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Research paper

An integrated bayes soft switching interleaved and sliding window PWM for DC-DC boost converter

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Abstract

In order to develop the efficient dc-dc boost converter in high output power application, an Integrated Bayes Interleaved and Sliding Window (IBI-SW) based PWM framework is proposed. Initially, the integration of interleaving and PWM improves the power factor correction in very high output power applications (photovoltaic panels) and near optimal voltage and current losses. Multiple phase shifts with soft switched Bayes interleaving technique maximizes the power generated in photovoltaic panels and the optimization of power conversion is achieved with sliding window based PWM that performs Maximum Power Point Tracking (MPPT) algorithm on the PV cells connected to the converter. The proposed dc-dc boost converter is efficiently tested on various load conditions for measuring the scalability of IBI-SW framework in multiple high power demanded application. When compared with traditional model, the simulation result of proposed IBI-SW based PWM framework demonstrates that the dc-dc converter improves the power generated in photovoltaic panels accurately and rapidly.

Keywords: *Pulse width modulation (PWM), bayes interleaved, sliding window, photovoltaic panels, maximum power point tracking and Dc-Dc boost converter.*

1. Introduction

Photovoltaic (PV) applications are mainly suitable for distributed power conversion obtained by transmitting the part of electronics from inverter to module during converter. Output voltages of each photovoltaic (PV) panel are quite low. Several research works have been conducted in this field to improve the power output. An interleaved 3-phase Continuous Conduction Mode Boost Power Factor Correction Converter in [1] was designed with the objective of improving light load efficiency and output voltage stability. However, little efforts were made in terms of quantification analysis. The quantification analysis in [2] measures the current in both switching cycle and main half cycle was presented.

In the recent years, dc-dc converters played a significant role in renewable energy applications including PV systems, fuel energy system, and automobile applications and so on. In [3], to achieve high output voltage gain, reverse recovery energy employs isolated primary and secondary terminal during switching. To improve the efficiency, zero voltage zero current pulse width modulation [4] was used thereby increasing the switching frequency also. However, the fault detection remained unsolved. Soft switching and high frequency was applied in [5] with the core objective of reducing the faults at an early stage.

Interleaved boost DC-DC converter using Zero-current-switching pulse-width modulation auxiliary circuit operates at constant frequency and also reduces the commutation losses. Therefore, to improve the conversion efficiency, traditional dc-dc converters was replaced by novel dc-dc converter in [6]. Another method to improve the efficiency was performed using Maximum Power Point Tracking [7]. Despite efficiency, the switching noise in conventional schemes increased with the voltage instability. A new PWM controller was designed in [8] improves the efficient output power. Semi Active Quadrupler Rectifiers (SAQR) was intended in [9] to maximize converter efficiency.

Boost converter operates at ZCS turn on and turn off. Recent works developed various converter prototypes for soft switching solutions was designed, constructed and tested to perform wide variations in input voltage. Wide range soft switching solutions to PWM were discussed in [10]. Another PWM three level dc-dc converters [11] were designed for improving the load efficiency. Analysis of high performance power conditioning unit was presented in [12] to reduce the power loss. Maximum Power Point Tracking was applied in [14] with pulse width modulated control signal to realize the energy conversion efficiency.

Electro Magnetic Interference (EMI) filters are conventionally used in power converters to attenuate switching noise for many years now. In [15], PWM technique was combined with passive filter to reduce the switching noise. In [16], a novel soft switching mechanism was designed to utilize zero voltage switching that aims to operate at voltage and efficiency. However, switching loss remained unaddressed. The principles of switching and conduction losses were discussed in [17]. Another PWM based soft switching dc-dc converter was presented in [18, 19] to reduce switching losses. Despite efficiency, trade off with respect to zero current and voltage was observed. In [20], zero voltage zero current switching converters were designed using pulse width modulated buck converter. In order to overcome the above limitation, a novel dc-dc boost converter based on Integrated Bayes Interleaved and Sliding Window (IBI-SW) based PWM framework to improve high output power application is proposed.

2. Materials and Methods

Integrated Bayes Interleaved and Sliding Window (IBI-SW) based PWM framework is planned to enhance the power factor correction with very high output power and near optimal voltage and current losses due to centralized converter. Power electronics converters with switching devices turn on and off when the power conversions is performed from one form to another for operating very high switching frequencies. Despite conversion being performed in an efficient manner, such high switching frequency operation, increases the power loss due to switching losses and therefore compromises power converter efficiency. In soft switched Bayes interleaving framework, the voltage across or current flowing through a switch is made to zero during switching transition. Therefore, it minimizes the switching loss for zero voltage switching and zero current switching modes of operandi. The soft switched Bayes interleaving using Naïve Bayes Classification for Zero-Voltage Switching (ZVS) turns the transistor on at zero 'V', reducing the turn on switching loss. At the same time, the soft switched Bayes interleaving using Naïve Bayes Classification for Zero-Current Switching (ZCS) turns the transistor off at zero 'I', reducing the turn off switching loss. Also, the soft switching frameworks reduces the switching losses for enabling high frequency based on input current between the parallel converters resulting in the improvement of converter power output. Despite reducing the switching loss and improving converter power output, the switching noise increases with variable phase signal.

The Sliding Window based PWM approximates the voltage at the desired threshold and therefore controls the power delivery. The power delivery is controlled on the basis of the 'on-off' behaviour of PWM with the aid of slider window control. This in turn reduces the switching noise in terms of 'on-off' that alternates the behaviour of PWM for different time intervals. Despite minimizing the switching noise, with the complexity of circuitry necessary for implementation compromises the converter accuracy and efficiency which is a major drawback of Sliding Window based PWM.

3. Integrated Bayes Interleaved and Sliding Window (IBI-SW) Based PWM Using MPPT Algorithm

The proposed Integrated Bayes Interleaved and Sliding Window (IBI-SW) based PWM framework with Maximum Power Point Tracking (MPPT) algorithm is described. That is essentially uses multiple boost converters placed in the connection box of the PV panels for replacing the bypass diodes. This multiple boost converters minimizes the current loss and switching noise and therefore the weakness of converter accuracy occurs during conventional soft switched Bayes interleaving and sliding window based PWM. The IBI-SW based PWM framework uses present (i.e. current) PV output power and previous power perturbation cycle to generate maximum power in photovoltaic panels through switching. During switching transition, the inverter ripple tracks the maximum power point for obtaining ZVS and ZCS using MPPT algorithm. Fig.1 shows the flow diagram of IBI-SW based PWM framework.

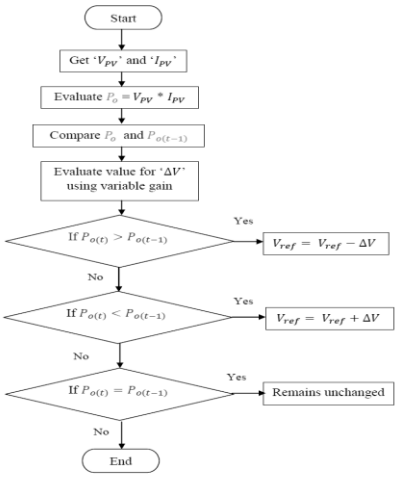


Fig. 1: Flow chart of IBI-SW based PWM framework

In order to achieve maximum power, the IBI-SW based PWM framework takes the measurement of voltage 'V_{pv}' and current 'I_{pv}' at the time interval 't_i'. The power output can be mathematically formulated as given below.

$$P_o = V_{PV} * I_{PV} \tag{1}$$

With the obtained output power for PV 'P_o', comparison is made with the power of previous perturbation cycle at time 't_{i-1}'. Then the power 'P_o' measured at 't_i' is compared with the power 'P_o' measured at 't_{i-1}'. In order to optimize the MPPT control with the objective of producing high power output, reference voltage is obtained with the aid of variable gain voltage 'ΔV'. The value of 'ΔV' is measured based on the variable gain and is expressed as given below.

$$if\ P_{o(t)} > P_{o(t-1)}\ ;\ V_{ref} = V_{ref} - \Delta V \tag{2}$$

$$if\ P_{o(t)} < P_{o(t-1)}\ ;\ V_{ref} = V_{ref} + \Delta V \tag{3}$$

$$if\ P_{o(t)} = P_{o(t-1)}\ ;\ V_{ref} = V_{ref} \tag{4}$$

$$\Delta V = \frac{\Delta V_i}{1+\left(\frac{i}{i_0}\right)} \tag{5}$$

From (2), (3) and (4), in this variable gain, a small amount of voltage is adjusted to obtain high power output. From (2), if there occurs a variation operating voltage of PV with change in power, '$P_{o(t)} > P_{o(t-1)}$', the MPPT control in IBI-SW based PWM framework, moves the operating point in a harmonious direction. From (3), on the other hand, if there occurs a variation operating voltage of PV with change in power, $P_{o(t)} < P_{o(t-1)}$', the MPPT control in IBI-SW based PWM framework moves the operating point in a unharmonious direction. Finally, from (4), if the change in power is observed to be '$P_{o(t)} = P_{o(t-1)}$', resulting in maximum power point no change in the position of the operating point is said to occur. Fig.2 explains the principle of MPPT control. The MPPT control is mainly depending on adaptive control algorithm to preserve the photovoltaic module in the Maximum Power Point (MPP). The temperature and irradiance is termed as 'T 'and 'G'. In order to optimize the MPPT control with the objective of producing high power output, reference voltage is obtained with the aid of variable gain voltage 'ΔV'. For evaluating the value of 'ΔV' is essentially based on the variable gain and is expressed as given below.

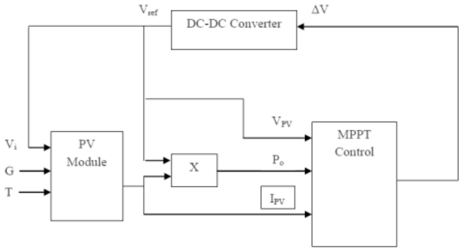
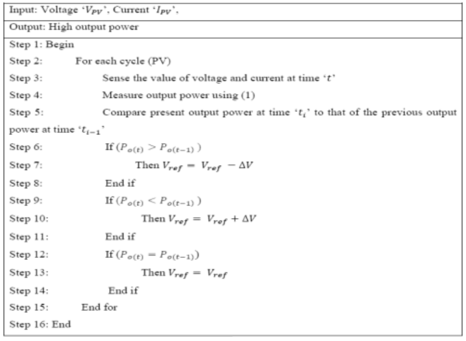


Fig. 2: Principle of MPPT control

The algorithmic process of Maximum Power Point Tracking (MPPT) for high power provided in photovoltaic (PV) panels is presented using IBI-SW based PWM technique. The fig.3 explains the MPPT algorithm is shown below,



```
Input: Voltage '$V_{PV}$', Current '$I_{PV}$'.
Output: High output power
Step 1: Begin
Step 2:     For each cycle (PV)
Step 3:         Sense the value of voltage and current at time '$t$'
Step 4:         Measure output power using (1)
Step 5:         Compare present output power at time '$t_i$' to that of the previous output power at time '$t_{i-1}$'
Step 6:         If ($P_{o(t)} > P_{o(t-1)}$)
Step 7:             Then $V_{ref} = V_{ref} - \Delta V$
Step 8:         End if
Step 9:         If ($P_{o(t)} < P_{o(t-1)}$)
Step 10:            Then $V_{ref} = V_{ref} + \Delta V$
Step 11:        End if
Step 12:        If ($P_{o(t)} = P_{o(t-1)}$)
Step 13:            Then $V_{ref} = V_{ref}$
Step 14:        End if
Step 15:    End for
Step 16: End
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Fig. 3: MPPT algorithm

Initially, MPPT algorithm sense the value of voltage and current at the time interval 't'. Next, it compares the present output power at time 't_i' to that of the perturbation cycle at time 't_{i-1}' by using photovoltaic panels. Using MPPT algorithm, the process of maintaining maximum power from PV panel is transferred to load duty cycle through inverter ripple [12] and is expressed as given below.

$$Duty\ Cycle\ (D) = \frac{1}{2}\left(1 - \frac{V_i}{V_o}\right) \tag{6}$$

From (6), the duty cycle is denoted as 'D' and is measured using the input voltage 'V_i', and the output voltage 'V_o'. Finally, the multiple phase shifts with soft switched Bayes interleaving technique that is executed to maximize the output power generated in photovoltaic panels with better efficient. The multiple boost dc-dc converter is efficiently executes the switching mode power supply for improving the performance of proposed IBI-SW based PWM approach. Fig.4 shows that the circuit topology of multiple boost converters [13] performed with IBI-SW based PWM framework.

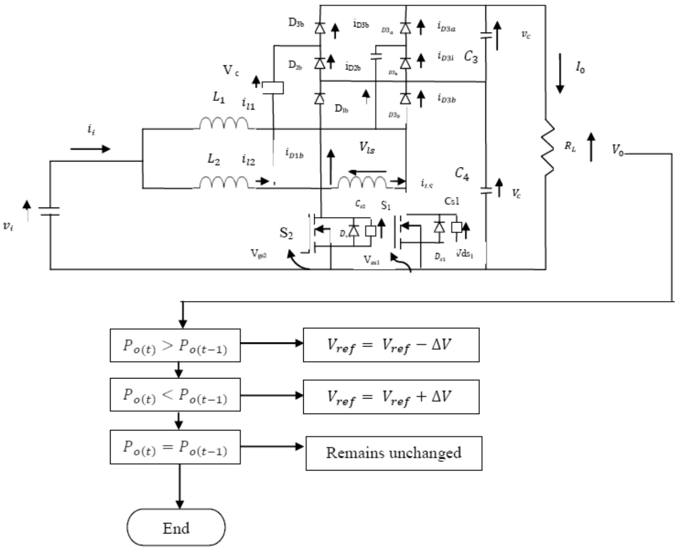

Fig. 4: Circuit topology of multiple boost converters with IBI-SW based PWM framework

The multiple boost converters performed with soft switched Bayes interleaving circuit consists of two multilevel boost converters with an auxiliary inductor 'L_s'. One multilevel boost converter comprises of a dc source 'V_i', an inductor 'L_1', diodes 'D_{1a}', 'D_{2a}' and 'D_{3a}', capacitors 'C_1', 'C_3' and 'C_4', and a switch 'S_1'. The second multilevel boost converter comprises of the common dc voltage source 'V_i', an inductor 'L_1', diodes 'D_{1b}', 'D_{2b}' and 'D_{3b}'capacitors 'C_2', 'C_3' and 'C_4', and a switch 'S_2'. The body diodes of 'S_1' and 'S_2' are 'D_{S1}' and 'D_{S2}'. The two capacitances of 'S_1' and 'S_2' are 'CS_1' and 'CS_2'. The input current ripple is minimized by connecting two converters in parallel and share the dc voltage source 'V_i' and capacitors 'C_3' and 'C_4'. On the other hand, the output voltage ripple is minimized by sharing the capacitors 'C_3' and 'C_4'. The auxiliary inductor 'L_s' is connected with two switches 'S_1' and 'S_2' to achieve zero-voltage turning on with high output power.

The circuit diagram of proposed Integrated Bayes Soft Switching Interleaved and Sliding Window (IBI-SW) based PWM for High Power dc-dc Boost Converter in shown in fig.5.

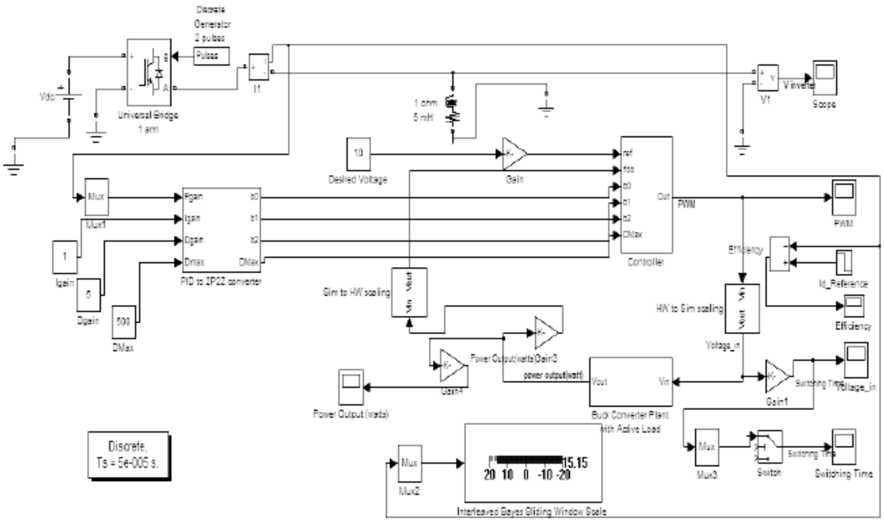

Fig. 5: Integrated bayes soft switching interleaved and sliding window (IBI-SW) based PWM for high power dc-dc Boost converter

The IBI-SW based PWM technique contains six types of parameter such as dc to dc voltage bridge parameter level, saturation dynamic rounding mode, data type conversion, pulse generator parameters, capacitance and switch block parameter level. Initially, the block executes the bridges for choosing efficient power electronics device and series RC snubber circuit are associated in parallel with each switch device. The saturation dynamic is essentially bound the range of second input by using the first and third input. The data type conversion has two types like real world values and stored integer values of the input as well as the output are always equal that is very useful to prevent the quantization error. Then the discrete block provides pulses for carrier based PWM, self-commutated, IGBTs, GT0s or FET bridges. Based on the number of bridge arm selected in "Generator mode" parameter, thus the block employs either single-phase or three phase PWM control. The process of initial voltage parameter has the ability to sets the initial voltage across the capacitor. Finally, the switch block represents the switch controller by an external Physical Signal (PS). If the external PS is a greater than the threshold, then the switch is open or else the switch is close.

4. Results and Discussions

The proposed Integrated Bayes Interleaved and Sliding Window (IBI-SW) based PWM framework aiming to develop an efficient dc-dc boost converter for employing high output power application. There are three modes converter is implemented in MATLAB. The performance analysis of proposed IBI-SW framework based PWM is compared with the existing Interleaved Boost Power Factor Correction (IB-PFC) [1] and Quantification of Interleaved Power Factor Correction (QI-PFC) [2]. The feasible study of the system is performed by experimenting through the metrics such as power output, ripple effect, switching time, switching noise and converter efficiency with voltage and current settings. The performance of IBI-SW based PWM framework for dc-dc converter is carried out using MATLAB for various simulation settings. Soft switched Bayes interleaving framework is essential to reduce the switching loss for zero voltage switching and zero current switching modes of operandi. Several load conditions are tested on the proposed dc-dc boost converter that is essential to measure the scalability of IBI-SW approach in multiple high power demanded application. It is compared with the existing (IB-PFC) [1] and (QI-PFC) [2]. The performance is evaluated according to the following metrics.

Power Output

The output power for the dc-dc boost converter using three methods measured based on input voltage and current. The power output is measured using the product of input voltage 'V_i' and input current 'I_i'. The converter power output is measured in terms of watts. An input is provided with dc supply and the inverter converts the dc input into an ac output power. The mathematical evaluation for converter power output 'P_o' is given as below.

$$P_o\,(\text{watts}) = V_i\,(\text{Dc supply in volts}) * I_i\,(\text{mA}) \quad (7)$$

The range of input voltage that is measured in terms of Volts (V) are chosen initially as 5V and then increased in step to 10V, 15V, 20V, 25V, 30V as described above. The best performance is achieved using the framework IBI-SW and the optimal power output on input voltage was found to be at 30V. In this learning strategy, the power output gets increased. The IBI-SW framework requires large training sets and long training time, but to conduct experiments on MATLAB it considered till 30V. Also when the input voltage is higher, the power output gets increased.

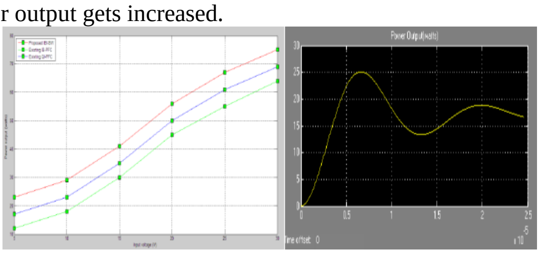

Fig. 6: Measure of power output for different input voltage

In a perspective to evaluate the power output it is simulated the voltage using the multiple boost converters with input voltage 'V_i =5V' to 'V_i=30V' as illustrated in Fig.6. The power output rate converges to 23watts at voltage 'V_i=5V' to IB-PFC and QI-PFC whose power output rate converges to 17watts and 12watts respectively. This is observed due to the application of Maximum Power Point Tracking (MPPT) algorithm that is efficiently maximizes the power point using multiple boost converters. This in turn improves the power output using IBI-SW by 15% compared to IB-PFC. In addition, using multiple boost converters in IBI-SW further improves the power output rate by 27% when compared to QI-PFC.

Ripple Effect

Ripple effect is defined as the ratio of the root mean square (rms) value of the ripple voltage to absolute value of the dc component of the output voltage. It is measured in terms of percentage (%) and the mathematical evaluation of ripple effect 'R' is mathematically formulated as given as follows.

$$R(\%) = \frac{\text{RMS value of ripple voltage}}{\text{absolute value of output voltage}} * 100 \quad (8)$$

In order to evaluate the performances of proposed IBI-SW based

PWM framework, various absolute output voltages that are taken into account during the training process. The absolute output voltages are taken in the range of 10V to 60V.

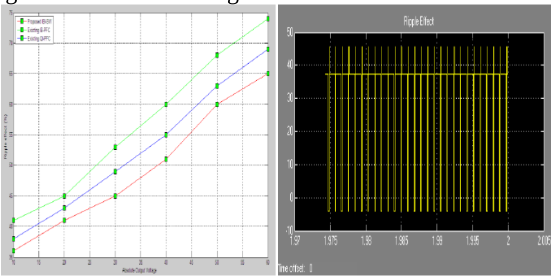

Fig. 7: Measure of ripple effect for different absolute output voltage

Fig.7 shows the fast convergence of the proposed IBI-SW method under the influence of different absolute output voltages, ripple effect at time 40 ms was simulated. It is noticed that the proposed IBI-SW based PWM framework makes it significantly possible to obtain higher ripple effect with good converter accuracy at a faster convergence time. The ripple effect with absolute output voltage at 10V observed a ripple effect of 36% with an absolute output voltage at 10V using the existing IB-PFC and QI-PFC, the ripple effect was observed to be 38% and 41% respectively. Thus the proposed IBI-SW based PWM framework reduces the ripple effect for dc-dc converter than the other two state-of-the-art methods. This is because with the integration of soft switched Bayes interleaving and sliding window based PWM, switching transition is made in an efficient manner in IBI-SW framework that helps to track the maximum power point using variable gain and therefore decreases the ripple effect by 6% and 14% when compared to IB-PFC [1] and QI-PFC [2] respectively.

Switching Time

Switching time 'T_{sw}' of the dc-dc converter for higher end power is defined as the summation of on time and off time. It is measured in terms of millisecond (ms) and is mathematically formulated as given as follows.

$$T_{sw} = T_{on} + T_{off}$$

$$T_{sw} = T_{on} + \left(\frac{V_i}{V_o - V_i}\right) T_{on} \qquad (9)$$

A large number of training data for different IBI-SW based PWM framework were generated using MATLAB software, taking into account various scenarios at different time and different input voltages, ranging between 10V and 70V.

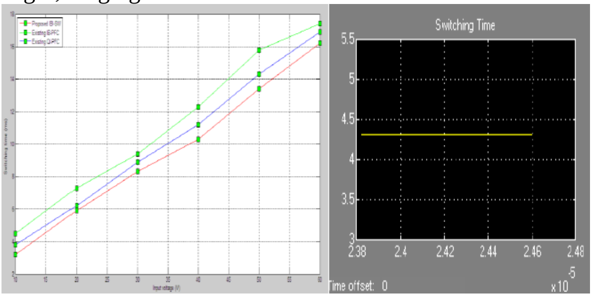

Fig. 8: Measure of switching time for different input voltages

In fig.8, the switching time is symbolized using the framework IBI-SW and compared with two other methods IB-PFC [1] and QI-PFC [2]. The switching time was observed under conditions with respect to different power output. The rate at which the switching time is performed is improved than that of the other methods. This is because the framework IBI-SW compared to value of power obtained through current and previous perturbed power with the simple if-then rule that results in the improvement of switching time by 8% when compared to IB-PFC. In addition, the multiple phase shifts done with soft switched Bayes interleaving maximize the power generated resulting in decreasing the switching time by 20% when compared to QI-PFC.

Switching noise

Switching noise 'SN' is defined as the ratio of the root mean square (rms) value of the output voltage to the absolute value of the reference voltage. The mathematical evaluation of switching noise (i.e. switching voltage) is given below and is measured in terms of percentage (%).

$$SN\ (\%) = \frac{\text{RMS value of output voltage}}{\text{absolute value of reference voltage}} * 100 \qquad (10)$$

Indeed the system switching noise is measured with respect to different reference voltage values between 10V and 60V for experimental evaluation.

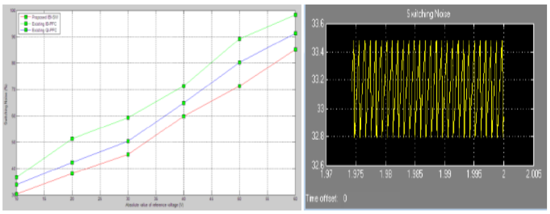

Fig. 9: Measure of switching noise for different absolute reference voltages

The switching noise under different reference voltages is presented in Fig.9. These results proved that by the coordination of the multiple boost converters on power transmission line using MPPT algorithm, the stability of the power transmission line is significantly improved compared to the two state-of-the-art methods namely IB-PFC and QI-PFC respectively, therefore reducing the switching noise. This is because with the help of variable gain using the proposed IBI-SW framework in multiple high power demanded application, the switching noise is proportionately reduced by 10% when compared to IB-PFC and 24% when compared to QI-PFC.

Converter Efficiency

Finally, the efficiency of converter was calculated at 'V_o=5V' and is shown in the figure. From the figure it is evident that the converter efficiency is improved using the IBI-SW framework than when compared to IB-PFC and QI-PFC. The converter achieves a power efficiency of around 94% under varying 'V_o' and 'V_i' conditions. The efficiency plots of the proposed IBI-SW framework with multiple boost converters are compared to those of the conventional cases that use power factor correction boost converter.

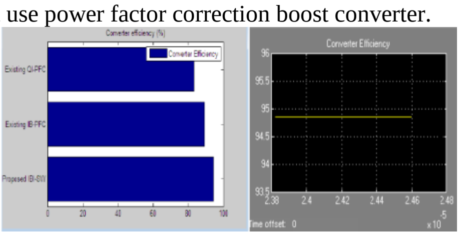

Fig. 10: Converter efficiency comparisons

From the convergence plots shown in the fig.10, it is observed that the efficiency plots of the IBI-SW framework are the highest under a light load condition, and IBI-SW framework shows higher efficiency plots than the conventional cases like IB-PFC and QI-PFC. This is because of the calculation of MPP at the centralized converter by using converter efficiency. Furthermore, multiple boost converters placed in the connection box of the PV panels, replaces the bypass diodes and therefore results in the improvement of converter efficiency by 5% compared to IB-PFC and 6% compared to QI-PFC.

5. Conclusion

In this paper, an efficient dc-dc boost converter is improved to provide high output power application with the aid of Integrated Bayes Interleaved and Sliding Window (IBI-SW) based PWM technique is presented. The integration of interleaving and PWM techniques is essential to design high output power and near optimal voltage and current losses that measures the scalability of multiple high power demanded application. For reducing the switching noise and switching time, the integration through Maximum Power Point Tracking algorithm is presented to improve the power output. Multiple boost converters were placed in the connection box for replacing the conventional bypass diodes that helps to increase the converter efficiency. A comparative study of the proposed framework with two other existing state-of-the-art method demonstrate that the integrated framework using soft switching Bayes interleaving and sliding window based PCW provides more output power. The simulation result shows that the different input voltage and current settings with lesser switching noise and switching time. Therefore, the proposed IBI-SW based PWM method is significantly improves the converter accuracy and efficiency by developing a dc-dc boost converter for generating higher power applications with enhanced reliability and stability.

References

[1] Chen YC, Hsu JD, Ang YA & Yang TY, “A new phase shedding scheme for improved transient behavior of interleaved Boost PFC converters”, Twenty-Ninth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), (2014), pp. 1916-1919.

[2] Zhang S, Garner R, Zhang Y & Bakre S, “Quantification Analysis of Input / Output Current of Interleaved Power Factor Correction (PFC) Boost Converter”, IEEE Applied Power Electronics Conference and Exposition, (2014), pp.1902-1908.

[3] Gopi A & Saravanakumar R, “High step-up isolated efficient single switch DC-DC converter for renewable energy source”, Ain Shams Engineering Journal, Vol.5, No.4, (2014), pp.1115–1127.

[4] Shiva Kumar S, Panda AK & Ramesh T, “A ZVT–ZCT PWM synchronous buck converter with a simple passive auxiliary circuit for reduction of losses and efficiency enhancement”, Ain Shams Engineering Journal, Vol.6, No.2,(2015), pp.491–500.

[5] Mohammadpour A, Parsa L, Todorovic MH, Lai R, Datta R & Garces L, “Series-input parallel-output modular-phase dc–dc converter with soft-switching and high-frequency isolation”, IEEE Transactions on Power Electronics, Vol.31, No.1,(2016), pp.111-119.

[6] Hu Y, Wu J, Cao W, Xiao W, Li P, Finney SJ & Li Y, “Ultrahigh step-up DC–DC converter for distributed generation by three degrees of freedom (3DoF) approach”, IEEE Transactions on Power Electronics, Vol.31, No.7,(2016), pp.4930-4941.

[7] Yuvaraju M & Sheela Sobana Rani K, “Maximum Power Point Tracking For Photovoltaic Optimization Using Seeker Algorithm”, International Journal of Advanced Engineering Research and Science (IJAERS), Vol.1, No.2, (2014), pp.6-9.

[8] Kong TH, Hong SW & Cho GH, “A 0.791 mm On-Chip Self-Aligned Comparator Controller for Boost DC-DC Converter Using Switching Noise Robust Charge-Pump”, IEEE Journal of Solid-State Circuits, Vol.49, No.2,(2014), pp.502-512.

[9] Lu Y, Xing Y & Wu H, “A PWM plus phase-shift controlled interleaved isolated boost converter based on semiactive quadrupler rectifier for high step-up applications”, IEEE Transactions on Industrial Electronics, Vol.63, No.7,(2016), pp.4211-4221.

[10] Shi Y & Yang X, “Wide Range Soft Switching PWM Three-Level DC-DC Converters Suitable for Industrial Applications”, IEEE Transactions on Power Electronics, Vol.29, No.2,(2013), pp. 603 – 616.

[11] Das P, Pahlevaninezhad M & Singh AK, “A Novel Load Adaptive ZVS Auxiliary Circuit for PWM Three-Level DC-DC Converters”, IEEE Transactions on Power Electronics, Vol.30, No.4,(2014), pp. 2108–2126.

[12] Kim W, Duong VH, Nguyen TT & Choi W, “Analysis of the effects of inverter ripple current on a photovoltaic power system by using an AC impedance model of the solar cell”, Renewable Energy, Vol.59, (2013), pp.150–157.

[13] Matsumura K & Koizumi H, “Interleaved Soft-Switching Multilevel Boost Converter”, 39th Annual Conference of the IEEE Industrial Electronics Society, IECON, (2013), pp.936-941.

[14] Hwu KI, Tu WC &Wang CR., “Photovoltaic Energy Conversion System Constructed by High Step-Up Converter with Hybrid Maximum Power Point Tracking”, International Journal of Photo energy, (2013), pp.1-10.

[15] Natarajan S & Natarajan R, “An FPGA Chaos-Based PWM Technique Combined with Simple Passive Filter for Effective EMI Spectral Peak Reduction in DC-DC Converter”, Advances in Power Electronics, (2014), pp.1-12.

[16] Panda AK, Pattnaik S & Mohapatra KK, “A Novel Soft-Switching Synchronous Buck Converter for Portable Applications”, International Journal of Power Management Electronics, (2008), pp. 1-10.

[17] Dudrik J & Oetter J, “High-Frequency Soft-Switching DC-DC Converters for Voltage and Current DC Power Sources”, Acta Polytechnica Hungarica, Vol.4, No.2, (2016), pp.29-46.

[18] Mahor A & Sharma P, “Modelling of New PWM Based Soft Switching for DC/DC Converters Incorporated with PID Controller”, International Journal of Electrical, Electronics and Computer Engineering, Vol.1, No.1,(2012), pp.66-68.

[19] Pattnaik S, Panda AK & Mahapatra KK., “A Novel Improved Soft Switching PWM DC-DC Converter”, Annual IEEE India Conference, (2008), pp. 92–97.

[20] Nigam S, Baul P, Sharma SK, Elangovan D & Saravanakumar R, “Soft Switched Low Stress High Efficient ZVT PWM Dc-Dc Converter for Renewable Energy Applications”, International Conference on Energy Efficient Technologies for Sustainability (ICEETS), (2013), pp.1189–1194.