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Simulation of Transformer less Eleven Level Converter Connected to Grid and PV Systems

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Abstract—
Photovoltaic energy is a wide kind of green energy. A high performance on these systems is needed to make the most of energy produced by solar cells. Also, there must be a constant adaptation due to the continuous variation of power production. The switching strategy is employed such that to regulate the flying-capacitor voltage, improves the efficiency for most devices switch at the frequency and will minimize the minimum the common-mode leakage current with the help of a novel dedicated circuit. Simulation results confirm the feasibility and good performance of the proposed converter.

Keywords: Multilevel inverters; Pulse width modulation; Cascaded Full Bridge (CFB); Transformer less Photovoltaic systems

I.INTRODUCTION

Grid-connected single-phase photovoltaic (PV) systems are nowadays recognized for their contribution to clean power generation. A primary goal of these systems is to increase the energy injected to the grid by keeping track of the maximum power point (MPP) of the panel, by reducing the switching frequency, and by providing high reliability. In addition, the cost of the power converter is also becoming a decisive factor, as the price of the PV panels is being decreased [1]. This has given rise to a big diversity of innovative converter configurations for interfacing the PV modules with the grid. Currently, the state-of-the-art technology is the two-level multi string converter. This converter consists of several PV strings that are connected with dc–dc converters to a common dc–ac converter [2], [3]. This topology features several advantages such as the independent tracking of the MPP of each string to the existing plant. This converter topology can reach peak efficiencies up to 96% [4]. In the last years, multilevel converter topologies have been also considered in PV applications [5]. These converter topologies can generate high-quality voltage waveforms with power semiconductor switches operating at a frequency near the fundamental [6]. Although, in low-power applications, the switching frequency of the power switches is not restricted, a low switching frequency can increase the efficiency of the converter [7].

This issue must be confronted in all transformers less PV converters, regardless of architecture. In particular, in full-bridge-based topologies, the ground leakage current is mainly due to high frequency variations of the common-mode voltage at the output of the power converter [4]. Several solutions can be found in literature aiming at the reduction of the common-mode voltage harmonic content [5]–[7]. Once the grid frequency transformer is removed from a PV converter, the bulkiest wound and reactive components that remain are those that form the output filter used to clean the output voltage and current from high frequency switching components. Further reduction in cost and weight and improvement in efficiency can be achieved by reducing the filter size, and this is the goal of

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multilevel converters. For years multilevel converters have been investigated [8], but only recently have the results of such researches found their way to commercial PV converters. Multilevel converters outperform conventional two- and three-level converters in terms of harmonic distortion since they can synthesize the output voltages using more levels.

A huge advantage is that single-phase NPC converters are virtually immune from ground leakage currents, although the same is not true for three-phase NPC converters [12]. A recent paper has proposed an interesting NPC design for exploiting next-generation devices such as super junction or SiC MOSFETs. The main drawback of NPC designs is that they need twice the dc-link voltage, with respect to full bridge. CFBs make for highly modular designs. Usually, each full bridge inside a CFB converter needs an insulated power supply, matching well with multi-string PV fields.

II. PROPOSED NINE LEVEL CONVERTER TOPOLOGY

The proposed converter is composed of two CFBs, one of which is supplied by a flying capacitor (see Fig. 1). In this paper, a different PWM strategy was developed in order to allow grid connected operation with no galvanic isolation (transformer less solution) for this basic topology. Since the PWM strategy alone is not sufficient to maintain a low ground leakage current. As it will be described in the following, the proposed PWM strategy stretches the efficiency by using, for the two legs where PWM frequency switching does not occur, devices with extremely low voltage drop, such as MOSFETs lacking a fast recovery diode. In fact, the low commutation frequency of those two legs allows, even in a reverse conduction state, the conduction in the channel instead of the body diode (i.e., active rectification). Insulated-gate bipolar transistors (IGBTs) with fast anti parallel diodes are required in the legs where high-frequency hard switching commutations occur. In grid-connected operation, one full-bridge leg is directly connected to the grid neutral wire, whereas the phase wire is connected to the converter through an LC filter.

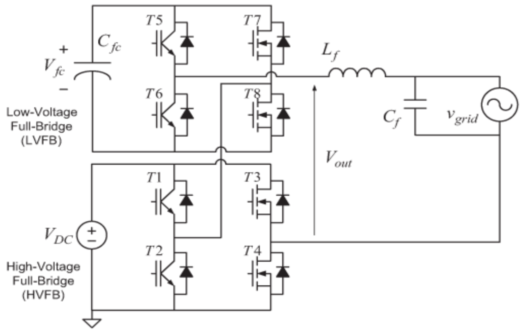

Fig. 1. CFB with a flying capacitor

As it will be described and justified in the following section, flying-capacitor voltage Vfc is kept lower, at steady state, than dc-link voltage VDC. Accordingly, the full bridge supplied by the dc link is called the high voltage full bridge (HVFB), whereas the one with the flying capacitor is the low-voltage full-bridge (LVFB). The CFB topology allows certain degrees of freedom in the control, so that different PWM schemes can be considered; however, the chosen solution needs to satisfy the following requirements.

1) Most commutations must take place in the LVFB to limit the switching losses.

2) The neutral-connected leg of the HVFB needs to switch at grid frequency to reduce the ground leakage current.

3) The redundant states of the converter must be properly used to control the flying-capacitor voltage.

4) The driving signals must be obtained from a single carrier for a low-cost DSP to be used as a controller.

The switching pattern described in Table I was developed starting from the above requirements. Requirement 2), in particular, is due to the aforementioned parasitic capacitive coupling between the PV panels and their frames, usually connected to the earth. Capacitive coupling renders the common-mode current inversely proportional to the switching frequency of the neutral-connected leg.

TABLE I
DESCRIPTION OF THE CONVERTER OPERATING ZONES

Zone	Output Voltage	On Devices	Off Devices	Switching Devices
Zone 3B	$-V_{DC}-V_{fc} \leftrightarrow -V_{DC}$	T2, T3, T7	T1, T4, T8	T5, T6
Zone 3A	$-V_{DC} \leftrightarrow -V_{DC}+V_{fc}$	T2, T3, T8	T1, T4, T7	T5, T6
Zone 2A	$-V_{DC}+V_{fc} \leftrightarrow 0$	T3, T7	T4, T8	T1, T2, T5, T6
Zone 2B	$-V_{DC} \leftrightarrow -V_{fc}$	T3, T7	T4, T8	T1, T2, T5, T6
Zone 1B	$-V_{fc} \leftrightarrow 0$	T1, T3, T7	T2, T4, T8	T5, T6
Zone 1A	$0 \leftrightarrow V_{fc}$	T2, T4, T8	T1, T3, T7	T5, T6
Zone 2A	$V_{fc} \leftrightarrow V_{DC}$	T4, T8	T3, T7	T1, T2, T5, T6
Zone 2B	$0 \leftrightarrow V_{DC}-V_{fc}$	T4, T7	T3, T8	T1, T2, T5, T6
Zone 3B	$V_{DC}-V_{fc} \leftrightarrow V_{DC}$	T1, T4, T7	T2, T3, T8	T5, T6
Zone 3A	$V_{DC} \leftrightarrow V_{DC}+V_{fc}$	T1, T4, T8	T2, T3, T7	T5, T6

The converter can operate in different output voltage zones, where the output voltage switches between two specific levels. The operating zone boundaries vary according to the dc-link and flying-capacitor voltages, and adjacent zones can overlap (see Fig. 2). In zones labeled A, the contribution of the flying-capacitor voltage to the converter output voltage is positive, whereas it is negative in B zones. Constructive cascading of the two full bridges can, therefore, result in limited output voltage boosting. Depending on the Vfc/VDC ratio, one of the (a) or (b) situations in Fig. 2 can ensue; nevertheless, the operation of the converter does not differ much in the two cases. If two overlapping operating zones can supply the same output voltage, the operating zone to be used is determined taking into account the regulation of Vfc, as will be described in Section III. As mentioned in the introduction, the duty cycles are calculated on-line by a simple equation, similarly to the approach presented. The switching pattern depends on the instantaneous fundamental component of output voltage Vout ∗ and on the measured values of Vfc and VDC.

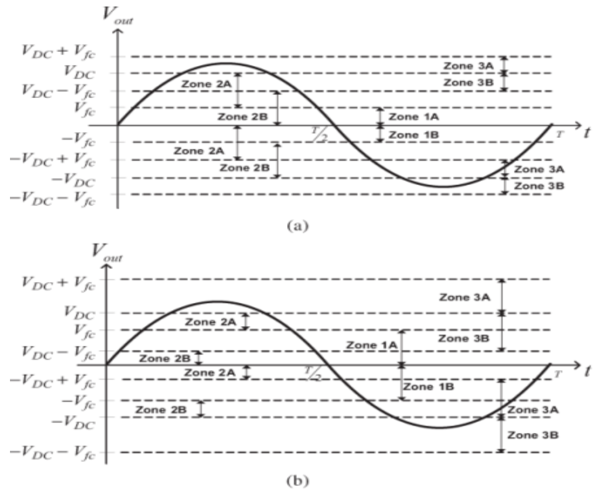

Fig.2. Operating zones under different Vfc ranges. (a) Vfc < 0.5VDC.
(b) Vfc > 0.5VDC.

If Vfc = VDC/3, the converter can synthesize nine equally spaced output voltage levels. Fig. 3 refers to this case and shows the theoretical waveforms, where one leg of the HVFB operates at grid frequency and one leg of the LVFB at five times the grid frequency. Moreover, apart from zone 2, no high-frequency commutations occur in the whole HVFB (see Fig. 2). Since the voltage regulation of the flying capacitor takes place in zone 2, the zone-2 behavior is more articulated and will be described in detail in the following section.
Since the main task facing a grid-connected P converter is the transfer of active power to the electrical grid, controlling the voltage of the flying capacitor is critical. Flying-capacitor voltage Vfc is regulated by suitably choosing the operating zone of the converter depending on the instantaneous output voltage request. Depending on the operating zone of the converter (see Fig. 2), Vfc can be added to (A zones) or subtracted from (B zones) the HVFB output voltage, charging or discharging the flying capacitor. In particular, considering a positive value of the current injected into the grid, the flying capacitor is discharged in A zones and charged in B zones. Since a number of redundant switch configurations can be used to synthesize the same output voltage waveform, it is possible to control the voltage of the flying capacitor, forcing the converter to operate more in a zones when the flying-capacitor voltage is higher than a

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reference value or more in B zones when it is lower than a reference value. Similar considerations hold in case of a negative injected grid current. In each case, some commutations between nonadjacent output levels must inevitably occur (level skipping), with the drawback of a certain increase in the output current ripple. The voltage control of the flying capacitor (which determines the zone-A or zone-B operation) is realized by a simple hysteresis control.

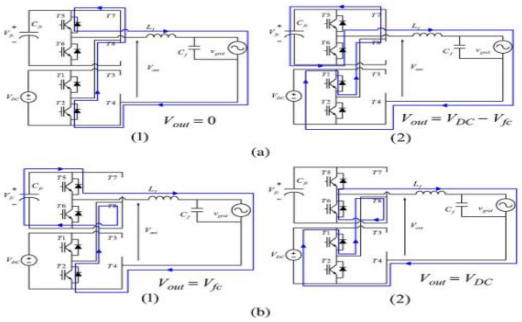

Fig. 3. Converter configurations for the regulation of the flying capacitor. (a) Flying-capacitor charge. (b) Flying-capacitor discharge.

Fig. 3 illustrates the regulation of Vfc supposing a positive grid current with Vout > 0 and Vfc < 0.5VDC. If Vfc is too low, output level Vfc can be replaced by VDC − Vfc, thus switching between the 0 and VDC − Vfc output levels [zone 2B, Fig. 3(a)]. Similarly, if Vfc is too high, VDC − Vfc can be replaced with Vfc, causing the converter to switch between the Vfc and VDC output levels [zone 2A, Fig. 3(b)]. In Fig. 3, the devices switching at low frequency are short circuited when on and not shown when off.

Similar Vfc regulation strategies can be likewise developed for the case when Vfc > 0.5VDC.

If Vfc < 0.5VDC, in order to minimize the current ripple, zone 2 is chosen only when Vfc < Vout ∗ < VDC − Vfc (zones 3 are otherwise chosen), limiting level skipping. Level skipping always occurs if Vfc > 0.5VDC; hence, any A or B zone can be chosen according to the voltage regulation algorithm. Since the dc-link voltage can go through sudden variations due to the MPPT strategy, it is important that the converter is able to work in any [VDC, Vfc] condition. While the distortion of the output voltage is minimized through the on-line duty cycle computation, it is important to assess the capability of the converter to regulate the flying-capacitor voltage under different operating conditions. The ability to control the flying-capacitor voltage through the proposed PWM strategy has been studied in simulation by determining the average flying-capacitor current under a large span of VDC and Vfc values. In the simulations, grid voltage vgrid is sinusoidal with amplitude of 230√2 V; however, the same results hold even for different voltages if the ratio V grid/VDC remains constant.

III.SIMULATION RESULTS

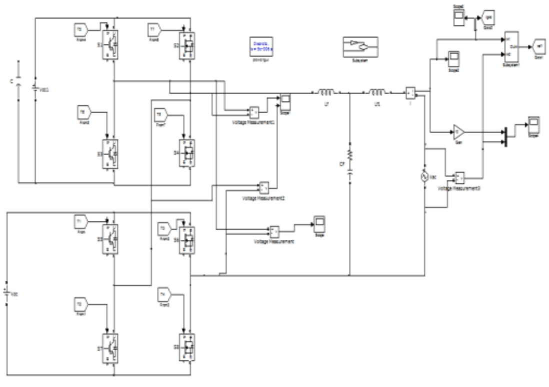

Fig.4.Matlab/Simulink Model of a Nine Level with Grid Connected Systems.

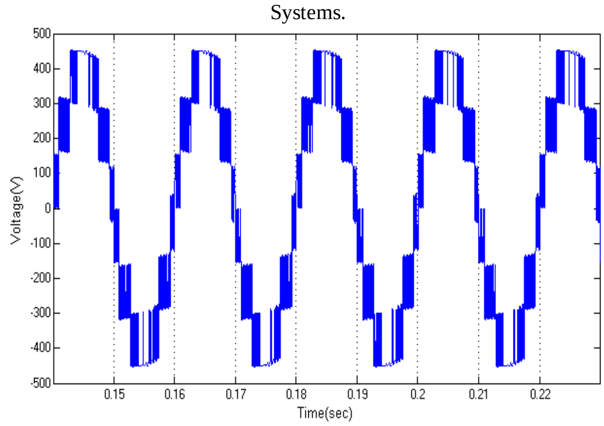

Fig.5.Simulation results for output voltage of inverter with ½ Vdc.

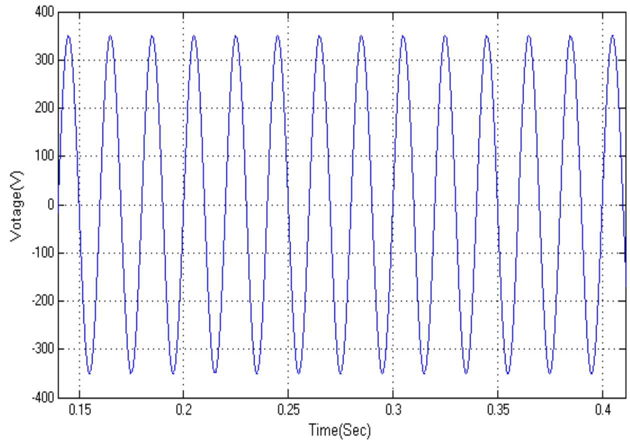

Fig.6. Simulation results for grid voltage.

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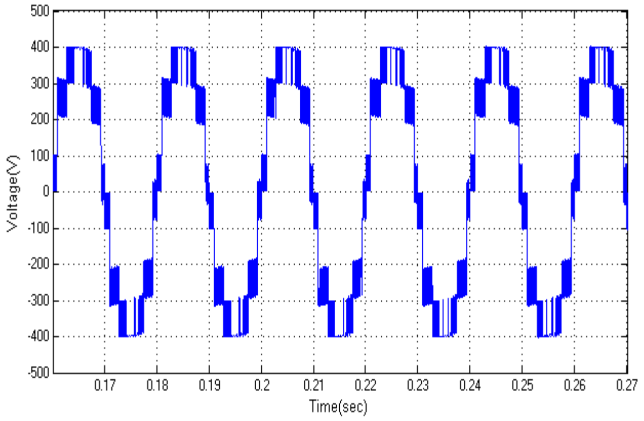

Fig.7.Simulation results for output voltage of inverter with 1/3 Vdc.

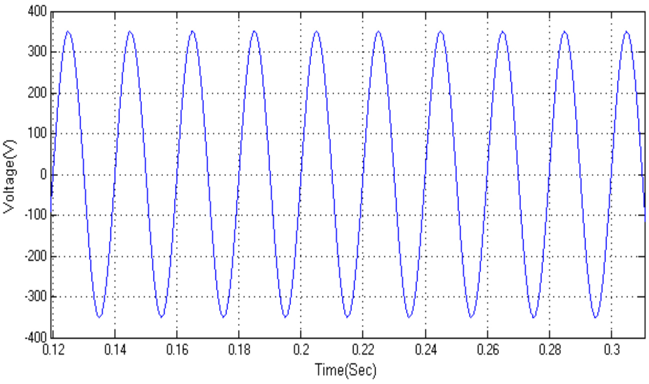

Fig.8. Simulation results for grid voltage.

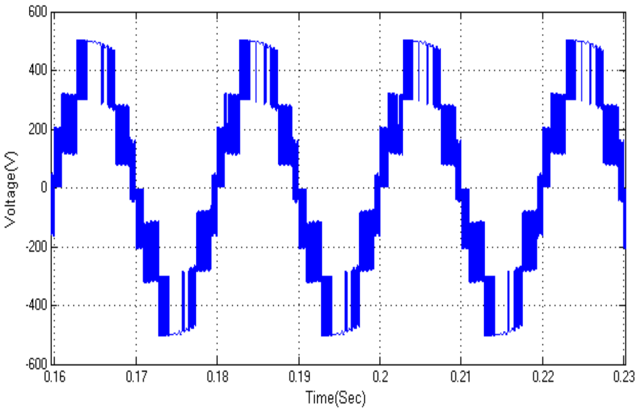

Fig.9.Simulation results for output voltage of inverter with 2/3 Vdc.

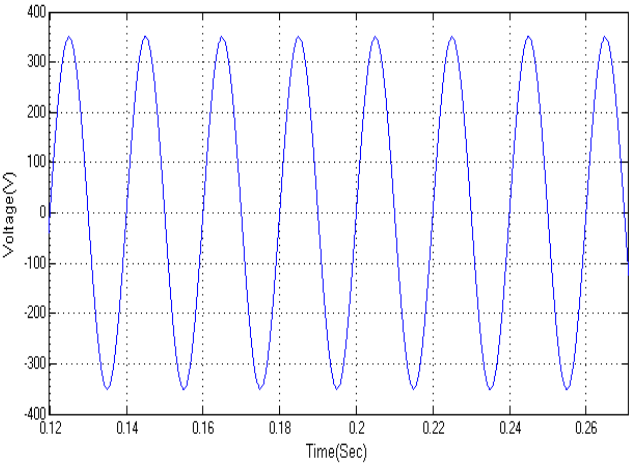

Fig.10.Grid Voltage.

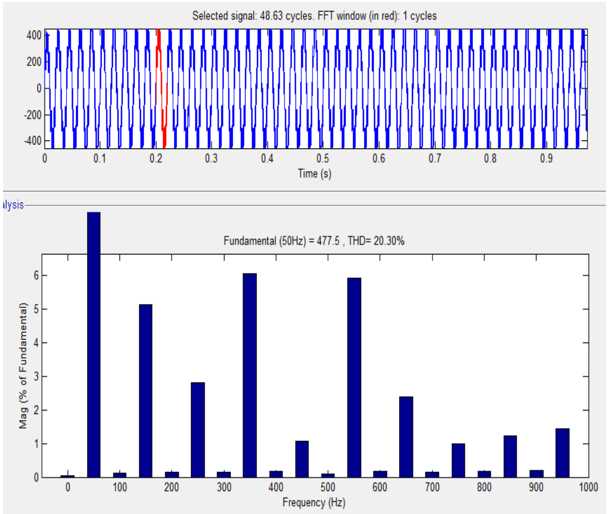

Fig.11.THD for nine level inverter.

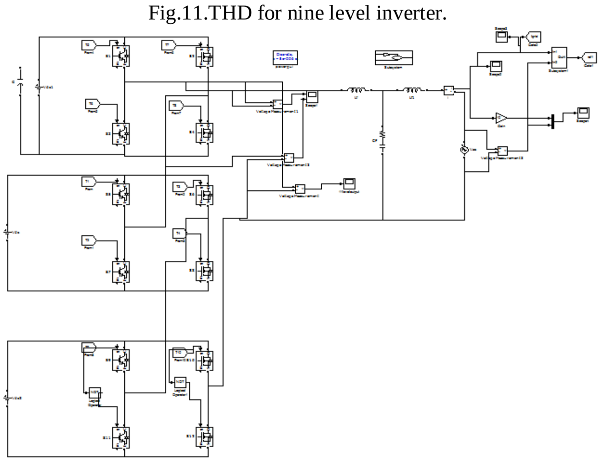

Figure.12.Matlab/Simulink Model of a eleven Level inverter.

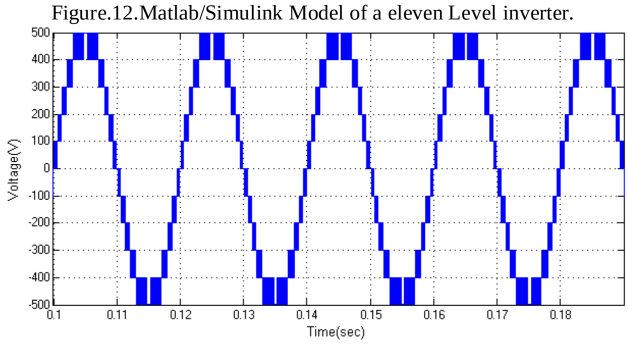

Fig.13.Simulation results for output voltage of eleven level inverter.

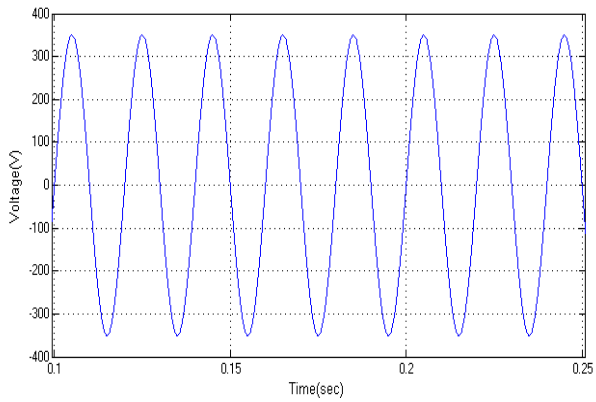

Fig.14. Simulation results for grid voltage.

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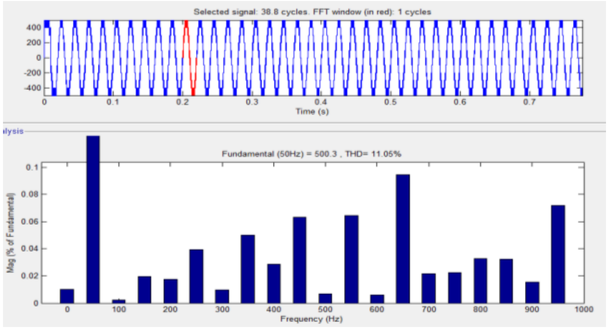

Fig.15.THD for Eleven Level Inverter.

V. CONCLUSION

This paper has proposed a novel eleven-level grid-connected transformer less PV converter based on a CFB topology with three full bridges, one of which is supplied by a floating capacitor. A suitable PWM strategy was developed in order to improve efficiency (most power devices commutate at low frequency) and, with the help of a specific TC, minimize the ground leakage current. The proposed converter can continuously operate at arbitrary power factors, has limited boosting capability, and can produce eleven level output voltage levels with 15 power switches, of which three are low power switches for the TC and only four need to be controlled by PWM. The proposed PWM strategy can regulate the voltage across the flying capacitor. Simulations were performed to assess the ability to regulate the flying-capacitor voltage in a wide range of operating conditions.

REFERENCES

[1] M. Calais and V. G. Agelidis, "Multilevel converters for single-phase grid connected photovoltaic systems—An overview," in *Proc. IEEE Int. Symp. Ind. Electron.*, 1998, vol. 1, pp. 224–229.

[2] 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, Sep./Oct. 2005.

[3] P. K. Hinga, T. Ohnishi, and T. Suzuki, "A new PWM inverter for photovoltaic power generation system," in *Conf. Rec. IEEE Power Electron.Spec. Conf.*, 1994, pp. 391–395.

[4] J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galvan, R. C. P. Guisado, M. A. M. Prats, J. I. Leon, and N. MorenoAlfonso, "Power-electronic systems for the grid integration of renewable energy sources: A survey," IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1002– 1016, Jul. 2008.

[5] H. Xiao and S. Xie, "Leakage current analytical model and application in single-phase transformerless photovoltaic grid-connected inverter," IEEE Trans. Electromagn. Compat., vol. 52, no. 4, pp. 902–913, Nov. 2010.

[6] O. Lopez, F. Freijedo, A. Yepes, P. Fernandez-Comesaa, J. Malvar, R. Teodorescu, and J. Doval-Gandoy, "Eliminating ground current in a transformerless photovoltaic application," IEEE Trans. Energy Convers., vol. 25, no. 1, pp. 140–147, Mar. 2010.

[7] E. Gub´ıa, P. Sanchis, A. Ursua, J. Lopez, andL. Marroyo," Ground Currents in Single-Phase Transformerless Photovoltaic Systems," *Prog. Photovolt., Res. Appl.*, vol.15,no. 7, pp. 629–650, Nov. 2007.

[8] W. Yu, J.-S Lai, H Qian and C. Hutchens "High-Efficiency MOSFET Inverter with H6-Type Configuration for Photovoltaic Nonisolated AC Module Applications," *IEEE Trans. Power Electron*., vol.26, no.4, pp.1253-1260, April 2011.

[9] M. Saeedifard, R. Iravani, and J. Pou, "A space vector modulation strategy for a back-to-back five-level HVDC converter system," IEEE Trans. Ind.Electron., vol. 56, no. 2, pp. 452–466, Feb. 2009.

[10] R. Stala, S. Pirog, M. Baszynski, A. Mondzik, A. Penczek, J. Czekonski, and S. Gasiorek, "Results of investigation of multicell converters with balancing circuit—Part I," IEEE Trans. Ind. Electron., vol. 56, no. 7, pp. 2610–2619, Jul.2009.

[11] F. Z. Peng, "A generalized multilevel inverter topology with self voltage balancing," IEEE Trans. Ind. Appl., vol. 37, no. 2, pp. 611–617, Mar./Apr. 2001.

[12] G. Konstantinou, S. Pulikanti, M. Ciobotaru, V. Agelidis, and K. Muttaqi, "The seven-level flying capacitor based ANPC converter for grid integration of utility-scale PV systems," in Proc. IEEE PEDG, Aalborg, Denmark, Jun. 2012, pp. 592–597.