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Proposed PV Transformer-Less Inverter Topology Technique for Leakage Current Reduction

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ABSTRACT

Importance and demand of using renewable energy is dramatically escalated globally. Hence, the use of renewable energy is going to touch in peak. This demand is varying according to the site choosing. For instance, Wind is preferable where air is following highly as well as solar recommended place is high sun ray reducing places. Especially, the renewable system is highly recommended for electrification issues where it's possible to produce the electricity for fulfilling rural and remote areas electricity problem. The photovoltaic (PV) panel of connecting with transformer based system is popular where some limitations are occurred especially cost and weight. In contrast, in this paper is focusing these issues where the transformer-less inverter system is used. Here will discuss some transformer-based and transformer-less inverter topologies and the leakage current issue which is occurred when transformer-less inverter system is used. Moreover, here is proposed a topology for reducing the leakage current after doing switching technique in both 50% and 75% duty cycle where output voltage remains quite same.

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1. INTRODUCTION

To generate the electricity the most uses sources are coal, oil and natural gas where these sources actually the main causes pollution our environment [1] as well as those source are diminishing rapidly. To make our environment friendly, today's most important energy is renewable energy such as hydro, solar, wind, bio-mass and so on [2-4]. The Photovoltaic (PV) panel is becoming a very part and parcel due to electricity production. PV system to produce electricity needs inverter which is establishing interfaces between the PV-panels and the utility-grid for decreasing the cost and reducing power loss [1, 5]. The most solar-to-grid connections in the single-phase inverters which are followed by single-phase transformer. The use of transformer, although helps in providing for galvanic isolation between the PV panel and the grid, leads to increase in loss of power, and hence loss in revenue. Although compensating considerably for the issues of cost and size, transformer-less topologies result into increased leakage current due to coupling and parasitic capacitances [5, 6]. These leakage currents form their paths through the way of low-pass filter (LPF) elements (used for AC wave-shaping) and the exterior grid-network back to earth because of developed common mode problems which may reason of varying in voltage. In the common-mode issues of the system, a voltage which is generated around the parasitic capacitor helping the inverter to produce leakage current, causing to produce even electric shocks. Hence, the common mode voltage variations, the very reason for leakage currents, is to try using different approaches in newly reported topologies aimed at minimizing these currents. Another approach by same authors in [7] suggests a multi-stage single-phase converter of a transformer-less topology for maintaining a constant common-mode voltage thus reducing leakage current considerably [8-11].

In this paper has been shown some topologies which are both transformer-based and transformer-less inverter. The effect of parasitic capacitance and leakage current occurring paths has been shown below. Here will be proposed a PV panel to transformer-less inverter topology with AC and DC decoupling based where two extra switches are used. Hence, here will show the switching effect of proposed topology for 50% and 75% duty cycle.

2. TRANSFORMER AND TRANSFORMER-LESS TECHNIQUES

In a typical conversion uninterrupted power supply system, the main power quality objectives are adaptability and availability of power in times when the utility mains are either unavailable or can be replaced by battery supply from alternative sources of wind or solar power. In both of the approaches, conversions are taking place twice, in the case of using power from utility mains there is Rectifier to charge DC battery storage as shown in Figure 2.1.

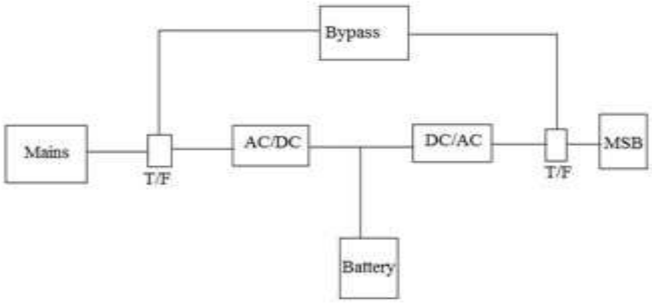

Figure 2.1. Functional block diagram, of a typical conversion system

AC-to-DC conversion takes just after the transformer (T/F) which is used to charge up battery or other storage system. In this case when the mains get interrupted, the reverse takes place to provide conditioned AC power to the load once again through a transformer. Both transformers are equipped with switch-gear devices for their connection and disconnection at convenience. In this case the of getting power from non-conventional sources, some other conditioning circuits are required as well, however transformers remain at place providing isolation. In the DC-to-AC conversion is used as a result of switches being turned and off in a well defined switching sequences, slicing the DC into samples before being put through low-pass filter for producing a sinusoidal AC output. Advances in power semiconductors and control have also allowed PWM (Pulse Width Modulation) converter switching frequencies to increase, encouraging the use of IGBTs (Insulated Gate Bipolar Transistors) within the rectifier stage. IGBTs have been utilized within inverters for many years; higher PWM switching frequencies improve inverter overall performance. Hence in transformer-less inverters PWM plays a role in reducing the leakage current on their leakage current paths.

The large number of solar photovoltaic (SPV) cells which has been connecting to make solar panel module. These achieving modules are connected with each other where will be achieve fluctuated DC. In additionally used DC to DC converter to make this pure DC. Hence, here is used inverter for convert it to AC. After that used Transformer or Transformer-less technique and sequence wise used filter and prepared for grid connected load. In below Figure 2.2 and has been shown the block diagram of overall PV panel to transformer/transformer less technique for grid connected load.

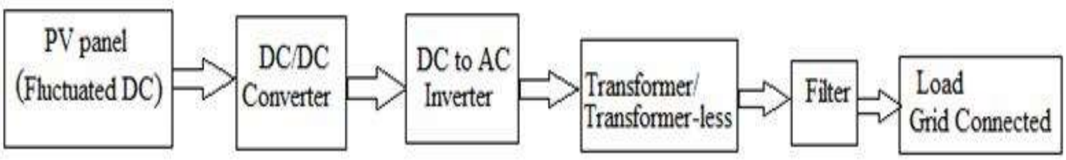

Figure 2.2. Block Diagram of Transformer and Transformer-less techniques

2.1. Transformer-Based Techniques

Distributed generation is becoming commonly used technique for harvesting electric power from solar, to be installed very soon in most of the new township schemes. In this case the solar needs be stabilized before it is converted into a proper AC for connectivity to supply from main grid. For proper connectivity, the voltage waveform on the grid is being checked constantly by a DSP-based controller which is going to control switches such that the voltage gets connected at proper time and at a perfect zero crossing. Such kind of DG are also termed as micro generation as shown in Figure 2.1.1.

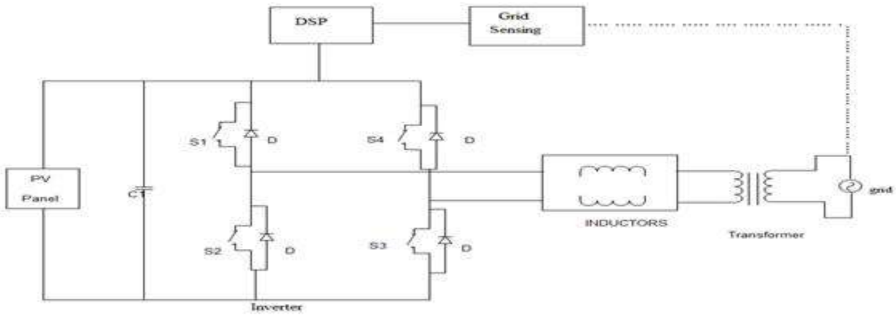

Figure 2.1.1. Transformer-Based Inverter [12]

To reduce the transmission line burden, micro grid system is becoming a hugely favourable choice and useful too as it is able to share power from each other grid including that from rooftop solar panels also. Micro grid structure is essential for power consideration purposes, as a result [13] discusses about transformer-based multi winding converter that actually is capable to monitor the dynamic power flow with maximum power tracking features, to do so, briefly discuss about multi grid structure and local power network for better knowing about the whole system. Common transformer core is shown in different condition with a common diagram and load winding voltage and operation mode in both charging and discharging purpose of a battery. Meanwhile, in this paper uses some controllers where these controllers have implemented using TMS320F2812 DSP-based evaluation board by Texas Instruments.

Inverters are used for industrial applications, and hence power conversion efficiency is its main limitation alongside its output waveform. These issues are addressed through suggesting the use of multilevel inverter topologies reducing thus the Total Harmonic Distortion (THD) while reducing the power losses through the use of appropriate switching sequence [14] generation. With a given Pulse Width Modulation (PWM) are shown output voltages at different points such as the auxiliary inverter, main inverter, the auxiliary transformer, main transformer, and hybrid multilevel inverter for both units.

2.2. Transformer-Less Techniques

Transformer-less topology is used to compensate for the limitations of transformer-based topology such as weight and high cost, however it leads to the appearance of common mode voltage (CMV) problem, and hence ground leakage current due to parasitic capacitance between the PV panels and the ground [5, 8]. A solar PV panel has got a surface area facing a grounded structure, which stores charge under applied voltage difference, making as an undesirable side-effect of what is referred to as "parasitic capacitance". The leakage current due to common mode voltage development reduces the efficiency of power conversion stage, affects the quality of resulting grid current, and hence gives rise to the safety threats. In order to eliminate the common mode leakage current in transformer-less PV system, the concept of virtual DC bus is proposed. By connecting the grid neutral line directly to the negative pole of the DC bus, the stray capacitance between the PV panels and the ground is bypassed. The CM ground leakage current can be suppressed completely. Virtual DC bus is created to provide the negative voltage level for the negative AC grid current generation. The virtual DC bus is realized with the switched capacitor technology that uses less number of elements. Therefore, the power electronics cost can be reduced.

In Figure 2.2.1 is shown a DC source assumed to be from a PV panel, which is fed to an inverter made of switches followed by coupled coils, and Electro Magnetic Compatible filter to produce an AC output for connection to a load via grid. A PV panel to ground parasitic capacitance, filter to ground and neutral to ground parasitic capacitances are shown making up leakage current paths. In Figure 2.2.2 has been shown the transformer-less inverter topology where DC decoupling [16] is used with four switching based inverter.

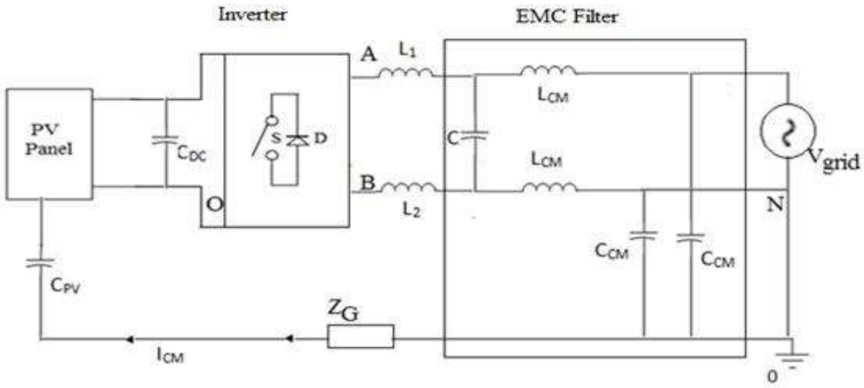

Figure 2.2.1. Transformer-less inverter topology [15]

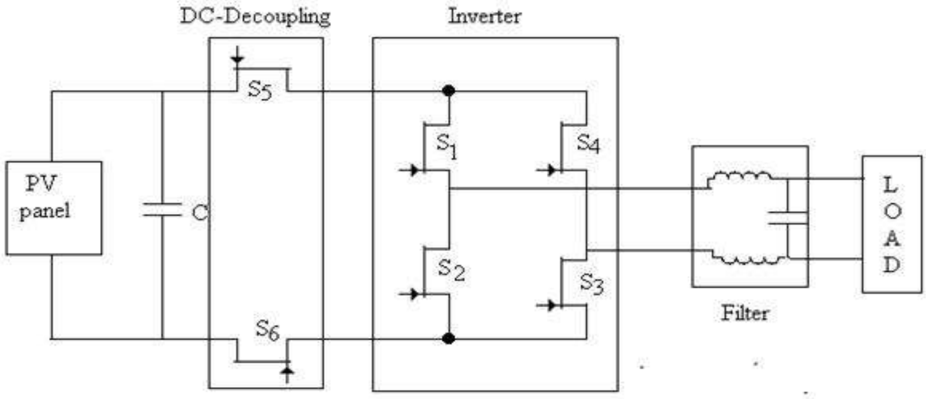

Figure 2.2.2. DC-decoupling based transformers-less inverter topology

In above Figure 2.2.2 is a DC-decoupling based transformer-less inverter topology which is helped to switch the DC value and below use the Duty Ratio to see the effect of switches in the system which can be verified by output voltage and also changes of Leakage current where only one path (PV panel to ground)is consider. AC decoupling Inverter topology [1, 16] and the figure has been shown in Figure 2.2.3.

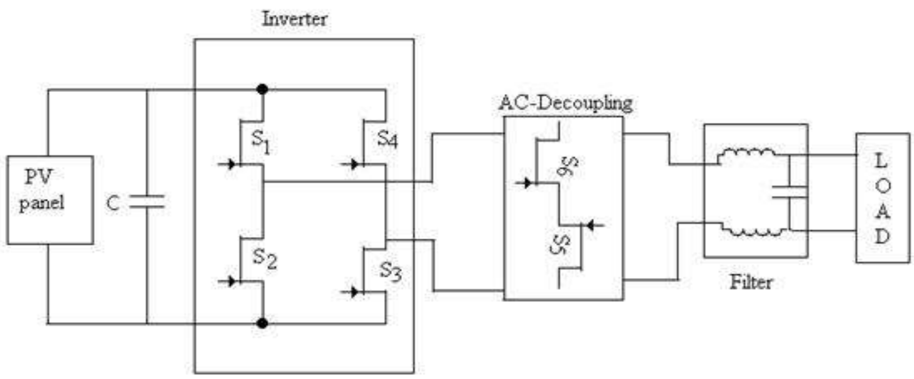

Figure 2.2.3. AC-decoupling based transformers-less inverter topology

In above Figure 2.2.3 is an AC-decoupling based transformer-less inverter topology which is helped to switch the AC value and below use the Duty Ratio to see the effect of switches in the system which can be verified by output voltage and also changes of Leakage current where only one path (PV panel to ground) is consider.

3. LEAKAGE CURRENT PATHS AND ISSUE

Electromagnetic compatibility (EMC) filters is used to describe the work/function of devices in a system of an electromagnetic environment and its filter helps to reduce the common mode problem from the system. However, this filter is included with different inverter topologies such as the full-bridge of the bipolar pulse width modulation (PWM) and half-bridge have been proposed for avoiding the common mode leakage issues where these topologies show some limitations which are overcome in [17] for giving high efficiency with require low input voltage. To do so, it uses EMC filter with inverter and using BJT switches with freewheeling diodes. However, the extra features of this work is in the form of two extra switches S5 and S6 with freewheeling diodes which is actually compared with normal full-bridge inverter with EMC filter where it uses unipolar PWM with 400V peak to peak voltage and 5 kHz switching frequency. The proposed topology shows better outcome in the case of inductor current, output voltage of the inverter, common mode voltage, measure efficiency and European efficiency. Moreover, the achieved efficiency is shown 97.4% where the European efficiency are varied between 97.16% and 95.2% with using input voltage range is in-between (350–800 V). In Figure 3.1 is given the block diagram of a circuit topology showing leakage current and the parasitic capacitor that actually has in between PV panel and ground.

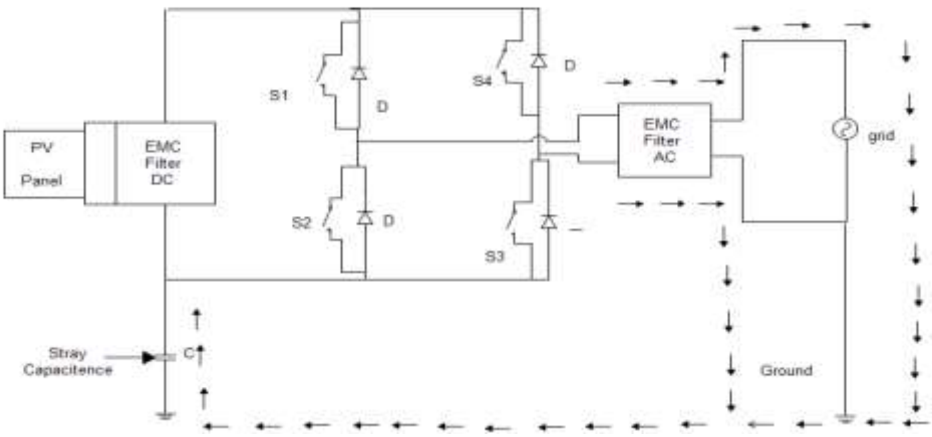

Figure 3.1. Current Direction and Parasitic Capacitor are Shown [17, 18]

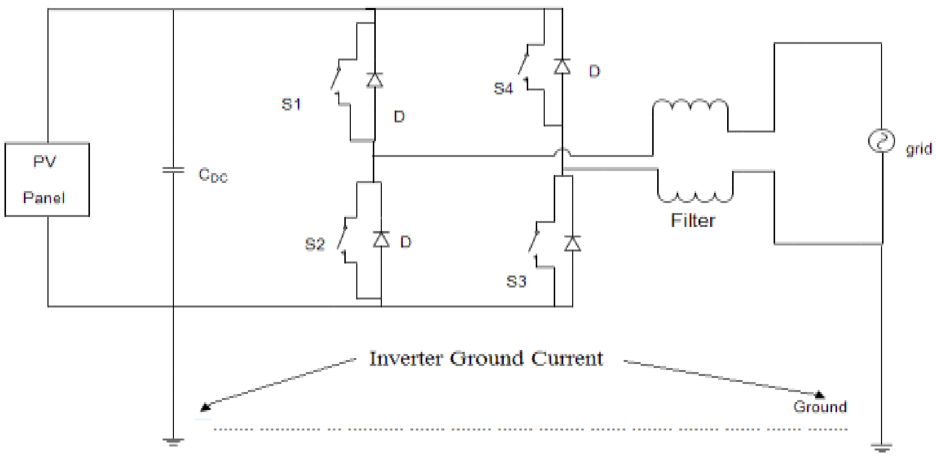

Figure 3.2. Ground current is around the system [16]

An increase in leakage current induces harmonics on the grid side and makes the overall system unbalance, and as a result converter topology helps to overcome this problem because the amplitude as well as spectrum of leakage currents depend on it, at a time, switching condition also bring the vital role to reduce the leakage current. Here in [19] is used AC filter, resonant circuit and it is tried to measure the ground current for different conditions, hence, making a system where have inverter, low pass filter and connected to grid and here clearly showed that leakage current flowing at points to ground. Also, is shown different paths to show the inverter output, ground voltage and ground current when experimental setup was done that showed through oscilloscope. Meanwhile, using resonant circuit it has been shown and simulated with respect to frequency. It is used in NPC PV inverter to see the inverter output, ground voltage and leakage current as well. Although here may has no problem for using resonant frequency, however, they are not considered the switching losses and switching condition. In Figure 3.2 shows the ground current that flows in the system.

Highly populated renewable energy does recover from the power loss problem although are suggested enormous number of photovoltaic system with transformer-less topologies. The same objective is followed in paper [20] where the main target is aimed at increased power efficiency, as a result of which common mode leakage current is reduced. A new transformer-less topology had been proposed using the concept of AC Decoupling as well as DC Decoupling. Here is given simulation results verified by experimental results proving power efficiency of the overall system. Moreover, almost same work is done in paper [20-22] where the authors use a little bit approach.

4. PROPOSED TRANSFORMER-LESS INVERTER TOPOLOGIES

In above section 2 has been shown the AC decoupling and DC decoupling based inverter topology and after that it combined and verified the output voltage, now in Figure 4.1 is shown the circuit diagram that actually based on AC and DC decoupling and added extra two switches and diode that actually proposed here. Here is shown that the leakage current is reduced and the harmonics are reduced pushing the output further to higher value.

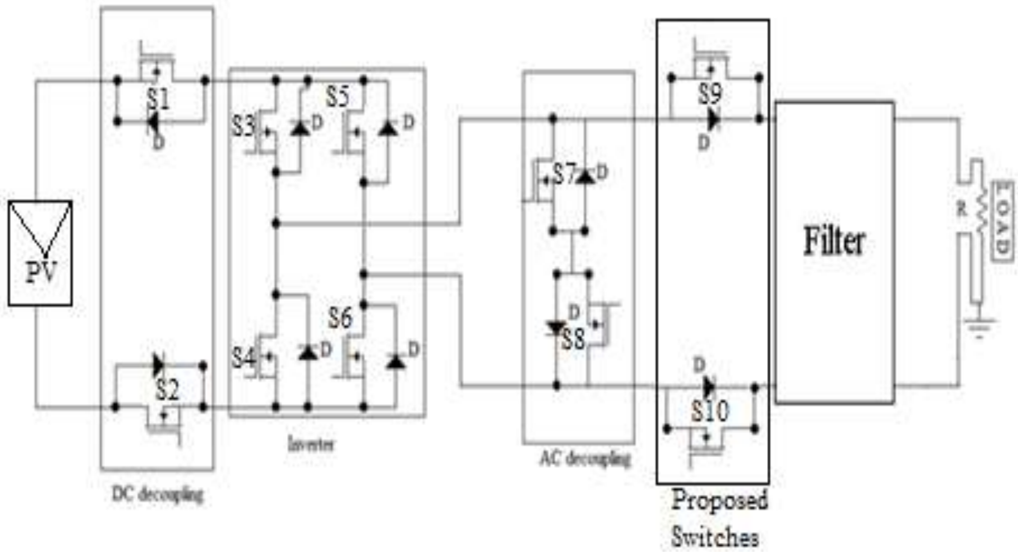

Figure 4.1. Circuit Diagram of Proposed Topology

In proposed approach is a transformer-less topology which is made by AC and DC decoupling with ten switches. AC decoupling has two switches that are connected with output of inverter and DC decoupling has two switches after DC signal that control the DC signal. Moreover last two switches are connected after AC decoupling which is helping to get signal for filter. Here it has been used a four switches based inverter where switches are connected in alternative way. It’s possible to get AC signal of load output due to the filter. Figure 4.2 shows the approach topology which is discussed above.

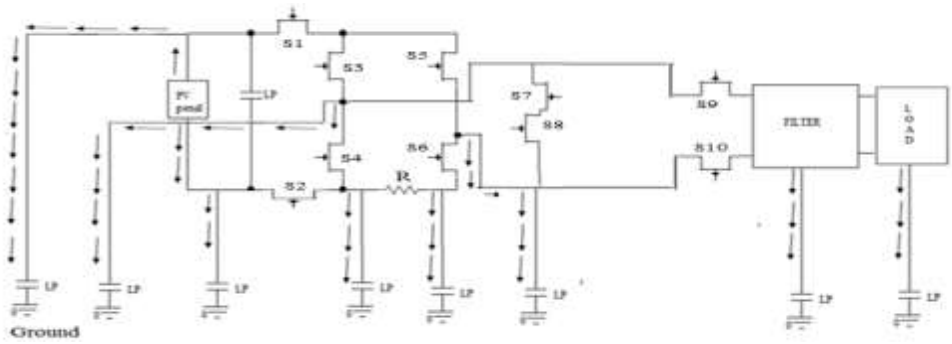

Figure 4.2. Approach topology where leakage paths are shown

5. SWITCHING TECHNIQUE FOR LEAKAGE CURRENT MITIGATION

Due to power electronic developments, the inverter is highly important and applicable in many fields and according to the DC power supply, it can be either current-source inverter (CSI) or voltage-source inverter (VSI), however commonly used inverter is VSI. In common today's situation basis, highly used technique is Pulse Width Modulation (PWM) for inverter switching purposes where it actually two types Unipolar Pulse Width Modulation (UP-PWM) and Bipolar Pulse Width Modulation (BP-PWM), meanwhile both types of PWM is used in different topologies, however, BP-PWM is more useable and perfect in the case of current distortion at zero crossing and distortion factor accuracy [23-25]. In the case of DC-DC converter where uses the PWM that can be divided in three categories such as buck, boost, buck-boost and the using power switches can be MOSFET, BJT, or IGBT. Moreover, the frequency for the switches is high (KHz or MHz range) where the achieving output is voltage regulation that varies through input voltage, output current and circuit components. On the other hand, this power switching is varied through duty ration (D), hence voltage gain (M) that shows the conduction mode for buck, boost and buck-boost when M=D, M=1/(1-D) and M=D/(1-D) respectively [26]. Transformer-less topology also need to maintain the turn on/ off time through duty ratio. In below shows the switching conditions in for different transformer-less topologies. Now in below, shows the switching conditions of approaching topology in tabular form in Table 5.1 and 5.2 for 50% and 75% duty ratio respectively.

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

Here in Table 5.1 and 5.2 are shown some switching conditions where inverter switches are fixed 50% and 75% duty ratio respectively while the other switches are conducted in 50% duty ration, hence it is clear to observe that in my approaching circuit output voltage is around 8.5V and the occurring leakage current is very small amount in pico and nino range and 75% duty cycle shows reducing leakage current compared to 50% duty ration. Indeed, in both cases leakage current shows very small range.

Table 5.1. 50% duty cycle of inverter and different switching conditions are used for Approach topology

S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Vout	Leakage current PV-G (A)
ON	OFF	ON	OFF	OFF	ON	ON	OFF	ON	ON	8.29V	-380.21n
OFF	ON	ON	OFF	OFF	ON	OFF	ON	OFF	OFF	8.20V	225.997p
OFF	ON	ON	OFF	OFF	ON	ON	OFF	ON	ON	8.7010V	-89.45n
ON	OFF	OFF	ON	ON	OFF	OFF	ON	OFF	OFF	8.7010V	-305.75f

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

Table 5.2. 75% duty cycle of inverter and different switching conditions are used for Approach topology

S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	V out	Leakage current PV-G (A)
OFF	ON	ON	OFF	ON	OFF	ON	OFF	ON	ON	8.272V	82.474n
ON	OFF	ON	OFF	OFF	ON	OFF	ON	OFF	OFF	8.28V	173.997p
ON	ON	ON	OFF	OFF	ON	ON	OFF	ON	ON	8.2819V	-525.7n
OFF	OFF	OFF	ON	ON	OFF	OFF	ON	OFF	OFF	8.2910V	-29.75f

6. CONCLUSION

Leakage current is occurred through different paths which have been shown in this paper. The proposed topology is used by AC and DC decoupling where two extra switches are used. Hence, the leakage current is reduced up to femto range for both 50% and 75% duty cycle. The leakage current reduced more when 75% duty cycle is applied. Moreover, the output voltage across the load is remained quite same after using the switching technique.

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