ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 6, April 2017

Common-mode voltage compensation technique for the removal of ground leakage current in PV grid connected inverters

Reshma B.
M.Tech, Power System & Control
Govt. Engineering College, Barton Hill, Thiruvananthapuram
Kerala, India

Remya Mol N.
Assistant Professor
Govt. Engineering College, Barton Hill, Thiruvananthapuram,
Kerala, India

Lekshmi Sree
Lecturer
Govt. Engineering College, Barton Hill, Thiruvananthapuram,
Kerala, India

***Abstract*— This paper proposes an active common-mode filter for the compensation of common-mode voltage in PV grid connected inverters driven by unipolar PWM.As a result the ground leakage current in transformerless grid connected PV system is minimized.At first a comparison study is done on bipolar and unipolar PWM.The paper relies on using an active filter followed by common-mode transformer able to compensate the variations of output common mode voltage.Design considerations of common-mode transformer is presented.Control strategy implemented is also explained.Simulation of proposed scheme was done in MATLAB simulink and results are obtained.Ground leakage current was reduced to 14mA .**

***IndexTerms*—Activefilter,common-mode transformer,leakage current**

INTRODUCTION

IN the last decade, a large number of photovoltaic (PV) systems were built worldwide. The first designs of PV grid connected converters featured a line-frequency transformer,which ensured the galvanic separation of the PV field from the grid. In the last years, research on single-phase photovoltaic grid-connected converters has been focused on the use of dc-dc power conversion stages based on high-frequency transformers or transformerless topologies. The latter solution is preferred by most power converter manufacturers since it allows to reduce the costs and increase converter efficiency.

However, the absence of galvanic isolation enables an increase in the ground leakage current circulating in the PV system because of the parasitic capacitance of the photovoltaic field.

This paper evaluates the ground current in a full-bridge single-phase transformerless inverter connected to the grid .Ground voltage and currents were measured in a 3.8-kW PV installation using unipolar and bipolar modulation strategies.

Ground current differences between both strategies are discussed.

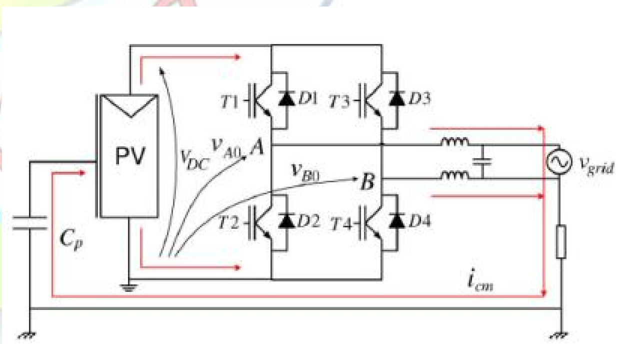

Fig. 1. Common-mode current path in a transformerless grid connected converter based on Full Bridge topology

The ground leakage current is a common-mode current, and its path in a full-bridge transformerless converter is shown in Fig 1. In this kind of power converter topology, the increase of this common-mode current is caused by the variations of the common-mode voltage at the output of the full-bridge converter i.e.,

$$v_{cm} = \frac{v_{A0} + v_{B0}}{2} \quad (1)$$

As per international regulations leakage current has to be less than 300mA or else the system needs to be

All Rights Reserved © 2017 IJARTET

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 6, April 2017

disconnected from the grid.

A simple method to mitigate the ground leakage current was proposed in [1]. It relies on the use of a passive common-mode filter where the capacitors are connected to the midpoint of the dc source, as shown in Fig. 2. This solution can determine good results in terms of power converter cost and efficiency when the variation of *vcm* (due to power converter switching) is limited.

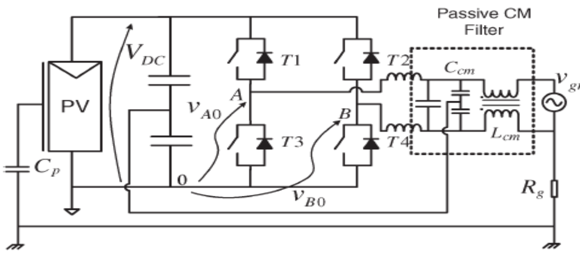

Fig.2.Passive common-mode filtering for ground leakage currents.

Fig. 3 shows the needed additional power switches for three topologies based on the same philosophy: the disconnection of the grid from the photovoltaic string during the freewheeling phases of the full-bridge. The Heric topology realizes the decoupling in the ac side, whereas the H5 and the UniTL [2] topologies realize the decoupling in the dc side. Obviously, different PWM strategies are used in these topologies.

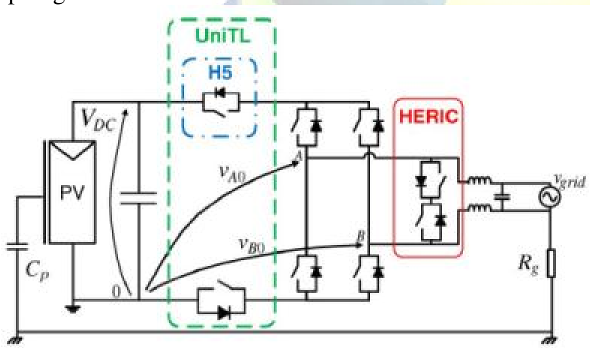

Fig.3.H4,HERIC and UniTL topologies.

This paper proposes a solution to the ground leakage current problem based on an active common-mode filter able to compensate for the output common-mode voltage variations.

The basic idea is to use the active filter together with the full-bridge power converter topology driven by the most efficient pulse width modulation (PWM), i.e., the three-level (unipolar)PWM.

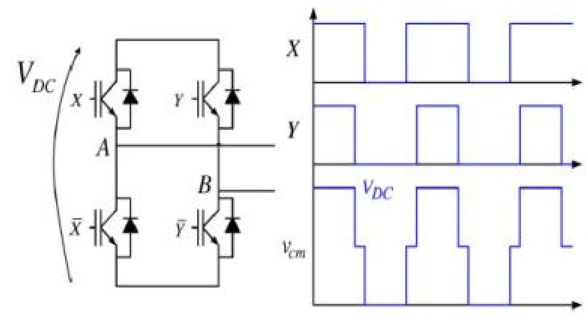

Fig.4. Output common-mode voltage in case of full-bridge driven by unipolar modulation.

II.FULL-BRIDGE TOPOLOGY

Different pulsewidth modulation (PWM) switching patterns can be used in transformerless singlephase inverter bridges. By using bipolar PWM, the diagonal switch pairs are fired alternately and the bridge voltage changes between +*V*dc and −*V*dc. Using unipolar switching strategy, the bridge voltage output has three possible levels: +*V*dc, 0, and −*V*dc. Unipolar PWM has various advantages over bipolar PWM. Ripple current is significantly less because of the three-level switching pattern that reduces filtering requirements[3]. Unipolar PWM changes the voltage across the inductor by *V*dc for each switch transition, which implies that the *dv/dt* is reduced. This results in lower switching losses, lower switch stresses, and reduced electromagnetic emissions.

III.PROPOSED TOPOLOGY

The full-bridge topology driven by a three-level (unipolar) PWM is the most popular solution for single-phase power converters due to its simplicity and effectiveness. However, this topology cannot be used in transformerless PV systems because of large variations of the output common-mode voltage.Fig. 4 shows the full-bridge driving signals in case of unipolar modulation and the resulting v_{cm}, which presents a peak-topeak amplitude equal to the dc link voltage v_{DC} at switching frequency. The full-bridge driven by unipolar modulation can be used in PV systems only if other devices are added to this basic structure.

This paper proposes the use of the efficient and simple full-bridge topology driven by unipolar modulation followed by a device able to cancel the commonmode voltage variations at the converter output.[4].Obviously, this additional device should be characterized by low power losses, simplicity, and low cost.

The additional magnetic component needed for the proposed solution can be obtained, adding a third winding to

All Rights Reserved © 2017 IJARTET

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 6, April 2017

the standard common-mode inductors used at the output of power converters in order to comply with electromagnetic compatibility (EMC) standards. By adding another winding to the common-mode choke (see Fig. 5), it is possible to consider this new magnetic component as a common-mode

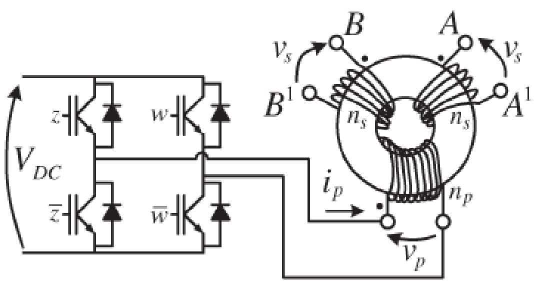

Fig.5.Active common-mode filter topology

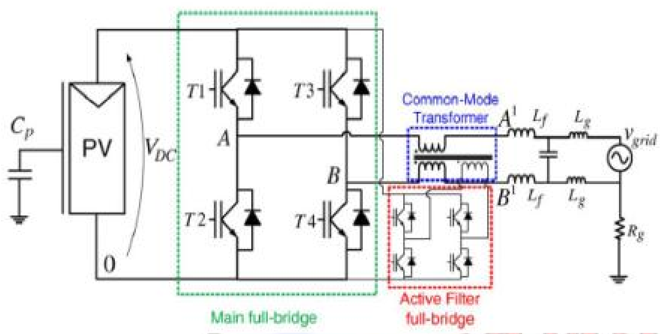

Fig.6.Proposed Topology

transformer. If a specific voltage is supplied to its primary winding through an additional low-power fullbridge, the secondary voltages (v_s) of the transformer can be used to compensate for the variation of v_{cm} . This way, the total common-mode voltage at the converter output, i.e., v_{cmT} , can be effectively kept constant.The application of the active common-mode filter (composed of the additional low-power full-bridge and the common-mode transformer) to a three-level PWM full-bridge is shown in Fig. 6.
The total common-mode voltage can be expressed as

$$V_{cmT} = \frac{v_{A^1 0} + v_{B^1 0}}{2} \qquad (2)$$

The common-mode voltage v_{cm} generated by a full-bridge driven by unipolar PWM is shown in Fig. 7. Gate signals *x* and *y* are also reported. The same figure shows the secondary voltages of the commmon-mode transformer v_s , which are used to compensate for v_{cm} . Therefore, v_s must have a shape equal to v_{cm} , but without the dc voltage component. This way, v_{cmT} = v_{cm} $- v_s$ results constant, as shown in Fig. 7.

In order to synthesize the desired waveform for v_s , a specific voltage v_p must be fed to the primary winding of the common-mode transformer. Since the additional low-power full-bridge is supplied with the same dc link voltage of the main full-bridge, fixing the turn ratio at $n_p/n_s = 2$, the PWM driving signals (*z* and *w*) can be simply obtained from the PWM signals of the main full-bridge as $z = x$ and $w = y$. It is important to put in evidence that the power losses of the active common-mode filter are very low since the primary current i_p of the common-mode transformer is practically equal to its magnetizing current only. Christo Ananth et al.[5] presented a brief outline on Electronic Devices and Circuits which forms the basis of the Clampers and Diodes.

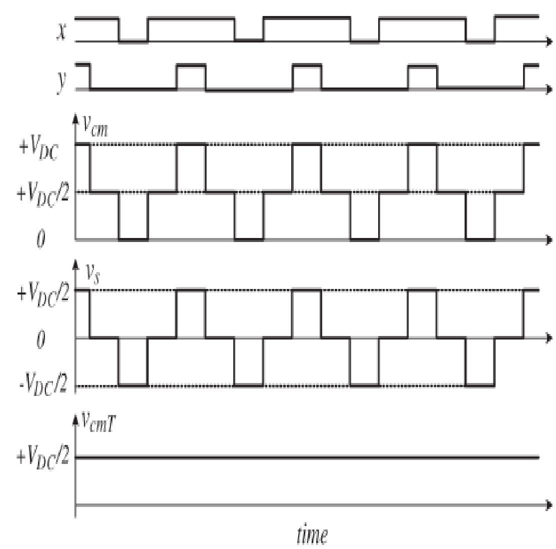

Fig.7.Compensation of v_{cm} variations by active filter

IV.COMMON-MODE TRANSFORMER DESIGN

The design of the common-mode transformer has the primary goal of avoiding the magnetic core saturation. The magnetic flux is generated by the supply of the primary winding and by the common-mode current at the converter

All Rights Reserved © 2017 IJARTET

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 6, April 2017

output, which flows into the two secondary windings of the common-mode transformer.

Under the hypothesis of no magnetic saturation, the principle of superposition of effects can be used to compute the total magnetic flux.The first component of the magnetic flux density, i.e., *BVC*, is caused by the primary voltage of the common-mode transformer,whose amplitude changes during a grid voltage period. Equation (3) computes the peak value of *BVC*, which arises around grid voltage zero crossings (*fsw* represents the switching frequency, whereas *S* is the effective area of the magnetic core), i.e.,

$$B_{VC-peak} = \frac{V_{dc}}{4 f_{sw} n_p S} \qquad (3)$$

The second contribution of the magnetic flux density component, which is named *Bicm*, is due to the common-mode current at line frequency flowing in the PV system. This component has a sinusoidal waveform with amplitude equal to

$$I_{cm-peak} = \sqrt{2}\pi f_{grid} C_P V_{grid-rms} \qquad (4)$$

Considering *Lcm*, the inductance of each secondary winding of the common-mode transformer, (4) allows to calculate the peak value of this second flux density component. In the first approximation, neglecting the magnetic saturation, L_{cm} can be computed as $\frac{n_s^2}{R_m}$

where R_m indicates the reluctance of the magnetic core.

It is important to note that L_{cm} represents the common-mode inductance of the magnetic component when the primary winding is disconnected and not used. This way, the common-mode transformer becomes a simple common-mode inductor, i.e.,

$$B_{Icm-peak} = \frac{L_{cm} I_{cm-peak}}{S n_s} \qquad (5)$$

The ferrite material used for this application needs to have a high magnetic flux density and low power losses for frequencies up to 200 kHz. Materials of this kind present a relative magnetic permeability usually lower than 5000, determining for typical PV system parameters a $B_{Icm-peak}$ strongly lower than $B_{VC-peak}$.

V.CONTROL TECHNIQUES

The control features that are realized with the inverter are:-

• MPPT algorithm for harvesting the maximum available power from the PV string;

• Grid Synchronization for locking the phase of the grid voltage;

• Current Control for controlling the quality of the current injected into the grid.[6]

Among the different MPPT technique in this work the PERTURB AND OBSERVE(P&O) algorithm was adopted .(Fig.8)

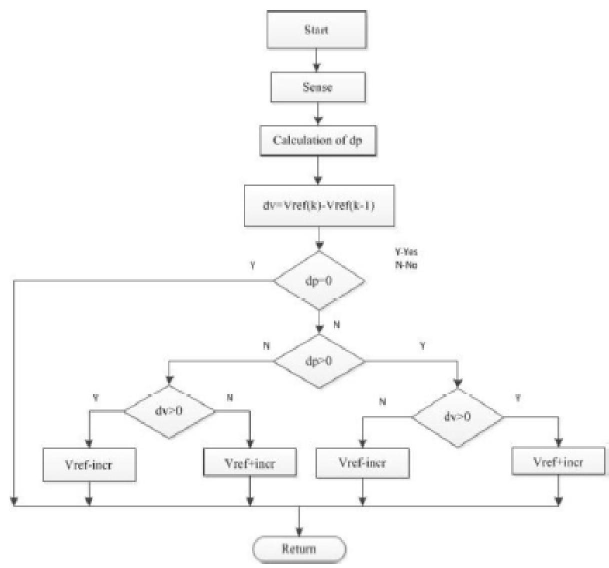

Fig.8.MPPT algorithm

Grid synchronization is an important task in grid-connected converter since the international regulations impose limits to the frequency and amplitude variations of the grid voltage.To ensure synchronisation transport delay PLL is used in the work.(Fig.10)

All Rights Reserved © 2017 IJARTET

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 6, April 2017

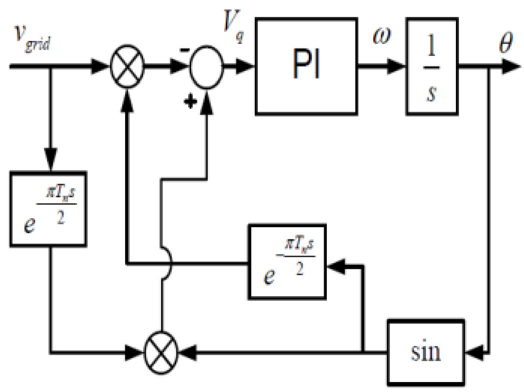

Fig.9.Block diagram of transport delay PLL

Grid current controller used is classical PI+grid voltage feedforward.The overall control structure is as shown in Fig.10.

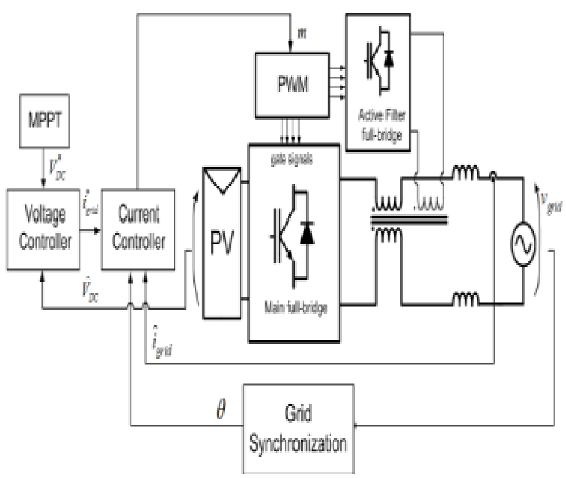

Fig.10.Overall Control Structure

VI.SIMULATION RESULTS

Simulation of the proposed system was done using MATLAB software.Parameters chosen for simulation are shown in Fig.11.At first,operation of normal grid connected PV inverters using both bipolar and unipolar PWM inverters are studied.Simulation is done and waveforms are recorded.A comparison is made with the two.It is as seen in table 1.The simulations were realized with a PV panel of 3.8kW 400 V, a grid voltage of 230V_{RMS} @50Hz and a switching frequency f_{sw} = 30 kHz. The output filter was formed by two inductors L_f = 0.75mH and a capacitor C_f = 4.4mF. The parasitic capacitance of the photovoltaic field was modeled with two equivalent capacitors connected to the positive and negative poles of the DC Link, and their values were fixed equal to 300nF.

Name	Description	Value
V_{DC}	input DC voltage	$400V$
v_{grid}	grid voltage	$230V_{RMS}$
f_{grid}	grid frequency	$50Hz$
f_{sw}	Switching frequency	$30kHz$
L_f	AC inductor filter	$0.75mH$
C_f	AC capacitor filter	$4.4\mu F$
C_p	equivalent PV parasitic capacitances	$200nF$ or $6.6nF$
n_P	primary turns common-mode transformer	30
n_S	secondary turns common-mode transformer	15
L_m	primary inductance common-mode transformer	$6.3mH$
L'_{cm}	inductance of the additional common-mode inductor	$1mH$

FIG.11.DESIGN PARAMETERS.

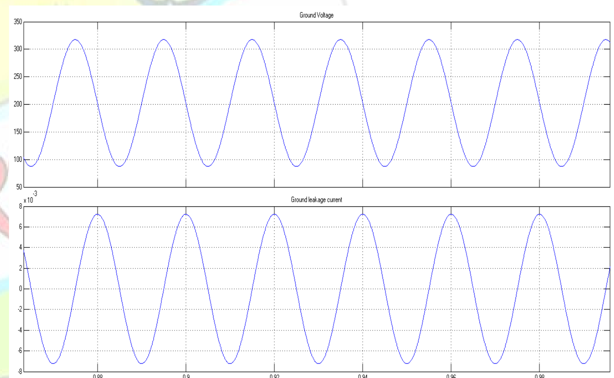

Fig.12.Ground voltage and leakage current for bipolar PWM

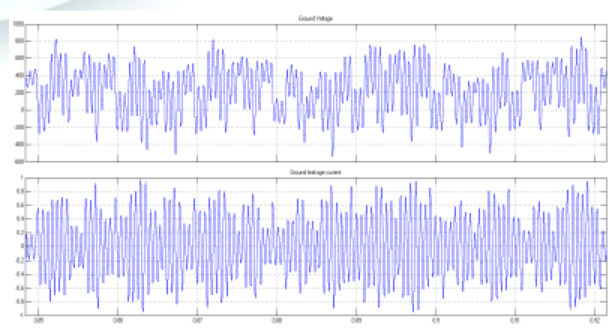

Fig.13.Ground voltage and leakage current for unipolar PWM

All Rights Reserved © 2017 IJARTET

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 6, April 2017

For the ground connection, a resistance Rg = 3W was considered. Two inductors $Lgrid$ = 40mH accounted for the distributed inductance of the grid.

	Bipolar PWM	Unipolar PWM
1.	Ground leakage current is near to zero	Ground leakage current is 0.4291A
2.	Ground Voltage has only fundamental voltage component	Ground voltage and current has high frequency components superimposed together with fundamental.
3.	No need of any compensation for common mode voltage	Compensation is required for common mode voltage
4.	Current ripple in injected grid current is more.	Current ripple in injected grid current is less.

Table.1.Comparitive Study of PWM techniques.

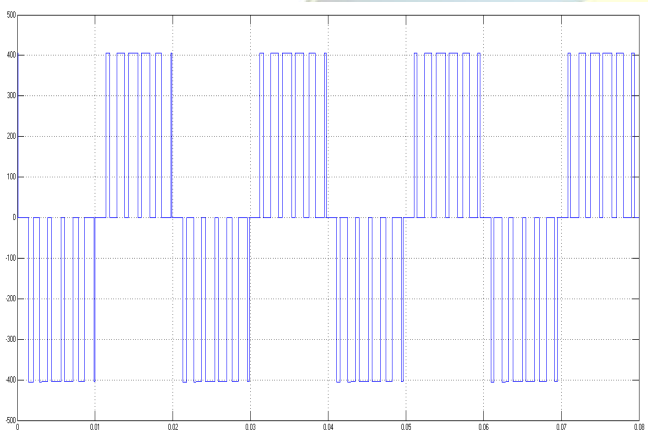

Fig.14.Inverter output Voltage

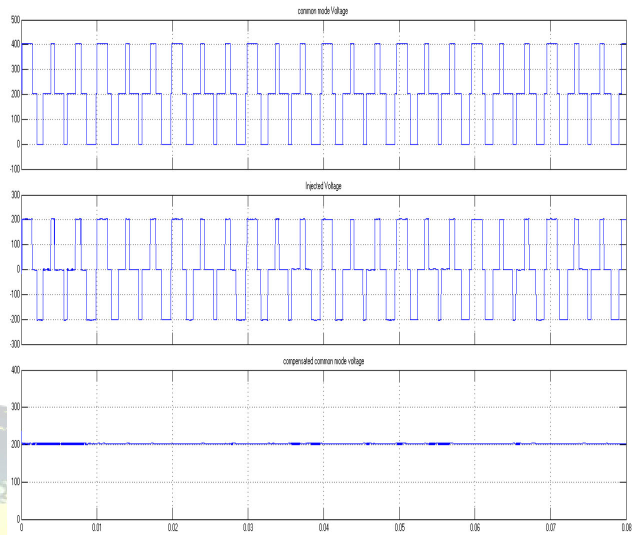

Fig 15.Waveforms showing 1) v_{cm} 2) v_s 3) v_{cmT}

VII.CONCLUSION

In this paper, the issue of ground leakage current in PV trasformerless gridconnected converters was investigated and analyzed.A comparitive study of bipolar and unipolar PWM inverters is done and results are presented.A novel approach to cancel the common-mode voltage variations at the output of transformerless grid-connected converter is proposed.The solution relies on the use of an active filter followed by a common mode transformer connected at the output of power converter to compensate the common mode voltage variations.The additional winding used to form common mode transformer will only consume low magnetising current resulting in no additional losses.Simulation results are shown in the paper.By employing the proposed system constant common-mode voltage of 200V is obtained.Ground leakage current was reduced from 0.5A to 14mA .With the control technique implemented PV panel is operated at maximum power point of 3.8kW and inverter voltage is synchronised in phase and frequency of grid voltage.

ACKNOWLEDGMENT

I would like to thank my guide Remyamol N. ,CO-Guide Lekshmi Sree and all other faculties of department of electrical and electronics ,Govt Engineering college Bartonhill for guiding me to fulfill this project. Also I would like to thank all my friends and family members for their support to my work.

All Rights Reserved © 2017 IJARTET

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 6, April 2017

REFERENCES

[1] D. Dong, F. Luo, D. Boroyevich, and P. Mattavelli, "Leakage current reduction in a single-phase bidirectional ac-dc full-bridge inverter,"*IEEE Trans. Power Electron.*, vol. 27, no. 10, pp. 4281–4291,Oct. 2012.

[2] D. Barater, G. Buticchi, A. Crinto, G. Franceschini, and E. Lorenzani,"Unipolar pwm strategy for transformerless pv grid-connected converters,"*IEEE Trans. Energy Convers.*, vol. 27, no. 4, pp. 835–843,Dec. 2012.

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

[4] J. Yanshu, X. Dianguo, and C. Xiyou, "Analysis and design of a feedforward-type active filter to eliminate common-mode voltage generated by a pwm inverter," in *Proc. IEEE 28th Annu. IECON Soc.*, 2002, vol. 1,pp. 771–775.

[5] Christo Ananth, W.Stalin Jacob, P.Jenifer Darling Rosita. "A Brief Outline On ELECTRONIC DEVICES & CIRCUITS.", ACES Publishers, Tirunelveli, India, ISBN: 978-81-910-747-7-2, Volume 3,April 2016, pp:1-300.

[6] M. Ciobotaru, R. Teodorescu, and F. Blaabjerg. "Control of singlestagsingle-phase PV inverter,". in European Conference on Power Electronicand Applications, September 2005.

All Rights Reserved © 2017 IJARTET