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Leakage Current Mitigation in Roof-Top Grid Tied Photo Voltaic Systems

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Abstract: Photovoltaic is desirable due to its ubiquity, abundance, sustainability, ecofriendly nature, cheapness etc. Solar plants are struck by several technical as well as non-technical challenges. Transformer less inverters are highly efficient, light and cost effective. Leakage current is a major threat for transformer less PV systems. Parasitic capacitance and high frequency varying common mode voltage is responsible for leakage current. This cologne current cause losses, radiated interferences, damage of PV array, harmonic distortion in grid and safety disasters. The causes, magnitude, path, detrimental, point of measurement and preventive measures of leakage current are analyzed. Details of leakage current study in a rooftop grid tied systems near to the college is cited to substantiate problem identification. DC decoupling implemented through H5 topology of inverter can mitigate leakage current to great extent. An efficient system is designed with solar panel, MPPT using perturb and observe method utilizing cuk converter and H5 inverter. LLCL filter is used to suppress harmonics**.** MATLAB simulation is done for 230V, 50 Hz system to get topological verification. The leakage current profile is compared with conventional H bridge, HERIC and H6 topologies. H5 topology gave minimum leakage current.

Keywords: Leakage current, Common mode voltage, differential mode voltage, parasitic capacitance, transformer less inverter, Maximum Power Point Tracking (MPPT), LLCL filter, hysteresis control.

I. INTRODUCTION

Fossil based energy sources are depleting day by day. Advent of solar energy could resolve the dreadful scenario created by the carbonic fuels. Solar energy is admitted due to the plurality of its merits like ubiquity, abundance, sustainability, cheapness etc. Photovoltaic energy systems is capable of creating a balanced and buoyant environment for better quality of life. Recently Distributed rooftop grid tied plants are employed for household and commercial purposes.

Gradual decline in the price of solar panels has increased its popularity. Exhbitorant installation cost demand maximum utilization of available reserves. Well versed studies and experiments were conducted to [1] remove the dys-functionality and to improve the overall efficiency of grid tied systems. Regulatory authorities has enacted installation code for rooftop grid tied plants. These codes are adamant about the earthing of rooftop PV panels above nominal ratings. The metal frame of panel is earthed this develops a parasitic capacitance with respect to ground. The magnitude of parasitic capacitance depends on type of metallic frame, surface area of metallic frame, height of PV panel above ground, atmospheric conditions like humidity, moisture, temperature etc.

Mean of bridge voltages V_{AN} , V_{BN} with respect to ground is called common mode voltage V_{CM}

$$V_{CM} = \frac{V_{AN} + V_{BN}}{2} \qquad (1).$$

High frequency operation is preferred to tackle harmonic problems. At high frequency of operation common mode voltage varies rapidly [2] .The constantly varying common mode voltage generates high potential between the inverter output port and ground. When a grounded load is connected to inverter, a closed path is created and common mode leakage current flows through it. Fig 1 illustrates the path of leakage current. This current is cologne current and results in shock hazards, radiated electromagnetic interference, injection of current harmonics to grid, damage of PV cells, malfunctioning of power conditioning system, false tripping of Residual Current Devices(RCD) etc. Leakage current is

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intractable with conventional H bridge inverters and leads to derailing of power supply systems. The paramount solution to tackle leakage current is to provide galvanic isolation by means of a transformer.

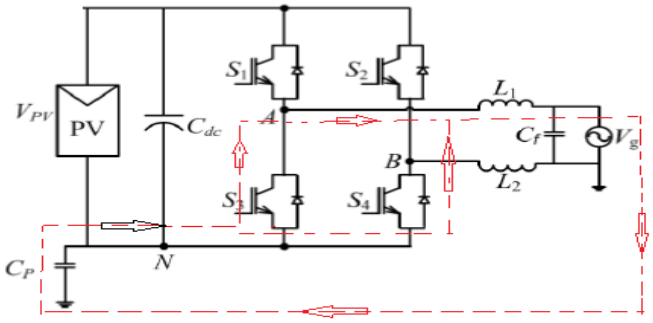

Fig.1. Leakage current path in a transformer less inverter

Even though this a feasible solution there are certain discrepancies for inverter with transformer like bulkiness, cost, complexity, increased number of power stages etc, hence overall efficacy is poor [3].

Transformer less inverters are promoted because of simplicity, light weight, easy installation, cheapness etc. However leakage current possess vicious threat to transformer less inverters. Creative power electronic topologies are proposed to obstruct leakage current [4].AC decoupling and DC decoupling are two methods to tackle leakage current. In this paper a system employing H5 topology of inverter for eliminating leakage current is discussed. Harmonic elimination and ripple less operation are also incorporated by means of LLCL filter and Cuk converter. The paper is organised as section II describes leakage current elimination strategies, section III explains system eliminating leakage current, in section IV simulation results are discussed.

II. LEAKAGE CURRENT MITIGATION STRATEGIES

A. CIRCUIT ANALYSIS OF LEAKAGE CURRENT

Rampantly varying common mode voltage and parasitic capacitance is responsible for leakage current [5]. The photovoltaic system can be simplified and studied by using different theorems and principles of circuit theory. Equivalent circuit diagram of Fig 1 is shown below.

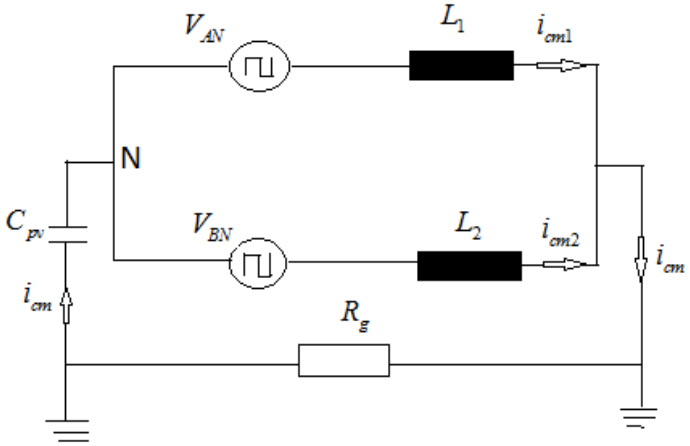

Fig.2. Equivalent circuit diagram of PV grid tied inverter

Equation (1) give common mode voltage V_{CM} .The differential mode voltage, V_{DM} can be expressed as

$$V_{DM} = \frac{V_{AN} - V_{BN}}{2} \qquad (2)$$

Where,

V_{AN} = Potential between “A” and “N”

V_{BN} = Potential between “B” and “N”

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The individual bridge voltages can be expressed in terms of common mode voltage V_{CM} and differential mode voltage V_{DM} as

$$V_{AN} = V_{CM} + 0.5V_{DM} \quad (3)$$

$$V_{BN} = V_{CM} - 0.5V_{DM} \quad (4)$$

These voltage equations together with Millmanns theorem reduce model shown in Fig.2 as below

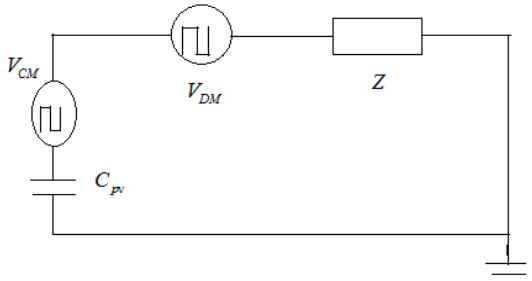

Fig.3.Simplified circuit diagram of PV grid tied system.

B. MECHANISMS OF LEAKAGE CURRENT ELIMINATION

Circuit theory analysis brings out four methods to jolt down common mode leakage current [6] . They are following:

(a) Maintaining high impedance during high frequency variation of common mode voltage.This strategy is implemented through AC or DC decoupling, panel is isolated from inverter and path for leakage current is cut-off. Highly Efficient and Reliable Inverter Concept (HERIC), H6, H5 are some of the popularly implemented topologies

(b) Employing appropriate Sinusoidal Pulse width modulation techniques to keep V_{CM} constant. Bipolar, unipolar and hybrid modulation techniques are capable of regulating V_{CM} in controllable levels. Ripple free operation and minimum switching losses make unipolar modulation as supreme.

(c) Keeping both V_{CM} and V_{DM} constant by matching circuit parameters. Developing infinite parasitic capacitance, uniform distribution of line impedance, three level neutral point clamping are some methods to maintain constant V_{CM} and V_{DM} . However this is only a theoretical solution, its practical implementation create asymmetry in the circuit, hence not favoured.

(d) Decreasing parasitic capacitance by placing a series capacitor in series to it. Insertion of series capacitance decrease overall impedance and can limit leakage current to safe levels. Transformer is equivalent to a series capacitor, addition of transformer makes circuit complex and bulky, hence this method is not preferred. [7]

(e) Theoretical analysis proclaim strategy (a) as the best method, it is followed in this work .DC decoupling through H5 topology is implemented.

III. SYSTEM ELIMINATING LEAKAGE CURRENT

A robust system capable of tackling leakage current is designed. The system comprises of PV panel, cuk converter, MPPT, LLCL filter and grid. Following is the block diagram of entire system.

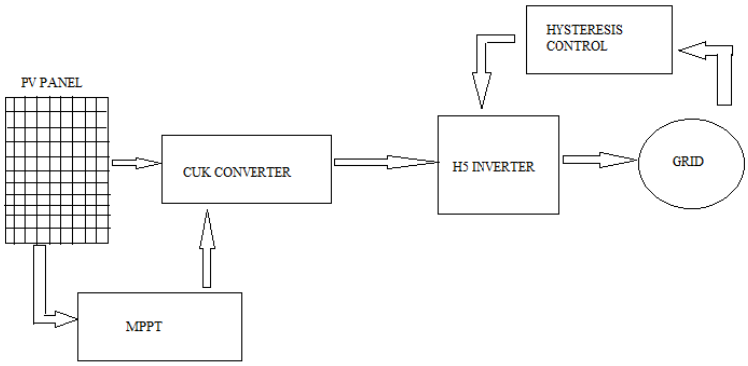

Fig.4. Block diagram of leakage current mitigation system

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A. H5 inverter

H5 inverter consists of additional 4+1 switch to the conventional H bridge inverter. The topology has well defined sequential switching action which cam mitigate leakage current to a great extent [8]. The switching cycle includes two periods: active period and freewheeling period. The operating modes is illustrated below

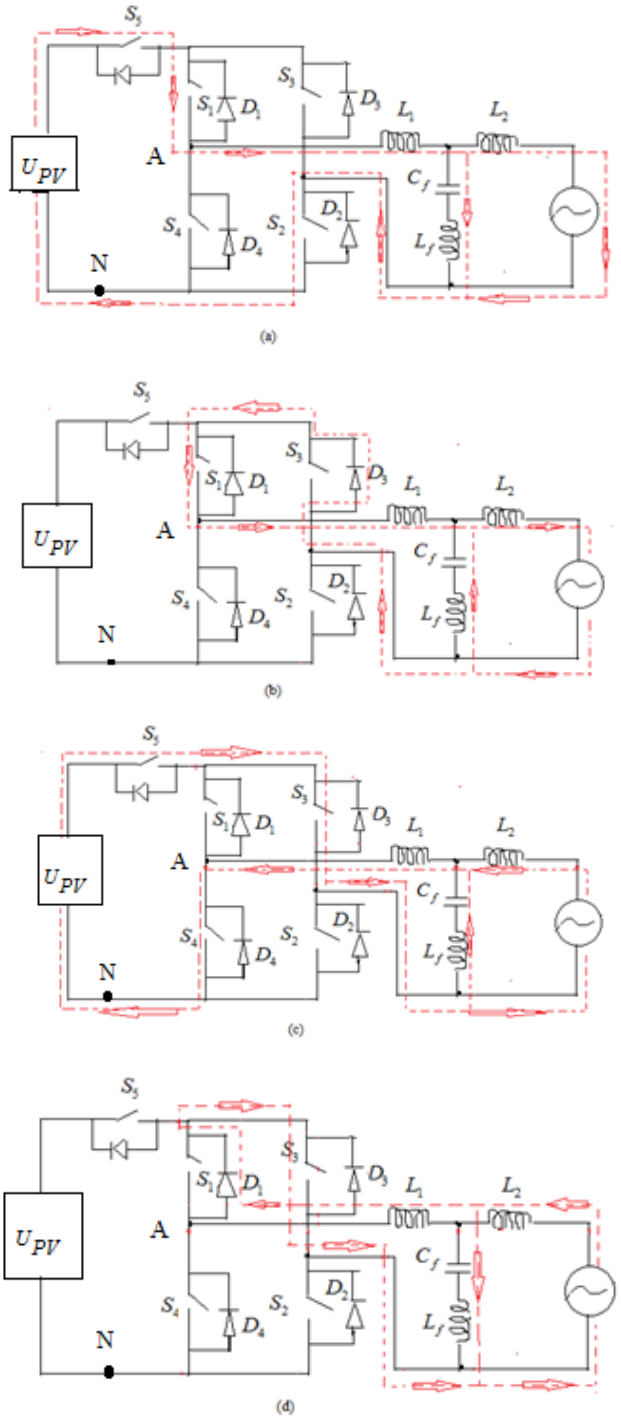

Fig.5 .(a)Current path during mode-1 operation b) Current path in mode-2 operation,(c) Current path during mode 3 operation, (d)Current path during mode4 operation

Mode1: Active period of positive half cycle

During this mode switches S_5, S_1 and S_2 conduct, all other switches are turned OFF, current flows from inverter to grid through filter. The voltages are

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$$V_{AN} = U_{PV}, V_{BN} = 0, V_{CM} = \frac{U_{PV}}{2}$$

Mode2: Freewheeling period in positive half cycle

During this mode S_1 is ON, all other switches are turned OFF. Current from grid freewheels through S_1 and anti-parallel diode D_3 .The voltages are

$$V_{AN} = U_{PV}, V_{BN} = U_{PV}, V_{CM} = \frac{U_{PV}}{2}$$

Mode 3: Active period during negative half cycle

During this mode switches S_5, S_3 and S_4 are turned ON, all other switches are turned OFF .Current is fed from inverter to grid through filter. The voltages are

$$V_{AN} = 0, V_{BN} = U_{PV}, V_{CM} = \frac{U_{PV}}{2}$$

Mode4: Freewheeling period during negative half cycle

During this mode switch S_3 is turned ON, all other switches are turned OFF. Current freewheels though S_3 and diode D_1 .The voltages are

$$V_{AN} = U_{PV}, V_{BN} = U_{PV}, V_{CM} = \frac{U_{PV}}{2}$$

From above analysis it is evident that the PV array can be disconnected from the utility grid when the output [9] voltage of inverter is at zero voltage level and the leakage current path is cut off. The CM voltage of the proposed topology in each operation mode is equals to $\frac{U_{PV}}{2}$, and it results in low leakage current profile.

IV. LLCL FILTER

The inverter is interfaced with grid using a filter. It is conventional to use LCL filter. Instability of closed loop operation and resonance between grid and inverter are black marks for LCL filter. Resonance can be minimised by passive damping. Passive damping can be brought by introducing a $R_d - C_d$ branch in shunt with capacitor. [10] Series inductor L_f can eliminate dominant harmonics. The $L_f - C_f$ branch bypass high frequency harmonics and reduce filter inductance and volume.

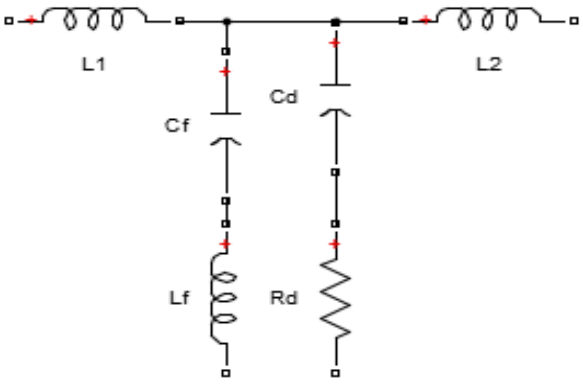

Fig.6. Circuit diagram of LLCL filter

L_f is smaller than L_1 and L_2 .In the switching frequency range inductance is affected only by double the switching frequency, hence scaling down of grid side inductance is possible. Transfer function of the filter is given below

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$$T_{f(s)} = \frac{R_d C_d s + 1}{s(L_1 L_2 R_d C_d C_f s^3 + L_1 L_2 (C_d + C_f) s^2 + R_d C_d (L_1 + L_2) s + L_1 + L_2)} \quad (3)$$

The resonant frequency is given by

$$\varpi_r = \frac{1}{\sqrt{(\frac{L_1 L_2}{L_1 + L_2} + L_f) C_f}} \quad (4)$$

ϖ_r and Q factor can be designed optimally by proper selection of R_d and C_d .To reduce power losses usually $C_d = C_f$ is followed. Total capacitance is kept below 5% of apparent power to satisfy power balances. This filter has better attenuation effect and harmonic reduction compared to LLCL. The aforementioned advantages make this filter preferable for this work. [11]

B. HYSTERISIS CONTROLLER

The hysteresis controller can modify and regulate the output current to match the reference current. A tolerance band is generated. Controller provides current control over this range. Mechanism of hysteresis current control is illustrated in Fig.7.The reference current I_{ref} and output current I_o are fed to the controller.

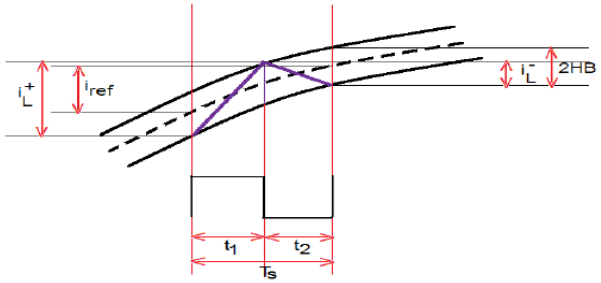

Fig.7.Hysterisis current control

The reference current is generated by dspace controller; the output current is sensed by optical isolated sensor. A opamp calculate the error signal. [16]

$$I_{error} = I_{out} - I_{ref} \quad (5)$$

The current signals are converted to equivalent voltage signals and is used in controller.

The hysteresis controller compares I_{error} with the tolerance band. The width of band is given by

$$HB = \frac{R_i}{R_i + R_f} * V_{DD} \quad (6)$$

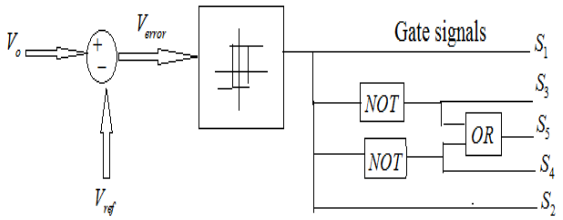

Fig.8. Pulse generation in hysteresis control

The controller control gate signals and control load current. When load current exceed tolerance limit the controller adjust gate signals and bring down the load current. This method is simple, efficient, and fast is capable of controlling the peak currents. [17]

IV. SIMULATION AND RESULTS

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To validate the theoretical analysis simulations are done in MATLAB and results are verified. The simulation parameters areParasitic capacitance = $0.1\mu f$
Duty ratio of cuk converter = .75
Inverter switching frequency = 1KHz
Grid voltage = 230V
Grid reference current = 10 A
Filter details
L_1 =0.026mH, L_2 = 0.22mH, C_f =.00079 μ f,
L_f = 32 μ H,

The simulation of the overall grid connected system with hysteresis control is done and following result is obtained.

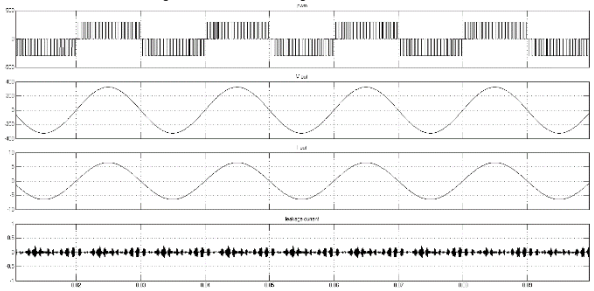

Fig.9. [a] Output of H5 inverter, [b] grid voltage, [c] grid current, [d] leakage current

The leakage current measured was 24mA, which is above standard norms. The common mode voltage was persistent and this lead to low leakage current. The presence of LLCL helped in improving the harmonic profile. THD of the system was found to be 2.28%.When conventional LCL filter was employed THD was observed to be 4.37%. Maximum power point tracking was implemented with Perturb and observe algorithm. MPPT generated the gate signals for cuk converter. Cuk converter could produce ripple free and continuous currents. Hysteresis controller was successful in feeding grid current in phase with grid voltage. Spikes were observed in the leakage current waveform this is due to constant hysteresis band width. The simulation was repeated with H4, HERIC and H6 topologies. Leakage current was measured was 472mA, 132mA and 92mA respectively. The overall efficiency of H5 was found to be 97.2%.The switching loss is very less in H5 compared to other topologies.

V. CONCLUSION

Lucrative system limiting leakage current in grid tied photo voltaic systems is discussed in this paper. MPPT is implemented with cuk converter, this could provide better results than conventional dc-dc converters. Cuk converter facilitated continuous input current to inverter. PV output power was constant throughout. LLCL filter gave improved harmonic profile. With H5 topology the common mode voltage was found to be constant and minimum leakage current was observed. The system could reduce potential variations of bridge voltages with respect to ground. Leakage current obtained was with in the safe limits. The leakage current profile obtained satisfies standards pertaining leakage currents.

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