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An Efficient Transformerless Inverter Topology with Reduced Leakage Current for Grid Tied PV System

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***Abstract*—The interest for transformerless inverter topologies is increasing day by day. The advantages of these topologies are low cost, light weight, improved efficiency.etc.But the elimination of transformer causes some technical problems in grid connected photo voltaic system.Leakage current is the main problem among these.Leakage current flow in the entire photovoltaic grid system violates safety regulations.Also the reactive power flow in the whole system cannot be regulated.The stray capacitance between the photovoltaic module and ground is the main reason for the leakage current.All these problems can be reduced by improving the conventional transformerless topologies.Such an improved topology is presented here.The control scheme of this advanced topology mainly involves of MPPT controller and dead beat controller. The suggested topology is capable of supplying reactive power into the grid with reduced leakage current .**

Keywords—MPPT controller, Dead beat controller, Leakage current, Transformerless inverter

I. INTRODUCTION

Energy demand increasing day by day.So inorder to satisfy this increasing in energy demand we should explore renewable energy sources.Water ,Photovoltaic(PV), fuel, geothermal energy, wind.etc are some examples of renewable energy sources.Out of these PV systems are most preferred one due to its robust structure,increased life time,reduced maintenance etc[1][2].PV systems have wide range of applications such as from low power to high power applications[3]. Solar arrays and power conversion unit are the main elements of photovoltaic power generation system[4],[5].In many countries transformers has been utilized inorder to provide a galvanic isolation between the photovoltaic module and the grid .But the inclusion of transformers leads to the complete system bulky,more expensive and less efficient

The popularity for transformerless inverters are increasing now a days because of its increased efficiency, reduction in cost, light weight and reduced size[6],[7],[8].But because of the exclusion of transformers the galvanic isolation is lost.Therefore it is very important to consider the problems arises from the lack of galvanic isolation.The stray capacitance beween the photovoltaic module and ground causes variation in the common mode voltage which relies on the structure of the topology and the type of switching scheme used.This voltage fluctuation inturn leads to a capacitive leakage current which flows through the entire PV grid system[9].The existance of leakage current causes technical problems such as grid current harmonics in grid current, system losses and it also causes electromagnetic interference[5],[10].

Another important aspect regarding the transformer less inverters is its capability of supplying reactive power to the utility grid.it should have the ability to handle both active and reactive power.It should have the ability to generate active power and compensate reactive power.The suitable power factor is chosen based on the active and reactive power that is required by the grid.

Many transformerless topologies have been proposed which deals with the minimisation of leakage current[6],[7],[10] .Each topology suggests different solution to solve the leakage current issues.Some of such topology uses MOSFET switches but some other topology uses IGBT switches.Many such transformerlessPV inverters have been proposed with different control scheme.Most of the proposed topologies deals with the injection of real power only.In this paper,injection of both real and reactive power is considered.Highly efficient and reliable inverter concept (HERIC) topology, H5 topology and H6 type topology are some of the existing transformer less topologies.

The control scheme of the proposed system mainly involves of MPPT(maximum power point tracking) controller and dead beat controller. For extracting maximum power from photo voltaic array, MPPT technique using perturb&observe(P&O)algorithm is used here.By using maximum power point tracking technique the efficiency of the photo voltaic module can be improved.Inorder to guarantee the quality of injected current into the utility grid a dead beat controller is also used.Dead beat controller is one of the most commonly used predictive controller[10].The efficiency of the complete system can be improved because of the inclusion of dead beat controller.

A single phase transformer less inverter for grid tied PV system with reduced leakage current is proposed here. Its performance verification has done using MATLAB/Simulink software.section II represents the circuit structure and operating principle of the proposed topology.Section III presents the leakage current analysis of the proposed topology. section IV presents the control scheme of the proposed topology.Section V represents the simulation results of the proposed topology.

II. CIRCUIT STRUCTURE AND OPERATING PRINCIPLE OF THE PROPOSED TOPOLOGY

The suggested single phase transformerless inverter is displayed in Fig.1.It involves six MOSFET switches(S1-S6) and six diodes(D1-D6)and inductors L_{1A},L_{1B},L_{2A},L_{2B},L_{1g},L_{2g}, and capacitor C_O.The inductors L_{1A},L_{1B},L_{2A},L_{2B},L_{1g},$L_{2g}$and capacitor C_O together consists of LCL filter. V_{PV} is the photovoltaic panel voltage.C_{dc} is the input link capacitor.S5,D5 and S6,D6 together constitutes the ac side switch pairs.It provides one directional current flow in the branches throughout the freewheeling periods Thus the grid can be decoupled from photovoltaic module.

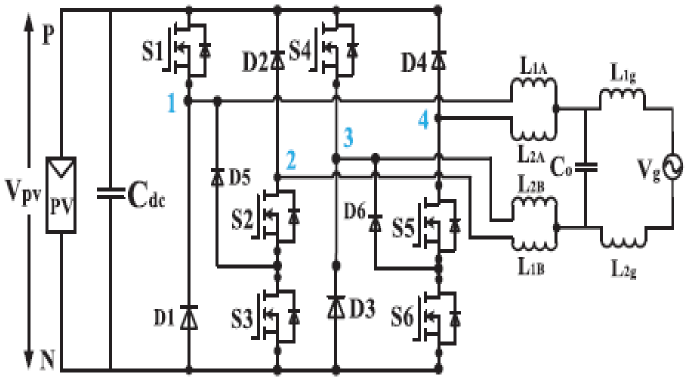


Fig.1circuit diagram of the proposed transformerless inverter

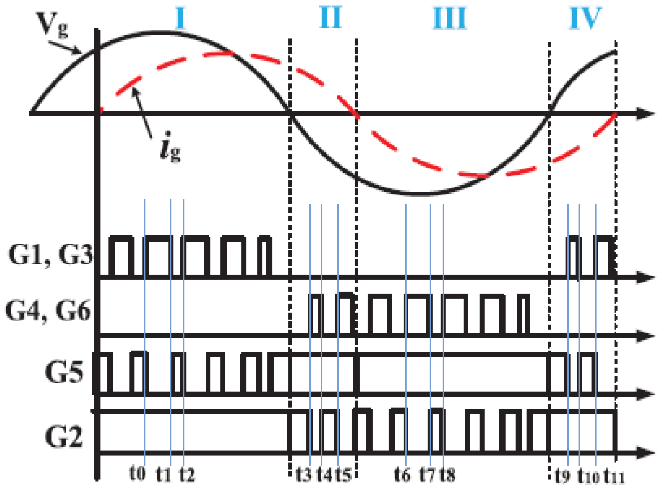


Fig.2.Switching pattern of the proposed topology with reactive power flow

The inverter is controlled based on the cycle of grid voltage and grid current.So these two quantities are the main controlling parameters. The gate signal for the suggested topology is displayed in Fig.2. When the load is inductive or in the case of reactive power flow there is a phase shift occurs between voltage and current. That is the grid current lags behind the voltage.But in case of active power flow the voltage and current wave forms are in phase.The circuit operation for the positive half cycle is described here.

Region1: Here, the grid voltage and grid current are positive and the switch S2 is always conducting. Switches S4, S5, S6 operates complementary with S1, S2, S3. Two states are considered here. Output voltage of +V_{pv}& 0 are generated in this state State1: During state1 the switches S1, S2, S3 will conduct and inverter output voltage will be +V_{pv}..

State 2: In the state 2 the switches S1 & S3 will be turned off Freewheeling of inductor current occurs through through S2 and D5. During this period, input voltage $V_{pv}$is not connected to inverter, so the inverter output voltage is zero.

State 3: During state 3, the filter inductors are demagnetized through the path D1 and D2.

RegionII: Here, grid voltage Vg is negative,but grid current Ig is positive.The switch S5 is always on. The switches S1, S2 & S3 operates complementary with S4, S5, S6. . Here also two switching states are considered. Output voltage of –Vpv and 0 are generated here.

State 4: During state 4 , the switches S4, S5 and S6 are conducting, current flows through opposite to the direction of state1. Hence the output voltage of -Vpv is obtained.

State 5: During the state5 switches S4 and S6 are turned off.Freewheeling of the inductor current occurs through S5 and D6. Since input is not connected with inverter output terminals, output voltage of inverter is equal to zero.

III. LEAKAGE CURRENT ANALYSIS FOR THE PROPOSED TOPOLOGY

An electrically chargeable surface area is generated by the PV module.This generated chargeable area faces the ground.In such case an undesirable capacitance is produced between the photovoltaic module and ground.That capacitance is termed as parasitic capacitance or stray capacitance.As a result of the missing galvanic separation,variation in common mode (CM) voltage occurs.This inturn leads to the flow of leakage current from photovoltaic module to the system through the parasitic capacitance.

Analysis of leakage current can be done by using the equivalent CM model which is shown in fig.3.Controlled voltage sourcesV_{1N}, V_{2N}, V_{3N} V_{4N} are connected to the negative terminal N.L_{CM} is the common mode inductor and C_{CM} is the common mode capacitor.C_{PVg} and Zg are parasitic capacitance and grid impedance respectively. Both V_{3N} and V_{4N} are zero throughout the positive half cycle due to the off condition of switches S3 and S4.Hence the controlled voltage sources V_{3N} and V_{4N} can be removed.

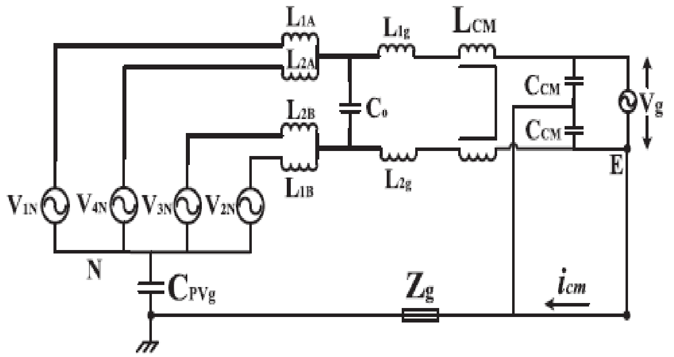


Fig.3.Equivalent common mode model of the proposed topology

Based on the definition, both common mode and differential mode voltages can be expressed as;

$$V_{CM}=\frac{1}{2}(V_{1N}+V_{2N}) \qquad (1)$$

$$V_{DM}=V_{1N}-V_{2N} \qquad (2)$$

By solving equations (1) and (2)V1N and V2N can be written as follows;

$$V_{1N}=V_{CM}+\frac{1}{2}V_{DM} \qquad (3)$$

$$V_{2N}=V_{CM}-\frac{1}{2}V_{DM} \qquad (4)$$

For illustrating the common mode model at switching frequency,the equations (3) and (4) can be substituted for the bridge leg in Fig.3. The grid being a low frequency voltage source,the influence of grid on leakage current can be ignored. The differential mode capacitor C_{DM} can also be neglected because it has no impact on leakage current.Therefore the simplified high frequency common mode model of the suggested transformerless inverter topology can be drawn as displayed in Fig.4

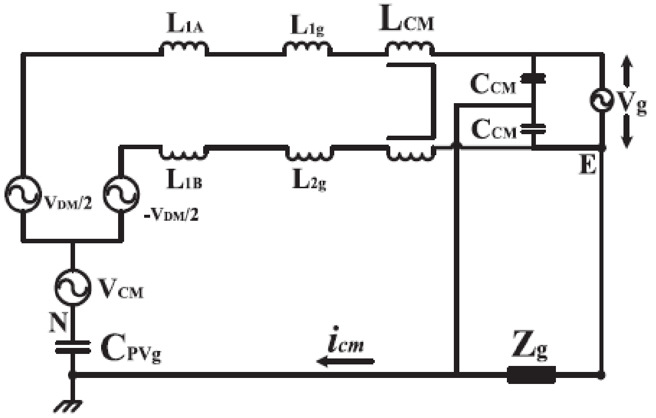


Fig.4.Simplified common mode model at switching frequency for positive half cycle.

Further simplified single loop common mode model of the proposed topology is shown in Fig.5.

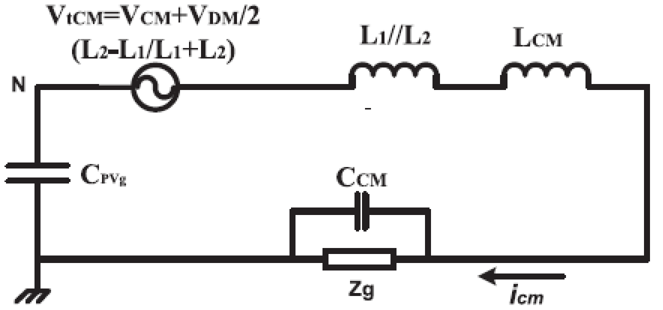


Fig.5.Simplified single loop CM model.

Total common mode voltage can be written as:

$$V_{tCM}=V_{CM}+\frac{V_{DM}}{2}\frac{L_2-L_1}{L_2+L_1} \qquad (5)$$

Here V_{tCM} is the total common mode voltage and $L_1=L_{1A}+L_{1g}$ And $L_2=L_{1B}+L_{2g}$.In the proposed topology if $L_{1A}=L_{1B}$ and $L_{1g}=L_{2g}$ the equation (5) can be rewritten as follows

$$V_{tCM}=V_{CM}=\frac{1}{2}(V_{1N}+V_{2N}) \qquad (6)$$

Based on the operating principle, we can calculate the common mode(CM) voltage for each state of the positive and negative half cycle[1].The total CM voltage is same for each state.That is given as

$$V_{tCM}=\frac{1}{2}V_{PV} \qquad (7)$$

It can be said that the CM voltage is kept constant at half of the dc input voltage throughout the positive and negative half cycle of the operation..

IV. CONTROL SCHEME OF THE PROPOSED TOPOLOGY

Control scheme of the proposed system with dead beat controller and MPPT controller is shown in Fig.7.The main elements of the control scheme are orthogonal signal generator(OSG),two proportional integral controller(PI) and an SPWM generation block. MPPT controller helps in extracting maximum extent of power from the PV module.Hence improving the efficiency of the entire system.Dead beat controller is one of the most commonly used predictive controllers.It helps in improving the quality of power supplied into the utility grid.Orthogonal Signal Generator(OSG) calculates the real power and reactive power using the equations given below.

$$P_{cal}=1/2\,[V_{g\alpha}i_{g\alpha}+V_{g\beta}i_{g\beta}] \qquad (7)$$

$$Q_{cal}=1/2\,[V_{g\beta}i_{g\alpha}-V_{g\alpha}i_{g\beta}] \qquad (8)$$

$V_{g\alpha},V_{g\beta},i_{g\alpha},i_{g\beta}$ denotes the α and β components of grid current and grid voltage.

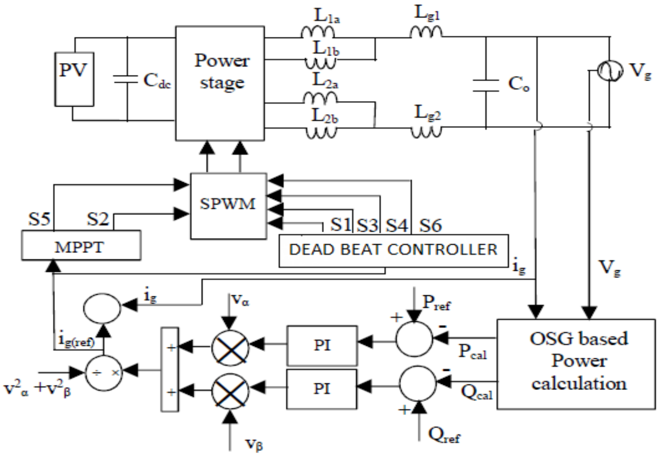


Fig.6.Control scheme of the proposed topology with dead beat controller and MPPT controller

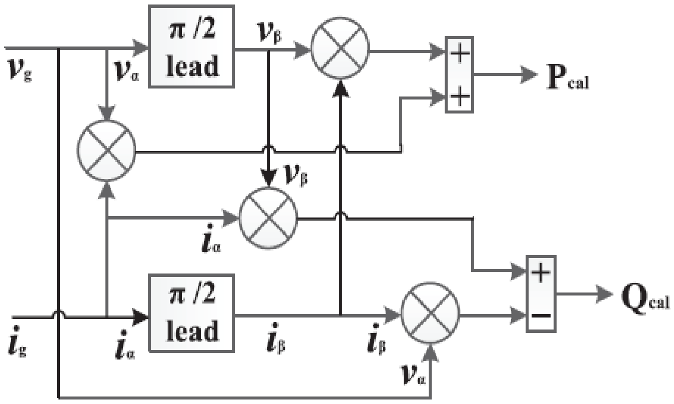


Fig.7.OSG based power calculation

The current inαβ reference frame is given by the following equations

$$i_{g\alpha} = 2(P_{cal} * V_{g\alpha} + Q_{cal} * V_{g\beta})/(V_{g\alpha}^2 + V_{g\beta}^2) \qquad (9)$$

$$i_{g\beta} = 2(P_{cal} * V_{g\beta} + Q_{cal} * V_{g\alpha})/(V_{g\alpha}^2 + V_{g\beta}^2) \qquad (10)$$

In steady state both active and reactive power are constant.The grid.So two PI controllers are used for controlling the active and reactive power.The grid reference current can be derived by the following equations.

$$i_g *= [\left(P_{ref} - P_{cal}\right) * G_p(s) * V_{g\alpha} + \left(Q_{ref} - Q_{cal}\right) * G_q(s) * V_{g\beta}] / ({V_\alpha}^2 + {V_\beta}^2) \qquad (11)$$

$P_{ref}$and$Q_{ref}$are the active and reactive power references.$G_p(s)$ and $G_q(s)$ are the transfer functions of PI controller.

$$G_P(S) = K_{PP} + K_{pi} * \frac{1}{s} \qquad (12)$$

$$G_P(S) = K_{qP} + K_{qi} * \frac{1}{s} \qquad (13)$$

Where K_{PP} ,K_{Pi} ,K_{qP},$K_{qi}$are proportional and in for active and reactive power.

A. *MPPT Technique*

Output of PV panel mainly depends on irradiation and temperature conditions.Because of the varying nature of irradiance and temperature conditions,PV panel cannot deliver constant output. Therefore it cannot attain maximum efficiency. MPPT technique helps in extracting maximum power from the photovoltaic module. By using MPPT technique the efficiency of PV panel can be improved.P&O Algorithm based MPPT technique is used here.P&O algorithm is generally used MPPT technique due to its low cost and less complexity.Output of a PV module increases with solar irradiance and decreases with cell temperature. P&O gives optimum duty cycle to abstract maximum extent of power output. In this method, photovoltaic module voltage is periodically perturbed and the corresponding output is compared with the earlier perturbation cycle. If there is a rise in output power then perturbation should be in the same direction. This process is continued until the maximum power point is reached (MPP). When the output power is declined, then the perturbation is reversed. The P&O algorithm oscillates around peak point when the stable condition is attained.

The proposed transformerless inverter has a disadvantage of ground leakage current.By using MPPT, maximum power from PV panel is obtained and is given as an input to the inverter thereby increasing the efficiency of the complete system. This reduces the current flowing from PV to ground and further decreases total leakage current. Here,MPPT technique is used for the generation of switching sequences of S2 and S5. By using this technique,fluctuation of common mode voltage is reduced and hence the leakage current can be further minimized.

B. *Dead beat current control*

Dead beat controller is one of the most common type of predictive controllers used. Dead beat current control is used here.Reference value of current is computed first inorder to achieve the desired value of current.The required reference value of current is computed by the use of system state space model.By knowing the reference value of the present instant, the reference value of current at the next instant also can be predicted.Here dead beat current control is given to switches S1,S3,S4 and S6.

The reference current is estimated according to the fact that the predicted value and the reference value of filter current should be equal. Predicted value of filter current can be computed as follows:

$$i_{fi}(k+1) = G_{11}V_{fc}(k) + G_{12}i_{fi}(k) + H_{11}u(k) + H_{12}i_{ft}(k) \qquad (14)$$

Predicted value of reference current can be estimated by using second order Lagrange’s extrapolation formula:

$$i_{fi}(k+1) = 3i_{fi}*(k) - 3i_{fi}*(k-1) + i_{fi}*(k-2) \qquad (15)$$

The deadbeat current control law is given by:

$$u(k) = \frac{i_{fi}(k+1) - G_{11}V_{fc}(k) - G_{12}\, i_{fi}(k) - H_{12}i_{ft}(k)}{H_{11}} \qquad (16)$$

Where $G_{11} = 1 - \frac{{T_d}^2}{2L_f C_{fc}}$, $G_{12} = \frac{T_d}{C_{fc}} - \frac{{T_d}^2 R_f}{2L_f C_{fc}}$,

$$H_{11} = \frac{{T_d}^2 V_{dc}}{2L_f C_{fc}} \quad \text{and} \quad H_{12} = \frac{-T_d}{C_{fc}}$$

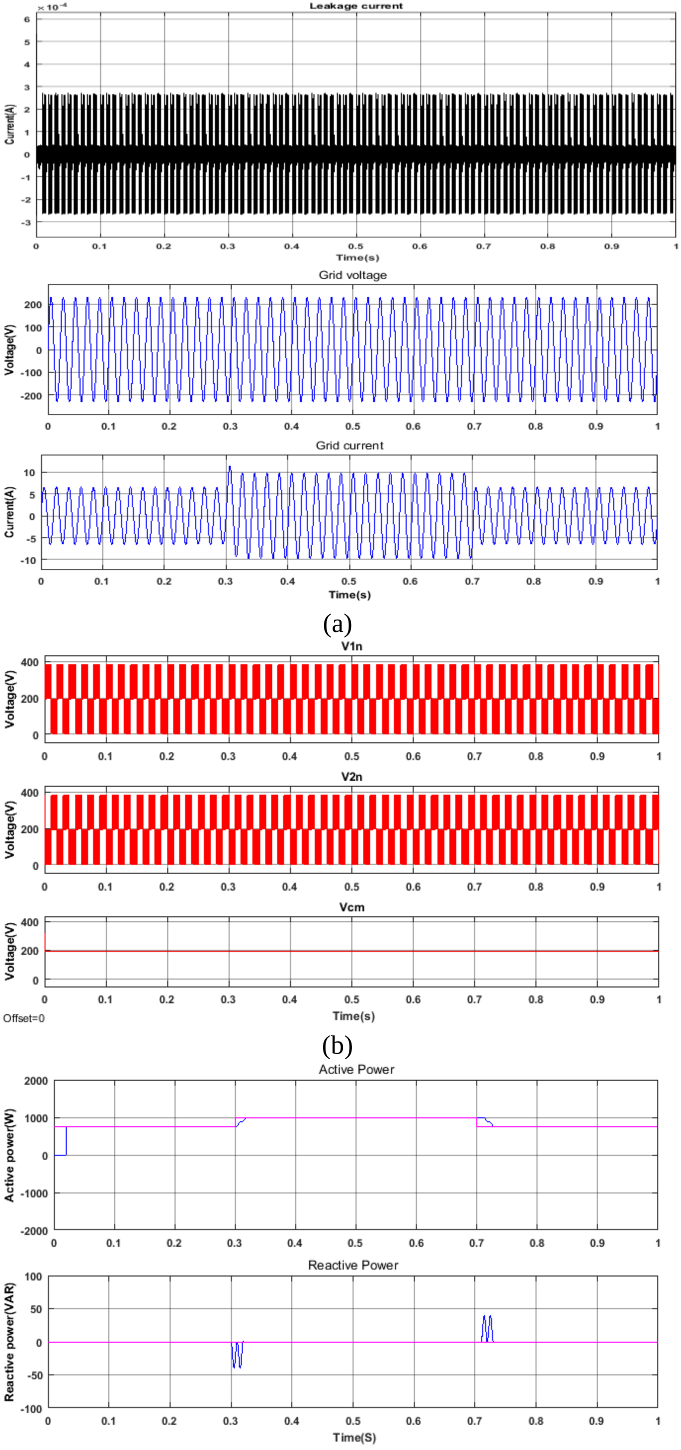
The term $i_{fi}(k+1)$ is valid for a wide range of frequency and when substituted in equation (20) yields to a one step ahead dead beat current contol law. At last u(k) is changed into on/off switching commands to the respective inverter switches using a dead beat hysteresis controller

V. SIMULATION RESULTS

The simulation are done using the MATLAB/Simulink software.Different parameters are analysed here.Two cases are considered in the simulation of the proposed topology..

1. CaseI: Performance analysis of the suggested topology with real power injection only

2. CaseII: Performance analysis of the suggested topology with active and reactive power injection

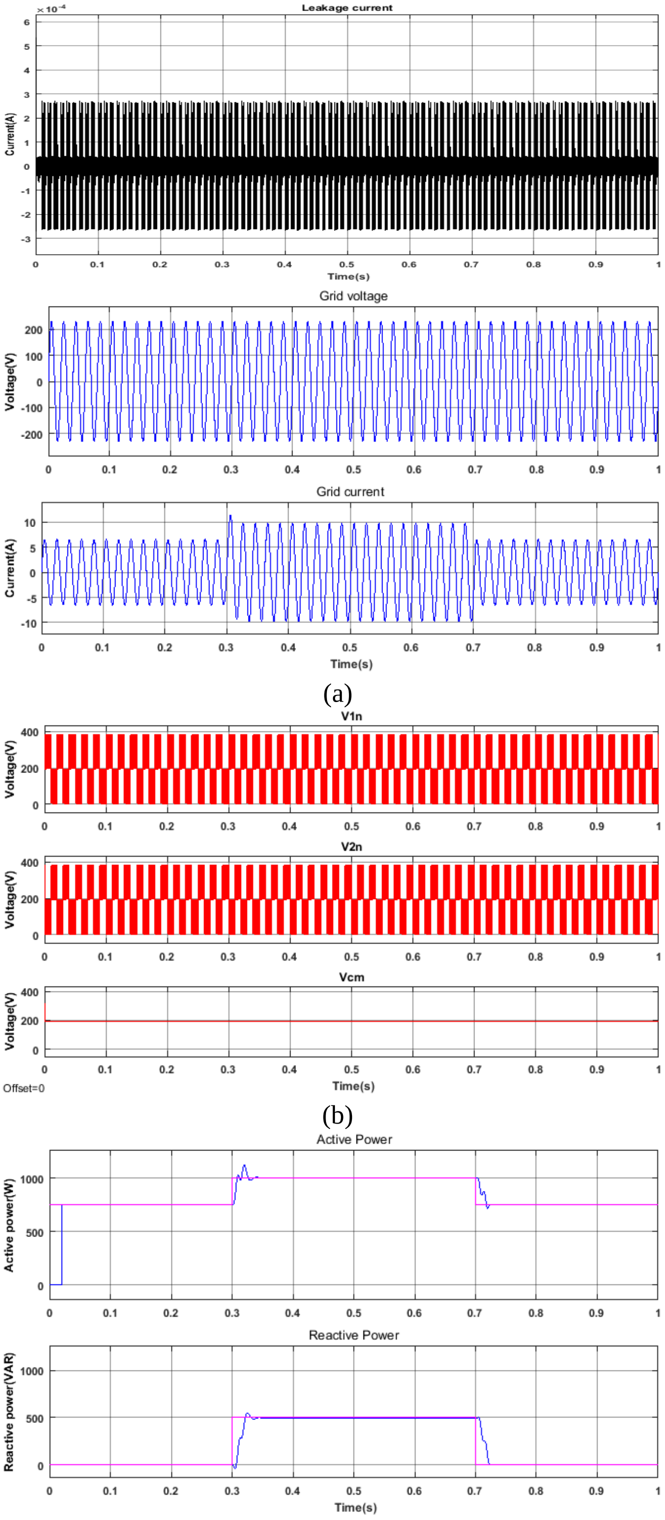


(a)

(b)

(c)

Fig.8.Simulation results of the suggested topology with real power injection only:(a)Leakage current, Grid voltage, Grid current (b)Common mode characteristics of the suggested topology (c)Real power with reference, Reactive power with reference



(a)

(b)

(c)

Fig.9.Simulation results of the proposed topology with active and reactive power injection:a)Leakage current, Grid voltage, Grid current (b)Common mode characteristics of the proposed topology (c)Active power with reference, Reactive power with reference.

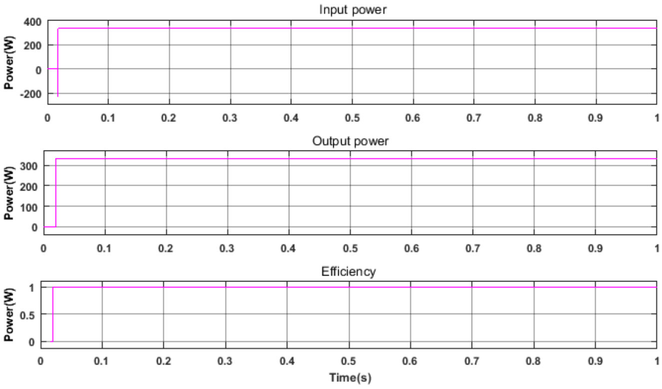


Fig.10.Wave form showing input power,output power and efficiency of the proposed topology

Fig.8.displays the simulation results of the suggested topology with real power injection only. Grid voltage and grid current wave forms are purely sinusoidal and attained unity power factor.The common mode voltage is kept constant at half of the input dc voltage.Here leakage current is around 0.00025A.Here load is changed 750W to 1000W.From the wave forms it can be easily seen that the controller can rapidly track the reference power change.

Fig.9.shows the simulation results of the proposed topology with both active and reactive power injection. Here also the load change is from 750W to 1000W and 250VAR to 500VAR.From the waveforms it can be clearly observed that the proposed topology can supply both real and reactive power into the utility grid with very low leakage current.

Fig.10.is the Wave form showing input power,output power and efficiency of the proposed topology with dead beat controller and MPPT controller. In this case efficiency is nearly equal to unity.

Compared with other conventional topologies ,the proposed topology has very less leakage current.Its reactive power control capability is also higher than conventional topologies. From the simulation results it can be noticed that the control scheme including dead beat controller and MPPT controller is better than other conventional control schemes.This advanced control scheme can efficiently reduce the leakage current.

VI. CONCLUSION

A new transformerless inverter topology for grid tied photovoltaic system is presented here.From the results it can be said that the proposed topology with dead beat controller and MPPT controller is an efficient topology when compared with conventional topologies

The significant features of the proposed topology are:

1. The proposed topology is capable of injecting real and reactive power into the utility grid with very low harmonic distortion.
2. The common mode voltage is retained constant throughout the complete grid period. As a result the leakage current flows through the complete system is very less.
3. The proposed topology is highly efficient than that of conventional topologies.

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