INVESTIGATION ON INTELLIGENT SOFT COMPUTING TECHNIQUES FOR QUALITY ENHANCEMENT OF POWER GRID

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Abstract—In this paper, a four power semiconductor switch based three-phase inverter is proposed. The proposed topology b-4 of three-phase inverter is investigated to make the commercial micro-grid system to be cost effective and hardware optimized. A simple Sine PWM (SPWM) based control strategy is proposed for the b-4 inverter topology instead of the traditional complex four-switch based Space Vector techniques. A novel technique of using the Spatial Repetitive Controller (SRC) is also proposed to eliminate the effect of mid-point voltage fluctuation of the DC link even in the case of asymmetrically split DC link capacitors without any extra voltage or current sensors unlike conventional methods.

Key words—four-switch based three-phase inverter (b4- topology), Sine PWM based control, Non-linear load

1. INTRODUCTION

Speed controlled induction motor drives are widespread electromechanical systems suitable for a large spectrum of industrial applications. When high dynamic performance and precision control are required for an induction motor in a wide speed range, the speed must be measured. In contrast, in this medium low performance application, sensorless control without measuring the motor speed is becoming an industrial standard because of advantages in terms of cost, simplicity, and mechanical reliability of the drive. As a consequence of this, a great deal of research has been carried out on sensorless drives over the last few decades [1]. Several solutions for sensorless control of induction motor drives have been proposed based on the machine fundamental excitation model and high frequency signal injection methods, as summarized recently [2]. Fundamental model based strategies use the instantaneous values of stator voltages and currents to estimate the flux linkage and the motor speed. Moreover, pure integration for flux represents a crucial difficulty which may cause dc drift and initial condition problems.

Low Pass Filters (LPFs) with low cut-off frequency have been proposed to replace the pure integrator [12]. This introduces phase and gain errors and delays the estimated speed relative to the actual, which may affect the dynamic performance of the drive in addition to inaccurate speed estimation below the cut-off frequency [7]. To overcome this problem introduce a programmable cascaded low pass filter (PCLPF) to replace the pure integration by small time constant cascaded filters to attenuate the dc offset decay time.

In another technique is used where the rotor flux is estimated by defining a modified integrator having the same frequency response as the pure integrator at steady state. A nonlinear feedback integrator for drift and dc offset compensation has been proposed. Further research has tried to entirely replace the voltage model (VM) with a state observer with current error feedback or with full order stator and rotor flux observers which reduces the scheme’s simplicity.

Semiconductor switches mainly determine the overall price of the power converter devices. So, there has been always a desire to develop new topologies with reduced number of semi-conductor devices aiming for reduced costs. Especially in the range of a few ten kilowatts and above, this may cause considerable savings. Among various topologies, half-bridge converter has shown the best performance thanks to the reduced number of semiconductor devices, minimized conduction and switching losses, regeneration capability, higher DC-link voltage utilization, etc.

Over the years induction motor (IM) has been utilized as a workhorse in the industry due to its easy build, high robustness, and generally satisfactory efficiency. By tradition, 6 - switch 3 - phase inverters have been widely used for variable speed IM drives. The last work on (Four Switch Three Phase Inverter) FSTPI for IM drives investigated the performance of a 4 - switch, 3 - phase inverter fed cost effective induction motor in real time, which has been implemented by vector control . A standard three - phase voltage source inverter utilizes three legs six - switch three - phase voltage source inverter , with a pair of complementary power switches per phase. The FSTPI structure generates four active vectors in the plane, instead of six, as generated by the (six-switch three-phase inverter) SSTPI topology. A reduced switch count voltage source inverter four switch three - phase voltage source inverter uses only two legs, with four switches.

Several articles report on FSTPI structure regarding inverter performance and switch control. This paper presents a general method to generate pulse width modulated (PWM) signals for control of four - switch, three phase voltage source inverters, even when there are voltage oscillations across the two dc - link capacitors. The method is based on the so called space vector modulation, and includes the scalar version. This permits to implement all alternatives, thus allowing for a fair comparison of the different modulation techniques. The proposed method provides a simple way to select either three, or four vectors to synthesize the desired output voltage during the switching period. In the proposed approach, the selection between three or four vectors is parameterized by a single variable. The influence of different switching patterns on output voltage symmetry, current waveform, switching frequency and common mode voltage is examined.

This converter topology, shown in Fig. 1a, is often called voltage-doubler. As it can be seen, the DC-link voltage is twice the conventional full-bridge converter. This topology is widely employed in industrial applications. The three phase extension of this topology is shown in Fig. 1b and is usually referred to as four switch three phase inverter, component minimized converter, low cost converter, or component minimized converter.

The six-switch (b-6 topology) three-phase voltage source inverter (VSI) for interfacing renewable energy sources were emphasized. It is also highlighted that the VSI is operated in current control mode (CCVSI operation) to ensure power balance between different elements in the micro-grid. The number of power electronic switches needed for b-6 inverter topology is six during the overall operation. To optimize the overall power circuit of the micro-grid, a cost effective solution for the power circuit is to replace the traditional six-switch (b-6 topology) based three- phase

inverter with a four-switch based three-phase inverter topology is proposed.

2. MODEL OF FOUR SWITCH THREE PHASE INVERTER

The circuit of Fig. 1b has two converter legs and third phase is connected to the middle point of the DC-link capacitor bank. Because of its benefits, this topology has also found a lot of industrial applications. Let us assume that the states of the four power switches are denoted by the binary variables S_1 to S_4, where the binary ‘‘1’’ corresponds to an ON state and the binary ‘‘0’’ indicates an OFF state, where Vs is a single phase utility ac supply voltage to dc-voltage, I_s is the supply current, and L_s is the boost inductor connected in series with the utility supply voltage.

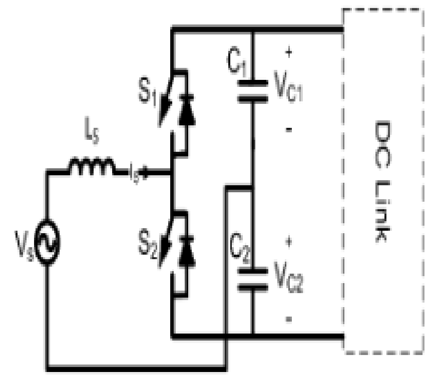

Figure 1a Half-bridge converter (voltage-doubler).

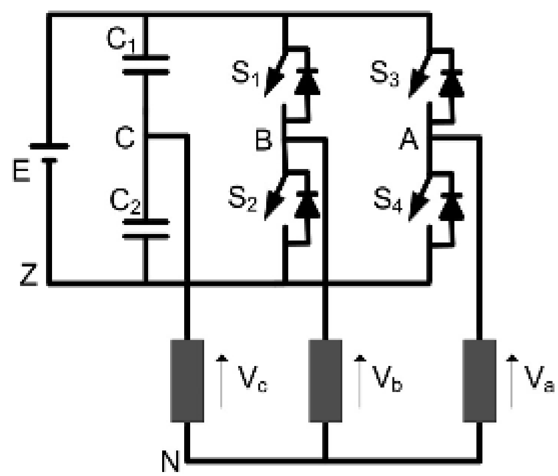

Figure 1b 4-Switch voltage source converter.

The states of the upper and lower switches in Fig. 1b of a leg are complementary, which yields

$S_3 = 1 - S_1$

$S_4 = 1 - S_2$

Let us consider a Y-connection of phases of the induction motor; therefore, their terminal voltages V_a , V_b , and V_c can be expressed as a function of the states of the upper switches as follows

$V_a = E\,(4S_1 – 2S_2 – 1) / 6$

$V_b = E\,(– 2S_1 + 4S_2 – 1) / 6$

$V_c = E(S_1 + S_2 – 1) / 3$

where

E is the DC-link voltage,

Z is the zero voltage point, and

N is the neutral point. Four combinations of the states of the power switches could be distinguished.

3. CONTROL STRATEGY OF THE SERIES INVERTER

The inverter block typically consists of a Sine PWM (SPWM) inverter followed by a high- frequency transformer and a power L–C filter to eliminate the high-frequency PWM signal. The high-frequency transformer is used after the PWM inverter to boost the inverter voltage and to provide electrical isolation between renewable energy side and the micro grid side. From testing point of view, both the requirements are optional. Therefore, for the present scope of the paper, transformer is not used to avoid the complexity in the inverter power circuit.

For the sake of analysis of the control strategy of the inverter, it is assumed that, the renewable energy extractor is assumed to be operating steadily. Therefore, the dc-link voltage V dc is at the steady level and the inverter output power P inv is maintained at a steady value. Thus, the dc-link (i.e., renewable energy extractor along with PEC converter together with the battery) can be modelled as a dc power supply. The load is assumed to be a linear R–L load. The local bus voltage, where the targeted load and the renewable source based inverter is connected, is defined as grid voltage, V_g . The power circuit of the series inverter is shown in Fig. 2. The inverter is essentially an SPWM voltage source inverter. The raw output voltage of the inverter contains not only fundamental power frequency voltage, but also the switching-frequency-based harmonic voltages. The L–C filter as shown in Fig. 2, is connected to filter the switching frequency components of the voltage harmonics, so that the inverter output voltage, only contains fundamental power frequency component. The filter resistance R_f , placed in series with the filter capacitor C_f , to limit the inrush current from the inverter. It can also be noted that the inverter output is connected in series with the grid and also to the load. Both the inverter as well as the grid acts as voltage sources to supply the load. The inverter operates to transfer renewable power to the load and the rest of the load power comes from grid along with the voltage regulation of the load. In the proposed control strategy [28] in this paper, the inverter voltage, v inv , is added vectorially in series with the grid voltage, v g , to form the load voltage, v L , to facilitate both the load voltage regulation as well as the inverter output power flow control unlike the condition proposed in [21] to regulate only the load voltage

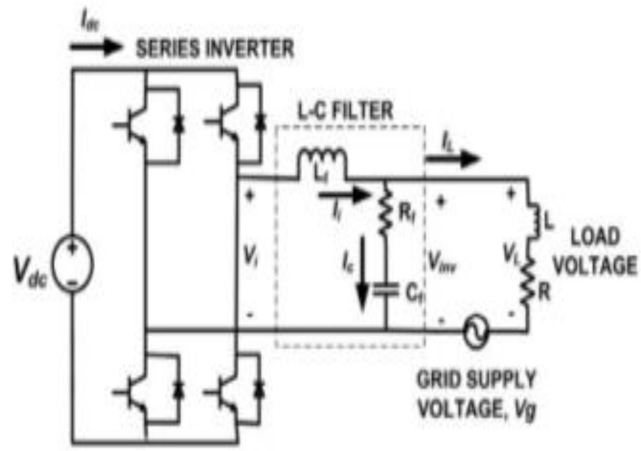

Fig. 2 power circuit of the series inverter

4. POWER CIRCUIT CONFIGURATION OF THE THREE - PHASE INVERTER

A typical three-phase multi-bus micro-grid system connected to the grid at the point of common coupling (PCC). Different distributed generators interface to the micro-grid and the load using power electronic converters. The Voltage Source Inverter (VSI) operates in current control mode (as CCVSI) to manage the harvested energy from the renewable energy sources not only to share the load active power (P L) between power consumption from the Local Bus (P g) and power supplied by CCVSI (P inv) but also the reactive power and harmonic power drawn by the load are also compensated by the CCVSI to ensure that the currents drawn from the Local Bus (I_{ga}, I_{gb}, I_{gc}) are sinusoidal and with unity displacement power factor. The utility grid neutral N is electrically isolated from the DC link mid-point of the VSI. The three-phase Local Bus voltage with respect to utility grid neutral N is marked as V_{ga}, V_{gb}, V_{gc} as shown in Figure 2. From this stage onwards, the Local Bus voltages are referred as grid voltages. In this paper the proposed three-phase VSI is implemented using four switch b-4 topology

5. SIMULATION RESULTS

The simulated results have been discussed in this session. The inverter plays a major role in this study, the switching of PWM triggers the inverter to operate in the enhanced mode. Thereby the quality of the power is improved. The voltage and current of the abc load is depicted in Figure 3. From figure it can be observed that, the voltage and current overlaps and has smaller sag in it which is lesser when compared to [15]. The voltage and current of the abc load is depicted in Figure 4. From figure it can be observed that, the voltage and current in grid has lesser harmonics and the quality

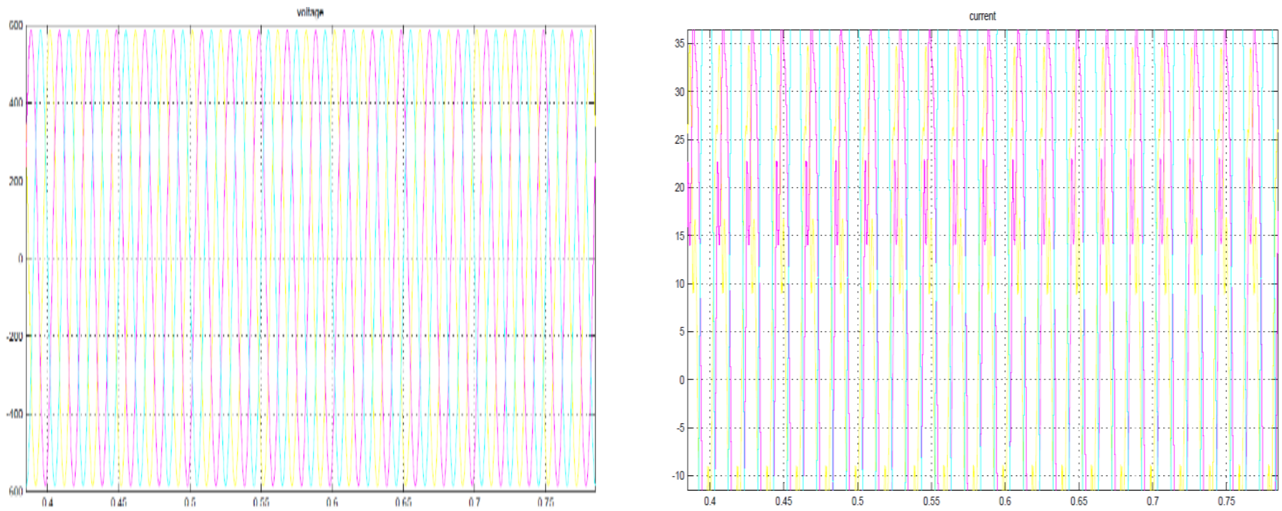

Fig. 3 The voltage and current graph for the abc load

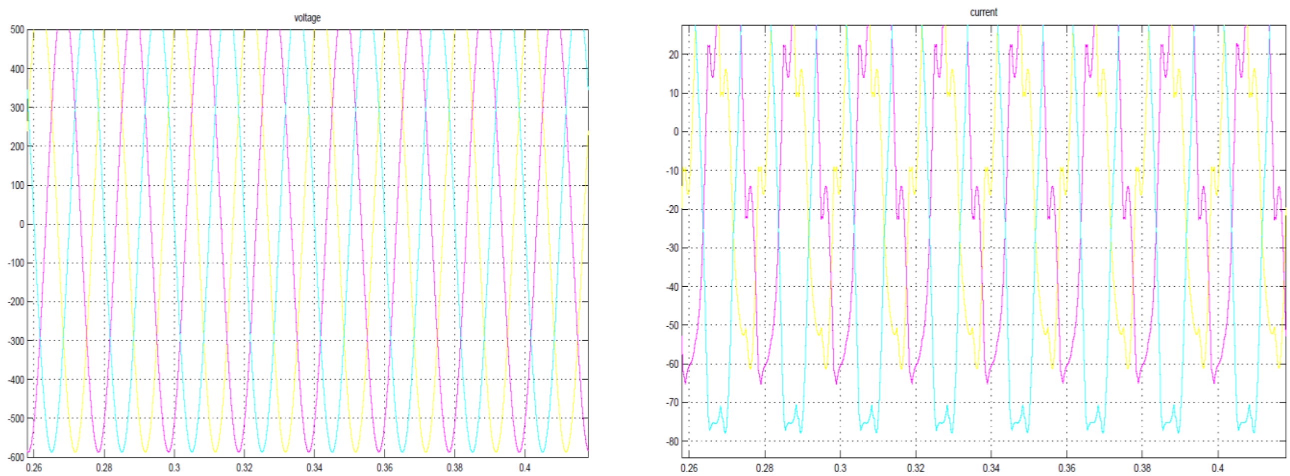

Fig. 4 The voltage and current graph for the abc grid

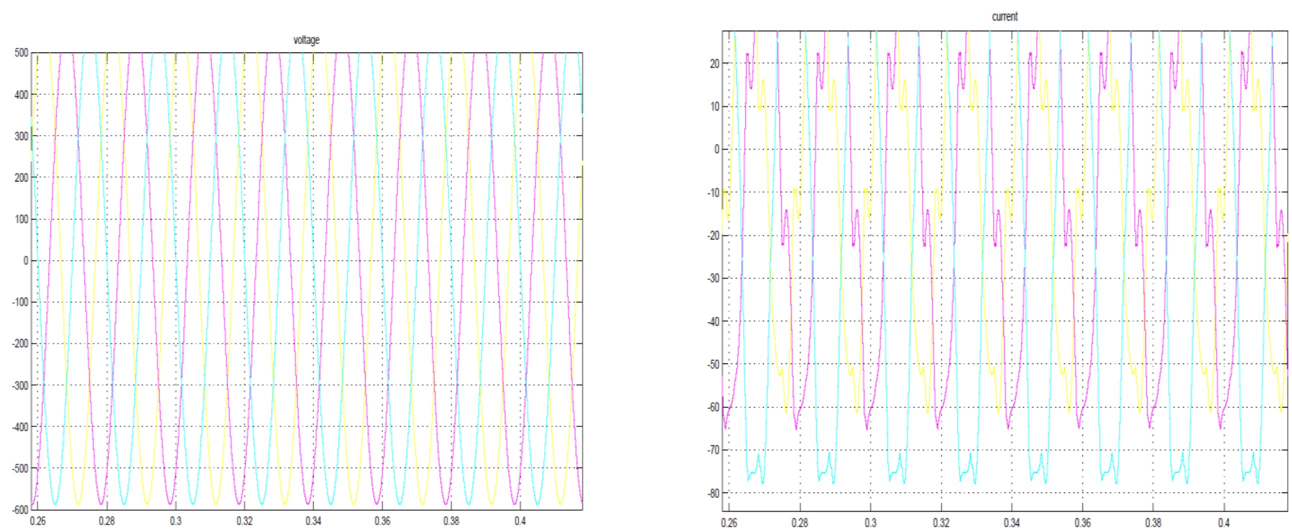

Fig. 5 The voltage and current graph for non-linear load

of the grid voltage has been enhanced to 85% when compared to earlier strategy. The non-linear load is depicted in Figure 5. From figure it can be observed that, the harmonic level has been reduced very less.

6. CONCLUSION

In this paper, the four-switch three-phase b-4 topology is applied in the grid connected application in an effort to reduce the cost of the inverter. Admittedly, this topology warrants higher voltage ratings of the semiconductor devices used and the DC link split capacitors used with respect to a conventional six-switch three-phase b-6 topology inverter for a specific set of grid voltages. For high voltage application it is expected that the inverter semiconductor switches cost more than capacitors and incremental increase in the voltage rating, while the low voltage application, the argument can be reversed. The current control of the inverter ensures proper active and reactive power flow from the grid along with grid current THD control in the presence of the non-linear load at the grid. The DC link mid-point voltage oscillation is eliminated by the proposed technique using Spatial Repetitive Controller. The proposed method described is not only quite simple with respect to the conventional four switch space vector modulations of the b-4 topology inverter but also needs no extra voltage or current sensors unlike conventional systems.

REFERENCES

1. N.V. Nho, T. H. Phuc and N. X. Bac, "Novel Carrier PWM Technique with Extension Range For 4-Switch Inverter," Proc. of the 7th International Conference on Power Electronics , Daegu, Korea, October 2007, pp. 1056-1060.
2. Grant A. Covic, Grant L. Peters and John T. Boys, "An Improved Single Phase to Three Phase Converter for Low Cost AC Motor Drives," Proc. of International Conference on Power Electronics and Drive Systems , Singapore, 1995, pp. 549 – 554.
3. Frede Blaabjerg, Sigurdur Freysson, H. Henrik Hansen and S. Hansen, "A new optimized space vector modulation strategy for a component minimized voltage source inverter," IEEE Trans. on Power Electronics , Vol. 12, No. 4, pp. 704-714, July 1997.
4. Frede Blaabjerg, Dorin O. Neacsu and John K. Pedersen, "Adaptive SVM to Compensate DC-Link Voltage Ripple for Four-Switch Three-Phase," IEEE Trans. on Power Electronics , Vol. 14, No. 4, pp. 743-752, July 1999.
5. Maurício Beltrão de Rossiter Corrêa, Cursino Brandão Jacobina, Edison Roberto Cabral da Silva and Antonio Marcus Nogueira Lima, "A General PWM Strategy for Four-Switch three phase inverter," IEEE Trans. on Power Electronics , Vol. 21, No. 6, pp. 1618-1627, Nov. 2006.
6. Tuyen D. Nguyen, Hoang M. Nguyen and Hong-Hee Lee, "An adaptive carrier-based PWM method for four-switch three-phase inverter," Proc. of IEEE International Symposium on Industrial Electronics ISIE 2009, 5-8 July 2009, pp. 1552-1557.
7. Yong Xue, Jiamei Deng and Shuangbao Ma, "Power Flow Control of a Distributed generation Unit in Micro-grid," in Proc. IEEE International Power Electronics and Motion Control Conf., 2009, pp. 2122-2125.
8. J.M. Carrasco, L.G. Franquelo, J.T. Bialasiewicz, E.G. Galvan, R.C.P. Guisado, Ma.A.M. Prats, J.I. Leon and N.M. Alfonso, "Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survay," IEEE Trans. Industrial Electronics, vol. 33, pp. 1002-1016, Aug 2006.
9. F. Blaabjerg, R. Teodorescu, M. Liserre and A.V. Timbus, "Overview of Control and Grid Synchronization for Distributed Power Generation Systems," IEEE Trans. Industrial Electronics, vol. 53, pp. 1398-1409, Oct 2006.
10. J. M. Guerrero, J. C. Vasquez, J. Matas, L. G. de Vicuna and M. Castilla, "Hierarchical Control of Droop-Controlled AC and DC MIcrogrids - A General Approach Towards Standardization," IEEE Trans. Industrial Electronics, vol. 58, pp. 158-172, Jan 2011.
11. J. M. Guerrero, J. C. Vasquez, J. Matas, M. Castilla and L. G. De Vicuna, "Control Strategy for Flexible Microgrid Based on Parallel Line-Interactive UPS Systems," IEEE Trans. Industrial Electronics, vol. 56, pp. 726-736, March 2009.
12. S.Dasgupta, S.K.Sahoo and S.K.Panda, "Single-phase inverter control techniques for interfacing renewable energy sources with micro-grid – Part I: Parallel connected inverter topology with active and reactive power flow control along with grid current shaping," IEEE Transactions on Power Electronics, vol. 26, no. 3, pp. 717-731, March 2011.
13. S.Dasgupta, S.K.Sahoo, S.K.Panda and G. A. J. Amaratunga, "Single-phase Inverter control techniques for interfacing renewable energy sources with micro-grid–Part II: Series Connected Inverter topology to mitigate voltage related problems along with active power flow control," IEEE Transactions on Power Electronics, vol. 26, no. 3, pp. 732-746, March 2011.
14. Y. Li, D. Mahinda. V. and P. C. Loh, "A Grid-Interfacing Power Quality Compensator for Three-Phase Three-Wire Microgrid Application," IEEE Trans. on Power Electronics, vol. 21, pp. 1021-1031, July 2006.
15. Tao Zhou, B. Francois, "Energy Management and Power Control of a Hybrid Active Wind Generator for Distributed Power Generation and Grid Integration " IEEE Trans. on Industrial Electronics, vol. 58, pp. 95 - 104 , Jan 2011.
16. Rodriguez. P, A. Luna, I. Candela, R. Mujal, R. Teodorescu, F. Blaabjerg, "Multiresonant Frequency-Locked Loop for Grid Synchronization of Power Converters Under Distorted Grid Conditions " IEEE Trans. On Industrial Electronics, vol. 58, pp. 127 - 138 , Jan 2011.
17. M.P. Kazmierkowski, M. Jasinski, G. Wrona, "DSP-Based Control of Grid-Connected Power Converters Operating Under Grid Distortions ," IEEE Trans. on Industrial Informatics, vol. 7, pp. 204-211, May 2011.
18. Jinwei He, Yun Wei Li, M.S. Munir, "A Flexible Harmonic Control Approach Through Voltage-Controlled DGGrid Interfacing Converters ," IEEE Trans. on Industrial Electronics, vol. 59, no. 1, pp. 444 – 455 , Jan 2012.
19. F. Gonzalez-Espin, E. Figueres, G. Garcera, "An Adaptive Synchronous-Reference-Frame Phase-Locked Loop for Power Quality Improvement in

a Polluted Utility Grid " IEEE Trans. on Industrial Electronics, vol. 59, no. 6, pp. 2718 - 2731 , June 2012.

20. G. Buticchi, D. Barater, E. Lorenzani, and G. Franceschini "Digital Control of Actual Grid-Connected Converters for Ground Leakage Current Reduction in PV Transformerless Systems", IEEE Trans. On Industrial Informatics, vol 8, no. 3, Aug 2012.
21. X.H. Wu, S. K. Panda, J. X. Xu, "Design of a Plug-in Repetitive Control Scheme for Eliminating Supply-side Current Harmonics of Three Phase PWM Boost Rectifiers Under Generalized Supply Voltage Conditions," IEEE Transactions on Power Electronics, vol. 25, pp. 1800-1810, July 2010.
22. R. Wang, J. Zhao, Y. Liu,"DC-Link Capacitor Voltage Fluctuation Analysis of Four-Switch Three-Phae Inverter," Conf. Rec. IECON, 2011 , pp. 1276-1281.
23. F. Blaabjerg, S. Freysson, H. Hansen, S. Hansen, "A new optimized space-vector modulation strategy for a component minimized voltage source inverter," IEEE Trans. Power Electron., vol. 12, no. 4, pp. 704714, Jul. 1997.
24. Frede Blaabjerg, Dorin O. Neacsu, John K. Pedersen, "Adaptive SVM to Compensate DC-Link Voltage Ripple for Four-Switch Three-Phase Voltage Source Inverters", IEEE Transactions on Power Electronics, Vol. 14, No. 4, pp. 743-752, July. 1999.
25. T. D. Nguyen, H. M. Nguyen, H. H. Lee,"An Adaptive carrier-based PWM for Four-Switch Three-Phase Inverter," Conf. Rec. ISIE, 2009 , pp. 1552-1557.
26. H. H. Lee, P. Q. Dzung, L. M. Phung, N. X. Bac,"A New Switching Techneque for Direct Torque Control of Induction Motor using Four-Switch Three-Phase Inverter with DC-Link Voltagage Imbalance," Conf. Rec. ICIT, 2009 , pp. 1-6.
27. J. S. Jang, B. G. Park, T. S. Kim, D. M. Lee, D. S. Hyun, "Sensorless Control of Four-Switch Three-Phase PMSM Drive Using Extended Kalman Filter," Conf. Rec. IECON, 2008 , pp. 1368-1372.
28. J. Kim, J. Hong, K. Nam, "A Current Distortion Compensation Scheme for Four-Switch Inverters", IEEE Trans. on Power Electronics, Vol. 24, No. 4, pp. 1032-1040, April 09