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A Comprehensive Review on Single Phase Grid Connected PV System

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A B S T R A C T

The inverter technologies used to connect photovoltaic (PV) modules to a single-phase grid are the main topic of this review.The Maximum Power Point Tracking (MPPT) algorithm and a new single phase grid linked cascaded multilevel inverter with the fewest possible switches for PV-based power conversion systems is the main area of concern.This inverter uses the fewest possible switching elements to produce a greater variety of voltage levels.The quantity of gate driving circuits is decreased, which results in a reduction in the size and power usage of the driving circuits. The output waveform's THD is decreased. The control of single-phase grid interactive inverters with nonlinear loads is also discussed in this study. Both stand-alone and grid-connected modes of operation should be possible for the utility-connected inverter.Photovoltaic (PV) inverters, which can run in the low voltage ride through mode with reactive current injection, in the non-unity power factor, or with maximum power point tracking on overcast days. The study is done on single-phase PV systems, and the mechanism of the harmonic current injection from grid-connected single-phase inverter systems is thus examined in this work. The investigation is particularly concerned with how the feed-in grid current quality from single-phase inverters is affected by the power factor and feed-in grid current level. All these things we discuss in this review paper.

Keywords:Single-Phase Grid-Connected Inverters,Fifteen-level grid-connected inverter,Inverters with Nonlinear Loads, Current control, Harmonics control, Resonant Control.

1. Introduction

Due to rising energy demand, the depletion of fossil fuels, and their environmental effects, non-conventional energy sources have recently gained popularity as sources of energy. Photovoltaic (PV) solar energy stands out as a very intriguing choice among the clean and green power source. Solar energy is directly converted into electricity by a PV system, through inverters. Power produced by PV sources can be transmitted to the electrical single-phase grid typically, low-power applications with requirements under 10 kW inverters. In these applications, full-bridge three-level inverter topologies are frequently used.

1.1. Modelling and simulation of a PV system

Modelling and simulation of a PV system that is connected to the grid is based on the assessment of key PV module parameters. These kinds of applications rise in the number of PV systems installed globally and created a need for supervision and control algorithms [1-3] as well as design and simulation tools. Among the several methods for designing and simulating PV systems that are now in use [4,5] and PV system [6,7] are the most widely used commercial programmers for this purpose.More in-depth simulation is required to a deep understanding of the PV system design and behaviour under various working situations.

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1.2. Analysis of inverter topologies and control methods for grid-connected solar systems.

A thorough analysis of inverter topologies and control methods for grid-connected solar systems plays an important role in system design. The inclusion of a line frequency transformer (running at a low frequency) in a single stage inverter adds a significant contribute to the 2% peak efficiency losses as well as add weight to the inverter [8]. The most effective converter designs are those who are high-frequency transformer both economical and lightweight. The line frequency transformers are being replaced more frequently now [9–22] presents a number of inverter topologies, including the buck-boost and boost converter designs with certain advantages and disadvantages. The MPPT voltage amplification and DC to AC conversion[9–22] consist of a single stage. In these topologies, the energy storage component is either an inductor or an extremely high-frequency transformer.

1.3. Single-Phase Grid-Connected Inverter Current Harmonics.

The European Photovoltaic Industry Association (EPIA) reported that the global capacity of solar energy for the first time exceeded 100 GW 2012 [23], and it is now approaching 180 GW in 2014 [24]. More photovoltaic (PV) systems will likely be installed in the future due to the pressing need for clean energy [25]. The availability and power quality are both impacted by the grid's rapidly expanding PV integration. [26– 29] the PV system's emerging reliability as a whole, given its significant intermittency. Consequently, particular grid demands and specifications (such as IEEE Std 1547-2003 [30] and It is anticipated that (IEC Standard 61727 [31]) will be enhanced to better control grid-connected PV systems, particularly in terms of power quality and ancillary services [32].

Future single-phase grid-connected PV systems will be more active in various operating modes, have the capacity to provide Low Voltage Ride-Through (LVRT) in the event of a grid fault, and have functionality for reactive power adjustment [32–35]. In that situation, this operational mode may cause the power quality to deteriorate with a chance of creating resonances across the board. In order to preserve the power quality both during normal operation and at Maximum Power Point, the control system should be improved. To satisfy current or prospective grid regulations or needs [34–39], tracking (MPPT) and in other ancillary service modes (for example, non-unity power factor) are used. One crucial measure of power quality for grid-connected inverter systems, including PV systems, is the current distortion level [40, 41]. For example, it is specified in both the IEEE Std 1547-2003 and the IEC Standard 61727 that the Total Harmonic Distortion (THD) for the grid current should be lower than 5% to prevent negative effects on other equipment that is linked to the grid [31], [32], [42], [43].

Additionally, the limitation is 4% for each odd harmonic from the third to the ninth while also limiting the even harmonics to 25% of the limits of odd harmonics [31]. These clauses in the grid requirements need to be re-examined in order to guarantee a satisfactory current distortion level for grid-connected inverter systems in various operation modes, at the very least in the normal operation [33], [44], [45]. A virtual orthogonal system should be developed for single phase inverter systems, such as PV inverters, where a Proportional-Resonant (PR) controller [37], [46] is widely used. This can in fact be changed into a PI controller [47].

However, the PR controller can provide several advantages, such as much less computational burden and complexity due to its lack of Park transformations and simple to implement. Thus, the PR controller becomes a popular current regulator for grid connected single-phase systems [36–38], [46], [48–54]. It is well known that odd harmonics (e.g., the 3rd, 5th and 7th) are dominant in the spectrum of the output current of single-phase grid-connected inverters. In order to eliminate the current harmonic distortion effectively, Multi-Resonant Controllers (MRC) are plugged into the PR controller [48]. However, such a control scheme will increase the computational burden, particularly when high-order harmonics (e.g., 11th and 13th) are required to be compensated. This might also trigger the system resonances, if the phase lead compensators are improperly designed. In contrast, a Repetitive Current (RC) controller with a simple phase compensator can track or reject all harmonics below the Nyquist frequency [55–59], but it presents a much slower dynamic response than what a PR controller or a resonant controller does [60–63].

In order to suit power system specifications, high-performance control strategies should achieve a minimum steady-state error while maintaining a fast transient response, and also being feasible in practical implementations. To tackle these issues, a hybrid controller by combining the PR, the RC, and the MRC controllers is developed for a single-phase cascaded multi-level converter [64, 65]; a general parallel structure RC scheme is also introduced to multi-phase converters [63]. However, there is a still a gap to fill in on how to ensure single-phase grid-connected inverters (e.g., PV systems) to produce high quality currents in different operation modes. The root causes of harmonics from single-phase grid-connected inverter systems remain of high interest.

1.4. The integration of photovoltaic (PV) systems into the electrical grid

The integration of photovoltaic (PV) systems into the electrical grid has significantly increased as a result of technological advancements that have reduced the cost of power electronics devices and several incentive schemes launched by governments [66]. The most crucial goals for grid-connected PV systems are cost reduction and increased PV panel and converter efficiency and dependability [67, 68]. Utility-scale high-power PV systems appear to work best with single-stage three-phase dc-to-ac power converter systems to achieve these [69]. These megawatt-sized PV systems' constant interconnection with the distribution network necessitates research into the effects of PV systems on the distribution network and controller performance in both steady-state and dynamic situations.

2. Inverter Topology

2.1. Technological development in PV inverters

• **Centralized structure:** Past developments were focusing on a centralized concept, as shown in Fig. 1(a). In such structure a large number of solar modules are connected to the grid by an inverter.

• **Single-string structure and AC modules**: According to Fig. 1, the current technology consists of string inverters and an AC module (b). A single string of PV modules is incorporated into the inverter in a string inverter, whereas an AC module consists of a single module and an inverter as a single electric device.

• **AC cells, modules, and multi-string structures:** These constructions, as depicted in Figs. 1(c) and (d), combine old and new technologies. A single DC-DC converter is connected to several strings. Large PV cell integrated into a DC-AC inverter (AC module), or DC-AC inverter (multi-string). Unlike earlier technology, each string can be controlled separately. Compared to present technologies, there is an inherent flexibility to incorporate upcoming advancements into established systems.

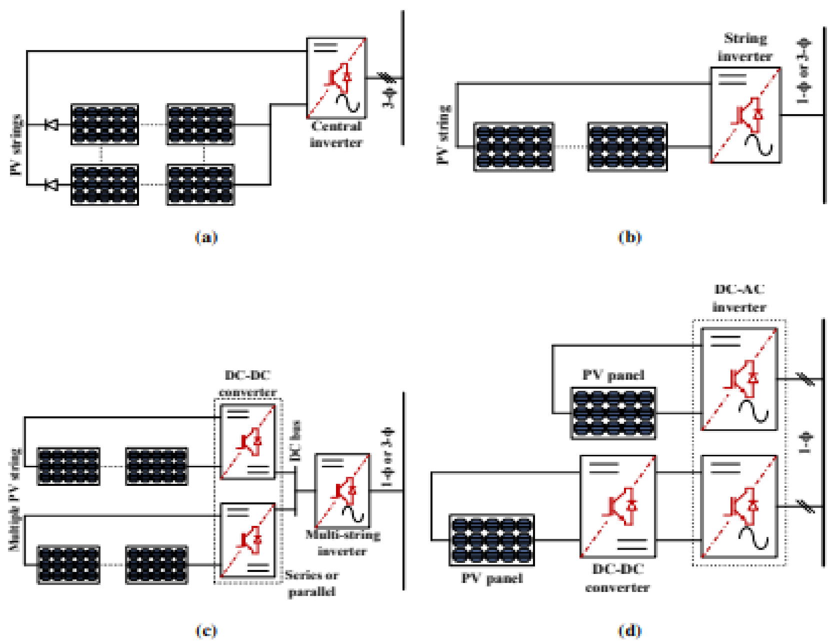

Fig. 1 – PV power system classification(a) Past centralized technology (b) Present string technology (c)Present and future multi-string technology (d)Present and future AC module and AC cell technology.

2.2. Divisions of inverter topology

The following criteria are used to group the different grid interface inverter topologies for PV systems:

- **Conversion topology for power**: Fig. 2(a) shows the topology of a single-stage inverter. Maximum Power Point Tracking (MPPT), inverter current, voltage boost, etc. are all controlled by the inverter. It is imperative that the inverter used for this single-stage conversion be built to withstand peak power that is twice the normal power. In Fig. 2, a two-stage topology is shown (b) the DC-AC converter controls the inverter current while the MPPT is produced by the DC-DC converter. In Fig. 2(c), which is part of multi-string technology, DC optimizers are DC-DC buck-boost converters that can interact with one another, equalize each panel output current in a series string, offer MPPT, and are coupled to a common DC-link. A DC-AC is used for grid interface.
- **The use of transformers and transformer less systems**:When PV voltage is low, the transformer can be used in two distinct ways. The first method involves using a high-frequency DC-DC converter (also known as a DC-DC converter that is isolated, as seen in Fig. 3(a). Another option is to use a line frequency transformer at the inverter output, as shown in Fig. 3(b). Using a line frequency transformer increases system size and weight, prevents DC current injection, and lowers efficiency. High frequency (HF) transformer utilization results in smaller, lighter, more modular, and more efficient devices, but it does not stop DC current injection. Consequently, the transformer is considered an additional element when the PV voltage is high enough.
- **A power conditioner:** The PCU, also known as an inverter or converter, serves as the connection point between PV systems and the grid. Suitable for PV systems is the grid interface or converter technology.

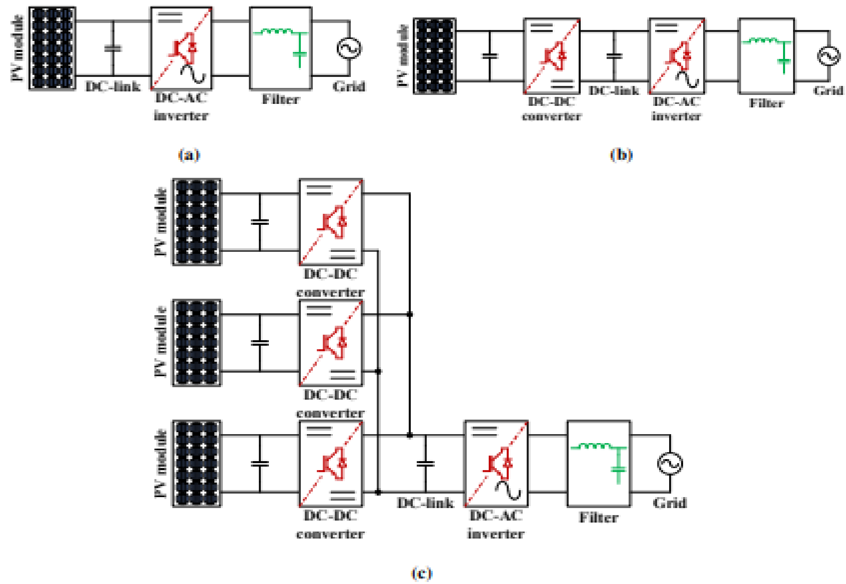

Fig. 2 – Grid interface topologies.(a) Single-stage power processing (b)two-stage power processing(c)Two-stage power processing with common DC-link.

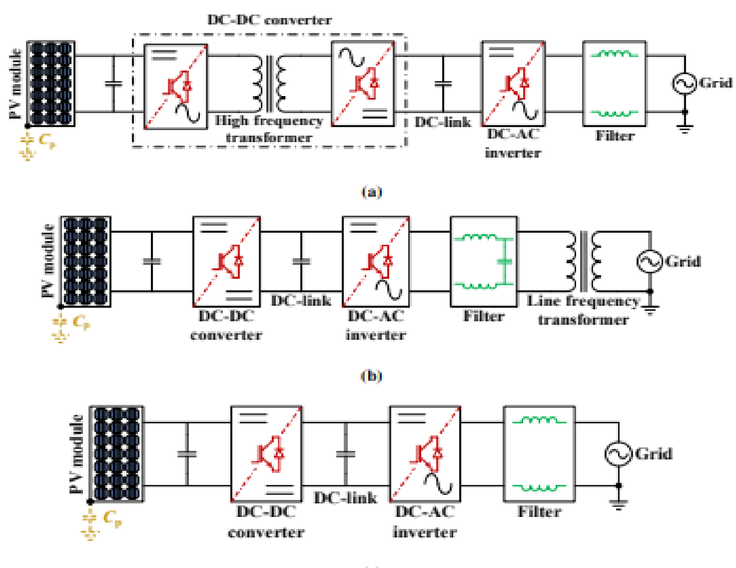

Fig. 3 – Grid-tied PV system.(a) With HF transformer(b)With line frequency transformer (c)Wit transformer configuration.

3. Photovoltaic Module Single-Phase Grid-Connected Inverters

3.1. Multi-String Inverters

The average or rms currents and peak voltages that semiconductors must be able to withstand are used to determine their ratings, together with a de-rating factor of 0.23 (consisting of a 0.75 and a 0.23).For instance, the PV side transistors in the inverterof Fig. 4 must tolerate 90 V peak and 7.6-A rms, thus their VA ratings are computed as 3.0 kVA apiece. This is because they must also withstand a 0.30 de-rate factor for the rms value of the current and a 0.10 de-rate factor for the peak voltage. Based on the geometrical core constant technique in [24] for the transformers.

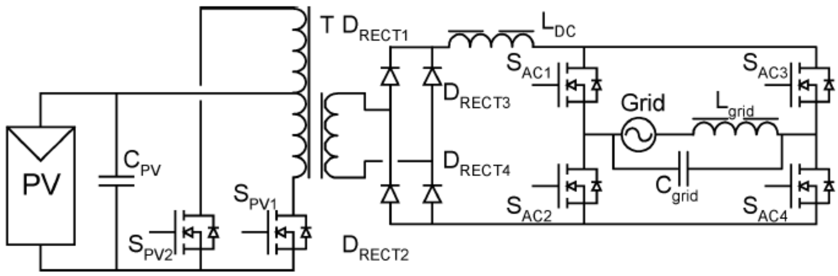

Fig. 4 –Soladin 120 commercial inverter

$$K_{g,\mathrm{Fe}} = \frac{\rho \cdot \lambda^2 \cdot I_{\mathrm{tot}}^2 \cdot (K_{\mathrm{Fe}} \cdot f_{\mathrm{sw}}^{\alpha})^{\left(\frac{2}{\beta}\right)}}{4 \cdot K_U \cdot P_{\mathrm{tot}}^{\left(\frac{(\beta+2)}{\beta}\right)}} \cdot 10^8 \ \mathrm{cm}^x$$

Where,

ρ= winding resistivity,
λ= Primary Turns (Volt-Sec),
I_{tot} = Total winding current,
F_{sw}=Switching frequency,
K_U =Copper fill factor,
P_{tot} =Total power loss in transformer,
K_{fe} = Coefficient of core losses,
α =Coefficient of Peak flux density,
β=Coefficient of frequency.

3.2. AC Module Inverters:

For the VSI, a tiny electrolytic capacitor can be used. When studying the European efficiency, just two circuits—the inverters in Fig.4 Shows high current flows in the circuit at the same time as high voltage ratings for the semiconductors on the PV side are the cause. Compared to the other inverters, the push-pull inverter in Figure 4 is more efficient. This is mostly because the PV-side converter, which uses just two transistors to transport current, has a low conduction loss. The push-pull inverter in Fig. 4 would be a better option if one were to choose an inverter architecture based on this comparison because it delivers high efficiency and is reasonably inexpensive, but care should be taken because the decoupling capacitor is the weakest link.

4. Conclusion

The above discussion includes some of the requirements for inverters used in PV and grid applications, including power quality, injection of dc currents into the grid etc. In particular, the function of power decoupling between the modules and the grid has been explored. The demands made by the PV modules have also been reviewed. A significant finding is that for a PV module to achieve a 98% utilization efficiency at full generation, the ripple's amplitude should not be greater than 3.0 V. Last but not least, the operator's fundamental requirements such as affordability, effectiveness, and longevity—have also been taken into consideration.

5. References

1. A. Chouder, S. Silvestre, Automatic supervision and fault detection of PV systems based on power losses analysis, Energy Conversion and Management 51 (2010) 1929–1937.
2. S.K. Firth, K.J. Lomas, S.J. Rees, A simple model of PV system performance and its use in fault detection, Solar Energy 84 (2010) 624–635.
3. Syafaruddin, EnginKaratepe, Takashi Hiyama, Polar coordinated fuzzy controller based real-time maximum-power point control of photovoltaic system, Renewable Energy 34 (2009) 2597–2606.
4. S. Silvestre, Review of system design and sizing simulation tools, in: T. Markvart, L. Castañer (Eds.), Practical Handbook of Photovoltaics, Fundamentals and Applications, Elsevier, Oxford, 2003, pp. 544–561.
5. EsfandyarMazhari, Jiayun Zhao, NurcinCelik, Seungho Lee, Young-Jun Son, Larry Head, Hybrid simulation and optimization-based design and operation of integrated photovoltaic generation, storage units, and grid, Simulation Modelling Practice and Theory 19 (2011) 463–481.
6. http://valentin-software.com/xcartgold/Photovoltaics/.
7. http://www.pvsyst.com/.

8. Attanasio* R, Cacciato M, Gennaro F*, ScarcellaReview on single phase PV inverters for grid-connected applications, In: Proceedings of the 4th IASME/WSEAS international conference on energy, environment, ecosystems and sustainable development (EEESD'08) Algarve, Portugal, June 11–13; 2008.
9. Cáceres RO, Barbi I. A boost dc-ac converter: analysis, design, and experimentation. IEEE Trans Power Electron, 1999;14:134–41.
10. Vázquez N, Almazan J, Álvarez J, Aguilar C, Arau J. Analysis and experimental study of the buck, boost and buck-boost inverters, In: Proceedings IEEE PESC'99, Charleston, SC, June 27–July 1, pp. 801–6; 1999.
11. Kasa N, Iida T, Iwamoto H, An inverter using buck-boost type chopper circuits for popular small-scale photovoltaic power system. In: Proceedings of IEEE IECON'99, San Jose, CA, Nov./Dec. 1999, pp. 185–190.
12. Nagao M, Harada K. Power flow of photovoltaic system using buck-boost PWM power inverter. In: Proceedings IEEE PEDS'97, Singapore, May 26–29, pp. 144–9; 1997.
13. Kusakawa M, Nagayoshi H, Kamisako K, Kurokawa K. Further improvement of a transformer less, voltage boosting inverter for AC modules. Sol Energy Mater Sol Cells 2001;67:379–87.
14. Myrzik JMA. Novel inverter topologies for single-phase stand-alone or grid connected photovoltaic systems. In: Proceedings IEEE PEDS'01, Oct. 22–25, pp. 103–8; 2001.
15. Wang C-M. A novel single-stage full-bridge buck-boost inverter. In: Proceedings IEEE APEC'03, Miami Beach, FL, Feb. 9–13, pp. 51–7; 2003.
16. Kær SB, Blaabjerg F, A novel single-stage inverter for the ac-module with reduced low-frequency ripple penetration. In: Proceedings 10th EPE European Conference Power Electronics and Applications, Toulouse, France, Sept. 2–4, 2003.
17. Ahmed NA, Lee HW, Nakaoka M. Dual-mode time –sharingsine wave-modulation soft switching boost fullbridge one-stage power conditioner without electrolytic capacitor DC link. IEEE Trans IndAppl 2007;43(3):805–13, [May-June].
18. Madouh Jamal, Ahmed Nabil A, Al-Kandari Ahmed M. Advanced power conditioner using sinewave modulated buck-boost converter cascaded polarity changing inverter. Int J Electr Power Energy Syst 2012:280–9, [ISSN 0142- 0615].
19. Kasa N, Iida T, Iwamoto H, An inverter using buck-boost type chopper circuits for popular small-scale photovoltaic power system, In: Proceedings IEEE IECON'99, San Jose, CA, Nov./Dec. 1999, pp. 185–190.
20. Schekulin D, Grid-Connected Photovoltaic System, Germany patent DE197 32 218 Cl, Mar. 1999.
21. Henk R. Practical design of power supplies. New York: McGraw Hill; 1998. p. 95–6.
22. Jain Sachin, AgarwalVivek. A single-stage grid connected inverter topology for solar PV systems with maximum power point tracking. IEEE Trans Power Electron2007;22(5).
23. C. Winneker, "Worlds solar photovoltaic capacity passes 100-gigawatt landmark after strong year," [Online], Feb. 2013
24. REN21, "Renewables 2015 - Global status report," Tech. Report, Online Available: www.ren21.net, 2015.
25. Fraunhofer ISE, "Recent facts about phovoltaics in germany," Fraunhofer Inst. Sol. Energy Syst., Freiburg, Germany, Tech. Report, [Online]. Available: www.pv-fakten.de, 19 May 2015.
26. D. G. Infield, P. Onions, A. D. Simmons, and G. A. Smith, "Power quality from multiple grid-connected single-phase inverters," IEEE Trans. Power Del., vol. 19, no. 4, pp. 1983–1989, Oct. 2004.
27. D. G. Infield, P. Onions, A. D. Simmons, and G. A. Smith, "Power quality from multiple grid-connected single phase inverters," IEEE Trans. Power Del., vol. 19, no. 4, pp. 1983–1989, Oct. 2004.
28. P. Acuna, L. Moran, M. Rivera, J. Dixon, and J. Rodriguez, "Improved active power filter performance for renewable power generation systems," IEEE Trans. Power Electron., vol. 29, no. 2, pp. 687–694, Feb. 2014.
29. J. He, Y. W. Li, F. Blaabjerg, and X. Wang, "Active harmonic filtering using current-controlled, grid-connected DG units with closed-loop power control," IEEE Trans. Power Electron., vol. 29, no. 2, pp. 642– 653, Feb. 2014.
30. P. Gonzalez, E. Romero, V. M. Minambres, M. A. Guerrero, and E. Gonzalez, "Grid-connected pv plants. power quality and technical requirements," in Proc. of Electric Power Quality Supply Reliability Conf., June 2014, pp. 169–176.
31. "IEEE standard for interconnecting distributed resources with electric power systems," IEEE Std 1547-2003, 2003
32. "Characteristics of the utility interface for photovoltaic systems," IEC Std 61727:2004, Dec. 2004.
33. "IEEE draft recommended practice for establishing methods and procedures that provide supplemental support for implementation strategies for expanded use of IEEE Standard 1547," IEEE P1547.8/D8, July 2014, Sept. 2014.
34. E.ON Netz, Grid Code – High and extra high voltage. E. ON Netz GmbH, Bayreuth, 2006.
35. ComitatoElettrotecnicoItaliano, CEI 0-21: Reference technical rules for connecting users to the active and passive LV distribution companies of electricity, 2011.
36. F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus, "Overview of control and grid synchronization for distributed power generation systems," IEEE Trans. Ind. Electron., vol. 53, no. 5, pp. 1398–1409, Oct. 2006
37. R. Teodorescu, M. Liserre, and P. Rodriguez, Grid converters for photovoltaic and wind power systems. John Wiley & Sons, 2011.
38. Y. Yang, F. Blaabjerg, and Z. Zou, "Benchmarking of grid fault modes in single-phase grid-connected photovoltaic systems," IEEE Trans. Ind. Appl., vol. 49, no. 5, pp. 2167–2176, Sept.-Oct. 2013.
39. Z. Shu, S. Xie, and Q. Li, "Single-phase back-to-back converter for active power balancing, reactive power compensation, and harmonic filtering in traction power system," IEEE Trans. Power Electron., vol. 26, no. 2, pp. 334–343, Feb. 2011.
40. R. Bojoi, L.R. Limongi, D. Roiu, and A. Tenconi, "Enhanced power quality control strategy for single-phase inverters in distributed generation systems," IEEE Trans. Power Electron., vol. 26, no. 3, pp. 798–806, Mar. 2011.
41. A. Kulkarni and V. John, "Mitigation of lower order harmonics in a grid-connected single-phase PV inverter," IEEE Trans. Power Electron., vol. 28, no. 11, pp. 5024–5037, Nov. 2013.
42. K. Zhou, Z. Qiu, N.R. Watson, and Y. Liu, "Mechanism and elimination of harmonic current injection from single-phase grid-connected PWM converters," IET Power Electronics, vol. 6, no. 1, pp. 88–95, Jan. 2013.
43. S. Chen, Y. M. Lai, S.-C. Tan, and C. K. Tse, "Analysis and design of repetitive controller for harmonic elimination in PWM voltage source inverter systems," IET Power Electronics, vol. 1, no. 4, pp. 497–506, Dec. 2008.
44. Y. Yang, P. Enjeti, F. Blaabjerg, and H. Wang, "Wide-scale adoption of photovoltaic energy: Grid code modifications are explored in the distribution grid," IEEE Ind. Appl. Mag., vol. 21, no. 5, pp. 21–31, Sept. 2015.
45. H. Kobayashi, "Fault ride through requirements and measures of distributed PV systems in Japan," in Proc. PES General Meeting. IEEE, 2012, pp. 1–6.
46. R. Teodorescu, F. Blaabjerg, M. Liserre, and P. C. Loh, "Proportionalresonant controllers and filters for grid-connected voltage-source converters," IEE Proceedings-Electric Power Applications, vol. 153, no. 5, pp. 750–762, Sept. 2006.
47. X. Yuan, W. Merk, H. Stemmler, and J. Allmeling, "Stationary-frame generalized integrators for current control of active power filters with zero steady-state error for current harmonics of concern under unbalanced and distorted operating conditions," IEEE Trans. Ind. Appl.,vol. 38, no. 2, pp. 523–532, Mar. 2002.

48. R. Teodorescu, F. Blaabjerg, U. Borup, and M. Liserre, “A new control structure for grid-connected LCL PV inverters with zero steady-state error and selective harmonic compensation,” in Proc. APEC, vol. 1, 2004, pp. 580–586.
49. A. G. Yepes, F. D. Freijedo, O. Lopez, and J. Doval-Gandoy, “Analysis and design of resonant current controllers for voltage-source converters by means of nyquist diagrams and sensitivity function,” IEEE Trans. Ind. Electron., vol. 58, no. 11, pp. 5231–5250, Nov. 2011.
50. .G. Yepes, F.D. Freijedo, O. Lopez, and J. Doval-Gandoy, “High performance digital resonant controllers implemented with two integrators,” IEEE Trans. Power Electron., vol. 26, no. 2, pp. 563–576, Feb. 2011.
51. F. D. Freijedo, A. G. Yepes, J. Malvar, O. Lopez, P. Fernandez- Comesana, A. Vidal, and J. Doval-Gandoy, “Frequency tracking of digital resonant filters for control of power converters connected to public distribution systems,” IET Power Electronics, vol. 4, no. 4, pp. 454–462, Apr. 2011.
52. S. A. Khajehoddin, M. Karimi-Ghartemani, P. K. Jain, and A. Bakhshai, “A resonant controller with high structural robustness for fixed-point digital implementations,” IEEE Trans. Power Electron., vol. 27, no. 7, pp. 3352–3362, Jul. 2012.
53. G. Shen, X. Zhu, J. Zhang, and D. Xu, “A new feedback method for PR current control of LCL-filter-based grid-connected inverter,” IEEE Trans. Ind. Electron., vol. 57, no. 6, pp. 2033–2041, Jun. 2010.
54. M. Ciobotaru, R. Teodorescu, and F. Blaabjerg, “Control of single-stage single-phase PV inverter,” in Proc. EPE. IEEE, 2005, pp. P.1–P.10.
55. K. Zhou and Y. H. Yang, “Multiple harmonics control of single-phase PWM rectifiers,” in Proc. ISIE, 2012, pp. 393–396.
56. K. Zhou, K.-S. Low, Y. Wang, F.-L. Luo, and B. Zhang, “Zero-phase odd-harmonic repetitive controller for a single-phase PWM inverter,” IEEE Trans. Power Electron., vol. 21, no. 1, pp. 193–201, Jan. 2006.
57. K. Zhou, D. Wang, B. Zhang, and Y. Wang, “Plug-in dual-modestructure repetitive controller for CVCF PWM inverters,” IEEE Trans. Ind. Electron., vol. 56, no. 3, pp. 784–791, Mar. 2009.
58. T. Hornik and Q.-C. Zhong, “A current-control strategy for voltagesource inverters in microgrids based on H-1 and repetitive control,” IEEE Trans. Power Electron., vol. 26, no. 3, pp. 943–952, Mar. 2011.
59. S. Jiang, D. Cao, Y. Li, J. Liu, and F. Z. Peng, “Low-thd, fast-transient, and cost-effective synchronous-frame repetitive controller for threephase UPS inverters,” IEEE Trans. Power Electron., vol. 27, no. 6, pp. 2994–3005, Jun. 2012.
60. R. Costa-Castell ´o, R. Grin´o, and E. Fossas, “Odd-harmonic digital repetitive control of a single-phase current active filter,” IEEE Trans. Power Electron., vol. 19, no. 4, pp. 1060–1068, Jul. 2004.
61. Y. H. Yang, K. Zhou, and M. Cheng, “Phase compensation resonant controller for single-phase converters,” IEEE Trans. Ind. Inform, vol. 9, no. 2, pp. 957–964, May 2012.
62. Y. H. Yang, K. Zhou, M. Cheng, and B. Zhang, “Phase compensation multiresonant control of CVCF PWM converters,” IEEE Trans. Power Electron., vol. 28, no. 8, pp. 3923–3930, Aug. 2013.
63. W. Lu, K. Zhou, D. Wang, and M. Cheng, “A general parallel structure repetitive control scheme for multiphase DC–AC PWM converters,” IEEE Trans. Power Electron., vol. 28, no. 8, pp. 3980–3987, Aug. 2013.
64. M. Rashed, C. Klumpner, and G. Asher, “Repetitive and resonant control for a single-phase grid-connected hybrid cascaded multilevel converter,” IEEE Trans. Power Electron., vol. 28, no. 5, pp. 2224–2234, May 2013.
65. M. Rashed, C. Klumpner, and G. Asher, “Control scheme for a single phase hybrid multilevel converter using repetitive and resonant control approaches,” in Proc. EPE. IEEE, 2011, pp. 1–13.
66. M. Oprisan and S. Pneumaticos, “Potential for electricity generation from emerging renewable sources in Canada,” in Proc. IEEE EIC Climate Change Technol. Conf., May 2006, pp. 1–10.
67. G. Petrone, G. Spagnuolo, R. Teodorescu, M. Veerachary, and M. Vitelli, “Reliability issues in photovoltaic power processing systems,” IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2569–2580, Jul. 2008.
68. S. Jain and V. Agarwal, “A single-stage grid connected inverter topology for solar PV systems with maximum power point tracking,” IEEE Trans. Power Electron., vol. 22, no. 5, pp. 1928–1940, Jul. 2007.
69. F. Katiraei and J. Aguero, “Solar PV integration challenges,” IEEE Power Energy Mag., vol. 9, no. 3, pp. 62–71, May-Jun. 2011.