# Review of Coupled Two and Three Phase Interleaved Boost Converter (IBC) and Investigation of Four Phase IBC for Renewable Application

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**Abstract-** The power level of a power electronic converter is limited due to several factors, increase in current causes an increase in the stress on switching devices. Besides, the diode reverse recovery current and parasitic resonance current become greater than the main switch can handle. Hence, the size of the boost inductor should be increased to avoid saturation and overheating problems. In order to advance the power level significantly the methods, including device paralleling, module paralleling and interleaving are widely utilized. For some applications, boost stages are designed modularly such that the converter stages can be connected in parallel to meet the increasing power requirement. This method is preferable as it is easy to increase the power rating by simply stacking converters with increased redundancy. The drawbacks of the method are it's relatively high cost, large volume covered, and cooling difficulties. Furthermore,to provide equal sharing of input current among the converters, additional circuitry should be utilized and the currents of individual converters do not return properly, current of one module can circulate through other module and some unexpected failures may occur. This paper reviews the ripple input current and output voltage of two and three phase Interleaved Boost Converter (IBC) and investigates the performance of four phase IBC for renewable applications.

**Keywords-** Renewable Energy Systems, Solar Photo Voltaic,Wind Turbine Generator Artificial Neural Network, Phase Shift Modulation, Interleaved Boost Converter,Hybrid Power System.

## 1. Introduction

Generating electricity from systems based on Renewable Energy Systems(RES) applications like Photo Voltaic(PV) cell ,fuel cell ,wind etc are one of the reliable remedies to conserve energy[1].For PV cell, PV model[2-5] is generated and analyzed in conjunction with power electronic switches for a maximum power point tracker[6-7][63].While considering fuel cells[8],it has been used as the phenomenon sources of distributed energy. Because of the high efficiency, low environmental impact and scalability [9], the fuel cell based supply system converts its generated low dc voltage using power conditioner[10]. Hence it is used for residential application. The battery model system is implemented using effective equivalent circuit model structure featuring lead-acid batteries[11-13].Diesel Wind Turbine is another application of RES which satisfies the power demand [14].These are superior when compared to the conventional sources like fossil fuels ,RES will fulfill the world's energy demand.[15] Novel ideas from various studies proposes the parallel switching of devices are used widely in telecommunication industry and operated under closed loop to regulate the output voltage which reduces current stress and maximize its performance[16-18].Paralleling two or more switching devices is a widely utilized approach to increase the current handling capability of switches. The advantages of the parallel converters scheme is to implicit proper design, dynamic response, robustness and tight steady state[19-21]. In high power high density converters, the power MOSFETs is being used in parallel as the main switch to meet the current rating requirement, also it increase the switching frequency and reduce the power loss. Proper gating by PWM signal is applied to devices in order to reduce switching losses and switch currents are shared [22].This method is useful in devices with positive temperature constant (PTC) such as MOSFETs. The device paralleling method is not practical for all applications.The power stage of the converter consists of semiconductor switches and magnetic components. The drawback such as unbalanced current sharing between semiconductor switches and magnetic saturation is partially overcome by the power stage paralleling method [23] shown in Fig.1.

In this configuration, transistors are not paralleled directly. Therefore current sharing problems mentioned previously are not an issue. Besides, energy storage requirement of the inductors is decreased, so the total magnetic component volume can be reduced significantly. Furthermore, hot swapping and increasing the power rating by simply stacking modules are possible.

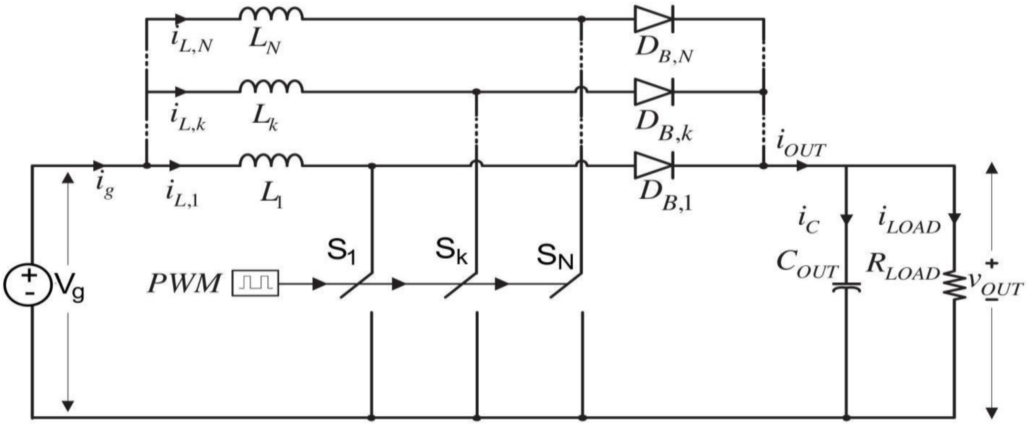


**Fig.1.** Boost rectifier with N–phase paralleled power stage

Power Stage paralleling is very practical, but it is not the optimal solution in terms of converter performance and size considerations. The same paralleling method can be utilized with a different switching pattern than the identical switching patterns in order to reduce input current and output voltage ripples. The separate power branches are controlled by interleaved switching signals but they have a phase shift. In this review RES such as SPV, wind turbine generator, battery and fuel cell is taken for study and analysis [24].

*1.1. Interleaved Boost Converter*

During the last few decades, power electronics research has focused on the development of multi-phase parallel DC-DC converters. It is useful to obtain the regulated output voltage from several input power sources such as a solar array, wind generator, fuel cell [26].Among the various topologies, interleaved boost converter (IBC) is considered as a better solution for fuel cell systems[65-66], due to improved electrical performance, reduced weight and size[66].This provides positive output voltage without any additional transformer and it is capable of bidirectional operation, increase the power processing capability and improves the reliability of the power electronic system[25]. While comparing conventional single input converters, this topology minimizes the total number of components [27] and has simple circuit structure [28].

*1.2. Advantages of Interleaved Boost Converter*

The advantages of constructing a power converter by means of interleaved parallel connected converters [29] are ripple cancellation in both the input and output waveforms to a maximum extent, and lower value of ripple amplitude and higher ripple frequency in the resulting input and output waveforms [30-31].By splitting the current into many power paths, conduction losses ($I^2R$) can be reduced, increasing overall efficiency [32].Multi-phase interleaved boost converter created by paralleling several phase legs and inductors to share the input current. Main asset of this configurations is to increase the power quality of the converter and the input current ripple is significantly reduced with the increase in number of phases[33].Designing converter with very stringent power quality, high current, low harmonic distortion [34] requires this configuration. Increasing the phase inductance is more essential in interleaved configuration [33].

Mathematically there is no limit for the number of interleaved power branches. But in practice as the phase number increases, the system complexity increases and maintenance becomes difficult. The input/ EMI filter size and output capacitor size are reduced in proportion with the ripple reduction [35-36]. The disadvantage of the interleaving method is the increase in the gate driving logic complexity, but necessarily the size and cost of the gate drive [35]. Logic signals to all the gates are equally phase shifted by the amount defined in (1).

$$\text{Phase shift} = K*2/N \qquad \text{Eq. (1)}$$

In Equation (1), '*N*' denotes the number of interleaved branches and '*k*' denotes the order of discrete interleaved branches ($k = 1, \ldots, N$).Coupled inductor is one of the main components in power electronics circuits, which plays an important role in DC/DC converters [37].From the literature review **,**the various configurations of the IBCs such as uncoupled, directly coupled and inversely coupled it is reported that the directly coupled IBC [42][62][86]gives a reduced input current ripple[40] ,output voltage ripple, responds fast.[39] than the other two systems and it is best suited for renewable energy applications[15][38].The soft switching dc-dc converter with the coupling inductor suppress the overvoltage [41].

## 2. IBC as the Basic Converter Unit of HPS

The RES, such as SPV panel [4][6] and fuel cell [43-45] generally have low output voltage which mandates the use of the boost converter to increase and match with the load voltage. But the use of conventional boost converters generally introduce large amounts of ripple content in the input current as well as in the output voltage. It inherently shortens the lifetime of RES sources such as SPV panel and fuel cell and also decreases the performance of the sources.With large input current ripple and output voltage ripple, the control of the system parameters such as output voltage control, power flow control becomes difficult as it mandates a sturdy averaging circuit for each input parameter of the controller. An input output magnetically coupled interleaved converter smoothen the operating modes and improves the inner dynamics and fuel cell application.

Based on the analysis performed it is proved that the IBC offers better input current ripple reduction and the output voltage ripple reduction.[15][17][29][31] Hence, in view of the advantages offered[32-36] [46], the IBC is recommended as the basic converter unit in the proposed Hybrid Power System.

### *2.1.Ripple Analysis in 2-Phase IBC*

In a two-phase converter, there are two output stages that are driven 180 degrees out of phase. By splitting the current into two power paths, conduction ($I^2R$) losses can be reduced, increasing overall efficiency compared to a single-phase converter. Because the two phases are combined at the output capacitor, effective ripple frequency is doubled, making ripple voltage reduction much easier. Likewise, power pulses drawn from the input capacitor are staggered, reducing ripple current requirements. To overcome these limitations multiphase interleaving technique is used [47].

Multiphase dc-dc converters are widely used in high-power applications[65] ranging from automotive to distributed generation [56][59-60][81] compared to single phase converters[48] .This topology uses a coupled inductor in the place of main inductors of the conventional IBC [48][51][69]By coupling the main inductors, the input current ripple and switching loss[58][64][67-68]can be reduced more further[38][48][53], improves the dynamic performance[52], efficiency[65][69], switching speed[49] and output voltage[54].Moreover the power density can be easily achieved because there is only one core adopted[50][62] .In case of high output power and low output voltage it is typically beneficial to use paralleled converters[61]. The circuit of the coupled inductor is shown in Fig.2

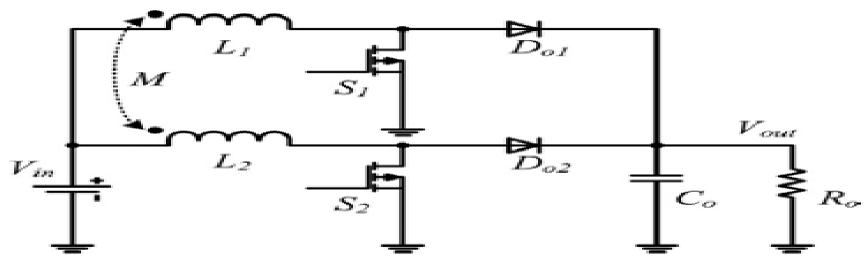


**Fig.2.** Schematic of coupled inductor IBC

**Table 1**. Input current ripple of the 2-phase IBC connected to SPV panel and WTG

| Parameter (N=2) | SPV panel | | | WTG | | |
|---|---|---|---|---|---|---|
| | $I_{Min}$ (A) | $I_{Max}$ (A) | $I$ A) | $I_{Min}$ (A) | $I_{Max}$ (A) | $I$ (A) |
| **Input current ripple in Inductor 1** | 4.01 | 4.18 | .17 | 4.22 | 4.39 | 0.17 |
| **Input current ripple in Inductor 2** | 4.05 | 4.24 | .19 | 4.17 | 4.35 | 0.18 |
| **Input source current Ripple** | 8.26 | 8.34 | .08 | 8.62 | 8.71 | 0.09 |

**Table 2**. Input current ripple of the 2-phase IBC connected to the Fuel cell and Battery

| **Parameter (N=2)** | **Fuel cell** | | | **Battery** | | |
|---|---|---|---|---|---|---|
| | $I_{Min}$ (A) | $I_{Max}$ (A) | $I$ (A) | $I_{Min}$ (A) | $I_{Max}$ (A) | $I$ (A) |
| **Input current ripple in inductor 1** | 4.19 | 4.37 | 0.18 | 4.08 | 4.25 | 0.17 |
| **Input current ripple in inductor 2** | 4.13 | 4.32 | 0.19 | 4.09 | 4.27 | 0.18 |
| **Input source current ripple** | 8.38 | 8.46 | 0.08 | 8.28 | 8.36 | 0.08 |

Table 2 and Table 3 shows the input ripple current across inductor 1 and 2 and the input source current in SPV , WTG , fuel cell and battery ,where $I_{Min}$and $I_{Max}$ are the minimum and maximum current across the inductors.

Table 2.2 shows the output ripple voltage of the 2 phase IBC for all the RES. Figure 3 shows the corresponding wave form.

**Table 3**. Output voltage ripple of the 2-phase IBC connected to RES's

| **Parameter (N=2)** | **Fuel cell** | | | **Battery** | | |
|---|---|---|---|---|---|---|
| | $I_{Min}$ (A) | $I_{Max}$ (A) | $I$ (A) | $I_{Min}$ (A) | $I_{Max}$ (A) | $I$ (A) |
| **Input current ripple in Inductor 1** | 4.19 | 4.37 | 0.18 | 4.08 | 4.25 | 0.17 |
| **Input current ripple in Inductor 2** | 4.13 | 4.32 | 0.19 | 4.09 | 4.27 | 0.18 |
| **Input source current Ripple** | 8.38 | 8.46 | 0.08 | 8.28 | 8.36 | 0.08 |

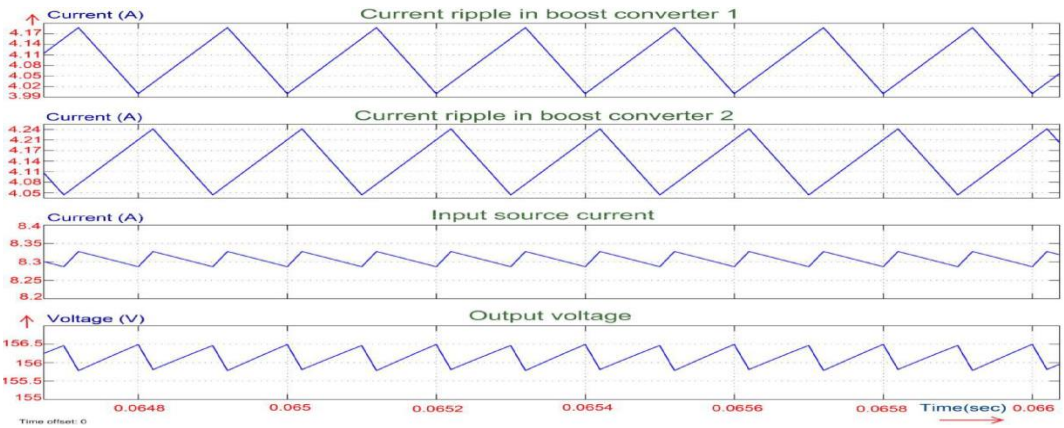


**Fig.3.** Current and voltage output of SPV panel fed 2-phase IB

## 3. Ripple Analysis in 3-Phase IBC

A three-phase high power dc/dc converter with an active clamp is capable of increased power transfer due to its three-phase power configuration, and it reduces the rms current per phase which is imposed into fuel cells thus reducing conduction losses compared to other conventional boost converters[84-85].Parallel control method of three-phase interleaved dc-dc converters can be used for the battery test system and it is used for improving the unbalance factor. Here the current sharing control method is used for maintaining dc-dc converter current equal [70].Three phase interleaved DC-DC converter[82] can be connected with electric vehicle to operate motors and inverters[71].The input ripple current is minimized by three phase interleaved operation and the transformer turn ratio is reduced by its inherent boost mode operation effectively[72].The interleaved structure of the current source port can provide the desired small current ripple to benefit the PV panel to achieve the maximum power point tracking (MPPT).The MPPT and power flow regulations are realized by duty cycle control and phase-shift angle control, and the zero-voltage switching can be guaranteed in the PV application even when the dc-link voltage varies[73]. The input ripple current is minimized by three phases interleave operation, and the transformer turn ratio is reduced by its inherent boost mode operation effectively [74][77].The battery is connected to the three-phase interleaved dc-dc converter in order to reduce the ripple current from 32.5% to 8%, increase of battery lifetime and reduction of total size of inductors. The ripple current[79] is further reduced to 2% from 8% by connecting a filter capacitor and design rule of filter capacitor is analyzed[75].

Also it reduces the core number[77],voltage stress[83],improves efficiency[79][81]by integrating three input inductors into a single core with coupling to achieve zero-voltage-switching (ZVS) over a wide range by hybrid pulse-width-modulation (PWM) and phase-shift-modulation (PSM) control.Single-switch boost stages, connected between three-phase rectifiers and DC link capacitors, allow good power factor correction when operated in the discontinuous conduction mode[80].This converter has a great potential application in fuel cell vehicle and distributed power generation [76]. The pulsation power decoupling control method can be used to minimize the dc capacitor with low cost[78].The output of the 3-phase IBC connected to WTG is shown in Fig.3.1. The magnitude of current ripple in the inductors ($I_{L1}$, $I_{L2}$,$I_{L3}$) and source current and output voltage ripple of the 3-phase IBC's connected to SPV panel, WTG, fuel cell and batteryare shown in table4,5 & 6. and corresponding waveforms is shown in figure 4

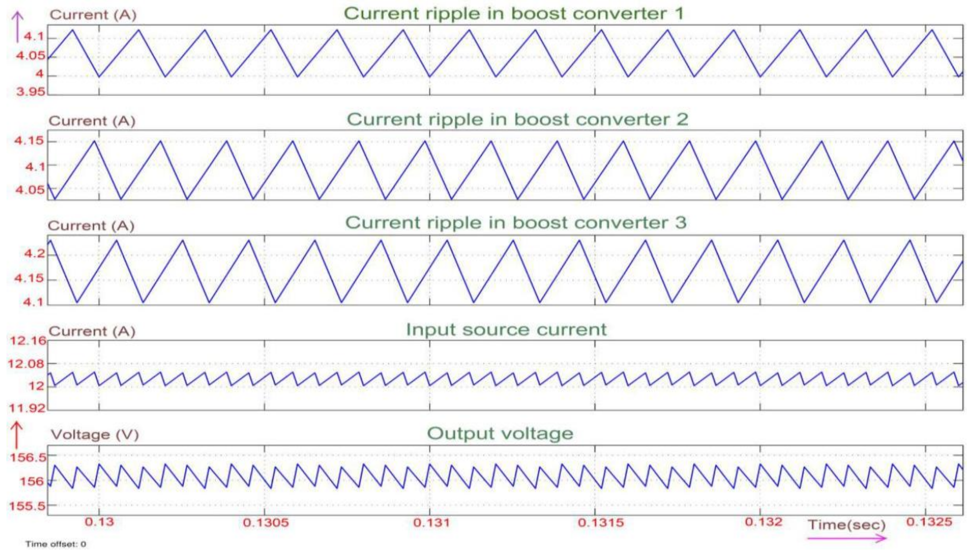


**Fig.4.** Current and voltage output of WTG fed 3-phase IBC

## 4. Ripple Analysis in 4-Phase IBC

The conventional boost converters has large size of the storage capacitor on the dc link and suffers from the disadvantage of discontinuous current injected to the load. The multi-phase operation of boost converter overcomes this disadvantage with appropriate phase shift in the control circuit of main switches.

**Table 4.** Input current ripple of the 3-phase IBC connected to SPV panel and WTG

| Parameter (N=3) | SPV panel | | | WTG | | |
|---|---|---|---|---|---|---|
| | $I_{Min}$ (A) | $I_{Max}$ (A) | $I$ (A) | $I_{Min}$ (A) | $I_{Max}$ (A) | $I$ (A) |
| **Input current ripple in inductor 1** | 3.99 | 4.12 | 0.13 | 4.00 | 4.12 | 0.12 |
| **Input current ripple in inductor 2** | 4.01 | 4.13 | 0.12 | 4.04 | 4.15 | 0.11 |
| **Input current ripple in inductor 3** | 4.04 | 4.15 | 0.11 | 4.11 | 4.24 | 0.13 |
| **Input source current ripple** | 11.98 | 12.03 | 0.05 | 12.00 | 12.05 | 0.05 |

**Table 5.** Input current ripple of the 3-phase IBC connected to fuel cell and battery

| Parameter (N=3) | Fuel cell | | | Battery | | |
|---|---|---|---|---|---|---|
| | $I_{Min}$ (A) | $I_{Max}$ (A) | $I$ (A) | $I_{Min}$ (A) | $I_{Max}$ (A) | $I$ (A) |
| **Input current ripple in Inductor 1** | 3.99 | 4.1 | 0.11 | 4.01 | 4.13 | 0.12 |
| **Input current ripple in Inductor 2** | 4.03 | 4.14 | 0.11 | 3.98 | 4.09 | 0.11 |
| **Input current ripple in Inductor 3** | 4.01 | 4.13 | 0.12 | 3.99 | 4.11 | 0.12 |
| **Input source current Ripple** | 11.94 | 11.98 | 0.04 | 11.97 | 12.01 | 0.04 |

This is done in such a way that at any time one of the inductors is supplying the load current. The frequency of ripple current in the output capacitor is n times compared to the single stage and therefore the value of the capacitor required can be reduced [87]. Also by virtue of paralleling the converters, the input current can be shared among the cells or phases [94], and reducing the overshoot [92] by controlling the switches ,conduction ($I^2R$) losses,ripples,EMI can be reduced, thus increasing overall efficiency[90][95] . An active snubber circuit can be used to reduce the switching losses of 1- to N- phase interleaved dc-dc converter, extra current, voltage stresses and reverse recovery current[88][93].By doing so efficiency can be increased upto 97% compared to 2 and 3 phase converters.

A four-phase interleaved boost converter with RES applications employing relatively low-valued inductive and capacitive components is suitable for distributed power conversion, wide input voltage range applications [89-90].

**Table 6.** Output voltage ripple of the 3-phase IBC connected to RES's

| **Output Voltage Ripple (N=3)** | $V_{Max}$ **(V)** | $V_{Min}$ **(V)** | $V$ (V) |
|---|---|---|---|
| **SPV Panel** | 155.88 | 156.50 | **0.62** |
| **Wind Turbine Generator** | 155.73 | 156.35 | **0.62** |
| **Fuel cell** | 155.83 | 156.46 | **0.63** |
| **Battery** | 155.67 | 156.30 | **0.63** |

This topology along with the inter-phase coupled inductors can be used in order to improve transient response[91].Simulink model of the proposed 4-phase IBC connected to AC grid and controlled by ANN as the local controller for voltage control, VDCC and current fine-tuning is shown in Fig.5

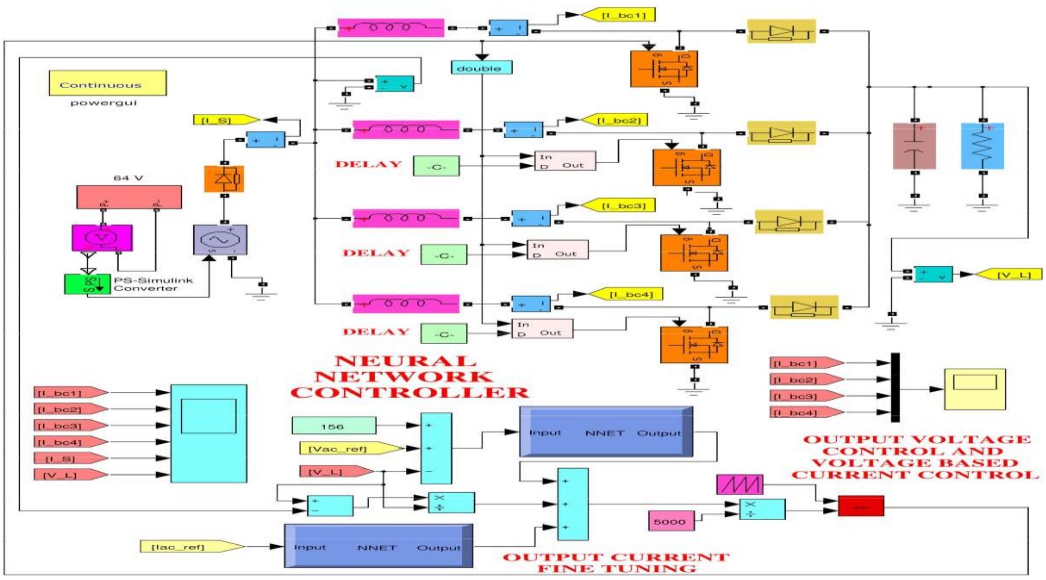


**Fig.5.** Simulink model of a 4-Phase IBC connected to SPV Panel

The ANN controller optimizes the duty cycle to restore the ‘$V_{ref\_pcc}$’ and to deliver ‘$I_{ac\_ref}$’ at the output of the IBC. The output of the ANN controller is in the form of a numeral and the PWM signal pertaining to that duty cycle is developed by comparing the ANN output with a triangular waveform of 5000Hz frequency using relational operators. The developed pulse width modulation (PWM) signal is interleaved using ‘discrete variable transport delay’ to create a delay by an angle of 90° (time delay of 0.00005 second) in the PWM signals applied to each of the consecutive phases in an IBC which is shown in Fig.6

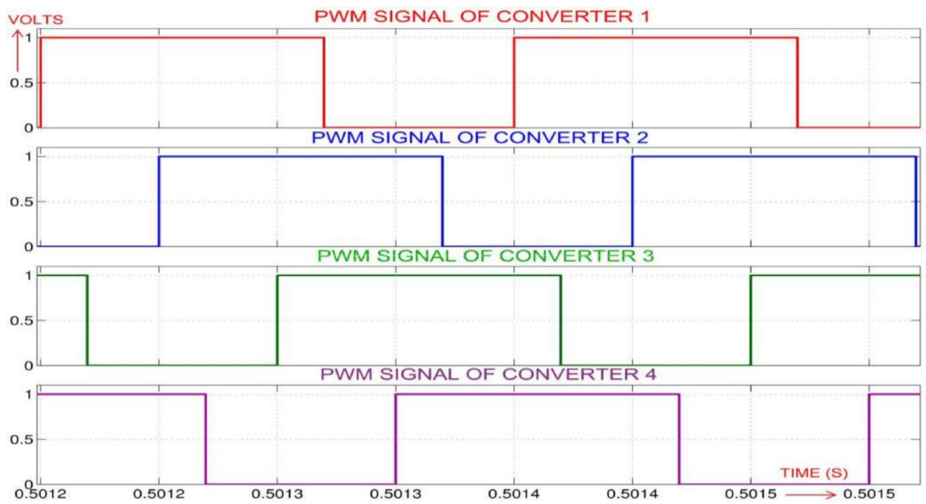


**Fig.6.** PWM signals applied to 4-Phase IBC

In case of the RE based HPS using the IBC as the basic converter topology, the instantaneous duty cycle of the IBC is mainly determined by the parameters such as the input voltage, the required output voltage, the instantaneous current needed to be delivered at the output of the IBC which is governed by the voltage control and VDCC technique. The input current ripple and the output voltage ripple of the IBC is also a function of duty cycle as seen in Fig.8

There exists a trade-off in estimating the duty cycle as the estimated duty cycle should complement all the desired task such as voltage control at PCC, VDCC and also the ripple reduction in input current and the output voltage.From the mathematical analysis performed, it is understood that in a 4-phase IBC, the input current and output voltage ripple is zero at the duty cycles 0.25, 0.5 and 0.75, and also the magnitude of the ripple around these duty cycle is negligible.With the primary objectives to reduce the ripple content and also to maintain a constant output voltage (156V), the source voltage is carefully selected to operate the IBC at or nearer to 0.25, 0.5 or 0.75.The proposed 4-phase IBC proves to achieve a greater reduction in the output voltage and input current ripple which can be revealed from Fig.7. which depicts the input current and the output voltage waveform of the IBC connected to SPV panel.

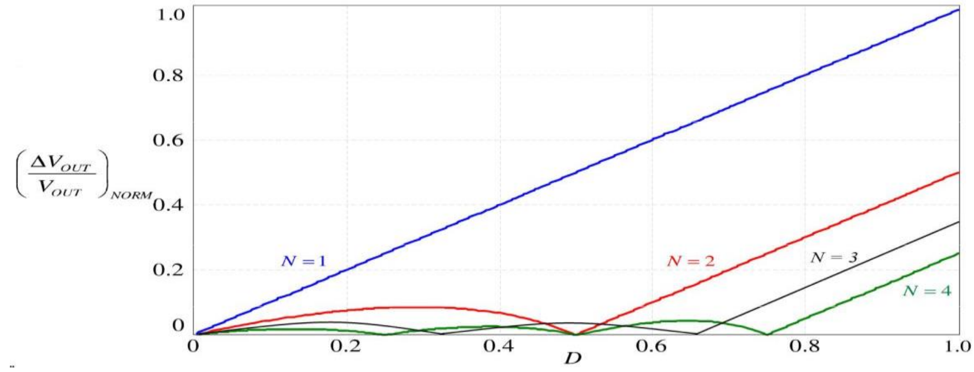


**Fig.7**.Input current and output voltage waveforms of the 4-phase IBC connected to SPV panel

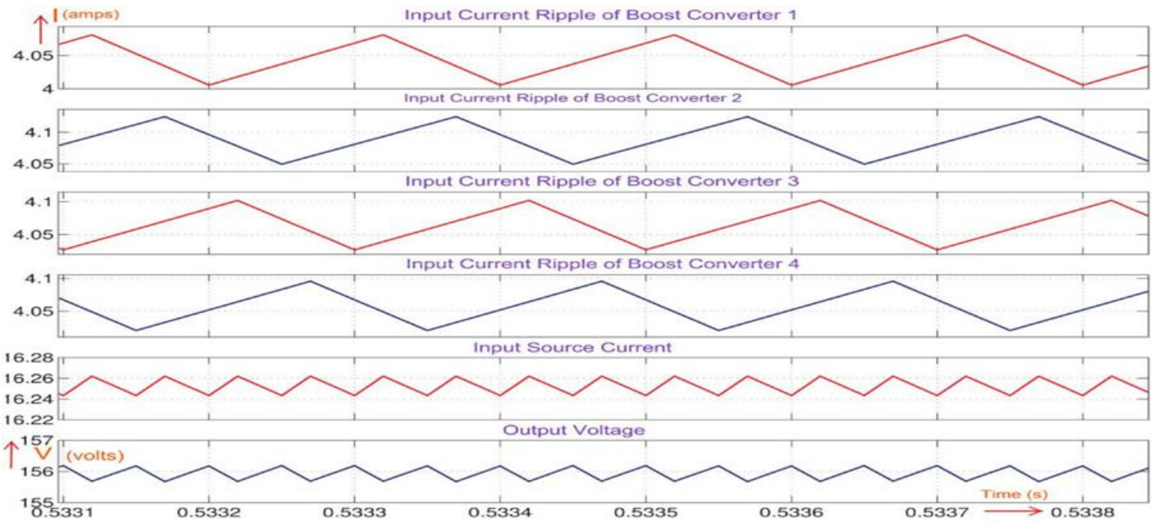


**Fig.8**.Input current ripple Vs duty cycle of an IBC based on number of phases

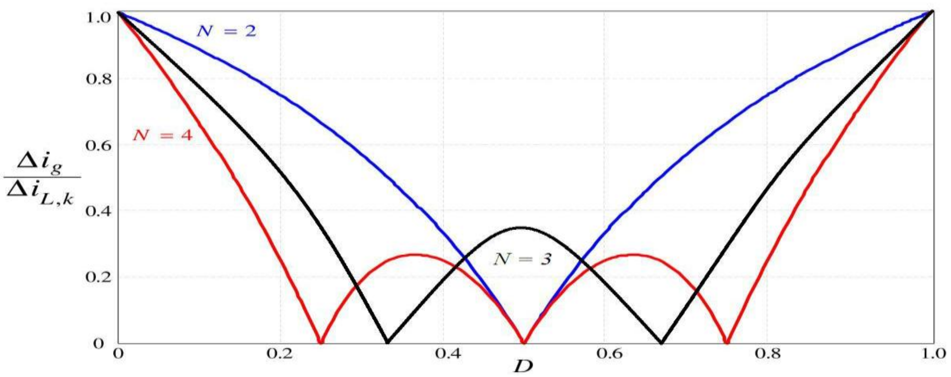


**Fig.9.**Normalized output voltage ripple ratio versus the duty cycle for different number of phases

An analysis on input current ripple and output voltage ripple is presented in Tables 7,8 &9 . It shows that the ripple in source current is significantly reduced to 0.02A by the 4-phase IBC which momentously improves the overall efficiency of the conversion system.

**Table 7**. Input current ripple of the 4-phase IBC connected to SPV panel and WTG

| Parameter (N=4) | SPV panel | | | WTG | | |
|---|---|---|---|---|---|---|
| | IMin (A) | IMax (A) | I (A) | IMin (A) | IMax (A) | I (A) |
| **Input current ripple in Inductor 1** | 4.002 | 4.085 | 0.083 | 4.121 | 4.050 | 0.071 |
| **Input current ripple in Inductor 2** | 4.045 | 4.130 | 0.085 | 4.128 | 4.055 | 0.073 |
| **Input current ripple in Inductor 3** | 4.022 | 4.106 | 0.084 | 4.110 | 4.036 | 0.071 |
| **Input current ripple in Inductor 4** | 4.017 | 4.100 | 0.083 | 4.095 | 4.021 | 0.074 |
| **Input source current Ripple** | 16.263 | 16.243 | 0.020 | 16.312 | 16.292 | 0.020 |

**Table 8.** Input current ripple of the 4-phase IBC connected to fuel cell and battery

| Parameter (N=4) | Fuel cell | | | Battery | | |
|---|---|---|---|---|---|---|
| | $I_{Min}$ (A) | $I_{Max}$ (A) | $I$ (A) | $I_{Min}$ (A) | $I_{Max}$ (A) | $I$ (A) |
| **Input current ripple in Inductor 1** | 4.109 | 4.036 | 0.071 | 4.164 | 4.091 | 0.073 |
| **Input current ripple in Inductor 2** | 4.102 | 4.027 | 0.073 | 4.172 | 4.098 | 0.074 |
| **Input current ripple in Inductor 3** | 4.121 | 4.047 | 0.074 | 4.121 | 4.046 | 0.075 |
| **Input current Ripple in Inductor 4** | 4.086 | 4.012 | 0.074 | 4.112 | 4.038 | 0.074 |
| **Input source current Ripple** | 16.951 | 16.929 | 0.022 | 16.423 | 16.402 | 0.021 |

**Table 9**. Output voltage ripple of the 4-phase IBC connected to RES's

| **Output Voltage Ripple** | $V_{Min}$ (V) | $V_{Max}$ (V) | $V$ (V) |
|---|---|---|---|
| **SPV Panel** | 156.20 | 155.67 | 0.53 |
| **Wind Turbine Generator** | 156.26 | 155.73 | 0.53 |
| **Fuel cell** | 156.19 | 155.65 | 0.54 |
| **Battery** | 156.15 | 155.62 | 0.53 |

## 5. Observations and Conclusion

On detailed investigation carried out on literature on 2 3, and 4 interleaved boost converterd with various parameters of input current ripple , output voltage ripple it is understood that withincresae in number of phases the ripple can be reduced[Tab 10].

**Table 10.** Comparison of input current ripple and out voltage ripple in 2, 3 & 4 Phase IBC's

| Number of phase | Input source current Ripple | | | | Output Voltage Ripple | | | |
|---|---|---|---|---|---|---|---|---|
| | SPV Panel | WTG | Fuel Cell | Battery | SPV Panel | WTG | Fuel Cell | Battery |
| 2 | 0.08 | 0.09 | 0.08 | 0.08 | 0.80 | 0.85 | 0.86 | 0.84 |
| 3 | 0.05 | 0.05 | 0.04 | 0.04 | 0.62 | 0.62 | 0.63 | 0.63 |
| 4 | 0.02 | 0.020 | 0.022 | 0.021 | 0.53 | 0.53 | 0.54 | 0.53 |

From the analysis, it is evident that the proposed 4-phase IBC offers a good reduction of ripple in the inputcurrent and in output voltage than that of the 2-phase, 3-phase IBC and conventional boost converter's the results and observations documented infer that with increases in number of phases, the ripple can be brought down. However, the challenges left are with the gate signals complexity with increase in number of phases. Investigations are currently in progress to identify the optimized number of phases in IBC with limited complexity in gate circuits.

## References

[1] Moradi Sizkohi, H., Milimonfared, J., Taheri, M., Salehi Dobakhshari, S., Mohammadi, M, "Non-isolated high step-up converter based on combination of Flyback and Forward for power conditioning of photovoltaic and fuel-cell systems" 6th Power Electronics, Drives Systems & Technologies Conference (PEDSTC), 2015,pp. 661-666.

[2] Gow, J.A. "Development of a photovoltaic array model for use in power-electronics simulation studies", IEE Proceedings Electric Power Applications, (Volume: 146, Issue: 2), pp. 193-200.

[3] Bourdoucen.H and Gastli.A, "Analytical Modelling and Simulation of Photovoltaic Panels and Arrays" The Journal of Engineering Research Vol.4, No.1 (2007), pp. 75-81.

[4] Nishioka K, T Hatayama, Y Uraoka, T Fuyuki, R Hagihara, M Watanabe, "Field-test analysis of PV system output characteristics focusing on module temperature", Solar Energy Materials and Solar Cells, Vol 75 (3–4) 1 February 2003, Pp. 665-671

[5] Huan-Liang Tsai., Ci-Siang Tu., and Yi-Jie Su, "Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK" Proceedings of the World Congress on Engineering and Computer Science 2008 WCECS 2008, October 22 - 24, 2008.

[6] Hiyama, T.Kouzuma, S. Imakubo, T, "Identification of optimal operating point of PV module using neural network for real time maximum power tracking control" IEEE T ENERGY CONVER, Vol:10 (2), pp. 360-367.

[7] Xiaofeng Sun WeiyangWu ., Xin Li., QinglinZhao, "A research on photovoltaic energy controlling system with maximum power point tracking" Proceedings of the Power Conversion Conference, 2002.PCC-Osaka 2002. (Volume:2 ),pp. 822-826.

[8] Cheng, K.W.E. Sutanto, D., Ho, Y.L., Law, K.K, "Exploring the Power Conditioning System for Fuel Cell", IEEE 32nd Annual Power Electronics Specialists Conference, 2001. PESC. 2001 (Volume: 4), pp. 2197 - 2202 vol. 4.

[9] Yu,X. Starke, M.R, Tolbert, L.M, Ozpineci, B. "Fuel cell power conditioning for electric power applications: a summary" Electric Power Applications, IET (Volume:1,Issue: 5 ), pp.643-656.

[10] Vázquez-Blanco, A. Aguilar-Castillo, C, Canales-Abarca, F, Arau-Roffiel, J. "Two- Stage and Integrated Fuel Cell Power Conditioner: Performance Comparison" Twenty-Fourth Annual IEEE Applied Power Electronics Conference and Exposition, 2009. APEC 2009. , pp. 452–458.

[11] Jackey, R., "A Simple, Effective Lead-Acid Battery Modeling Process for Electrical System Component Selection," SAE Technical Paper, 2007-01-0778, 2007, doi: 10.4271/2007-01-0778.

[12] Olivier Tremblay1, Louis-A. Dessaint, "Experimental Validation of a Battery Dynamic Model for EV Applications" World Electric Vehicle Journal Vol. 3, pp. 0289- 0298.

[13] Casacca, M.A,Salameh, Z.M. "Determination of lead-acid battery capacity via mathematical modeling techniques" IEEE T ENERGY CONVER (Volume:7 , Issue: 3 ), pp. 442 – 446.

[14] Kawamoto, H. "A Primary Power Supply System for Communications using a Darrieus Wind Turbine" Telecommunications Energy Conference, 1979. pp. 445– 452.

[15] Nithya Subramanian, PridhiviPrasanth, R Srinivasan, Dr.R.Seyezhai and R RSubesh, " Review of uncoupled, coupled inductor and RCN based two-phase interleaved boost converter for photo-voltage applications" International Journal of Electronics, Electrical and Computational System IJEECS., ISSN 2348-117X Volume 3, Issue 3, May 2014, pp.45-52.

[16] Vasiliy Vorobei, Janis Zakis, Oleksandr Husev, Oleksandr Veligorskyi, Oleksandr Savenko, "Simulation Study of the Three-Level Boost DC-DC Converter with Full ZVS or PV Application", 9th International Conference on Power Electronics-ECCE Asia June 1 - 5, 2015 / 63 Convention Center, Seoul, Korea, pp. 2038 – 2043.

[17] Ajit T. N, "Two Stage Interleaved Boost Converter Design and Simulation in CCM and DCM", India International Journal of Engineering Research & Technology (IJERT) Vol.3Issue7, July-2014, pp 847-851.

[18] Bashar Khasawneh, Maha Sabra, Mohamed A. Zohdy, "Paralleled DC-DC Power Converters Sliding Mode Control with Dual Stages Design", Journal of Power and Energy Engineering, 2014, 2, 1-10 (February 2014),pp 1-10.

[19] Mazumder, S.K.,Nayfeh, A.H., Borojevic, A, "Robust control of parallel DC-DC buck converters by combining integral-variable- structure and multiple-sliding-surface control schemes", IEEE T POWER ELECTR, (Volume:17 , Issue: 3 ),May 2002, pp. 428 – 437.

[20] Tamyurek, B, Birdane, E, Ceyhan, A, "Design and implementation of an improved controller for parallel-connected 400 Hz frequency converters", Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), 2010 (Feb.2010), pp. 1197 – 1203.

[21] Kohama, T,Ninomiya, T, Shoyama, M, Ihara, F, "Dynamic analysis of parallel-module converter system with current balance controllers" 16th International Telecommunications Energy Conference, 1994. INTELEC '94., 30 Oct-3 Nov 1994, pp.190 – 195.

[22] Hongfang Wang, Wang, F, "Power MOSFETs Paralleling Operation for High Power High Density Converters", Industry Applications Conference, 2006. 41st IAS Annual Meeting. Conference Record of the 2006 IEEE (Volume:5 )( Oct. 2006), pp. 2284– 2289.

[23] Shiguo Luo, Zhihong Ye, Ray-Lee Lin, Lee.F.C, "A Classification And Evaluation Of Paralleling Methods For Power Supply Modules", 30th Annual IEEE Power Electronics Specialists Conference, 1999. PESC 99. (Volume:2 )( Jul 1999), pp. 901 - 908 vol.2.

[24] Spiazzi. G., Buso, S., Biadene. D, "Efficient High Step-up Topology for Renewable Energy Source Interfacing", IEEE Applied Power Electronics Conference and Exposition (APEC),2015 (March 2015), pp. 1137-1144.

[25] Khaligh, A,Cao., J, Young-JooLee, "A Multiple-Input DC-DC Converter Topology", *IEEE T POWER ELECTR*, (Volume:24 , Issue: 3 ),( January 2009) pp.862 – 868.

[26] Matsuo H., Wenzhong Lin., Kurokawa F., Shigemizu. T, Watanabe, N. "Characteristics of the multiple-input DC-DC converter", *IEEE T IND ELECTRON*, (Volume:51 , Issue: 3 )( June 2004), pp. 625 – 631.

[27] Kwasinski A. "Identification of Feasible Topologies for Multiple-Input DC–DC Converters", *IEEE T POWER ELECTR*, (Volume:24 , Issue: 3 )(Feb 2009) pp.856-861.

[28] Yan Li., Xinbo Ruan., Dongsheng Yang., Fuxin Liu., Tse C.K. "Synthesis of Multiple-Input DC / DC Converters", IEEE T POWER ELECTR (Volume:25, Issue:9 )(April 2010), pp.2372-2385.

[29] Tin-Ho Li, R,Ho, C.N.M, "An Active Snubber Cell for N-Phase Interleaved DC-DC Converters", International Electronics and Application Conference and Exposition (PEAC), Nov 2014, pp. 953 – 958.

[30] Sung-Hoon Bae, Seong-Chon Choi, Bum-Jun Kim, Young-Ryul Kim, Chung-Yuen Won, "Control Method of Modular Interleaved Boost Converter for SOC Balancing in EV", 9th International Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia), June 2015, pp. 2904-2910.

[31] Dinca, L, Corcau, J.-I, Ureche E, "Optimization of a dc to dc boost converter using interleaved command technique", 9th International Symposium Advanced Topics in Electrical Engineering (ATEE), 2015 May 2015, pp. 644 – 649.

[32] Yijie Wang, Yueshi Guan, Jiaoping Huang, Wei Wang, Dianguo Xu, "A Single-Stage LED Driver Based on Interleaved Buck–Boost Circuit and LLC Resonant Converter", IEEE Journal of Emerging and Selected Topics in Power Electronics, (Volume:3 , Issue:3 ) April 2015, pp.732-741.

[33] Magne P, Ping Liu, Bilgin. B, Emadi. A, "Investigation of Impact of Number of Phases in Interleaved de-de Boost Converter", IEEE Transportation Electrification Conference and Expo (ITEC), (June 2015), pp. 1-6.

[34] Chun-An Cheng, Chien-Hsuan Chang, Hung-Liang Cheng, Ching-Hsien Tseng, "A Novel Single-Stage LED Driver with Coupled Inductors and Interleaved PFC", 9th International Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia), June 2015, pp. 1240 – 1245.

[35] Kumar Prasanna C, Ramu, T.S, "Optimal Design of an Interleaved DC-DC Switch Mode Converter" PCIM Asia 2015: International Proceedings of Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management; ( June 2015), pp. 1-7.

[36] Hongfei Wu Tiantian Mu, HongjuanGe, Yan Xing, "Full-Range Soft-Switching Isolated Buck-Boost Converters With Integrated Interleaved Boost Converter and Phase- Shifted Control", IEEE T POWER ELECTR, (Volume: 31, Issue: 2) (April 2015), pp. 987 – 999.

[37] Wuhua Li, Jianguo Xiao, Jiande Wu, Jun Liu, Xiangning, "Application Summarization of Coupled Inductors in DC/DC Converters", Twenty-Fourth Annual IEEE Applied Power Electronics Conference and Exposition, (Feb. 2009), pp. 1487 – 1491.

[38] Nithya Subramanian, Pridhivi Prasanth, Srinivasan.R, Dr.Seyezhai and Subesh.R, "Review Of Uncoupled, Coupled Inductor And Rcn Based Two-Phase Interleaved Boost Converter For Photo-Voltaic Applications", International Journal of Electronics, Electrical and Computational System (IJEECS) Volume 3, Issue 3 May 2014, pp. 45- 52.

[39] Guangyong Zhu, McDonald B., Kunrong Wang, "Modeling and Analysis of Coupled Inductors in Power Converters", *IEEE T POWER ELECTR*, (Volume: 26 Issue: 5) (September 2010), pp. 1355 – 1363.

[40] Yu Gu, Donglai Zhang, "Interleaved Boost Converter with Ripple Cancellation Network", *IEEE T POWER ELECTR*, (Volume: 28, Issue: 8) (November 2012), pp.3860 – 3869.

[41] Isozumi, K. Kimura, N., Morizane, T., Omori, H. "Soft Switching DC- DC Converter with Coupling Inductor for Continuous Current Mode Operation", 15th International Conference Electrical Machines and Systems (ICEMS), 2012 (Oct. 2012), pp. 1 – 6.

[42] Yan Dong Lee, F.C., Ming Xu, "Evaluation of coupled inductor Voltage Regulators", Twenty-Third Annual IEEE Applied Power Electronics Conference and Exposition, (Feb. 2008), pp. 831 – 837.

[43] Makda, I.A. Nymand, M, "Differential Mode EMI Filter Design for Ultra High Efficiency Partial Parallel Isolated Full-Bridge Boost Converter", IEEE 10th International Conference on Power Electronics and Drive Systems (PEDS), April 2013, pp. 99 –103.

[44] Dr Seyezhai.R. "Design Consideration of Interleaved Boost Converter for Fuel Cell Systems", International Journal Of Advanced Engineering Sciences And Technologies Vol No. 7, Issue No. 2, 2011 pp. 323 – 329.

[45] Vahid Samavatian, Ahmad Radan, "A high efficiency input/output magnetically coupled interleaved buck–boost converter with low internal oscillation for fuel-cell applications: Small signal modeling and dynamic analysis", International Journal of Electrical Power & Energy Systems (May 2015,), pp. 261-271.

[46] Rui Ling Guoyan Zhao, Qin Huan, "High step-up interleaved boost converter with low switch voltage stress", Electric Power Systems Research, Volume 128, November 2015, pp.11-18.

[47] Shah, M. Sutaria, J., Chauhan, C, "Design, simulation and implementation of two phase interleaved bi-directional DC-DC converter" International Conference on Electrical, Electronics, Signals, Communication and Optimization (EESCO), 2015 Jan. 2015, pp. 1 – 6.

[48] Joung_pillee, honnyoungcha, dongsulshin, kyoung_junlee, dong_wookyoo, and ji_yoonyoo. "Analysis and design of coupled inductors for two phase interleaved DC –DC converters", Journal of power electronics, vol .13 no.13, may 2013, pp. 339-348.

[49] Han Peng, Pala, V. ; Chow, T.P. ; Hella, Mona, "A 150MHz, 84% efficiency, two phase interleaved DC-DC converter in AlGaAs/GaAs P-HEMT technology for integrated power amplifier modules" Radio Frequency Integrated Circuits Symposium (RFIC), 2010 IEEE ( May 2010), pp. 259 – 262.

[50] Sung PilHa., Junghyo Lee., Jung Pill Hwang., Jun Hyuk Choi., Chung Yuen Won, "Two phase interleaved bidirectional DC-DC converter for electric vehicle using variable DC-link voltage", Vehicle Power and Propulsion Conference (VPPC), Oct 2012 IEEE, pp.748 – 752.

[51] Barry, B.C., Hayes, J.G., Rylko, M.S." CCM and DCM Operation of the Interleaved Two-Phase Boost Converter with Discrete and Coupled Inductors", IEEE T POWER ELECTR, (Volume: 30, Issue: 12) December 2014, pp. 6551 – 6567.

[52] Jen-Ta Su ,De-Min Liu ,Chih-Wen Liu ,Chung-Wen Hung. "An adaptive control method for two-phase DC/DC converter", PEDS International Conference on Power Electronics and Drive Systems, Nov 2009,pp. 288 – 293.

[53] Radianto, D., Shoyama, M. "Neural network based a two phase interleaved boost converter for photovoltaic system" International Conference on Renewable Energy Research and Application (ICRERA) Oct. 2014,pp. 430 – 434.

[54] Bong-Chul Kim., Ki-Bum Park., Chong-Eun Kim., Gun-Woo Moon, "Load sharing characteristic of two-phase interleaved LLC resonant converter with parallel and series input structure", IEEE Energy Conversion Congress and Exposition, 2009. ECCE 2009. pp. 750 – 753.

[55] Mohammed, S.S,Devaraj, D. "Simulation of Incremental Conductance MPPT based two phase interleaved boost converter using MATLAB/Simulink", IEEE International Conference Electrical, Computer and Communication Technologies (ICECCT), 2015 pp.1 – 6.

[56] Giacomini, D. Lollio, A. "A two-phases interleaved One Cycle Control PFC for automotive applications", Transportation Electrification Conference and Expo (ITEC), 2014 IEEE,pp.1 – 6.

[57] Hartnett, K.J., Rylko, M.S., Hayes, J.G., Egan, M.G. "A comparison of classical two phase (2L) and transformer — Coupled (XL) interleaved boost converters for fuel cell applications", Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), 2010, pp. 787 – 793.

[58] Lee, Jia-You, Shen, Hung-Yu, Chen, Yu-Kai. "Phase management control applied to two-phase interleaved half-bridge LLC resonant converter with phase-shift power factor correction", IEEE International Symposium Industrial Electronics (ISIE), 2013 ,pp. 2163-5137.

[59] Barry, B.C., Hayes, J.G., Rylko, M.S., Maslon, J.W. "Discontinuous conduction mode operation of the two-phase integrated-magnetic boost converter", IEEE Energy Conversion Congress and Exposition (ECCE), 2014, pp.5782 – 5789.

[60] Barry, B.C., Hayes, J.G., Rylko, M.S., Maslon, J.W. "Two-phase interleaved boost converters for

distributed generation", Power Electronics for Distributed Generation Systems (PEDG), 2014 IEEE 5th International Symposium, pp.1 – 8.

[61] Figge, H., Grote. T., Schafmeister. F., Frohleke. N. "Two-phase interleaving configuration of the LLC resonant converter - Analysis and experimental evaluation", 39th Annual Conference of the IEEE Industrial Electronics Society, IECON 2013 -, pp.1392 – 1397.

[62] Gleissner.M, Bakran.M.M. "Influence of inverse coupled inductors on fault-tolerant operation of two-phase DC-DC converters", 17th European Conference Power Electronics and Applications (EPE'15 ECCE-Europe), 2015, pp. 1 – 11.

[63] Anupama. A,Seema. P.N, Srikanth, V. "Variable step-size algorithm implemented two phase soft-switched interleaved boost converter", International Conference Computation of Power, Energy, Information and Communication (ICCPEIC), 2014 pp. 200 – 205.

[64] Jantharamin. N., Li Zhang. "Control of a two-phase bi-directional interleaved converter for maximum power point tracking", International Conference Electrical Machines and Systems, 2008. ICEMS 2008. pp. 2343 – 2345.

[65] HuiChen., Xinke Wu., FangzhengPeng., ZhaomingQian. "Current balance method for the two-phase interleaved LLC-RDCX with parallel PWM output regulation", International Electronics and Application Conference and Exposition (PEAC), 2014, pp.136 – 141.

[66] Harinee.M., Nagarajan., V.S.Dimple., Seyezhai. R. "Modeling and design of fuel cell based two phase interleaved boost converter", 1st International Conference Electrical Energy Systems (ICEES), 2011,pp.72 – 77.

[67] Thounthong.P., Sethakul.P,Rael., S. Davat.B, "Design and implementation of 2-phase interleaved boost converter for fuel cell power source", 4th IET Conference Power Electronics, Machines and Drives, 2008. PEMD 2008.,pp. 91 – 95.

[68] Phattanasak, M., Kaewmanee, W., Thounthong, P., Gavagsaz-Ghoachani, R. "Study of two-phase interleaved boost converter using coupled inductors for a fuel cell", 10th International Conference Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 2013,pp.1 – 6.

[69] Saadi, R., Bahri, M., Ayad, M.Y., Becherif, M. "Implementation and dual loop control of two phases interleaved boost converter for fuel cell applications", 3rd International Symposium Environmental Friendly Energies and Applications (EFEA), 2014,pp. 1 – 7.

[70] Hyunsik Jo., Hanju Cha." Parallel operation of three-phase bi-directional isolated interleaved DC-DC converters for battery test system", Twenty-Ninth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), 2014,pp. 1584 – 1589.

[71] RaecheongKang., Sehyun Kim., Inbeom Yang., KiyunJeong. "The use of FPGA in HIL simulation of three phase interleaved DC-DC converter", IEEE Vehicle Power and Propulsion Conference (VPPC), 2012,pp.772 – 776.

[72] Yujin Song., Han, S.B., Park,S.I., Jeong,H.G. "A power conversion system with a current-fed three-phase dc-dc converter for fuel cell applications", 31st International Telecommunications Energy Conference, 2009. INTELEC 2009.,pp.1 – 5.

[73] Zhan Wang., Hui Li. "An Integrated Three-Port Bidirectional DC–DC Converter for PV Application on a DC Distribution System", IEEE T POWER ELECTR, (Volume:28 , Issue: 10 ), pp. 4612 – 4624.

[74] Yujin Song., Han, S.B., Park, S.I., Jeong, H.G. "A current-fed three-phase half-bridge dc-dc converter with active clamping", IEEE Energy Conversion Congress and Exposition, 2009. ECCE 2009.,pp. 1362 – 1366.

[75] Wujong Lee., Byung-Moon Han., Hanju Cha. "Battery ripple current reduction in a three-phase interleaved dc-dc converter for 5kW battery charger", IEEE Energy Conversion Congress and Exposition (ECCE), 2011, pp.3535 – 3540.

[76] Danwei Liu., Hui Li. "A Three-Port Three-Phase DC-DC Converter for Hybrid Low Voltage Fuel Cell and Ultracapacitor", 32nd Annual Conference IEEE Industrial Electronics, IECON 2006. pp. 2558 – 2563.

[77] Changrong Liu., Johnson, A., Jih-Sheng Lai, "A novel three-phase high-power soft switched DC/DC converter for low voltage fuel cell applications", . Nineteenth Annual IEEE Applied Power Electronics Conference and Exposition, 2004. APEC '04 (Volume:3 ),pp.1365 – 1371.

[78] XiaohuLiu., Hui Li. "A new three-phase high-power soft-switched DC-DC converter based fuel cell power conditioning system with minimized DC capacitor", IEEE Energy Conversion Congress and Exposition (ECCE), 2013,pp. 4617 – 4672.

[79] DanweiLiu., Hui Li. "A Three-Port Three-Phase DC-DC Converter for Hybrid Low Voltage Fuel Cell and Ultracapacitor", 32nd Annual Conference IEEE Industrial Electronics, IECON 2006,pp. 2558 – 2563.

[80] Chunkag,V., Robinson, F.V.P. "Interleaved switching topology for three-phase power-factor correction", Fifth International Conference Power Electronics and Variable-Speed Drives, 1994.,pp. 280 – 285.

[81] Cornea, O. Muntean, N., Gavris, M. "Interleaved 3 phase DC/DC converter for automotive applications", 12th International Conference Optimization of Electrical and Electronic Equipment (OPTIM), 2010,pp. 589 – 594.

[82] Gong Shuqiu., Y'ang Ming., Ding Xiying., He Bin. "Research of interleaved three-phase bidirectional DC/DC converter based on control type soft switching", International Conference Electrical Machines and Systems, 2008. ICEMS 2008.,pp. 1738 – 1741.

[83] LonglongZhang., DehongXu., Haijin Li., GuoqiaoShen. "Three-phase interleaved high step-

up boost converter with voltage multiplier for fuel cell power system", IEEE Energy Conversion Congress and Exposition (ECCE), 2015,pp.4804 – 4811.

[84] K. Srinadh. "A New Three-Phase Interleaved Isolated Boost Converter With Solar Cell Application", International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 7, July - 2013 IJERT pp. 2278-0181.

[85] A.Ramesh Babu. "Performance analysis of novel three phase High step-up dc-dc interleaved boost converter using coupled inductor", 2015 International Conference on Circuit, Power and Computing Technologies [ICCPCT], pp. 1-8.

[86] R. Seyezhai, B. L. Mathur. "A Comparison of Three-Phase Uncoupled and Directly Coupled Interleaved Boost Converter for Fuel Cell Applications", International Journal on Electrical Engineering and Informatics - Volume 3, Number 3, 2011, pp. 394-407.

[87] NagulapatiKiran., V. Rangavalli., B. Vanajakshi. "Modeling, Analysis and Simulation of 4-Phase Boost Converter" International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:8, No:9, 2014,pp. 1452- 1462.

[88] River T. H. Li., Carl N. M. Ho. "An Active Snubber Cell for N-Phase Interleaved DC-DC Converters", IEEE Journal of Emerging and Selected Topics in Power Electronics, pp. 953 – 958.

[89] Pulvirenti, F., LaScala, A., Ragonese, D., D'Souza K. "4-Phase Interleaved Boost Converter With IC Controller for Distributed Photovoltaic Systems", IEEE T CIRCUITS-I: Regular Papers, (Volume:60 , Issue: 11 ),pp. 3090 – 3102.

[90] Gitau, M.N., Hofsajer, I.W. "Analysis of a 4-phase tapped-inductor DC-DC converter for high boost ratio wide input voltage range applications", 40th Annual Conference of the IEEE Industrial Electronics Society, IECON 2014 (Nov 2014), pp.5468 – 5474.

[91] Kroics, K., Sirmelis, U., Grigans, L., Brazis, V. "Digitally controlled 4-phase interleaved DC-DC converter with coupled inductors for storage application in microgrid", 9th International Conference on Compatibility and Power Electronics (CPE), 2015 June 2015, pp 504 – 509.

[92] Capponi, G., Livreri, P., Mocciaro, I., Librizzi, F. "A 5-V/1.5-V, 60-A interleaved four-phases voltage regulator module based on a new control technique", Proceedings of the 44th IEEE Circuits and Systems, 2001. MWSCAS 2001. Midwest Symposium on (Volume: 2), pp. 948 - 951 vol.2.

[93] Ching-Ming Lai., Yi-Hung Liao. "Modeling, Analysis, and Design of an Interleaved Four-Phase Current-Fed Converter with New Voltage Multiplier Topology", IEEE T IND APPL, (Volume: 49, Issue: 1) (November 2012), pp.208 – 222.

[94] Thounthong, P., Poonnoi, N., Sethakul, P., Davat, B. "Performance Evaluation of Modified 4-Phase Interleaved Fuel Cell Converter for High-Gain High-Power Applications", IEEE Industry Applications Society Annual Meeting, October 2009. pp. 1 – 8.

[95] Lute, C.D., Simoes, M.G., Brando, D.I., Al Durra, A., Muyeen, S.M. "Development of a four phase floating interleaved boost converter for photovoltaic systems" IEEE Energy Conversion Congress and Exposition (ECCE), 2014 (Sept. 2014), pp. 1895 – 1902.