Performance Analysis of Common Issues In the PV Transformer-Less Inverter Topology

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***Abstract*— The Photovoltaic (PV) Panel is part and parcel in recent time where it has been used in the electricity generation through either in Transformer based or Transformer-less inverter topology. To reduce the limitation of using transformer based system, no transformer topology is highly popular where the main and common issue is leakage current through parasitic capacitance. In this paper, main focusing issue is leakage current hence, a new topology is introduced and for leakage current reduction purposes, Pulse Width Modulation (PWM) has used as a switching combination and compared with another topology.**

***Index Terms*— Photovoltaic (PV), Pulse Width Modulation (PWM), Leakage Current, Parasitic Capacitor, Inverter.**

I. INTRODUCTION

Electricity demand is escalating dramatically in different sectors especially the education , health, technology as well as welfare [1]. However, maximum lack of fulfilling areas is rural areas where they are facing in different issues such as health care, illiteracy rate, transportations and low electrification rate as well [2-4] where economical side is the vital one[5-7]. The source of electricity can be renewable or non renewable energy. At present, the renewable energy takes the leading position to produce electricity due to reduce the electrification problem in rural areas [19, 20]. In 1660 to until now, there are few countries that are included under of OECD countries that already established the renewable energy in the rural sectors due to overcome the electrification problem. However, nowadays non OECD countries are also focused on Renewable Energy (RE) to find out the sustainable solution especially for the rural areas electrification problem. Hence, removing the electrification problem is becoming a big challenge[5, 12]in recent ages. For this issue, Government is also influencing the people to use RE technology to overcome the needs for rural electrification issue [13]. Before installing the power supply at remote areas, it is necessary to know the previous power installation system due to cost worries. [14-16]. RE demands are increasing day by day and because of two reasons that already discussed which are the electricity demands due to the increase of rural facilities as well as increasing of population and secondly the reduction of environmentally dangerous chemical emission for human which is CO2[17]. As the energy demand is escalated dramatically, the renewable energy especially solar takes the most important part where it's fully cost of free as well as environmental friendly [9]. Hence, the PV panels are commonly used nowadays in both cases stand alone and connected to grid as well where the core components are power conditioning and regulation make up. In the solar generation, inverters are used as a second core component where it may be used either in transformer-based or transformer-less system. However, in both cases, it does very good performance and expected outcome. Due to DC current management, PV panel works accurately when it converted to AC through inverter, although the main concentration is clean the environment as much as possible [21], [22]. Hence, transformer bears the most important part to handle the overall system. To achieve high range of power in the overall system, Grid connected inverter is highly popular through analog maximum or normal point tracking methods [23]. Throughout the researchers work transformer-less inverter system is being highly developed for getting high efficiency, less cost and size [20]. In contrast, galvanic isolation has been occurred in the PV-Transformer-less inverter topology where the main problem is common mode leakage issue which is actually the reason of reducing the efficiency and increasing the loss [20], [24]-[25].

This paper is presented the working principle of Transformer-less inverter topology with importance respect of high efficiency achieving and the occurring common issues as well as solution process. At last will be proposed a PV-Transformer-less inverter where will be shown the wave shapes of Common Mode voltage and reduction of leakage current through Pulse Width Modulation (PWM).

II. PV PANEL

Solar panels are made of a thin layer of semi-conducting material between a sheet of glass and a polymer resin. When exposed to daylight, the semi-conducting material becomes 'energized' and this produces electricity. Solar panel systems are mainly two types one is solar water heating and another one is photovoltaic (PV) solar panels. A solar PV system is usually made of solar panels, an inverter, isolator switches, a PV generation meter and cables [26-27]. European and Australian householders are widely accepted by Government to use PV systems due to no rotary component, silence, roof installation as well as no pollution [28]. A PV cell is shown like in Fig. 1, where all bears their individual meaning like I is overall current, IPH is the photo-generated current, Rs is panel series resistance and Rsh is the panel parallel (shunt) resistance [29].

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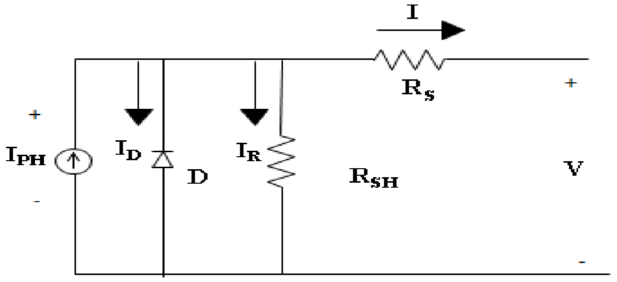

Fig. 1. Photovoltaic (PV) Cell equivalent circuit [29]

In photovoltaic (PV) panels the output depends on temperatures, load conditions as well as various irradiance which are very important for maximum power point tracking (MPPT) that can be found by I-V characteristics and V-P curves. Meanwhile, in above circuit diagram, maximum power depends on output achieving voltage and current where the output current is exponentially developed with junction thermal voltage Vt , that shown through below equation.

$$I = IPH - I0\,(e^{\frac{V+I_R}{n_s V_t}} - 1) - \frac{V+I_{R_S}}{R_{SH}} \text{ and where } V_t = \frac{AKT_{stc}}{q}$$

Where A= diode quality factor (ideally), K= Boltzmann's constant, q= the charge of the electron, ns=the number of cells, T_{stc}=standard test constant (stc) temperature in kelvin. Io= dark saturation current in STC. In Fig. 2 below is shown the I-V and P-V characteristics under given light irradiance level at which it gives Isc under short-circuit condition while Voc is the output voltage when the panel is open. Maximum power at Pmax is indicated at current IMP, and voltage VMP respectively.

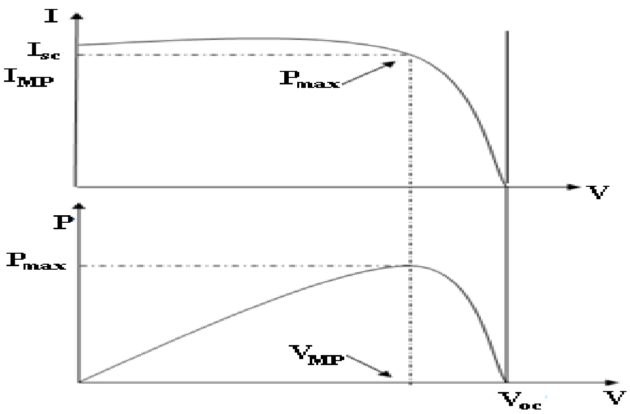

Fig. 2. I-V characteristics and P-V curve and maximum power achieving point [30].

The solar PV systems, the most important are size and types due to price consult as well as where it will be installed. Approximately costs will be € 5,000 to € 8,000 for 4kWp (kilowatt peak) PV system. In additionally, in this system initial cost is higher than overall processing cost. After generating the own electricity under the Feed-in Tariff (FIT), it's possible to savings on your bill. The idea behind the FIT is that as solar PV takes off, the cost will drop. And this is why the rate of the FIT is decreasing over time to compensate for the falling cost of solar systems. In below has been shown a graph where clearly shown the cost for solar PV from 2011 to 2015 [31].

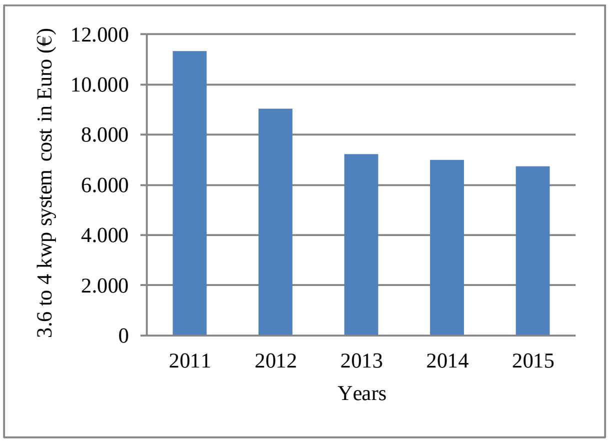

Fig. 3: 3.6 to 4 kwp PV system cost paid by members from 2011 to 2015

III. Transformer-less Inverter

Transformer-less inverter basically have some common advantages whereas transformer does not have such as in reduced size, complexity, and weight along with improved efficiency. At present, it's become highly part and parcel to get more electricity with low cost [32]. No transformer system in the PV inverter which is reduced losses, costs, and size [18, 33-37]. To introduce the common issue which is occurred due to galvanic isolation of the electrical grid in the PV no Transformer inverter system. This common issue is leakage current that flows through the parasitic capacitance between the PV array and the ground. In additionally, the leakage currents increase conducted and radiated harmonics injected, electromagnetic emissions in the electrical grid, and losses [38-39]. Grid-connected of photovoltaic (PV)-Transformer less Inverter systems have developed rapidly and widely hence, reduce the PV-panel price [40].

IV. Proposed PV-Transformer-Less Inverter Topology

In this approach shown in Fig.4 is a transformer-less topology, which is actually made by using full bridge transformer-less inverter topology and de decoupling technique where uses extra one switch (S7). In total, in this proposed topology used seven switches where four switches are connected alternatively to make a inverting process smoothly. This idea actually achieved from full bridge technique and the proposed topology has been compared with H6 topology. Here used extra switch with filter to make a new transformer-less inverter topology. Meanwhile, in fig.4 shows the leakage current path which is through parasitic capacitor that automatically created in between PV panel to ground.

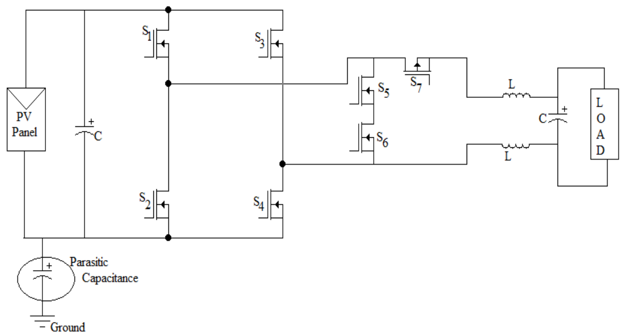

Fig. 4. Proposed PV-Transformer-less inverter Topology

V. REDUCED LEAKAGE CURRENT PROCESS

A. Switching Techniques for Leakage Current Reduction

In Fig.4 has been shown the proposed topology and it will be compared with H6 topology. In below mentioning table I and table II are the tables where show the values of leakage current and output voltages for both H6 and proposed technique.

Duty cycle, D=50% (switching on/off time is equal)

In the case of 50% duty cycle in table I when switch S1 and S4 is in on S2 and S3 is in off mode that works is in opposite direction and S5 and S6 is the DC decoupling switches and it connects alternatively to work accurately. After using the six switches in 50% duty ratio, output voltage can be got around 10.5V, but the leakage current is occurred more that varies from -325.75fA to -480.21nA. On the other hand, this leakage current is varies from 11.024u to 20.618pA for H6 transformer-less inverter topology and Here selected only one leakage path.

TABLE I: 50% DUTY CYCLE OF INVERTER AND DIFFERENT SWITCHING CONDITIONS ARE USED FOR APPROACH TOPOLOGY

S1	S2	S3	S4	S5	S6	S7	Vout (V)	Leakage current PV-G (A) (H6)	Leakage current PV-G (A) (Proposed Topology)
ON	OFF	OFF	ON	OFF	ON	ON	10.29	302.129u	-480.21n
OFF	ON	ON	OFF	OFF	ON	OFF	10.40	50.367u	360.997p
ON	OFF	OFF	ON	OFF	ON	ON	11.01	20.618p	-819.45n
OFF	ON	ON	OFF	ON	OFF	OFF	10.89	11.024u	-325.75f

Duty cycle, D=75% (switching off time is one fourth while on time is three quarter)

In the case of 75% duty cycle when leakage current has occurred through one path that has been shown in Table II for when switches S1 and S4 is in on mode than the switches S2 and S3 is in off mode that works is in opposite direction and S5 and S6 is the DC decoupling switches and it connects alternatively to work accurately that fixed in 75% duty ration and rest of the switch which is proposed switches are fixed in 50% duty cycle, output voltage can be got more than 11 V which is more that which is achieved for 50% duty ration but the leakage current is occurred which is reduced from the 50% duty ration that varies from -325.7n to -52.85f Amp.

TABLE II: 75% DUTY CYCLE OF INVERTER AND DIFFERENT SWITCHING CONDITIONS ARE USED FOR APPROACH TOPOLOGY

S1	S2	S3	S4	S5	S6	S7	V out (V)	Leakage current PV-G (A) (H6)	Leakage current PV-G (A) (Proposed Topology)
OFF	ON	ON	OFF	OFF	ON	ON	11.09	192.129n	182.874n
OFF	ON	ON	OFF	OFF	ON	OFF	11.04	502.387u	23.987p
OFF	ON	ON	OFF	OFF	ON	ON	10.86	-20.618n	-325.7n
ON	OFF	OFF	ON	ON	OFF	OFF	10.95	110.034p	-52.85f

B. Wave Shapes of Reducing Leakage Current by Load Effect

The Leakage current (LC) has occurred in different places and in this paper has been considered only two paths. It has been simulated through PSpice software after constricting the circuit together. The value of leakage current for PV panel to ground is changed from when we consider in one path that has been shown in above in a tabular form. Below is shown the considering paths where leakage current is occurred.

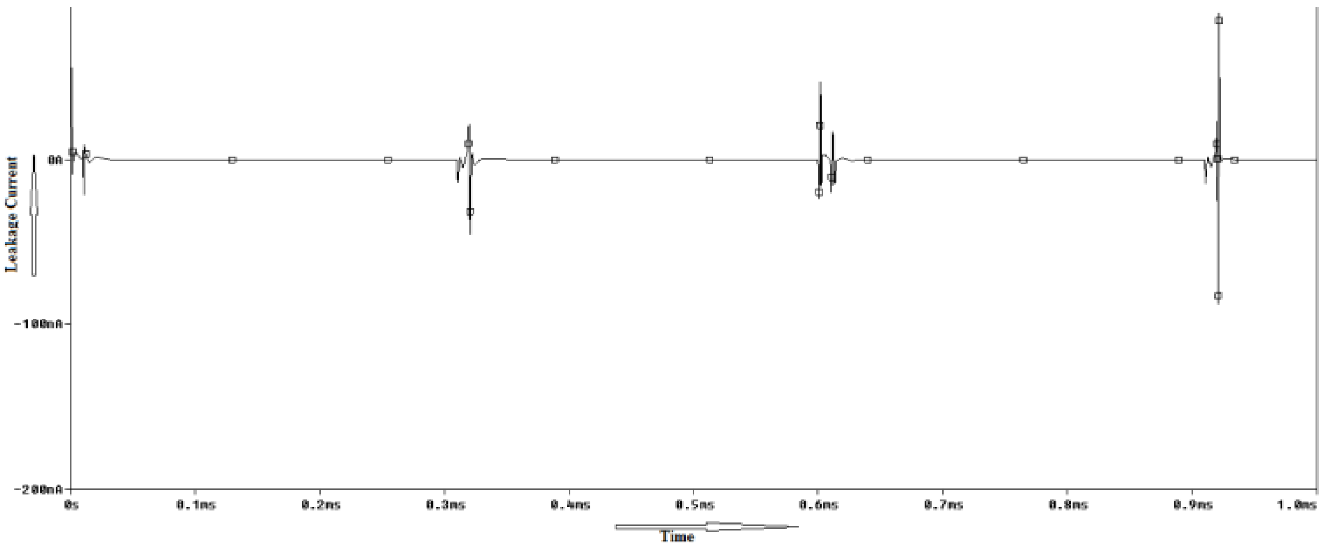

Fig.5. Leakage Current through PV panel to Ground through parasitic Capacitance (10Ω)

One path is in between PV Panel to ground and another one is in between two sides of PV panel.

In the Fig.5 shows the leakage current when the considering load is very low with 10Ω and the leakage current is occurred low amount in the switching on/off time.

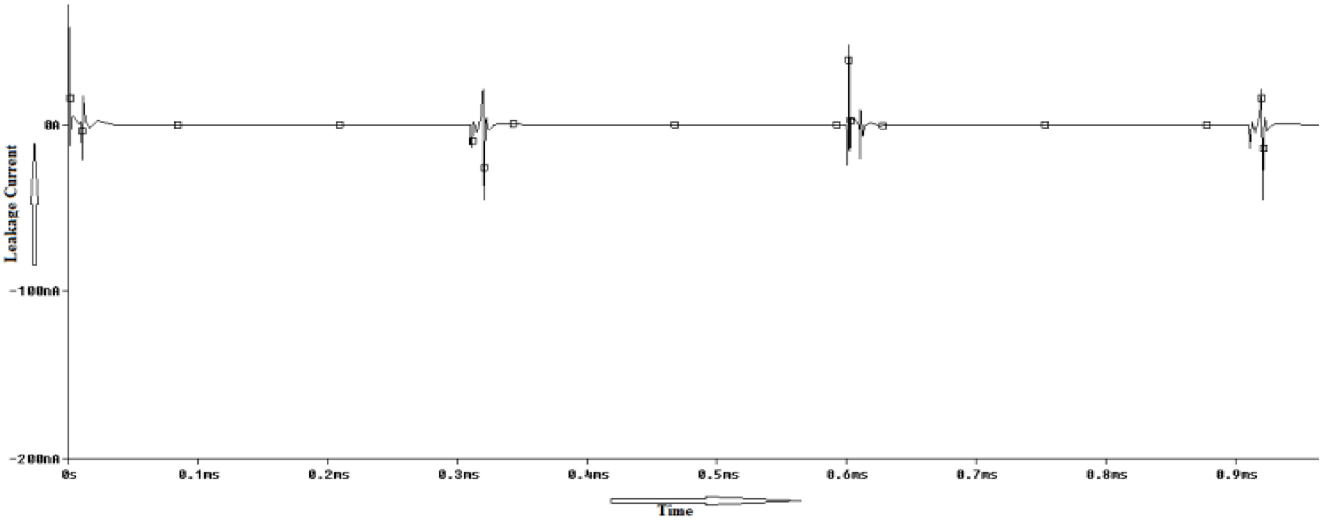

Fig.6. Leakage Current through PV panel to Ground through parasitic Capacitance (1KΩ)

Rest of the time it shows comparatively very low. On the other hand, Fig.6 and Fig.7 show the leakage current after changing the load to kilo and mega range.

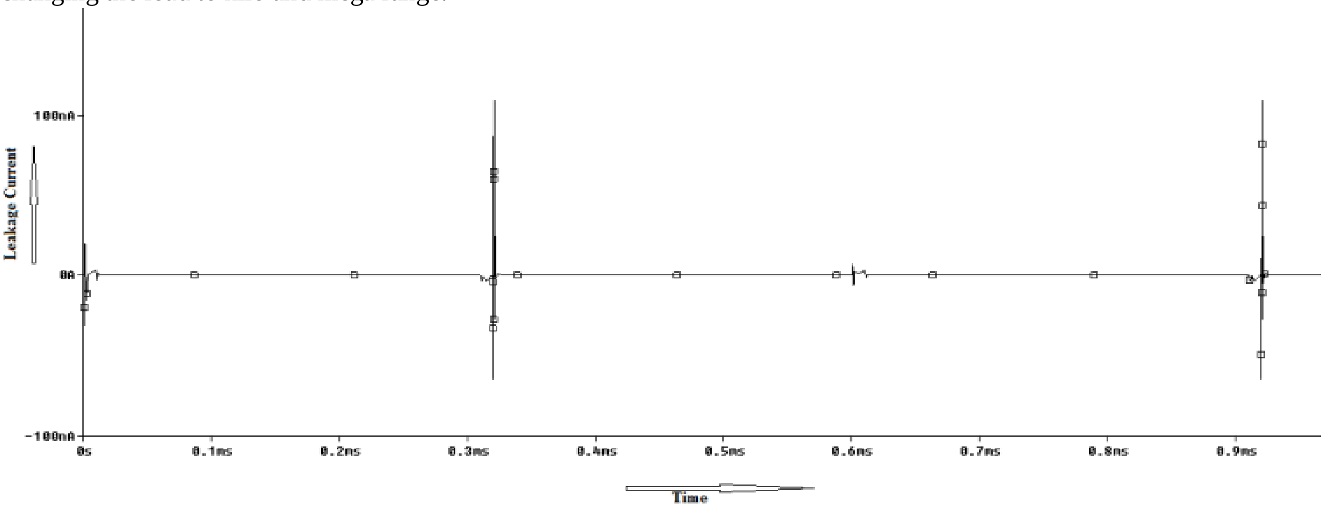

Fig.7. Leakage Current through PV panel to Ground through parasitic Capacitance (1megΩ)

When the effect is very clear and occurring leakage current is gradually increased respectively

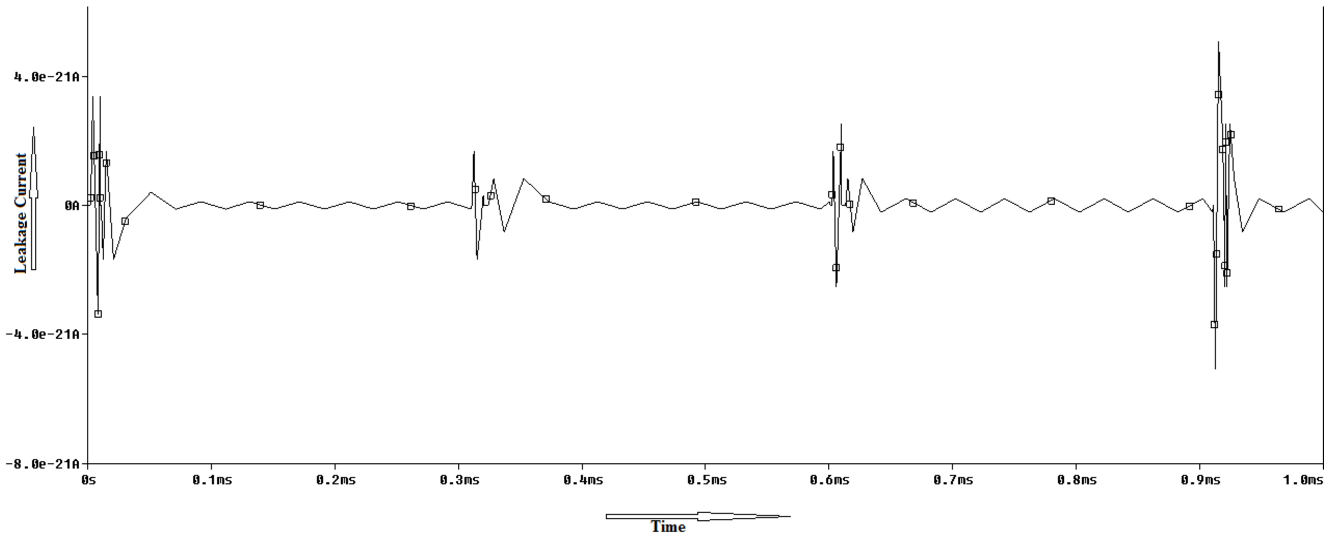

Fig.8. Leakage Current in between two sides of PV panel (10Ω)

Another considering path is mentioned before which is PV panel side where the leakage current is occurred very low amount.

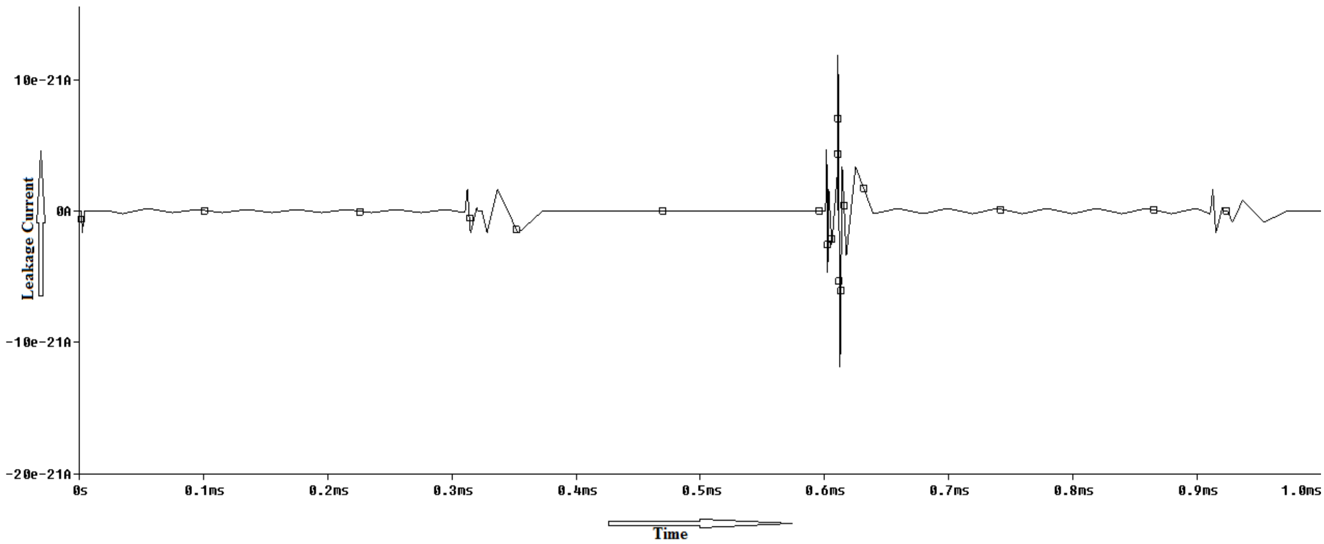

Fig.9. Leakage Current in between two sides of PV panel (1KΩ)

Here showed that the leakage current is flowing not only in the switching on/off time but whole time too. However, in the switching on/off time, it affected more.

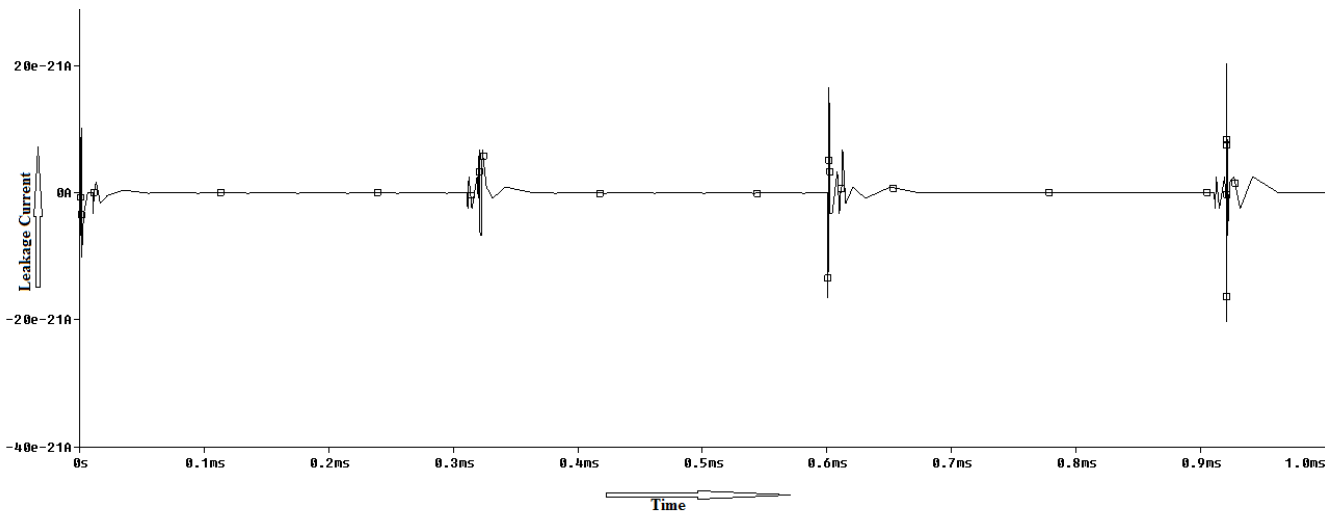

Fig.10. Leakage Current in between two sides of PV panel (1megΩ)

In the road effect, it works oppositely. When the load is 10 Ω, the leakage current is more occurred compared to increasing the load to kilo and mega range.

VI. CONCLUSION

Leakage current due to galvanic isolation is the main limitation of PV transformer-less inverter topology. To reduce the leakage current Pulse Width Modulation (PWM) brings the vital role. In this paper shows two leakage current paths and considering 50% and 75% duty cycle for reducing leakage current. Here shows the leakage current reduction in tabular form which has compared with another topology. Furthermore shows the effect of different load in the system for reducing the leakage current.

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