Isolated PFC Converter**	Low losses in front end converter	High component count	Fans, AC, Water-pumps
3.	**Isolated PFC Converters**	Low Component Counts + Isolation	Efficiency issues due to HFT	Refrigerators, Mixers and grinders
4.	**Bridgeless Isolated PFC Converters**	Low losses in front end converter + Isolation	High component count Efficiency issues due to HFT	Refrigerators,Mixers and grinders
5.	**Integrated and High Quality Rectifiers**	Better Dynamic Performance + Better Light Load Regulation	High component count Relatively Low Efficiency	-All-

The miniaturized design of PFC converter on account of integrated magnetic also helps to increase the power density of PFC converter. Moreover, a use of mixed conduction modes and integration of two converters for light load efficiency improvements has led to a new domain of research.

In future, it is expected for a continuing research in the quest of energy efficiency, size reduction, increasing the power density, miniaturization of components and reducing the overall cost of the system. The overall advancements in the BLDC motor and the PFC converter are expected to lead to new heights in the development of high performance PFC based BLDC motor drives. This improves the performance of the potential applications of the BLDC motor drives such as air-conditioners, water pumps, fans, refrigeration etc. The upcoming BLDC motor drive for such application is to be low cost, compact size, rugged and highly efficient.

6. Conclusion

A comprehensive study of various configurations of PFC converters has been presented for feeding BLDC motor drive. A detailed classification of 35 configurations of PFC converter has been given in five different categories of non-isolated, bridgeless non-isolated, isolated, bridgeless isolated and integrated and high quality rectifiers. These PFC converters have provided an improved power quality at AC mains for a wide range of speed control corresponding to the control of DC link voltage of the VSI. Moreover, these converters have also resulted in a satisfactory power factor correction at universal AC mains. Latest developments in high speed switches, improved design concepts, integrated magnetic and miniaturized design in these PFC converters have enhanced the possibility of efficiency improvements in these PFC converters. Moreover, the advancements in high density permanent magnets, sophisticated tools in motor design and efficient control methods have also led to the development of high performance and highly efficient BLDC motor drives. These technological improvements have led to various opportunities in development of highly efficient low cost BLDC motor drives with power factor correction and sensor reduction targeting a wide range of applications.

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