International Journal of Engineering Innovation & Research
Volume 3, Issue 3, ISSN: 2277 – 5668

An Effective Control Strategy for Ground Leakage Current Suppression in Photovoltaic Array Converters

Majid Pakdel
Electrical Engineering Department,
University of Zanjan, Zanjan, Iran
Email: pakdel@mail.ru

Saeid Jalilzadeh
Electrical Engineering Department,
University of Zanjan, Zanjan, Iran
Email: jalilzadeh@znu.ac.ir

***Abstract* – One of the major problems of solar photovoltaic panels is capacitive ground current. Because of the bulk size, higher cost and lower efficiency due to using transformer to solve the problem so in this paper a transformer-less inverter topology and a proper control strategy is proposed to suppress the ground leakage current caused by inverter switching and varying common mode voltages. The operation of the proposed topology and control strategy is simulated using Cadence ORCAD software and a prototype of experimental circuit elements and PCB of the proposed topology and control strategy is designed and implemented using Proteus software.**

***Keywords* – Ground Leakage Current, Photovoltaic Array Converters, Control Strategy, Microcontroller, Proteus.**

I. INTRODUCTION

Renewable energy sources are common issues in relation with energy problems. Photovoltaic array converters are more dominant among them because of theirs availability and reliability [1]. Transformer used in photovoltaic systems is large in size and very difficult to assemble in the whole photovoltaic system. Furthermore, the cost is higher and led to a lower efficiency due to higher loss of power [2]. In the absence of transformer due to the PV panel parasitic capacitance the common mode voltage forming leakage currents flowing through stray capacitor between the PV array and the ground [3]. In order to prevent common mode currents, various inverter topologies have been proposed [4-11]. With declining ground leakage current it ensures that no continuous current is injected into the grid and also increases the inverter output voltage level. Photovoltaic application in single phase grid connected photovoltaic system allows the possibility of eliminating the implementation of transformer [12]. According to [13], leakage current tends to flow through the resonant circuit which consists of DC source (photovoltaic array), input and output filter, inverter, parasitic ground capacitance and grid impedance as shown in Fig.1.

In this paper a transformer-less inverter topology and a proper control strategy is proposed to suppress the ground leakage current caused by inverter switching and varying common mode voltages. The operation of the proposed topology and control strategy is simulated using Cadence ORCAD software and a prototype of experimental circuit elements and PCB of the proposed topology and control strategy is designed and implemented using Proteus software.

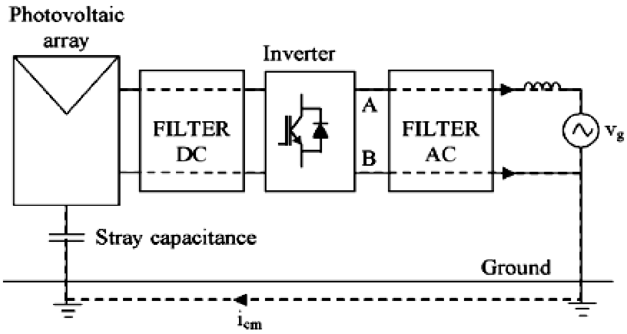


Fig.1. Leakage current flow in photovoltaic array converter

II. PROPOSED TOPOLOGY AND CONTROL STRATEGY

A. Proposed Topology

A full-bridge topology with a modified DC Decoupling block was proposed in [14] is used in this study, where two switches are added in series to the DC Link. Two diodes are connected in full-bridge converter as shown in Fig. 2. T5 and T6 supply the DC Link voltage. During the positive half cycle T1, T4 and T5 are on and during the negative half cycle T2, T3 and T6 are on.

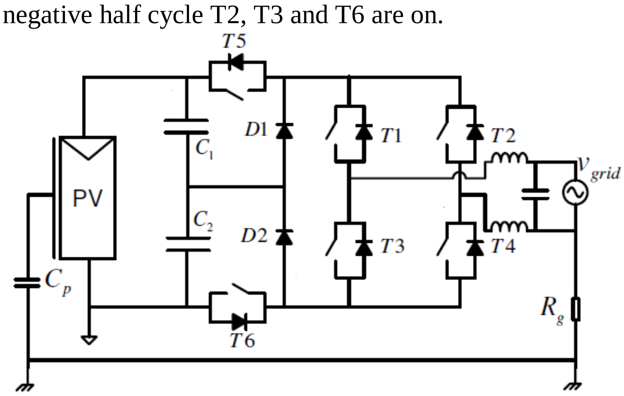
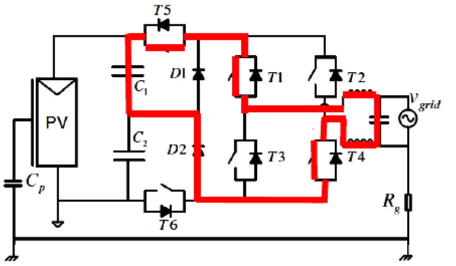


Fig.2.The proposed topology

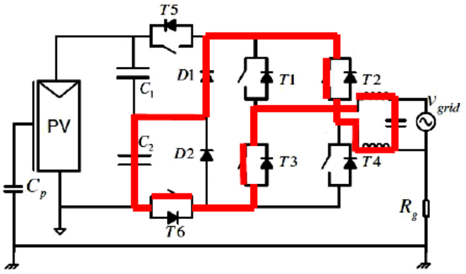
B. Control Strategy

As discussed earlier there are two modes of operation in the proposed topology i.e. during the positive half cycle T1, T4, T5 and D2 are on and during the negative half cycle T2, T3, T6 and D1 are on. The current flow route in two modes of operation is shown in Fig. 3.

International Journal of Engineering Innovation & Research
Volume 3, Issue 3, ISSN: 2277 – 5668



Mode I



Mode II

Fig.3. Operation modes of proposed PV array converter

III. Simulation Results

The operation of proposed topology and control strategy of the photovoltaic array converter is simulated using Cadence ORCAD software. The implemented circuit is shown in Fig. 4. MOSFET switches (IRF840) gate driver signals is shown in Fig.5. The MOSFET drain and diode currents are depicted in Fig.6. Currents flowing through capacitors C1 and C2 are shown in Fig.7.

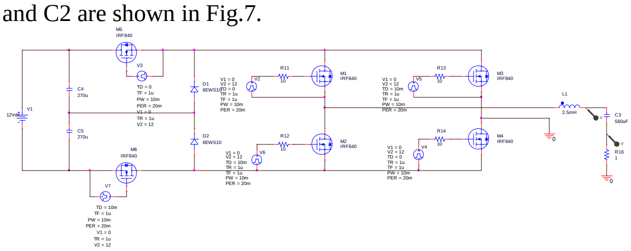


Fig.4. Proposed PV array converter topology in Cadence ORCAD software environment

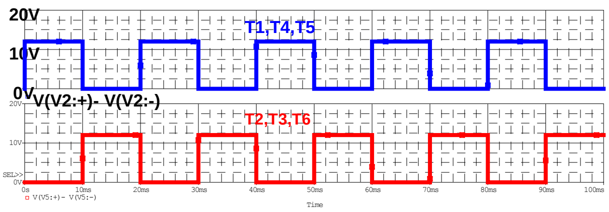


Fig.5. MOSFET switches gate driver signals: T1, T4, T5 (top) and T2, T3, T6 (down)

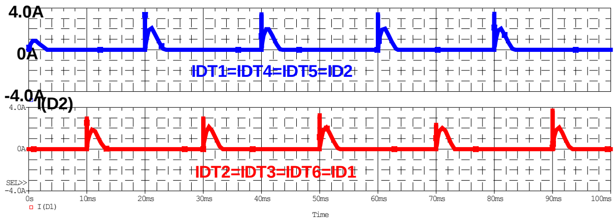


Fig.6. MOSFET drain currents: IDT1=IDT4=IDT5=ID2 (top) and IDT2=IDT3=IDT6=ID1 (down)

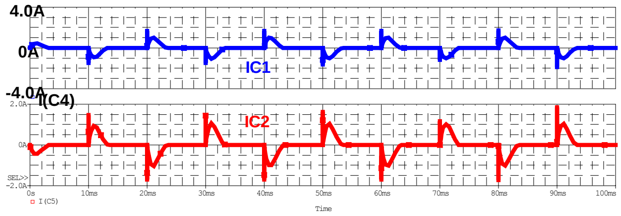


Fig.7. Capacitors C1 and C2 currents

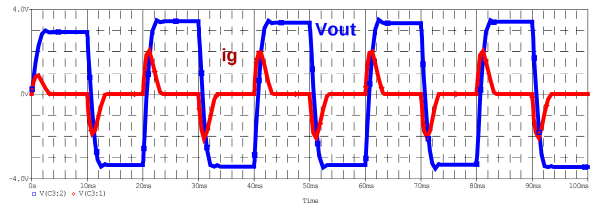


Fig.8. Output voltage and ground leakage current of proposed PV array converter

The output voltage and ground leakage current of proposed photovoltaic array converter are given in Fig. 8. To compare the effectiveness and ability of the proposed photovoltaic array topology and control strategy in suppressing ground leakage current the conventional inverter bridge is considered as depicted in Fig. 9. The output voltage and ground leakage current of conventional photovoltaic array converter are shown in Fig. 10. With comparing Fig. 8 and Fig. 10 signal waveforms it is concluded that the proposed topology and control strategy for photovoltaic array converter is very effective and suitable in ground leakage current suppressing.

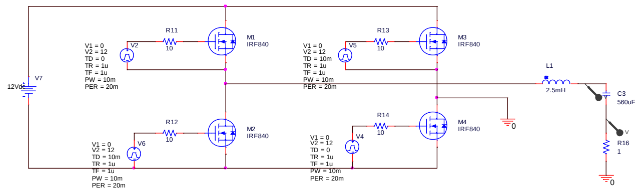


Fig.9. Conventional PV array converter topology

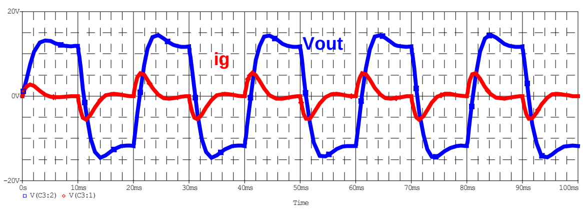


Fig.10. Output voltage and ground leakage current of conventional PV array converter

IV. Experimental Prototype

An experimental prototype of the proposed topology and control strategy is designed and implemented using Proteus software as shown in Fig. 11. MOSFET switches are IRF840 and IR2112 is used as MOSFET gate driver. A PIC microcontroller (PIC16F88) is used for generating MOSFET gate signals which are applied to MOSFET gate driver (IR2112). The C program code and resulted Hex program code of PIC16F88 microcontroller are given in appendix. C1 and C2 values are 270 μF also Lout is chosen as 2.5 mH and Cout is selected as 560 μF. Frequency of two generated square pulses with PIC16F88 microcontroller is 50 Hz. The PCB layout of proposed topology and control strategy for photovoltaic array converter with two layers (red copper route is top layer and blue copper route is bottom layer) is shown in Fig. 12 and 3D visualization of all circuit elements in proposed topology and control strategy of photovoltaic array converter is depicted in Fig.13.

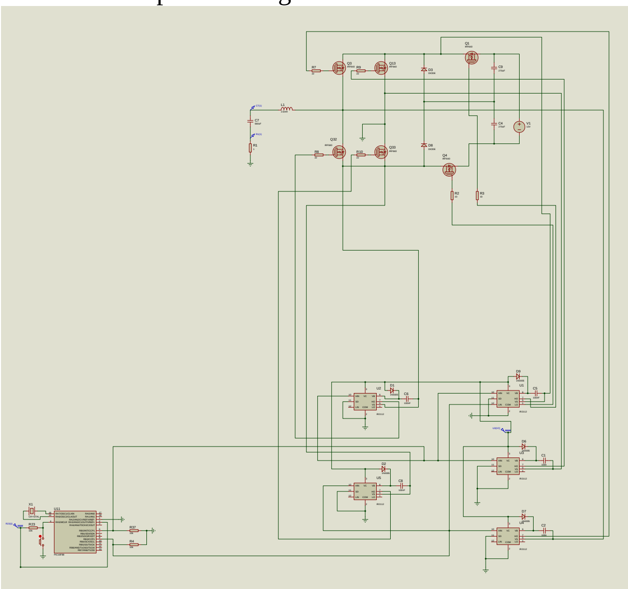


Fig.11. An experimental prototype of the proposed topology and control strategy using Proteus software

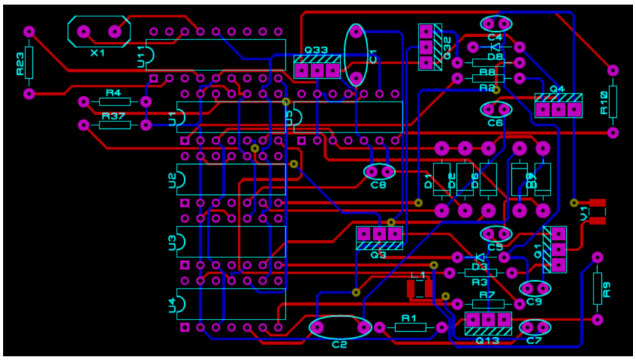


Fig.12. The PCB layout of proposed topology and control strategy for photovoltaic array converter with two layers

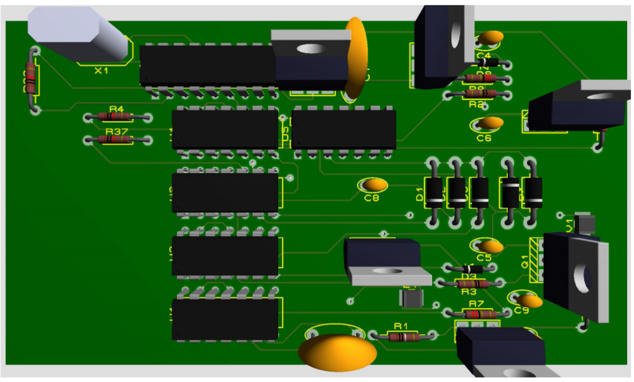


Fig.13. 3D visualization of all circuit elements

IV. Conclusion

In this paper a transformer-less inverter topology and a proper and effective control strategy was proposed to suppress the ground leakage current caused by inverter switching and varying common mode voltages. The operation of the proposed topology and control strategy was simulated using Cadence ORCAD software and a prototype of experimental circuit elements and PCB of the proposed topology and control strategy was designed and implemented using Proteus software. The simulation results justified the effectiveness and proper operation of the novel control strategy applied to the photovoltaic array converter.

Appendix

A. C Program Code

```
#define MX_PIC
//Defines for microcontroller
#define P16F88
#define MX_EE
#define MX_EE_TYPE2
#define MX_EE_SIZE 256
#define MX_SPI
#define MX_SPI_B
#define MX_SPI_SDI 1
#define MX_SPI_SDO 2
#define MX_SPI_SCK 4
#define MX_UART
#define MX_UART_B
#define MX_UART_TX 5
#define MX_UART_RX 2
#define MX_I2C
#define MX_I2C_B
#define MX_I2C_SDA 1
#define MX_I2C_SCL 4
#define MX_PWM
#define MX_PWM_CNT 1
#define MX_PWM_TRIS1 trisb
#define MX_PWM_1 0
#define MX_PWM_TRIS1a trisb
#define MX_PWM_1a 3

//Functions
#define MX_CLK_SPEED 4000000
#ifdef _BOOSTC
#include <system.h>
#endif
#ifdef HI_TECH_C
#include <pic.h>
#endif

//Configuration data
#ifdef _BOOSTC
#pragma DATA 0x2007, 0x3f2a
#endif
#ifdef HI_TECH_C
__CONFIG(0x3f2a);
#endif
#ifdef _BOOSTC
#pragma DATA 0x2008, 0x3ffc
#endif
#ifdef HI_TECH_C
__CONFIG(0x3ffc);
#endif

//Internal functions
```

```
#include "E:\Program Files\Matrix Multimedia\Flowcode V4\FCD\internals.h"

//Macro function declarations
//Variable declarations
//Macro implementations

void main()
{

    //Initialisation
    ansel = 0;
    cmcon = 0x07;
    //Interrupt initialisation code
    option_reg = 0xC0;

    //Loop
    //Loop: While 1
    while (1)
    {
        //Output
        //Output: 1 -> B0
        trisb = trisb & 0xfe;
        if (1)
            portb = (portb & 0xfe) | 0x01;
        else
            portb = portb & 0xfe;

        //Output
        //Output: 0 -> B3
        trisb = trisb & 0xf7;
        if (0)
            portb = (portb & 0xf7) | 0x08;
        else
            portb = portb & 0xf7;

        //Delay
        //Delay: 10 ms
        delay_ms(10);

        //Output
        //Output: 0 -> B0
        trisb = trisb & 0xfe;
        if (0)
            portb = (portb & 0xfe) | 0x01;
        else
            portb = portb & 0xfe;

        //Output
        //Output: 1 -> B3
        trisb = trisb & 0xf7;
        if (1)
            portb = (portb & 0xf7) | 0x08;
        else
            portb = portb & 0xf7;

        //Delay
        //Delay: 10 ms
        delay_ms(10);

    }

    mainendloop: goto mainendloop;
}

void MX_INTERRUPT_MACRO(void)
{
}
```

B. Hex Program Code

```
:02000000502886
:08000800FF00030E8312031335
:10001000B4000A0EB500040EB6008A110A12782840
:10002000C208031D14280800F930FF3E031D1528DF
:100030000000C20B14280800831603139B0107302D
:100040009C00C0308100FE30831606058600FE301D
:1000500083120605C200013042048600F730831681
:1000600006058600F7308312060586000A30C200B6
:100070001020FE30831606058600FE30831206052A
:100080008600F730831606058600F73083120605D2
:10009000C2000830420486000A30C2001020232823
:1000A000D53083120313A000C430A100BB30A200DE
:1000B000DC30A300A401A501A601A701A801A901A4
:1000C000AA01AB01AC01AD01AE01AF01BC01BD01A4
:1000D000B701B801BE01BF01C001C101B001B1014A
:1000E000B201B301BA01BB01B9018A110A121C287D
:1000F00083120313360E8400350E8A00340E8300FB
:06010000FF0E7F0E090056
:02400E002A3F47
:02401000FC3F73
:00000001FF
```

REFERENCES

[1] Roberto Gonzalez, Lopez, Pablo Sanchis, Gubia, Alfredo Ursua (2006), High-Efficiency Transformerless Single-phase Photovoltaic Inverter, *PowerElectronics and Motion Control Conference, EPE-PEMC*, pp. 1895-1900.

[2] Fen Tang, Fei Zhou, Xinmin Jin, Yibin Tong (2008), Leakage Current Analysisof a Single-Phase Transformer-less PV Inverter Connected to the Grid, *Sustainable Energy Technologies, ICSET 2008. IEEE International Conference*, pp. 285-289.

[3] Pankaj H zope, Pravin G.Bhangale, S.R.Suralkar (2012), Design and Implementation of Carrier Based Sinosoidal PWM (Bipolar) Inverter, *International Journal of Science and Research (IJSR), Indian Online ISSN:2319-7064*, pp.129-133.

[4] Barater, D. ; Buticchi, G. ; Crinto, A.S. ; Franceschini, G, "A new proposal for ground leakage current reduction in transformerless grid-connected converters for photovoltaic plants", 35th Annual Conference of IEEE Industrial Electronics (IECON '09), pp. 4531-4536, 2009.

[5] Garg, A. ; Rajasekar, S. ; Gupta, R. "A new modulation technique to eliminate leakage current in transformerless PV inverter", Students Conference on Engineering and Systems (SCES), pp. 1-6, 2013.

[6] Hao Huang; Wenjie Chen ; Xiaomei Song, "Improved modulation techniques to eliminate leakage ground currents in three-phase photovoltaic systems", 29th Annual IEEE Applied Power Electronics Conference and Exposition (APEC), pp. 2741-2745, 2014.

[7] A. Asaph, Dr. P. Selvan, " Design of Solar Power Optimizer And Eliminating Leakage Current In Multi-Level Inverter For PV Systems", International Journal of Emerging Technology and Advanced Engineering, Vol. 4, Issue 4, April 2014.

[8] S.Rajalakshmi, P.S.Ragavendran, "Leakage Current and Harmonic Reduction in Transformerless Grid Connected PV Systems", International Journal of Engineering and Technical Research (IJETR), ISSN: 2321-0869, Volume-2, Issue-4, April 2014.

[9] Wensong Yu, Jih-Sheng Lai, Hao Qian, and C. Hutchens. "High-Efficiency MOSFET Inverter with H6-Type Configuration for Photovoltaic Nonisolated AC-Module Applications". *IEEE Transactions on Power Electronics*, 26(4):1253–1260, April 2011.

[10] B. Gu, J. Dominic, J. Lai, C. Chen, and B. Chen. "High Reliability and Efficiency Single-Phase Transformerless Inverter for Grid-Connected Photovoltaic Systems". *IEEE Transactions on Power Electronics*, 57(9):3118 –3128, May 2013.

[11] Xiao Huafeng, Xie Shaojun, Chen Yang, and Ruhai Huang. "An Optimized Transformerless Photovoltaic Grid Connected Inverter". *IEEE Transactions on Industrial Electronics*, 58(5): 1887 –1895, May 2011.

[12] A.M. Trzynadlowski (1998), Introduction to modern power electronics, *John Wiley & Sons, Inc. ISBN 0-471-15303-6*.

[13] Remus Teodorescu, Marco Liserre, Pedro Rodriguez (2011) "Grid Converter for Photovoltaic and Wind Power Systems", *John Wiley & Sons, Ltd*, pp.21-23.

[14] R. Gonzalez, J. Lopez, P. Sanchis, and L.Marroyo. Transformerless Inverter for Single-Phase Photovoltaic Systems. *IEEE Transactions on Power Electronics*, 22(2):693 –697, March 2007.

AUTHOR'S PROFILE

Majid Pakdel
was born in Mianeh, Iran, 1981. He received his B.Sc. and M.Sc. degrees from Amirkabir University of Technology and Isfahan University of Technology, Iran, in 2003 and 2006, respectively all in electrical engineering. He is currently the Ph.D. student in department of electrical engineering, University of Zanjan, Zanjan, Iran. His research interests include power electronics, power system quality and renewable energies.

Saeid Jalilizadeh
was born in Salmas, Iran, 1962. He received his B.Sc. and M.Sc. degrees from Tabriz University, Iran, in 1986 and 1991, respectively and the PhD degree from Iran University of Science and Technology (IUST), Tehran, Iran, 2006 all in electrical engineering. He is currently the associate professor in department of electrical engineering, University of Zanjan, Zanjan, Iran. His research interests include renewable energies, power system planning, power system quality, power system dynamics and stability analysis.