Solar Optimizer –A New Hybrid Approach to the Power Electronics of Photovoltaic Modules

DR.GADDAM SRIDHAR[1]MOHAMMED GHOUSE[2]G.LAXMI PRASANNA [3]

P.SURYA[4]D.SAICHARAN[5]

[1]Professor, Department of EEE, Jyothishmathi institute of technology and science,Nustulapur, Karimnagar, TS, India
[2,3,4,5]Ug scholar, Department of EEE, Jyothishmathi institute of technology and science, Ramakrishna colony Nustulapur, Karimnagar, TS, India

Abstract:***In this paper, a new family of PV module level power electronics devices called Optimizers is introduced. For the Optimizer to work well, it must be able to track the PV power optimizer's ultra wide maximum power point tracking (MPPT) voltage window with the direct AC connectivity and inherent safety of PV microinverters. For example, the Optimizer's shade-tolerant MPPT algorithm and advanced multimode control with variable DC-link allow efficient energy collection from the PV module under various shading conditions. Prototypes of the PV Optimizer and industrial microinverters were tested in a variety of operating situations, including an extreme instance in which two out of three substrings of the PV module were completely covered by opaque shade.***

Keywords: Power electronics, microinverter, power optimizer, maximum power point tracking, partial shading, and efficiency are some of the features of photovoltaic systems.

I.INTRODUCTION

PV module level power electronics (MLPE) has gained increased attention from PV system operators and installers over the past decade because it allows each PV module to operate at its maximum power point, thus providing the best potential energy yield [1]. PV MLPE systems can be divided into two types based on the amount of power they process: partial-power conversion systems and full-power conversion systems. The latter has the advantage of greater adaptability and performance across a wider range of PV installation operating conditions [2]. PV power optimizers (PVPOs) and microinverters make up the bulk of today's full-power MLPE systems (PVMICs). Typically, PV modules are linked in series using the PVPO as an add-on component (Fig. 1a). Installed in the PV module's junction box, a PVPO is intended to improve module power output before sending an optimal DC voltage to the array's string inverter. [3] PVPOs are typically non-isolated DC/DC converters that continually adjust the current drawn from a PV module to maintain string voltage regardless of string characteristics and operating circumstances [3] of the PV modules. PVPOs have an essential advantage in that they may be used with a wide range of PV modules, including high-power 72- and 96-cell modules and thin-film PV panels, because of their wide input voltage range. Series string installations with a PVPO, despite their simplicity, have various design limits, such as the string length requirement of six to eight PV modules and the inability to oversize the PVPO. PVPOs often have efficiencies of over 98% and good dependability because of their tiny component count [4].

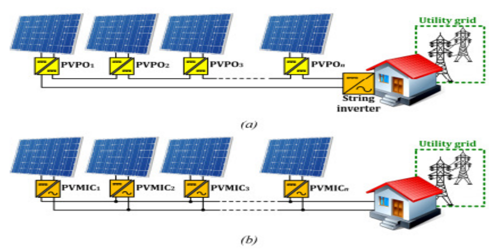


Fig. 1. Generalized schematics of MLPE based grid-connected PV systems: with(a) PVPOs and (b)with PVMICs

It's also possible that the string inverter that feeds PV electricity to the AC grid could become an "elbow" because of the single-point-of-failure concern. Additionally, arcing on the high-voltage DC wires between PV modules and the string inverter, which is normally placed in the climate-controlled room, could pose a risk of fire. So additional safety measures are needed, such as arc detection and rapid safety disconnection of the solar power plant. Aside from maximising energy harvest from solar modules, the PVMIC also converts module output voltage to a grid-compliant, AC-voltage-compliant voltage. The PVMICs are connected in parallel to the grid, therefore the necessity for a minimum number of PV modules is no longer a constraint. Adding or deleting PV modules and their associated PVMICs allows the PV installation to be flexibly scaled up or down. As a result of its multi-stage power conversion, the PVMIC has a substantially higher component count, which lowers its cost per watt and may have an adverse effect on the efficiency of the power conversion. As a result of the PVMIC's greater component count and higher operating temperatures (which can surpass 60 °C), the system's long-term dependability may suffer [5]. PVMICs suffer from a limited maximum power point tracking (MPPT) voltage range as a result of the need to balance price, efficiency, and reliability. The Optimizer (PVOPT) is a novel class of PV MPLE systems that is introduced in this research. For the most part, this is a hybrid technology, as the PVPOs have a very wide MPPT voltage range and the PVMICs have direct AC connectivity and inherent safety. MLPE systems must also have characteristics like PV module level monitoring and safety cut-offs, flexibility in installation, and PV power system size. An initial comparison of existing technologies is made before PVOPT's suggested technology is explained in detail. This is followed by an examination of the PVOPT's advanced feature known as Shade-Tolerant MPPT's hardware and control system architectures (ST-MPPT). A 300 W PVOPT was built to demonstrate the concept.

II.LITERATURE SURVEY

[1] S. Kouro, J. I. Leon, D. Vinnikov and L. G. Franquelo, "Grid-Connected Photovoltaic Systems: An Overview of Recent Research and Emerging PV Converter Technology," IEEE Ind. Electron. Mag., vol. 9, no. 1, pp. 47-61, March 2015.

With photovoltaic (PV) energy's growth exceeding one-third of the cumulative installed wind energy capacity in the last five years, it is swiftly becoming a significant part of the energy mix in various regions and power networks. The decrease in the price of PV modules has been a major factor in this development. As a result of this development, traditional single-phase grid-tied inverters have evolved into more complicated topologies, allowing for greater efficiency, extraction of power from the modules, and dependability without increasing the price. System configurations of several solar plants, as well as the PV converter topologies that have found practical use in grid-connected systems, are discussed in this article. Among other things, new PV converter technology and recent research are addressed, stressing their potential advantages over current technology.

[2] M. Kasper, D. Bortis and J. W. Kolar, "Classification and Comparative Evaluation of PV Panel-Integrated DC–DC Converter Concepts," IEEE Trans. Power Electronics, vol. 29, no. 5, pp. 2511-2526, May 2014.

When there is a mismatch between the panels, as can be the case with partial shadowing, the solar strings have a drastically reduced power output. For panels with mismatch, either panel-integrated diodes bypass the shady ones when the string is run at its unshaded panels' current level, or shady panels lose some of their power when the string current is lowered to that of the shady ones. The greatest amount of power available from each panel may be retrieved regardless of mismatches thanks to the use of dc-dc converters at the panel level. An evaluation is made of the suitability for panel integration of various concepts of panel-integrated dc-dc converters in this research. An efficiency/power density Pareto optimization of the buck-boost converter architecture is demonstrated as the most promising notion. In response to the optimization results, two 275 W converter prototypes are constructed for an input voltage range of 15 to 45 V and an output voltage range of 10 to 100 V using silicon MOSFETs with a switching frequency of either 100 kHz or 400 kHz. It is possible to compare the theoretical considerations with the efficiency measurements of a commercial panel-integrated converter.

[3] J.K. Kaldellis, et al "Temperature and wind speed impact on the efficiency of PV installations. Experience obtained from outdoor measurements in Greece," Renewable Energy, vol. 66, pp. 612-624, June 2014.

According to established test settings, the efficiency of photovoltaic (PV) modules may be accurately predicted by their performance in real-world conditions, such as in the field. In addition to solar energy, the temperature of the PV modules affects the conversion process. For example, module temperatures are affected by weather conditions and PV panel properties. Accordingly, this study investigates how temperature change affects commercial PV applications based on in-situ observations in varied weather conditions, taking into account the theoretical basis in the area so far. Solar power systems in South Greece, including an unventilated (81 kWp) building-integrated system and an open rack mounted (150 kWp) system, were studied for one year. Back surface temperature sensors were used to record module and ambient temperatures, and real wind speed measurements were taken to identify the primary effect of local wind speed on the PVs' thermal loss mechanisms. As a result of this study, the temperature coefficient of efficiency (or power) has been determined to be negative, with absolute values between 0.30% and 0.45% for free-standing ventilated frames.

[4] E. Liivik, A. Chub, R. Kosenko and D. Vinnikov, "Low-cost photovoltaic microinverter with ultra-wide MPPT voltage range," in Proc. 6th Int. Conf. on Clean Elect. Power, Santa Margherita Ligure, Italy, 2017, pp. 46-52.

In this research, a new low-cost PV microinverter with an extremely wide MPPT voltage range is presented. Using a two-stage energy conversion, a DC-DC boost half-bridge converter is used to step up the variable PV voltage to a stabilised high DC voltage, which is then changed to a grid-compliant AC voltage by the grid-tied inverter. The steady-state analysis aids in the explanation of the microinverter's functioning principle. A 250 W experimental prototype of a solar microinverter was built and tested to verify theoretical assumptions and evaluate the proposed concept's performance. Finally, a 60-cell Si PV module partially shaded is used to show the system's shade-tolerant operation.

III. PHOTOVOLTAIC OPTIMIZER

A novel type of photovoltaic MLPE systems dubbed Optimizer (PVOPT) is developed to cover the gap between the PVPO and the PVMIC. With the PVOPT, you have the ultra-wide MPPT voltage range and shade-tolerant performance of PVPOs with the direct AC connectivity and intrinsic safety of the PVMICs. To sum it up, an inverter with a grid-tied full-bridge configuration and multi-mode management is integrated into the Optimizer's front-end buck-boost DC-DC converter with a high-efficiency pass-through mode. The PVOPT's MPPT voltage window is more than four times broader than that of the standard PVMIC, thanks to its superior multimode control. Under addition, the PVOPT's minimum start-up voltage was lowered to 8 V, ensuring the energy collection from the majority of 60- and 72-cell PV modules in various shading conditions, including extreme opaque shading of two out of three PV module substrings.

Design of Power Conversion Stage

Figure 2 depicts a generalised power circuit diagram for the proposed PVOPT. The PVOPT was built using a double-stage technique in order to achieve an ultra-wide MPPT voltage window and the ability to track global maximums. There is little doubt that the front end quasi-Z-source series resonant DC-DC converter (qZSSRC) is a better option for MLPE applications. MPPT and voltage matching between the PV module and high-voltage DC-link are handled by it in this situation. There are a broad variety of high-performance DC-DC converter topologies that can be used for the front-end of the system, such as the boost half-bridge DC-DC converter [4] or the PWM boost converter [15]. The qZSSRC, on the other hand, has an exceptional input voltage regulation capacity and DC voltage gain range from 6.7 to 50 [16]. The PVOPT's design is primarily based on the trade-off between cost and performance, so the integrity and hybridization of functions of the primary components have received special attention. As an example, the transformer TX in the qZSSRC supports the resonance and ensures the soft switching of the semiconductors by providing the appropriate voltage step-up and galvanic isolation. qZSSRC is able to achieve high efficiency through the full-ZCS of the VDR diodes and, depending on the operating mode, ZVS and/or ZCS of the primary-side MOSFETs [17] by using the leakage inductance Llk of the transformer TX and the capacitors C1 and C2 of the voltage doubler rectifier (VDR) and proper dimensioning of the magnetising inductance and dead time in series [18]. The grid-tied inverter is based on a simple full-bridge topology using a combination of Si and SiC MOSFETs for the low-frequency (S5, S6) and high-frequency (S7, S8) legs, respectively, to simplify the design. The LCL filter was used at the output of the PVOPT to reduce switching noise and produce a sinusoidal waveform. Figure 6 depicts the 300 W PVOPT from a top-down perspective, while Table II lists the device's general parameters. In order to keep production costs as low as possible, one of the primary goals of this project was to make use of generic components. Everything, including the linked inductor LqZS and hybrid isolation transformer TX, was wound on the RM14 ferrite cores for the sake of unification. In order to prevent hotspots on the PCB due to the PVOPT's sole reliance on natural convection cooling, specially designed thermal pads and vias were incorporated into the board.

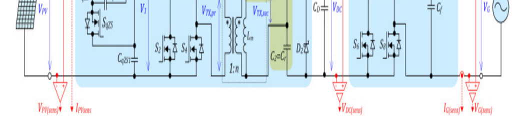
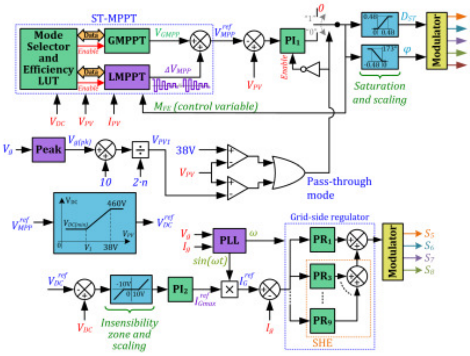


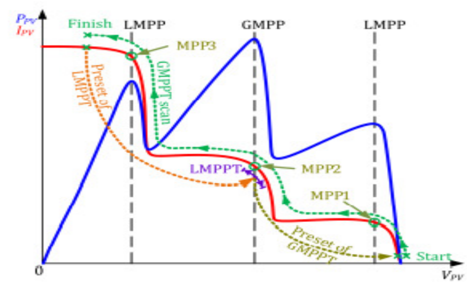
Fig. 2. The photovoltaic Optimizer's general power circuit diagram (PVOPT)

IV. MAXIMUM POWER POINT TRACKING WITH TOLERANT SHADE (ST-MPPT)

The control system of the PVOPT (Fig. 3a) contains two main proportional integral (PI) controllers: one for the qZSSRC (PI1) and the other for the grid-tied inverter (PI2). Positive output of PI1 activates the boost mode, the negative output is used for the buck mode. The grid current tracking is based on the proportional resonant (PR) controller and selective harmonic elimination (SHE) block comprising several PR controllers. The controller PR1 is used to force the grid current IG to follow the reference current (IGref). The SHE is a part of the grid-side regulator that eliminates the odd harmonics, while a single PR controller is required for each harmonic. In the given case, controllers PR3, PR5, PR7 and PR9 are used to eliminate 3rd, 5th, 7th and 9th harmonics, correspondingly. The PI controller PI2 defines the amplitude of the reference grid current (IGref), as shown in Fig. 3a. During the PTM in the qZSSRC, MPPT is performed by the controller PI2, while in the other two modes, both of the PI controllers are used for that. A. Description of the ST-MPPT Algorithm The PVOPT is superior to the PVMICs in partial shading and opaque shading conditions due to the implementation of the shade tolerant MPPT (ST-MPPT). From Fig. 14b it could be appreciated that the ST-MPPT consists of global MPPT (GMPPT) and local MPPT (LMPPT). This sketch preserves the essence of 60- and 72-cell Si PV modules that have three sub-strings and consequently, three integrated bypass diodes. The GMPPT is based on the P-V curve scanning those results in the identification of the MPPs: local (LMPPs) and the global one (GMPP). Next, the control system presents the control variables to obtain the operating point near the GMPP and activates the LMPPT that performs the perturbation of the operating point with variables steps to maximize the MPPT efficiency ηMPPT. The workflow of the ST-MPPT is presented in Fig. 4. The ST-MPPT defines the reference PV module voltage, while the control system from Fig. 3a ensures that the PVOPT is reaching this point.



(a)



(b)

Fig. 3 The PVOPT system (a) ST-MPPT control (b) implementation

The GMPPT rescanning is performed if the PV power changes by more than 10%, which is evidence of changed operating conditions, or elapse of 30 minutes. It starts from the preset of the qZSSRC. The preset ends when either maximum input voltage or maximum voltage step-down ratio of the qZSSRC is achieved. Then, the reference voltage of the PV module is gradually decreased until it reaches the minimum allowed value. The data stored during the GMPPT are postprocessed by the application of the PVOPT efficiency taken from the pre-defined look-up table. This enables PVOPT operation in MPP with higher voltage and higher output power when there are two MPPs of close power at two different voltages. Operation at higher voltage, i.e., higher efficiency, would result in fewer thermal cycles corrupting the reliability.

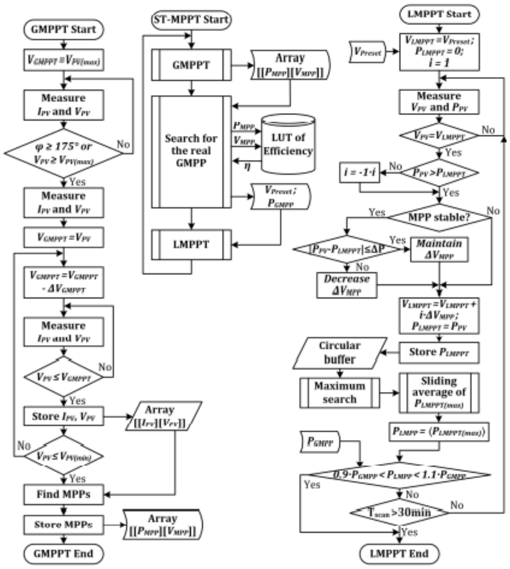


Fig. 4. The ST-MPPT routine's workflow

V.SIMULATION RESULTS

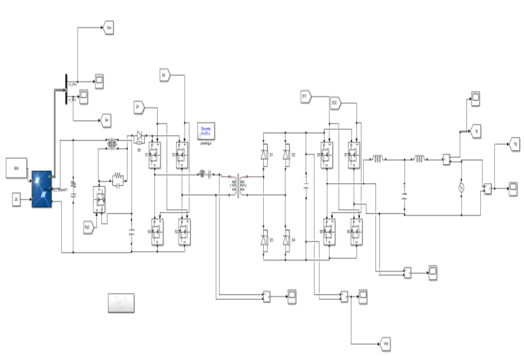


Fig.5 MATLAB/SIMULINK circuit of the proposed system

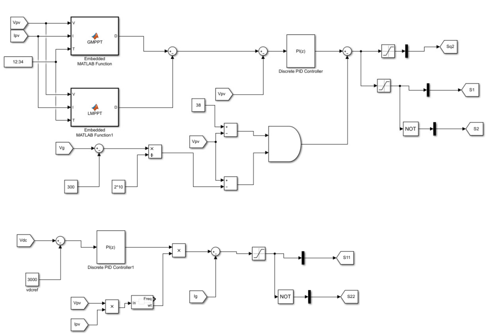


Fig.6 Controller subsystem

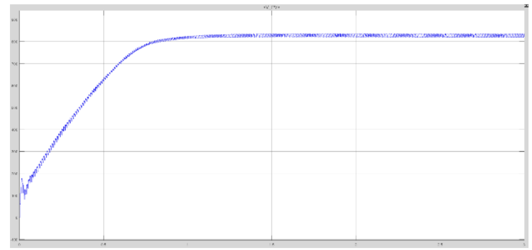


Fig. 7 Vpv

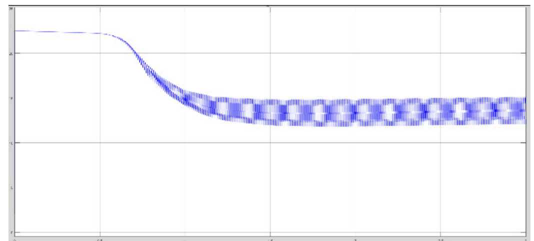


Fig.8 Ipv

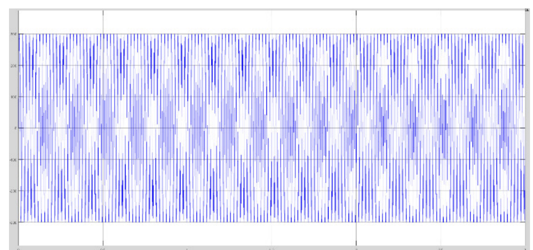


Fig.9 Vg

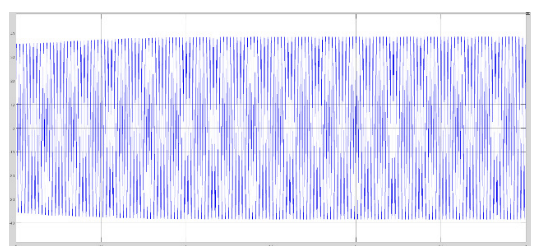


Fig.10 Ig

CONCLUSION

An ultra-broad input voltage range was offered and justified as a shade tolerant solution for residential and small business PV systems, which is compatible with a wide variety of current residential PV modules. It outperforms conventional microinverters under partial shading due to the implementation of the shade tolerant MPPT, and can deliver power under severe opaque shading conditions, when the microinverters fail to capture any power due to their limited input voltage regulation range in these conditions. In addition, the higher power rating allows it to be used with new high-power PV modules, thus power clipping is avoided. Galvanically isolated ultra-wide range buck-boost DC-DC converter and unique control method with changing DC-link voltage increases efficiency in the most probable input voltage working range are responsible for these features. P-V curve scanning enables shade-tolerance MPPT. Because of this, the PV Optimizer can be utilised for both household and small-scale commercial PV systems. The installation and shipping costs, as well as staff training, are all reduced when several PV modules are stored in a single stock keeping unit. Other DC-DC converter topologies with equivalent performance could be used instead of the qZSSRC one in the Optimizer. Additionally, optimizers with a large input voltage range may have efficiency issues. Cycle skipping modulation and high DC voltage gain reconfigurable rectifiers can both increase performance under light loads.

REFERENCES

[1] S. Kouro, J. I. Leon, D. Vinnikov and L. G. Franquelo, "Grid-Connected Photovoltaic Systems: An Overview of Recent Research and Emerging PV Converter Technology," IEEE Ind. Electron. Mag., vol. 9, no. 1, pp. 47-61, March 2015.

[2] M. Kasper, D. Bortis and J. W. Kolar, "Classification and Comparative Evaluation of PV Panel-Integrated DC–DC Converter Concepts," IEEE Trans. Power Electronics, vol. 29, no. 5, pp. 2511-2526, May 2014.

[3] “SolarEdge Fixed String Voltage, Concept of Operation.” [Online]. Available: https://www.solaredge.com [Accessed: 28-Jan-2018]

[4] E. Liivik, A. Chub, R. Kosenko and D. Vinnikov, "Low-cost photovoltaic microinverter with ultra-wide MPPT voltage range," in Proc. 6th Int. Conf. on Clean Elect. Power, Santa Margherita Ligure, Italy, 2017, pp. 46-52.

[5] J.K. Kaldellis, et al "Temperature and wind speed impact on the efficiency of PV installations. Experience obtained from outdoor measurements in Greece," Renewable Energy, vol. 66, pp. 612-624, June 2014

[6] L. Linares, R. Erickson, S. MacAlpine and M. Brandemuehl, "Improved Energy Capture in Series String Photovoltaics via Smart Distributed Power Electronics," Proc. APEC’2009, Washington, 2009, pp. 904-910.

[7] M. Fornage, “Method and apparatus for converting direct current to alternating current,” U.S. Patent 7 796 412 B2, September 14, 2010.

[8] H. Hu, S. Harb, N. Kutkut, I. Batarseh and Z. J. Shen, "A Review of Power Decoupling Techniques for Microinverters With Three Different Decoupling Capacitor Locations in PV Systems," IEEE Trans. Power Electron., vol. 28, no. 6, pp. 2711-2726, June 2013.

[9] S. B. Kjaer, J. K. Pedersen and F. Blaabjerg, "A review of single-phase grid-connected inverters for photovoltaic modules," IEEE Trans. Ind. Appl., vol. 41, no. 5, pp. 1292-1306, Sept.-Oct. 2005.

[10] P. Garrity, "Solar photovoltaic power conditioning unit," U.S. Patent 8 391 031 B2, March 05, 2013.

[11] “SolarEdge P300/P370/P404/P405/P500/P505 Power Optimizer.” [Online]. Available: http://www.solaredge.com [Accessed: 28-Jan2018].

[12] “Enphase M250 Microinverter Datasheet.” [Online]. Available: https://enphase.com [Accessed: 28-Jan-2018].

[13] “Enecsys 240-60-MP Microinverter Datasheet.” [Online]. Available: http://manualzz.com [Accessed: 28-Jan-2018].

[14] D. Vinnikov, A. Chub, E. Liivik and I. Roasto, "High-Performance Quasi-Z-Source Series Resonant DC–DC Converter for Photovoltaic Module-Level Power Electronics Applications," IEEE Trans. Power Electron., vol. 32, no. 5, pp. 3634-3650, May 2017.

[15] T. LaBella, W. Yu, J. S. Lai, M. Senesky and D. Anderson, "A Bidirectional-Switch-Based Wide-Input Range High-Efficiency Isolated Resonant Converter for Photovoltaic Applications," IEEE Trans. Power Electron., vol. 29, no. 7, pp. 3473-3484, July 2014.

[16] D. Vinnikov, A. Chub, E. Liivik, F. Blaabjerg and S. Kouro, "Maximizing Energy Harvest of the Impedance Source PV Microconverter under Partial Shading Conditions," in Proc. CPEPOWERENG’2018, Doha, Qatar, 10-12 April 2018, 7 pp.

[17] D. Vinnikov, A. Chub, I. Roasto and L. Liivik, "Multi-mode quasi-Zsource series resonant DC/DC converter for wide input voltage range applications," in Proc. APEC’2016, Long Beach, 2016, pp. 2533-2539.

[18] F. C. Schwarz, "A Method of Resonant Current Pulse Modulation for Power Converters," IEEE Trans. Ind. Electron. and Control Instrum., vol. IECI-17, no. 3, pp. 209-221, May 1970.

[19] J. E. Huber, J. Miniböck and J. W. Kolar, "Generic Derivation of Dynamic Model for Half-Cycle DCM Series Resonant Converters," IEEE Trans. Power Electron., vol. 33, no. 1, pp. 4-7, Jan. 2018.

[20] J. Park, M. Kim, S. Choi, "Zero-current switching series loaded resonant converter insensitive to resonant component tolerance for battery charger," IET Power Electron., vol. 7, no. 10, pp. 2517-2524, 2014.

[21] J. P. Vandelac and P. D. Ziogas, "A DC to DC PWM series resonant converter operated at resonant frequency," IEEE Trans. Ind. Electron., vol. 35, no. 3, pp. 451-460, Aug 1988.

[22] D. Vinnikov, T. Jalakas, I. Roasto, H. Agabus, and K. Tammet, “Method of shoot-through generation for modified sine wave Z-source, quasi-Z source and trans-Z-Source Inverters,” U.S. patent 9 214 876 B2, 2015.

[23] I. Roasto, D. Vinnikov, J. Zakis, O. Husev, "New Shoot-Through Control Methods for qZSI-Based DC/DC Converters", IEEE Trans. Ind. Informat., vol. 9, pp. 640-647, 2013, ISSN 1551-3203.

[24] D. Vinnikov, I. Roasto, L. Liivik, and A. Blinov, “Four novel PWM shoot-through control methods for impedance source DC-DC converters,” J. Power Electron., vol. 15, no. 2, pp. 299–308, 2015.

[25] I. Roasto, D. Vinnikov, T. Jalakas, J. Zakis and S. Ott, "Experimental study of shoot-through control methods for qZSI-based DC/DC converters," Proc. SPEEDAM 2010, Pisa, 2010, pp. 29-34.