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H6 Bridge Inverter Fed Grid-Connected Photovoltaic System without Transformer

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***Abstract* —** The transformerless inverter for grid connected photovoltaic system is proposed in this paper with the intent to improve the reliability and reduce the common-mode leakage current.the proposed inverter incorporates two coupled inductors along with series connected switch on ac side that operate alternately in positive and negative half period of grid. This inverter eliminates shoot through problem which is common in NPC topologies,resulting improved system reliability. Therefore ,dead time at both switching frequency commutations and grid current zero crossing instants are not required. The coupled inductor along with series connected switch will not allow current to flow through anti-parallel diode of switches, avoding reverse recovery issues.switch such as cool MOSFETs now can be used in the proposed inverter, which increases the converter efficiency. In addition to high reliability, the proposed inverter maintains common-mode voltage at a constant level resulting low common-mode leakage current. Derivation of the full-bridge NPC inverter from existing single-phase transformer less H6 topology is presented. Other alternative full-bridge NPC inverter topology is also illustrated. The principle of operation and leakage current analysis of proposed NPC inverter are described.*In order to communicate and synchronize H6 bridge inverter fed Grid-connected photovoltaic system without transformer is implemented by using MATLAB/SIMULINK.*

***Keywords*—** *single-phase transformer less H6 topology,MOSFET$_S$ switch,PV system.*

I. INTRODUCTION

TRANSFORMERLESS single-phase inverters are popular in grid-connected photovoltaic (PV) generation especially at low power (<5kW), due to their benefits of low cost, less volume and high efficiency. Low leakage current and high reliability are the key requirements for these inverters. Without the transformer, there is a path for leakage current between the PV array and the grid. This causes the flow of high leakage current from the inverter to the ground. If the leakage current is not regulated within a reasonable margin, it can cause electromagnetic interference, safety issues and grid current distortion. Therefore, in order to minimize the leakage current high frequency common-mode voltage must be avoided in transformerless grid connected PV inverters.

The single-phase full-bridge inverter using bipolar sinusoidal pulse width modulation (SPWM) do not generate varying common-mode voltage. But, this SPWM has disadvantages of high switching losses, large current ripple in filter inductor and low conversion efficiency. In order to maintain common-mode voltage at a constant level, neutral point clamped (NPC) inverters are presented. The half-bridge neutral point clamped threelevel inverter (NPCTL), which eliminates the leakage current is presented . However, this inverter requires high input voltage and additional voltage balancing circuit to clamp freewheeling mode voltage at half the input voltage. Shootthrough issues associated with full-bridge voltage source inverter remain in half-bridge NPCTL, which reduces the system reliability. In order to eliminate shoot-through issues associated with half-bridge NPCTL, a split inductor neutral point clamped three-level inverter (SI-NPCTL) is reported in [11]. With the use of split inductor, shoot-through issue at zero crossing of grid current is eliminated. The switches such as MOSFETs are used to enhance the inverter efficiency. However, the issue of high input voltage requirement for half-bridge NPCTL inverter is not addressed in SI-NPCTL topology. The full-bridge dc bypass inverter (FBDCBP) has following features: low leakage current, low input voltage, simple structure and low switch count [12]. This inverter uses IGBT devices as main switches, which has fixed on state voltage drop characteristics. Conduction losses of this inverter are high as four switches conduct during powering period. The body diode of switches always conduct during freewheeling period, limits the use of MOSFET devices as main switches for the inverter. This is due to the fact that the slow reverse recovery of MOSFET body diode increases turn ON losses. A family of full-bridge NPC inverters are derived from positive and negative neutral point clamped switch cells in [13]. Though leakage current is reduced, the switch count of eight and their gate drives make the system complex. *H6 bridge inverter fed Grid-connected photovoltaic system without transformer* model has been implemented by using MATLAB/Simulink.

II. PROPOSED SYSTEM

In order to improve the reliability and reduce the leakage current of the transformerless inverter, a new NPC converter is derived from H6 topology shown in Fig. 1 The H6 inverter can be realized by using MOSFETs. The switch - diode pair *S*4, *D*4 and *S*3, *D*3 provide path for filter inductor current during freewheeling period in positive and negative grid half period respectively. However, the common-mode voltage during freewheeling period is not maintained at a constant level due to capacitive coupling between input and output voltage sources [9]. A variant topology for H6 inverter is shown in Fig. 2. This is obtained by connecting output terminals across the lower mid-points of H6 inverter *C, D*.

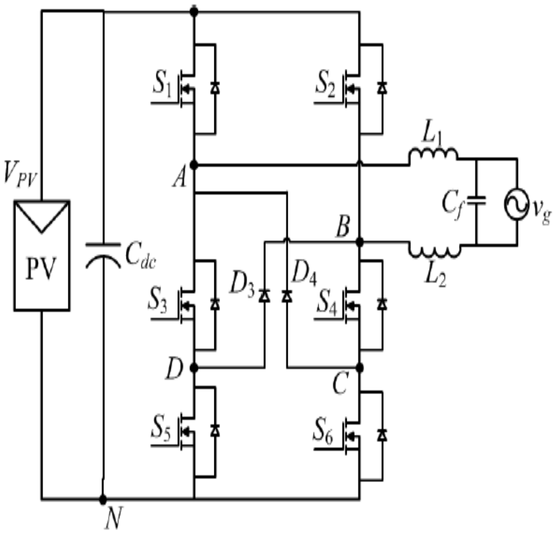


Fig. 1. H6 inverter proposed in [8].

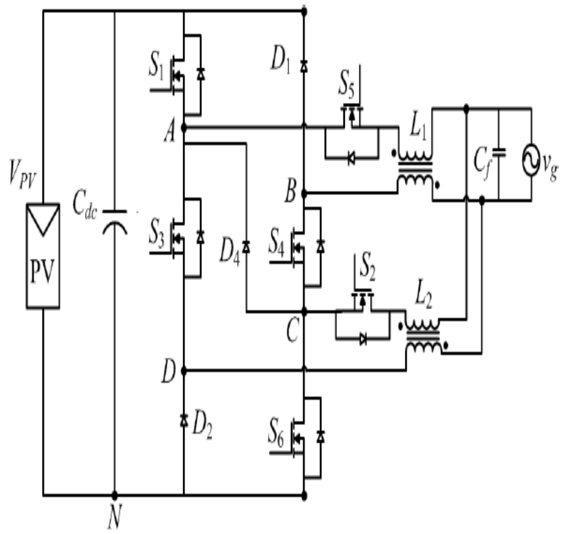


Fig. 3. Parallel H6 inverter.

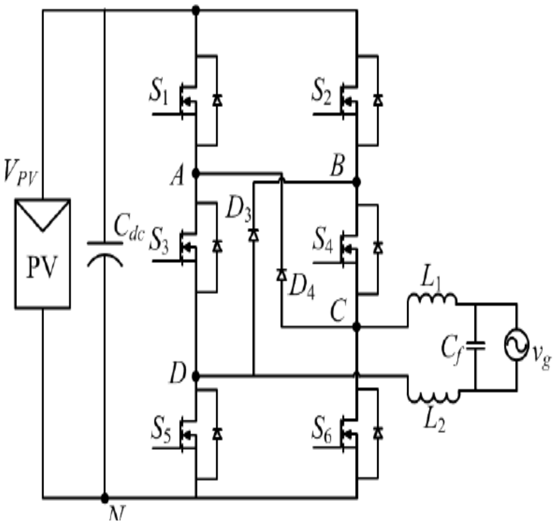


Fig 2 :varient H6 inverter

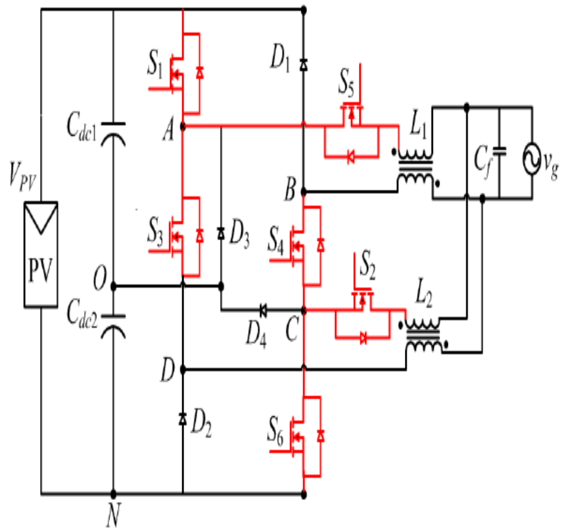


Fig 4 NPC transformerless PV inverter from H6 topolog

These inverter has low efficiency as IBGT devices are used as main switches. An optimized fullbridge neutral point clamped transformerless inverter topology is reported in [14]. In order to avoid short circuit across the upper half of dc split capacitor, sufficient dead time is provided between gate signals of switches connected across it. Therefore, the common-mode voltage during dead time period is not maintained at a constant level. This leads to high leakage current. Although, this inverter has low switch count and conduction losses, the leakage current reduction is not effective compared to the previously mentioned fullbridge NPC inverters [13], [12]. Furthermore, shoot-through issues associated with this inverter reduces the reliability of the system. This inverter has following advantages: 1) Low leakage current as commonmode voltage is maintained at a constant level, 2) High reliability due to absence of shoot-through issue, and 3) cool MOSFET devices can be used as the body diode of switches are not activated.

One of the ways to improve the reliability of transformerless grid-connected PV system is by eliminating shoot through problem in the inverter. Simulation results show that the proposed inverter eliminates leakage current and shoot-through issues.

The half-bridge neutral point clamped threelevel inverter (NPCTL), which eliminates the leakage current is presented in [10]. However, this inverter requires high input voltage and additional voltage balancing circuit to clamp freewheeling mode voltage at half the input voltage. Shootthrough issues associated with full-bridge voltage source inverter remain in half-bridge NPCTL, which reduces the system reliability.

III . NPC CONVERTER DERIVED FROM H6 TOPOLOGY:

In order to improve the reliability and reduce the leakage current of the transformerless inverter, a new NPC converter is derived from H6 topology shown in Fig. 1 The H6 inverter can be realized by using MOSFETs. The switch - diode pair *S*4, *D*4 and *S*3, *D*3 provide path for filter inductor current during freewheeling period in positive and negative grid half period respectively. However, the common-mode voltage during freewheeling period is not maintained at a constant level due to capacitive coupling between input and output voltage sources [9]. A variant topology for H6 inverter is shown in Fig. 2. This is obtained by connecting output terminals across the lower mid-points of H6 inverter *C*, *D*.

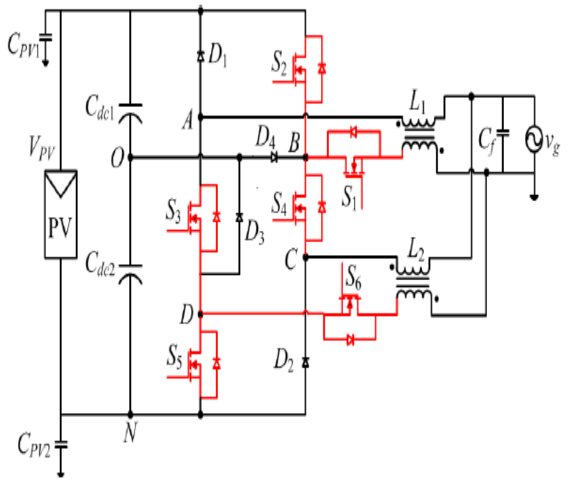


Fig 5: Proposed H6 Inverter Fed Grid-connected PV-System Without Transformer

IV . MODES OF OPERATION AND LEAKAGE CURRENT ANALYSIS OF PROPOSED NPC INVERTER:

The power stage shown in Fig. 5 is considered for analysing the modes of operation and leakage current. Fig.6 shows the unipolar SPWM scheme for the proposed NPC transformerless inverter where, *G*1,*G*6 represent gate signals for the switches *S*1,*S*6 respectively. The control signal *vcont* is obtained from current controller. The switches *S*2 and *S*5 are commutated simultaneously at switching frequency to modulate inverter output current. In the positive half cycle of grid current, *S*4, *S*6 are kept ON and *S*1, *S*3 are turned OFF. Similarly, in the negative half cycle of grid current, *S*1, *S*3 are kept ON and *S*4, *S*6 are turned OFF. Fig. 7 shows the four operating modes of the transformerless NPC inverter.

Mode 1:

This is the active mode in positive half cycle of grid current shown in Fig. 7(a). Switches *S*2, *S*4, *S*6 and *S*5 are turned ON and the remaining are turned OFF. The coupled filter inductor *L*2 is energized and current increases through *S*2, *S*4, *S*6 and *S*5. Fig. 7(c) shows the simplified leakage current model of proposed NPC inverter in the positive half cycle of grid current, with

$$v_{CM} = \frac{v_{CN} + v_{DN}}{2}, \qquad (1)$$

$$v_{DM} = v_{CN} - v_{DN}. \qquad (2)$$

Where, *vCN* and *vDN* are the potential of points *C*, *D* with respect to negative terminal *N* of PV array. Total commonmode voltage is given by

$$v_{tCM} = v_{CM} + v_{DM}\frac{L_{2C} - L_{2D}}{2(L_{2C} + L_{2D})}. \qquad (3)$$

During this active period *vCN* = *VPV* , *vDN* = 0 and *vCD* = *VPV* . In general self inductances *L*2*C*, *L*2*D* of symmetrically designed coupled inductor *L*2 are equal. Therefore, the total common-mode voltage is given by

$$v_{tCM} = \frac{v_{CN} + v_{DN}}{2} + (v_{CN} - v_{DN})\frac{L_{2C} - L_{2D}}{2(L_{2C} + L_{2D})} = \frac{V_{PV}}{2}. \qquad (4)$$

Using Kirchhoff's voltage law for the loop *vBN* - *S*1 - *L*1 - *vg*
- *vDN*, the drain - source voltage of switches *S*1, *S*3 is given
by

$$v_{S1DS} = v_{S3DS} = \frac{V_{PV} + v_g}{2} + v_{L1B} \qquad (5)$$

where, *vL*1*B* is voltage across self inductance *L*1*B*. It can be observed from (5) that the antiparallel diode of *S*1 is reverse biased and the coupled filter inductor *L*1 is not energized.

Mode 2:

This is the freewheeling mode in positive half cycle of grid current shown in Fig. 7(b). Switches *S*2 and *S*5 are turned OFF. The current flowing through *L*2 freewheels through *S*4, *S*6, *D*3 and *D*4 and the potential at points *C* and *D* is clamped at 0:5*VPV* . Therefore, *vCN* = *vDN* = 0:5*VPV* , *vCD* = 0 and the total common-mode voltage is

$$v_{tCM} = \frac{v_{CN} + v_{DN}}{2} + (v_{CN} - v_{DN})\frac{L_{2C} - L_{2D}}{2(L_{2C} + L_{2D})} = \frac{V_{PV}}{2}. \qquad (6)$$

The drain - source voltage of switches *S*1, *S*3 is given by

$$v_{S1DS} = v_{S3DS} = \frac{v_g}{2} + v_{L1B}. \qquad (7)$$

It is clear from (7) that the antiparallel diode of *S*1 is reverse biased. Therefore, the coupled filter inductor *L*1 is not energized in the positive half grid cycle.

Mode 3:

This is the active mode in negative half cycle of grid current shown in Fig. 7(d). Switches *S*2, *S*1, *S*3 and *S*5 are turned ON and the remaining switches are turned OFF. The coupled filter inductor *L*1 is energized and current increases through *S*2, *S*1, *S*3 and *S*5. Fig. 7(f) shows the simplified leakage current model of proposed NPC inverter in the negative half cycle of grid current, with

$$v_{CM} = \frac{v_{AN} + v_{BN}}{2}, \quad (8)$$

$$v_{DM} = v_{AN} - v_{BN}. \quad (9)$$

Where, *vAN* and *vBN* are the potential of points *A*, *B* with respect to negative terminal *N* of PV array. Total commonmode
voltage is described as

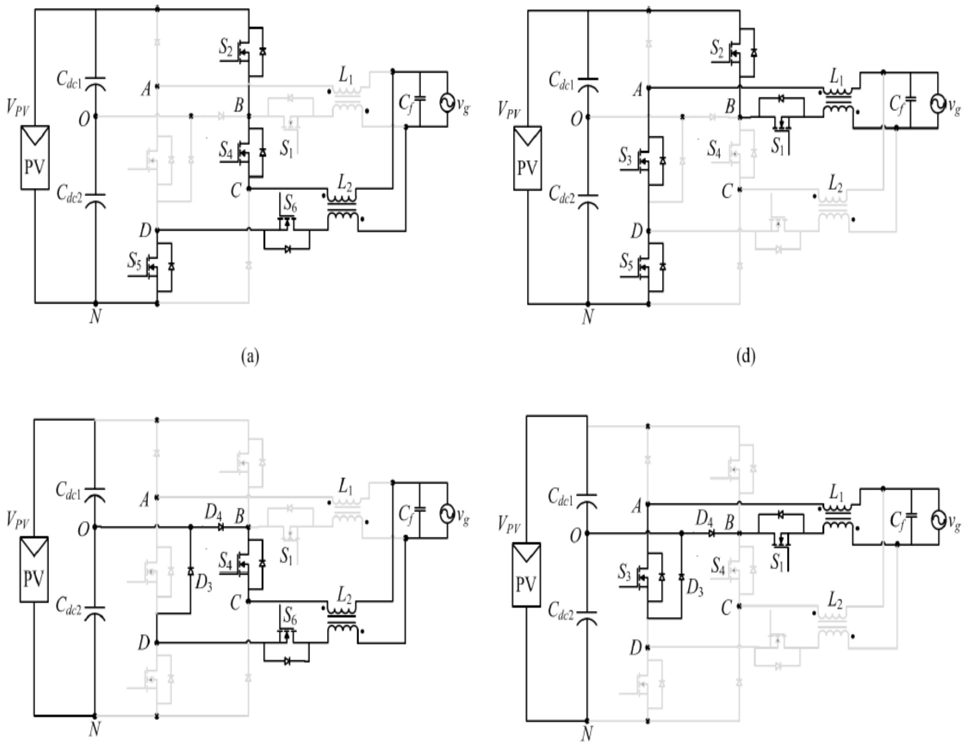
$$v_{tCM} = v_{CM} + v_{DM}\frac{L_{1A} - L_{1B}}{2(L_{1A} + L_{1B})} \quad (10)$$

$$v_{tCM} = \frac{v_{AN} + v_{BN}}{2} + (v_{AN} - v_{BN})\frac{L_{1A} - L_{1B}}{2(L_{1A} + L_{2B})} = \frac{V_{PV}}{2}. \quad (11)$$

During this active period the drain - source voltage of switches *S*4, *S*6 using Kirchhoff's voltage law is given by

$$v_{S4DS} = v_{S6DS} = \frac{V_{PV} + v_g}{2} + v_{L2C} \quad (12)$$

where, *vL2C* is the voltage across the self inductance *LL2C*.



(a) (d) (b) (e)

Mode 4:

This is the freewheeling mode in negative half cycle of grid current shown in Fig. 7(e). Switches *S*2 and *S*5 are turned OFF. The coupled filter inductor *L*1 current freewheels through *S*1, *S*3, *D*3 and *D*4 and the potential at points *A* and *B* is clamped at 0:5*VPV* . Therefore, *vAN* = *vBN* = 0:5*VPV* , *vAB* = 0 and the total common-mode voltage is

$$v_{tCM} = \frac{v_{AN} + v_{BN}}{2} + (v_{AN} - v_{BN})\frac{L_{1A} - L_{1B}}{2(L_{1A} + L_{1B})} = \frac{V_{PV}}{2}. \quad (13)$$

The drain - source voltage of switches during this period is given by

$$v_{S4DS} = v_{S6DS} = \frac{v_g}{2} + v_{L2C}. \quad (14)$$

It is clear from (12) and (14) that the antiparallel diode of *S*4 is reverse biased. Therefore, the coupled filter inductor *L*2 is not energized in the negative grid half period. It can be observed from (4), (5), (9) and (10) that the total commonmode voltage is maintained at 0:5*VPV* in all operating modes. Therefore, the common-mode resonant circuits shown in Fig. 2(c) and 2(f) are not activated and leads to low leakage current. In the positive half cycle of grid current *Mode1* and *Mode 2* are used to generate *VPV* and 0 at the output. In the negative half cycle of grid current -*VPV* , 0 are generated by continuously switching between *Mode 3* and *Mode 4*. The voltage stress on *S*2, *S*5 is equal to half of the input voltage and for remaining switches is equal to input voltage.

Table 1:
PARAMETERS OF NPC INVERTER :

Parameters	Values
Rated power	2:2*Kw*
Input voltage	380*V*
Switching frequency	20*kHz*
Coupled filter inductor *L*1, *L*2	1*mH*
Filter capacitor *Cf*	5*uF*
DC link capacitor *CDC*1, *CDC*2	940*uF*
Grid voltage/frequency	230*V*=50*Hz*
PV stray capacitor *CPV* 1,*CPV* 2	0:1*uF*

V . SIMULATION RESULT:

In order to validate the theoretical analysis of the proposed NPC inverter, a simulation setup of transformerless PV system for 2.2kW is designed. The MOSFET devices are used as main switches for the proposed NPC inverter. The simulation studies are carried out considering the parasitic capacitance of switches. The parasitic capacitance of power switches *S*1□*S*6 obtained from the data sheet of IPW60R041C6 as 110pF. It can be seen that *vCM* is maintained at a constant voltage level of 190V. This is due to fact that the voltages *vBN*, *vDN* are clamped to half of the input voltage during freewheeling period using diode neutral point clamp circuit. Therefore, the oscillations in *vBN*, *Vdn* during freewheeling period are eliminated. With the absence of oscillations during freewheeling period, the voltage across stray capacitances *CPV* 1, *CPV* 2 has grid frequency component as shown.

The simulated waveforms of the differential-mode voltage; *vDM*, the grid current; *ig* and the leakage current; *iCM* are shown The leakage current is low and its peak is limited less than 20mA. Therefore, distortion in the grid current is minimized. The proposed inverter operates at nearly unity power factor, which is verified from the simulation results of *vDM* and *ig*.

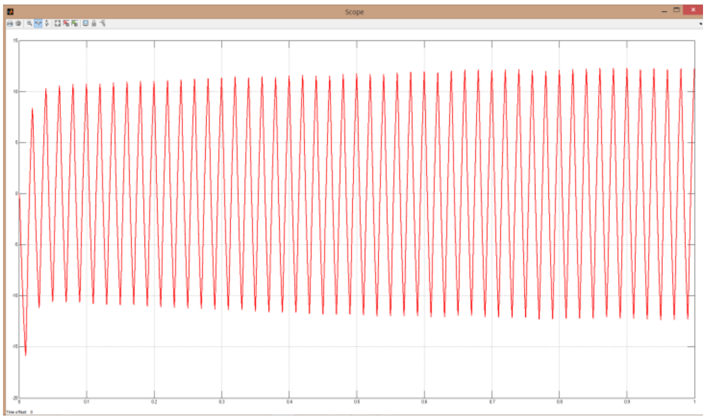


Fig 6 : proposed simulation

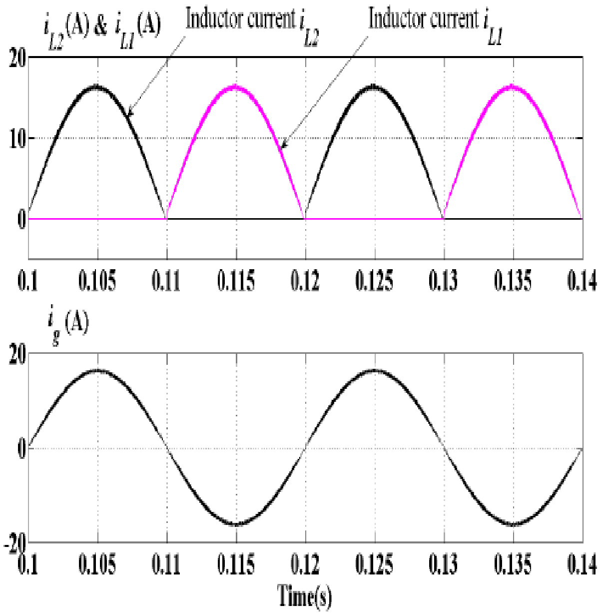


Fig 7 : Simulation results of inductor currents; *iL*2, *iL*2 and grid current i_g.

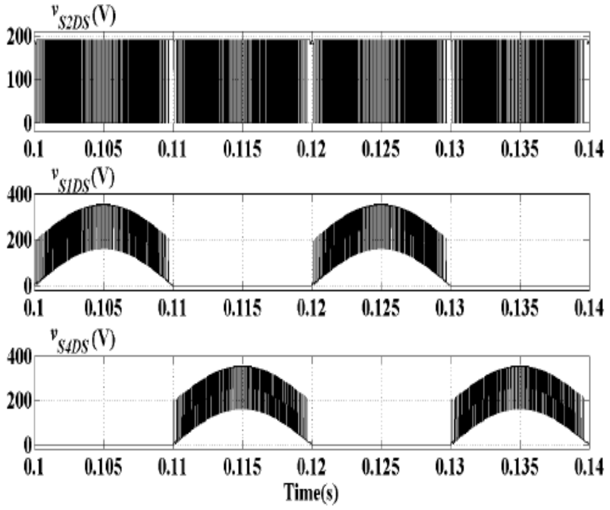


Fig 8: Drain-source voltage of switchs;s2,s1and s4

CONCLUSION

A novel full-bridge single-phase NPC transformerless gridconnected inverter is presented in this paper. A systematic derivation of the NPC inverter from existing H6 topology is presented. Using positive and negative group switch cell, a new NPC transformerless inverter is proposed. The performance of the proposed NPC inverter is ascertained through simulation studies at peak power rating of 2.2kW. The simulation results support the following features of proposed NPC inverter : 1) low leakage current as the common-mode voltage is maintained at a constant level using diode neutral point clamp circuit; 2) no shoot-through issues leads to improved system reliability; 3) MOSFETs can be used for all switches as body diode of switches are not activated; 4) low grid current distortion; 5) low input voltage is required due to its full bridge structure. With low leakage current, high reliability, low input voltage requirement and better quality of grid current, the proposed NPC topology is an attractive option for transformerless grid connected PV system.

References

[1] S. B. Kjaer, J. K. Pedersen, F. Blaabjerg, “A review of single-phase gridconnected inverters for photovoltaic modules,” *IEEE Trans. Ind. Appl.*, vol. 41, no. 5, pp. 1292 - 1306, Sep/Oct. 2005.

[2] Y. Xue, L. Chang, S. B. Kjaer, J. Bordonau, and T. Shimizu, “Topologies of single-phase inverter for small power generators: An overview,” *IEEE Trans. Power Electron.*, vol. 19, No. 6, pp. 1305 - 1314, Sep. 2004.

[3] Q. Li, P. Wolfs, “A review of the single phase photovoltaic module integrated topologies with three different DC link configurations,” *IEEE Trans. Power Electron.*, vol. 23, no. 3, pp. 1320 - 1333, May. 2008.

[4] T. Kerekes, R. Teodorescu, and U. Borup, “Transformerless photovoltaic inverters connected to the grid,” in *Proc. IEEE Appl. Power Electron. Conf .*, Anaheim, CA, pp. 1733 - 1737, Feb. 2007.

[5] H. Xiao and S. Xie, “Leakage current analysis model and application in single-phase transformerless photovoltaic grid-connected inverter,” *IEEE Trans. Electromagn. Compat.*, vol. 52, no. 9, pp. 2202 - 2211, Sep. 2009.

[6] M. Victor, F. Greizer, S. Bremicker, and U. Hubler, “Method of converting a direct current voltage from a source of direct current voltage, more specifically from a photovoltaic source of direct current voltage, into a alternating current voltage,” DE Patent DE102004030912 (B3), Jan. 1, 2006.

[7] H. Schmidt, S. Christoph, and J. Ketterer, “Current inverter for direct/ alternating currents, has direct and alternating connections with an intermediate power store, a bridge circuit, rectifier diodes and a inductive choke,” DE Patent DE10221592 (A1), Dec. 04, 2003.

[8] W. Yu, J. S. Lai, H. Qian, and C. Hutchens, “High-efficiency MOSFET inverter with H6-type configuration for photovoltaic nonisolated ACmodule applications,” IEEE Trans. Power Electron., vol. 26, no. 4, pp. 1253 - 1260, Apr. 2011.

[9] B. Yang, W. Li, Y. Gu, W. Cui, and X. He, “Improved transformerless inverter with common-mode leakage current elimination for a photovoltaic grid-connected power system,” *IEEE Trans. Power Electron.*, vol. 27, no. 2, pp. 752 - 762, Feb. 2012.

[10] R.Gonzalez, E. Gubia, J. Lopez, and L.Marroyo, “Transformerless singlephase multilevel-based photovoltaic inverter,” *IEEE Trans. Ind. Electron.*, vol. 55, no. 7, pp. 2694 - 2702, Jul. 2008.

[11] H. Xiao and S. Xie, “Transformerless split-inductor neutral point clamped three-level PV grid-connected inverter,” *IEEE Trans. Power Electron.*, vol. 27, no. 4, pp. 1799 - 1808, Apr. 2012.

[12] R. Gonzalez, J. Lopez, P. Sanchis, and L. Marroyo, “Transformerless inverter for single-phase photovoltaic systems,” *IEEE Trans. Power Electron.*, vol. 22, no. 2, pp. 639 - 697, Mar. 2007.

[13] Z. Li, K. Sun, L. Feng, H. Wu and Y. Xing, “A Family of neutral point clamped full-bridge topologies for transformerless photovoltaic grid-tied inverters,” *IEEE Trans. Power Electron.*, vol. 28, no. 2, pp. 730 - 739, Feb. 2013.

[14] H. Xiao, S. Xie, Y.Chen, and R. Huang, “An optimized transformerless photovoltaic grid-connected inverter.” *IEEE Trans. Ind. Electron.*, vol.no. 5, pp. 1887 - 1895, May. 2011.