A Techno-economic Overview of DC-DC Converter used in Photovoltaic System

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Abstract - *Due to shortage of fossil fuels, the problem of generation of energy is increasing worldwide. So use of the photovoltaic power system is growing with very fast rate in residential as well as industrial applications. In PV power system the major constraint is low and irregular PV output Voltage. Recently it is analyzed that for satisfying the safety requirement, PV-parallel connected configuration are mostly used in comparison to series connected configuration in residential generation system. So for achieving high efficiency in low cost, use of DC-DC converters are considered as a best way. In this paper, different topologies of DC-DC converters are covered. The advantage and disadvantages of these converters are also discussed in this paper. Beside this, comprehensive analysis of technical parts of some of the commercial DC-DC converter and different inverters are discussed*.

Key Words: Buck converter, Current fed, Maximum power point tracking (MPPT), Photovoltaic (PV), rectifier, soft switching.

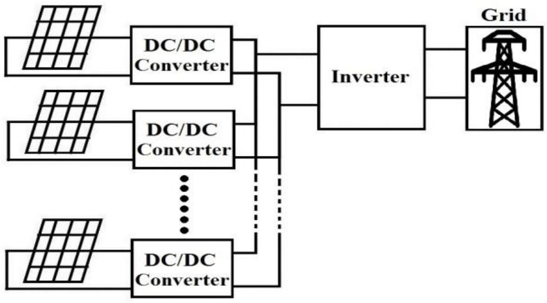
1. INTRODUCTION

Photovoltaic (PV) energy system is one of the fast growing renewable and sustainable energy production systems all over the world. Photovoltaic energy systems are utilized in two ways: Standalone PV system and Grid connected PV system. The standalone PV systems are generally placed at that location where power supplies are not available by grid distribution system. In this system for storage of energy battery bank are present which also increase the size of whole system. In grid connected system, the power generation system are connected to the utility grid and in case of night or when PV are not able to provide power supply in that condition power are fulfilled by utility grid. The grid connected system requires less maintenance as well as it is cost effective. In these the dc current generated by PV cells depends upon solar irradiance, temperature etc. is irregular in nature. So DC-DC converter is used to regulate the output power of PV-panels and provides a stable output to inverter followed by DC-link capacitor.

The DC/DC converter are designed in such way that it gives high efficiency and at the same time it can also able to tracks the Maximum Power Point (MPP) and set the PV panel direction in that location. The installation of DC-DC converter in PV system is also an important phenomenon for gaining high efficiency and higher voltage application. This paper presents brief study of the different types of DC-DC converters used in energy generation system using PV. Besides the basic difference this paper also explains some of the commercial DC-DC converters and their applications.

2. ARRANGEMENT OF DC-DC CONVERTERS WITH PV-SYSTEM

The connections of DC-DC converter or power conditioning system (PCS) with PV panels are arranged in three ways [1]: (1) Module Integrated Inverter (MIC) with a central inverter; (2) Multistring PCS and (3) Centralized PCS. In MIC with central inverter configuration that is shown in Fig. 1(a), the DC-DC converters are individual connected with every PV panels and then connected to centralized inverter with DC bus based on the concept of distributed MPPT. As each PV panels have its own MPPT controller so it is able to give high efficiency under partial shaded condition. This configuration is ideal for rooftop and Building-integrated PV (BIPV) systems.



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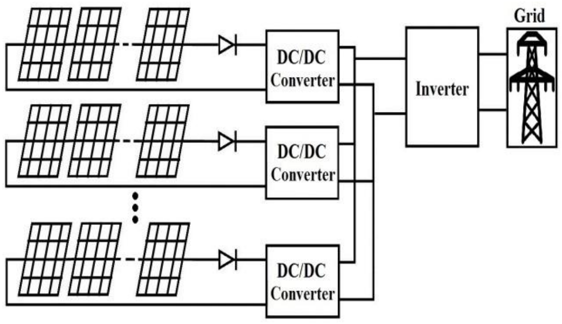

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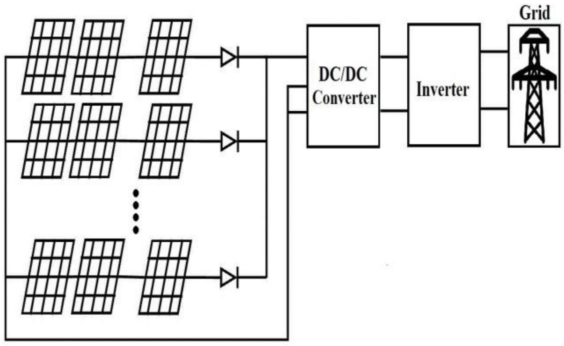

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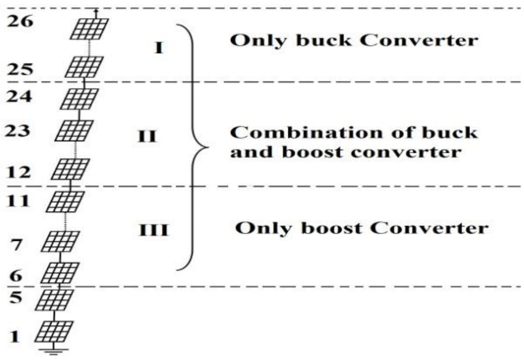

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Fig 1. Different types of PV PCSs. (a) MIC with central inverter. (b) Multistring PCS. (c) Centralized PCS.

Another type of system configuration is multistring system in which pair of DC-DC converters and a cascaded inverter is implemented with each PV string as shown in Fig. 1(b). In this configuration MPPT controller are connected with string of PVs that degrades efficiency of generated power under partial shading condition. Final configuration are centralized PCS which is simple in structure as shown in Fig. 1(c). In this central DC-DC converter is connected with multiple PV modules. It has low manufacturing cost and high power capacity. Due to string diodes there are some losses in power in this configuration. By using all of these configurations it is also easy to extend the power capacity. Some architecture implementation of large scale PV system is explained in [2].

3. DC-DC CONVERTER TOPOLOGIES

In photovoltaic application, High efficiency, high power density and low electromagnetic interference (EMI) have been required in DC-DC converter. For PV module integration, DC-DC converters have four different topologies: Buck, Boost, Buck-boost and Cuk [3]. According to the number of PV panels present in the string, these converters are used that is shown in Fig. 1(d) [4]. Buck converter (I) or boost converters (II) are used for maximum and minimum number of PV panels per string. For The unreachable region (II) buck boost converter are used that combines those two regions. Some of the DC-DC converters are explained as follows:

2.1 Coupled Inductor based Converter

One general problem in DC-DC converter is on applying high duty cycle, serious turn off loss due to high turn parasitic inductance and high turn off current in the switches. Besides this it also faces high recovery loss under high frequency. To solve this problem many types of dc-dc boost converter are developed [5]. One of those DC-DC converters is LLC type micro-converter is shown in the Fig. 2. In this the main design parameter are ratio of inductance LS/LP. For achieving high voltage gain, a voltage doubler rectifier is used. In this converter power MOSFETS are used for Zero Voltage switching (ZVS) and diodes for Zero Current Switching (ZCS) for wide load and input range. It is simple in construction and narrow switching frequency range.

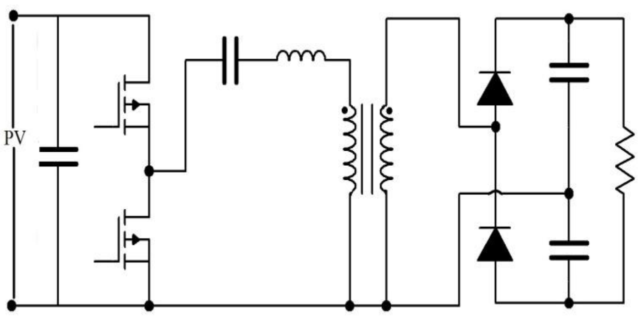
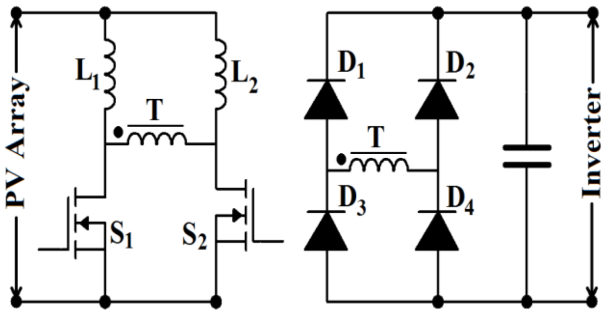


Fig. 2. High efficient LLC DC-DC converter

Another coupled inductor converters are proposed in [6]. For achieving high conversion efficiency, they have used two transformers in series with LLC. They have also proposed method to minimize magnetizing current and find the maximum magnetizing inductance. Here the converter supplies a rectified sinusoidal voltage to the dc-link.

2.2 Current Fed Converter

The current fed converter can be designed by two methods: (1) At high frequency or at any moment of low frequency, the voltage fed converter with an inductor at input terminals. (2) Current source at input with a parallel capacitor. The current two inductor boost converter are shown in Fig. 3(a) [7]. The front end two phase buck converter works as a current source and through an auto transformer provide current two the two inductor boost cell. A voltage doubler is present in the rectification stage of boost cell.



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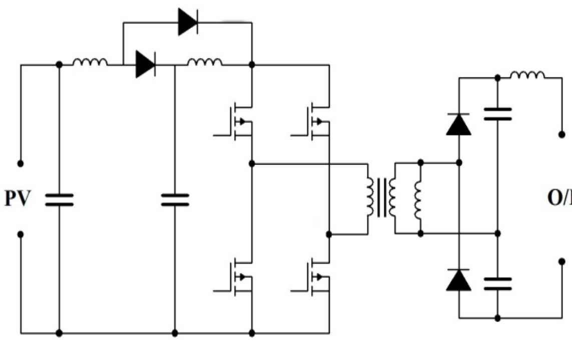

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Fig. 3. Current-fed converter (a) Two-inductor boost converter (b) Current-fed quadratic full-bridge buck converter

Another current feed converter which is proposed by [8] is shown in the Fig. 3(b). The static and dynamic properties of this converter show that it is a buck type converter. Also the use of quadratic conversion ration enables it operates under different operating points of PV generator.

2.3 Pulse width Modulated Converter

The concept of PWM converter is based on controlling of power switches by using PWM technology. The width of pulse provided at particular switch is controlled by PWM control to produce step up or step-down output voltage [9]. The switching of PWM converts are categorized into two types: soft switching and hard switching. The hard switching have disadvantage of switching losses, switching noise and switching stresses. Generally soft switching technique is mostly preferred. A soft switching based PWM converter is shown in Fig. 4 [10].

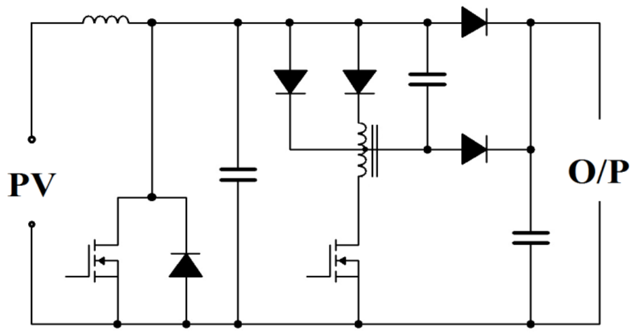
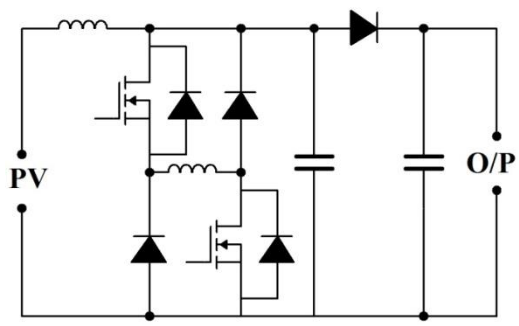


Fig. 4. ZVT-ZCT PWM boost Converter

In this soft switching are implemented by snubber cells that provides perfectly Zero Voltage Transition (ZVT) turn on and Zero current turn off (ZCT) together for the main switch of converter. As soft switching are applied at all semiconductor devices so main devices doesn't have any additional voltage and current stress.

2.4 Soft switching Converter

Soft switching converters have property to cut down the switching loss and stress produced at switch when condition of zero current and zero voltage by capacitor and inductor comes into existence. There are many soft switching based converter are designed by the researchers. Some of them are shown in Fig. 5. Fig. 5(a) shows general soft switching based converters that have high efficiency and small in size [11]. Conventally the efficiency of DC-DC converter with parallel connection is generally higher than series connected system. Fig. 5(b) shows inductor forward flyback soft switching converter that works with minimum off-time [12].



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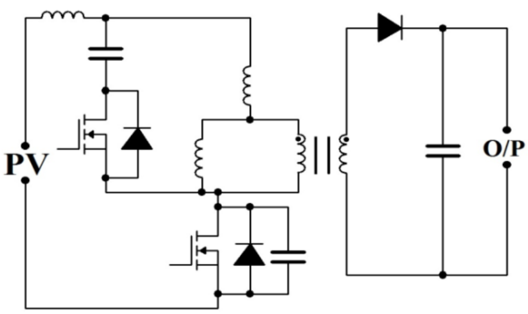

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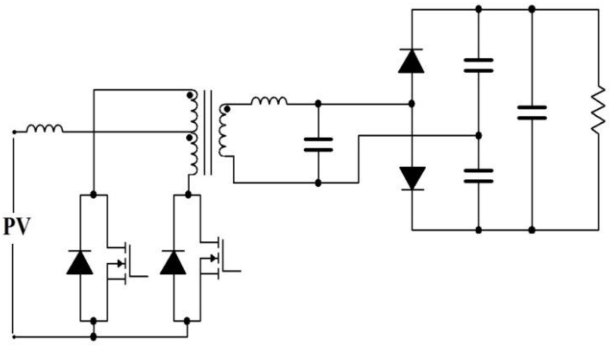

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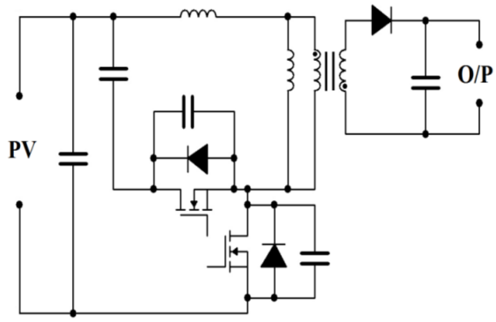
Fig. 5. Soft Switching Converter (a) Soft switching boost converter (b) Inductorless forward bus converter (c) Push-pull converter

Fig. 5(c) shows soft switching current fed push-pull converter. This is applicable for low-voltage photovoltaic AC-module system. The conventional push-pull converter uses hard switching due to which it has low efficiency [13]. The input side of this converter is connected with voltage fed-source. But in this converter ZVS condition are applied at primary-side switches to turn on these switches and ZCS are applied to turn off the switch. Beside this due to presence of voltage doubler of secondary side, the turn ration of transformer is also reduced.

2.5 Flyback Converter

Flyback converter using active clamp are good for achieving high efficiency for low and medium power application at higher frequency. Fig. 6(a) shows conventional flyback converter [14]. In flyback converter, there is a isolation between input and output that enables it to increase the voltage ratio multiple times. Flyback converter provides ZCS of the output diodes. There has some disadvantage of this conventional circuit like; leakage inductance of transformer creates difficulty in surge occurrence, output diodes shows reverse recovery problem etc.

To overcome these problems [15] proposed interleaved active clamp flyback converter using synchronous rectifier that is shown in Fig. 6(b). This converter reduces the voltage spike and also at the same time decreases the switching loss. The ripple current of capacitor is reduced that improves reliability and life of the system due to presence of interleaving technique.



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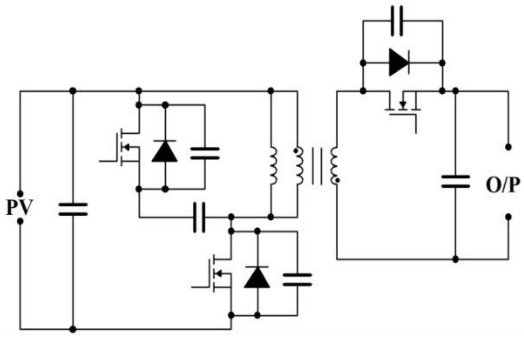

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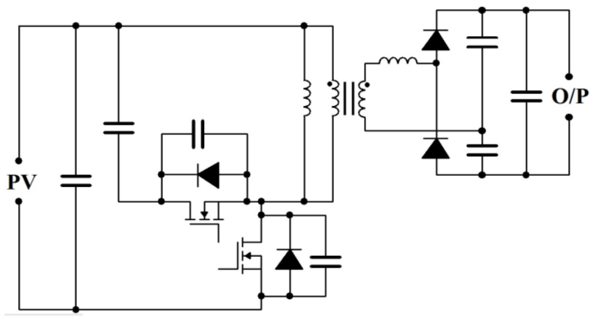
Fig. 6. Flyback Converter (a) Conventional Flyback Converter (b) Interleaved active clamp flyback converter

2.6 Resonant Converter

Resonant converter is widely used dc-dc converter in PV application due to its advantage of low switching losses. But this converter have also some limitations like some difficulty in size reduction, EMI noise etc. To overcome this problem the resonant circuits are used with other different circuit in combination that is also explained in above topologies. Fig. 7(a) shows dual series-resonant active clamp converter. It has advantage of voltage stress, current stress and the switching losses of the devices [15]. Fig. 7(b) shows another resonant converter for future renewable electrical energy delivery and management (FREEDM) system proposed by [16].

In this method the power transformed from source to load completely depends upon fundamental harmonics of current and voltage involved. In this converter, resonant mode can be changed according to the PV panel operating condition. Fig. 7(c) shows modified two-inductor boost converter proposed by [17]. This converter has advantage of simplicity in circuit, high efficiency, easy transformer flux balance, less number of component.



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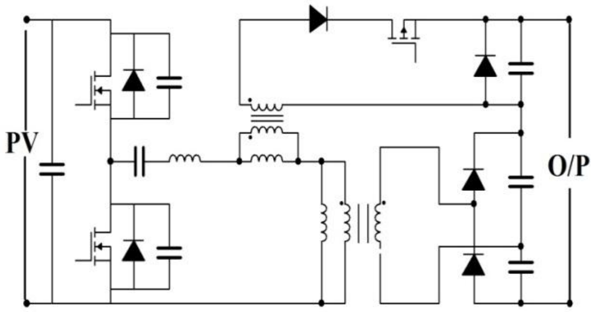

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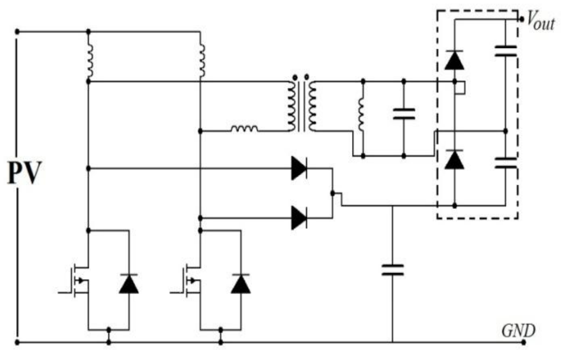

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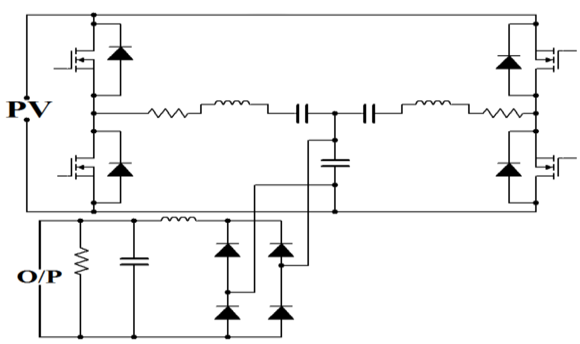

(d)

Fig. 7. Resonant converter (a) Dual series-resonant active clamp converter (b) Resonant converter for PV energy harvest in FREEDM system (c) Resonant two-inductor boost converter (d) Phase controlled series-parallel resonant converter

As the input current is distributed through two boost inductor so its ripple current amplitude halved at twice the PWM frequency. Fig. 7(d) shows phase-controlled series-parallel resonant converter. In this to regulate the output phase control or frequency control are used [18].

Table 1 summarizes important specification of the experimental prototypes of the discussed DC-DC topologies for PV application.

4. MPPT CONTROL

For maximum efficiency of PV system it is necessary that solar energy incident on the PV panels have maximum energy. So it is important to track the maximum power point at some instant of time. There are a lots of algorithm proposed to track the maximum power point some of which are integrated with the inverter. MPP algorithm are prepared in such a manner that Photovoltaic panel can operate at its maximum power point depending on the states of load, PV power generation, PV temperature, solar radiation and vibration [19].

5. TECHNICAL SPECIFICATION OVERVIEW

This section gives a brief comparison of different commercial DC-DC converter used for PV application as well as different types of inverter used for PV system. These converters have high efficiency and also at the same time they are able to control MPPT. Some of features of various DC-DC converts are shown in Table 1.

6. CONCLUSION

In this paper, a technical as well as commercial analysis of different types of DC-DC converter for PV power system has been discussed. It is seen that a combination of resonant with another DC-DC converters provides a high efficiency for wide range of input. Besides this impedance network are used in various ways to achieve voltage boost across the output terminal of DC-DC converter of input terminals of main converters. The switched capacitor technology decreases voltage stress of devices and increase the conversion ratio. Also it is found that the conventional boost converters have some limitations.

Table 1: Commercial DC-DC converters and comparison of parameter and features

Model NO	Company Name	Status	Input Voltage (Min.)	Input Voltage (Max.)	Output Voltage (Min.)	Output Voltage Max.)	Switching Frequency	Operating Temperature	Package
SM72445	Texas Ins.	Active	4.75	5.25	NA	NA	215	NA	28 TSSOP
LTC3150	Linear Technology	Active	0.225	5	1.6	5.25	1.4 MHz	-40 to 85	16-Lead SSOP
AP2200	Asahi Kasei	Active	0.4	1.6	3.96	5.25	500 KHz	-30 to 85	QFN 16-Pin
SPV1020	STMicroelectronics	Active	6.5	40	Min. Input Voltage	40	100 KHz	-40 to 125	NA
TCDC-7001	Tamura	Active	190	1000	24 V +/-2%	NA	130 KHz	-20 to 50	35 mm DIN Rail mounting
MB39C831	Fujitsu Semiconductor	Active	2.6	23	1.457	5.130	NA	-40 to 85	40-pin QFN

There are some challenges while designing DC-DC converters for PV application that are as follows: (1) Reduction of number of electrolyte capacitor and current ripple while maintaining better voltage gain; (b) Decreasing the switching losses by realizing soft switching performance (3) reduction of output diode reverse-recovery losses; etc.

REFERENCES

[1] Moon, S., Yoon, S. G., & Park, J. H. (2015). A New Low-Cost Centralized MPPT Controller System for Multiply Distributed Photovoltaic Power Conditioning Modules. Smart Grid, IEEE Transactions on, 6(6), 2649-2658.

[2] Choi, H., Ciobotaru, M., Jang, M., & Agelidis, V. G. (2015). Performance of Medium-Voltage DC-Bus PV System Architecture Utilizing High-Gain DC–DC Converter. Sustainable Energy, IEEE Transactions on, 6(2), 464-473.

[3] Kadri, R., Gaubert, J. P., & Champenois, G. (2012). Nondissipative string current diverter for solving the cascaded DC–DC converter connection problem in photovoltaic power generation system. Power Electronics, IEEE Transactions on, 27(3), 1249-1258.

[4] Kasper, M., Bortis, D., & Kolar, J. W. (2014). Classification and comparative evaluation of PV panel-integrated DC–DC converter concepts. Power Electronics, IEEE Transactions on, 29(5), 2511-2526.

[5] Dick, C. P., Titiz, F. K., & De Doncker, R. W. (2010, February). A high-efficient LLCC series-parallel resonant converter. In Applied Power Electronics Conference and Exposition (APEC), 2010 Twenty-Fifth Annual IEEE (pp. 696-701). IEEE.

[6] Hu, H., Fang, X., Chen, F., Shen, Z. J., & Batarseh, I. (2013). A modified high-efficiency LLC converter with two transformers for wide input-voltage range applications. Power Electronics, IEEE Transactions on, 28(4), 1946-1960.

[7] Li, Q., & Wolfs, P. (2005, June). A current fed two-inductor boost converter with lossless snubbing for photovoltaic module integrated converter applications. In Power Electronics Specialists Conference, 2005. PESC'05. IEEE 36th (pp. 2111-2117). IEEE.

[8] Huusari, J., & Suntio, T. (2012). Dynamic properties of current-fed quadratic full-bridge buck converter for distributed photovoltaic MPP-tracking systems.Power Electronics, IEEE Transactions on, 27(11), 4681-4689.

[9] Kumar, S. S., Panda, A. K., & Ramesh, T. (2015). A ZVT–ZCT PWM synchronous buck converter with a simple passive auxiliary circuit for reduction of losses and efficiency enhancement. Ain Shams Engineering Journal, 6(2), 491-500.

[10] Bodur, H., & Bakan, A. F. (2004). A New Zvt-Zct-Pwm Dc-Dc Converter.Power Electronics, IEEE Transactions on, 19(3), 676-684.

[11] Cha, G. R., Park, S. H., Won, C. Y., Jung, Y. C., & Song, S. H. (2008, September). High efficiency soft switching boost converter for photovoltaic system. In Power Electronics and Motion Control Conference, 2008. EPE-PEMC 2008. 13th (pp. 383-387). IEEE.

[12] Yu, W., York, B., & Lai, J. S. (2012, September). Inductorless forward-flyback soft-switching converter with dual constant on-time modulation for photovoltaic applications. In Energy Conversion Congress and Exposition (ECCE), 2012 IEEE (pp. 3549-3555). IEEE.

[13] Kim, Y. H., Shin, S. C., Lee, J. H., Jung, Y. C., & Won, C. Y. (2014). Soft-switching current-fed push–pull converter for 250-W AC module applications.Power Electronics, IEEE Transactions on, 29(2), 863-872.

[14] Lee, J. J., Kwon, J. M., Kim, E. H., & Kwon, B. H. (2008). Dual series-resonant active-clamp converter. Industrial Electronics, IEEE Transactions on, 55(2), 699-710.

[15] Ryu, D. K., Kim, Y. H., Kim, J. G., Won, C. Y., & Jung, Y. C. (2011, May). Interleaved active clamp flyback inverter using a synchronous rectifier for a photovoltaic AC module system. In Power Electronics and ECCE Asia (ICPE & ECCE), 2011 IEEE 8th International Conference on (pp. 2631-2636). IEEE.
[16] Liang, Z., Guo, R., Li, J., & Huang, A. Q. (2011). A high-efficiency PV module-integrated DC/DC converter for PV energy harvest in FREEDM systems. Power Electronics, IEEE Transactions on, 26(3), 897-909.
[17] Mapurunga Caracas, J. V., de Carvalho Farias, G., Moreira Teixeira, L. F., & de Souza Ribeiro, L. A. (2014). Implementation of a high-efficiency, high-lifetime, and low-cost converter for an autonomous photovoltaic water pumping system. Industry Applications, IEEE Transactions on, 50(1), 631-641.
[18] Zheng, S., & Czarkowski, D. (2007). Modeling and digital control of a phase-controlled series–parallel resonant converter. Industrial Electronics, IEEE Transactions on, 54(2), 707-715.
[19] Salah, C. B., & Ouali, M. (2011). Comparison of fuzzy logic and neural network in maximum power point tracker for PV systems. Electric Power Systems Research, 81(1), 43-50.

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