SUPPRESSION OF LEAKAGE CURRENT IN QUASI MULTILEVEL INVERTER BASED PHOTOVOLTAIC SYSTEMS FOR GRID CONNECTED APPLICATIONS

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ABSTRACT

The application of Transformer less cascaded multilevel inverter (CMLI) in Photovoltaic systems (PV) has led to low-cost and high efficient systems. However, removal of transformer would result in the failure of galvanic insulation which in turn lead to a physical connection between the PV panels and grid. The flow of leakage current due to the parasitic capacitance would result in higher losses, higher harmonic content, Electromagnetic Interference (EMI) and safety problems. So, the problem of Leakage current remains a threat in designing a reliable PV system. Comparing to the stand-alone PV system, the Grid connected PV systems are little complex because of the problem of synchronization of various MLI modules that are cascaded together. The outflow current problem has been rectified using appropriate PWM modulation strategy along with the filter solution in order to acquire the improved results. Thus the leakage current mitigation issue is expected to improve. Simulations are carried out using MATLAB/Simulink to verify the performance of the proposed method.

Keywords: Electromagnetic Interference (EMI), Leakage Current, Transformer Less Cascaded Multilevel Inverter (CMLI), Parasitic Capacitance, Pulse-Width Modulated.

I. INTRODUCTION

The renewable energy sources are gaining its importance in recent years due to the increasing power demand.Inspite of numerous renewable energy sources, PV plays an vital role since sunlight is abundant throughout the year and also it act as a clean source of energy. The increasing customer demand and the incentives provided by the government has increased renewable energy generation globally.PV systems appears in two forms: either a stand-alone or a grid-connected system. The count of distributed PV system installations are increasing in the past decade. However the system cost and potential impacts on the safe operation of utility grid are the two main barriers for the successful implementation of PV systems. The problems related to grid integration are mitigated using power electronic controllers. The maximum power from could be harvested from the PV by employing cascaded multilevel inverters [2][5]. The usage of cascaded multilevel inverters as an Utility interface system for the renewable energy systems [2] will give a high quality output waveform when the switches are operated at low frequency [4].The CMI topology features isolated DC inputs which helps to employ the maximum PowerPoint tracking at every strings. Unlike other inverters, Cascaded MLI does not require costlier semiconductor devices which have made CMI as an essential part of all commercial and residential applications. A survey of CMI based PV systems is portrayed in figure 1. In large scale PV systems ,the CMI topology with modified features is integrated to a high frequency transformers where the point of common coupling voltage is high for the given frequency[5].The main objective of the transformer is to provide insulation by preventing dielectric breakdown and also to isolate the circulating leakage current paths.In small scale residential/commercial applications where the point of common coupling is low,transformerless CMI is preferred due to lesser cost and better efficiency. However the removal of transformer would result in insulation failure and creates galvanic connections between the PV panels and the grid.Another parameter which contributes to the output distortion is the presence of parasitic capacitance between the PV source and ground.parasitic effect of the capacitors would also lead to higher losses,electromagnetic interference and safety problems.Moreover the aforementioned problem would be highly pronounced in the grid integrated issues.The paper adresses the mitigation of leakage current in grid connected PV system where a qZSI module is employed in each module of the cascaded structure.Generally the leakage current suppression solutions are classified as (1)Topology solutions (2)Filter Solutions (3)Modulation solutions.Out of which,modulation solution is chosen to sort out the leakage current issue.The leakage current suppression solutions for transformerless inverters has been well explained[8].The bipolar modulation strategy is not preffered since the output quality is degraded eventhough the common mode voltage is maintained constant.Other topologies like full-bridge and modified full bridge topologies requires extra switching components on both AC and DC sides[14].Finally,filter solutions are prescribed in the existing paper,since the filters will provide a bypass loop thereby preventing the leakage current to flow outside into the active circuits.[13].Another main advantage of using this solution is that lesser number of switching components are used.The leakage current problems also prevails in many other application such as CMI-based AC drives[17],CMI based magnetic resonance imaging system[18],and paralleled boost rectifiers.The main problem of employing the modulation schemes in PV-CMI system since the parasitic capacitors are distributed on DC side.Applications where no capacitance are involved in the circulating loop,high frequency circulating currents can be mitigated by interphase inductors.Only low-frequency circulating current would be problematic in drive applications.However in PV-CMI swtching frequency noises will be dominant.

This paper first describes about qZSI based CMI-PV systems with a R load and then it discusses about the possible difficulties expected while connecting the same system to a grid.Also,it breifly explains the significance of qZSI usage in the cascaded modules.Finally,by incorporating the effective Pulse Width Modulation[PWM] techniques and by adjusting the duty cycles ,the system is optimised to work better with the grid connected application also.The appropriate filter design is adopted and applied to the aforementioned system in which each switches are operated at 100kHz.The main parameters which is modified here is modulation index and the duty cycle of the reference signal.Simulations are carried out for both the stand-alone system and a Grid-connected system inorder to validate the efficiency of the proposed system.

II. THE ISSUES IN GRID CONNECTED SYSTEM

The Distributed generation [DG] networks contributes wide range of power quality problems like voltage fluctuations [sag, swell, interruptions], islanding problems when the power exceeds the set parameters.

Moreover for a standalone system, interactions with the neighboring networks will be less. In larger DG network, the integration of many renewable energy sources will be a complex issue due to the communication with the adjacent networks. However, the power quality problems could be eradicated using the power factor correction [PFC] methods, FACTS devices like STATCOM or SVC's on the inverter side.Also,other important factors that affects the PV cell performance are its Insolation and Energy, Power tracking, shading and dirt and temperature. It uses power from the central utility when required and supplies home-generated power back to the utility which is termed as a parallel system. Grid connected PV systems are gaining its importance due to high power conversion efficiency of the full bridge inverters.However,the full bridge inverters has its own drawbacks like high acoustic noise ,switching losses and electromagnetic interference. Later, cascaded structure has emerged which produces high quality output waveform with low distortion, lesser stress on the switching components. But the leakage current issue is a result of the parasitic effect among the capacitors. This problem is greatly addressed by altering either the topologies or the modulation strategies. But the survey reveals that applying filters both at the AC and DC side of the network would be a cost effective and most reliable solution. Control strategies for the MLI are explained well in [10].As for as the resistive load is concerned, the filters alone would be a convincing solution. But when grid is the constraint, then in addition to the filters, modulation adjustments are also expected in order to reduce the leakage current along with the grid integration issues. In the existing work, two filter solutions are suggested for leakage current suppression and is restricted to a R load alone. Suppression analysis is carried out using simple superposition theorem approach. The solutions are applied to two different circuits .Former is designed for the system with four cascaded quasi ZSI where each switches are operated at 100kHz[high frequency application].Latter is designed for a PV system with two cascaded H-bridges inverter in which switches are operated at 10kHz[low frequency application].Only the second solution is applied to the grid connected system while the first solution is restricted to the R load[12] since it has the minimum contribution to the total impedance of the leakage current loop at the switching frequency. In this paper, the same filter solution is adopted for qZSI circuit and it is interfaced with the grid without sacrificing the efficiency and THD.The second solution is not considered much ,since the higher amount of circulating capacitances to reduce the filter inductance are required. Moreover the internal circulating current would not create remarkable change in the Inverter efficiency drop.

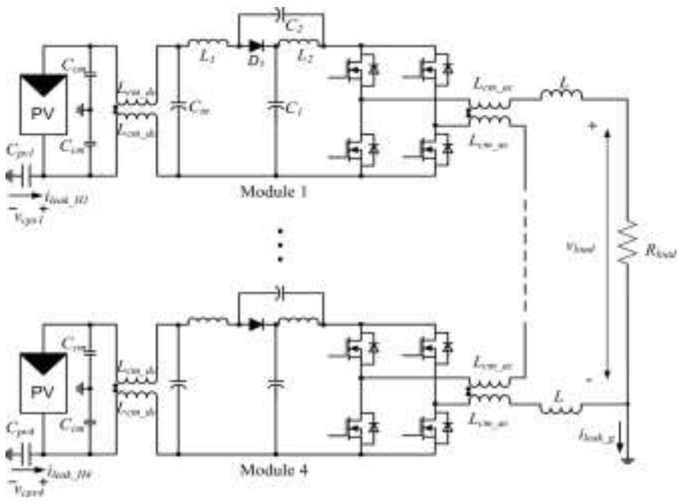


Fig 1.Existing PV-CMI system

The circuit analysis for the qZSI depends upon the two modes of the circuit (1)shoot through(2)non-shoot through states of the circuit which is described later part of the paper.

Higher the filter components, bulkier would the system. By effective usage of the quasi network, this can perform both buck and boost operation simultaneously. The control methods available in qZSI are (1) simple boost (2) maximum boost (3) maximum constant boost. In this paper, simple boost control strategy is adopted for the qZSI in order to obtain the buck/boost, inversion and power conditioning in the single stage with good reliability. The grid connected qZSI is shown in Fig.4. In order to achieve the better suppression of leakage current, the duty cycle of each qZSI module is adjusted such that the active or shoot through states are extended to a larger interval thereby the conduction of switches in the same leg would be more effective unlike the conventional ZSI.

III. EXISTING AND PROPOSED SYSTEM

In order to reduce the leakage current, the filter solutions are adapted for two different applications and later these solutions are verified experimentally. But the solutions are restricted to special constraints. The high frequency filter solutions are restricted to the resistive load. So the modulation strategy is adjusted such the active states of the qZSI are extended thereby eliminating the dead time between two adjacent intervals [6] without sacrificing the efficiency .Both the existing and proposed are simulated using MATLAB. The results of existing and proposed system are compared and the results are found be better with the lesser THD.

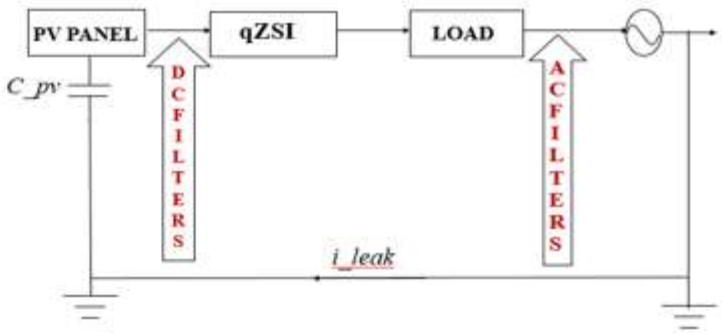


Fig 2.Block Diagram of the proposed system

IV. CIRCUIT ANALYSIS

The main aim of applying filters to the CMI is to construct the by-pass loop thereby preventing the leakage current to flow outside. Two kinds of loops are involved in all PV-CMI networks. First loop consists of parasitic capacitor, Inverter Bridge, line inductor, and grid groundand is called as module-line leakage current loop. Other one loop is formed among the inverters and is called as intermodule leakage current loop. It provides a capacitive coupling path with negligible inductance which will result in the production of pulse wise leakage current in the loop. Due to this fact, even in transformer less topology, the intermodule leakage current loop exists.Also,it cannot be eliminated even if the transformer is placed at the output side[15].Two main objective of considering qZSI network instead of the cascaded H-bridge is to cope up with wide range of PV input and also it will provide allow impedance path for high frequency noises.

4.1 Leakage current calculation

Analysis of the CMI network is carried out by considering a single intermodule leakage current loop and applying superposition principle to the filter loop which is formed by adding dc-side common mode [CM] chokes $L_{cm\_dc,}$ CM capacitors $C_{cm,}$ and ac side CM chokes $L_{cm\ ac}$ in each inverter module. Survey reveals that the CM output is mainly considered for determining the leakage current. The topological and modulation strategies are preferred mainly to maintain constant CM voltage. Unfortunately, it could not be achieved when a extra intermodule leakage current loop is formed .It is because that the Differential mode [DM] outputs would also contribute in such cases. The CM and DM mode voltages are given by

(1)

(2)

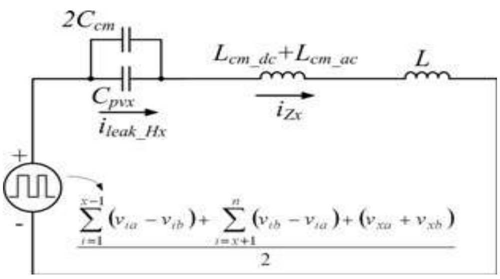


Fig.3 Intermodule Leakage current loop

Due to this aforementioned issue, a need for an alternative was expected which resulted in the filter solution. The impedance inside a single loop is expressed as

$Z_i =$. (3)

$$where\ i = 1,2,\ldots,n\ and\ Z_L = j\omega L.$$

Applying superposition theory, the current through the inductance $L_{cmdc}+L_{cmac}$ of the x_{th}inverter module is given by,

$$i_{Zx} = \sum_{i=1}^{1}\frac{v_{1a}}{z_{si}}\cdot\frac{z_{pi}}{z_x+z_{Pi}} + \sum_{i=2}^{x}\frac{v_{ia}-v_{(i-1)b}}{z_{si}}\cdot\frac{z_{Pi}}{z_x+z_{pi}} + \sum_{i=x}^{n-1}\frac{v_{ib}-v_{(i+1)a}}{z_{si}}\cdot\frac{z_{Pi}}{z_x+z_{Pi}} + \sum_{i=n}^{n} \quad (4)$$

n

Equation (4) can be simplified as

$$i_{Zx} = \frac{\sum_{i=}^{x}}{} \quad (5)$$

The leakage current expression i_{leak_Hx} can be obtained from the tank circuit formed by$L_{cm_ac}+L_{cm_dc}+L$ and $C_{pvx}+2C_{cm,}$

(6)

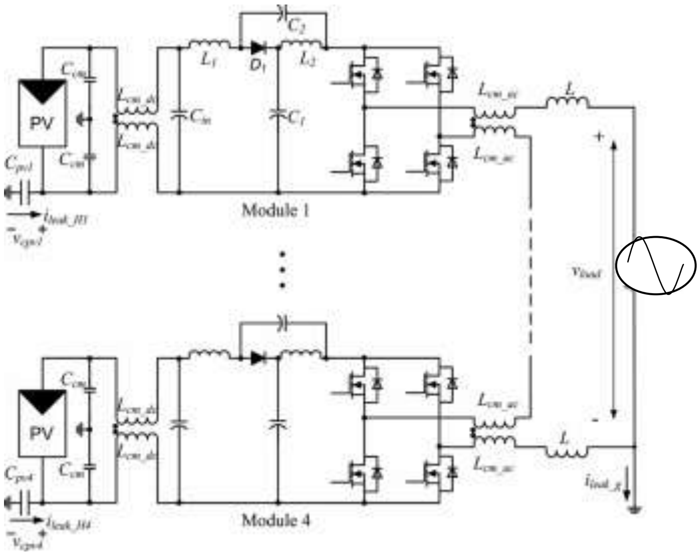


Fig 4.Proposed PV-CMI circuit

4.2 qZSI network

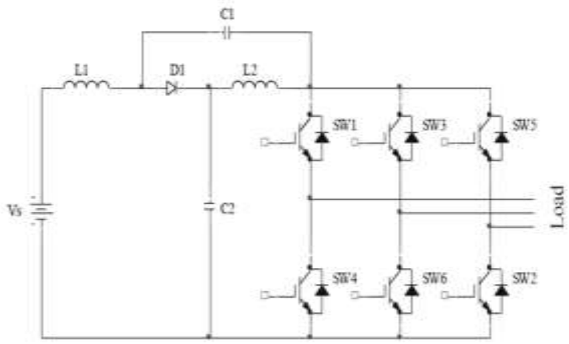


Fig 5.qZSI network

qZSI circuit differs from traditional ZSI in the LC network between the source and the inverter. The presence of LC and diode network connected to the bridge modify the operation of the circuit, thereby shoot through states arise which is forbidden in traditional VSI.The modified network protects the circuit from damage during shoot-through and also qZSI network boosts the DC link voltage.

4.3 Transformer less Appeal

Differences between standard and transformer less inverters are:

- .Conventional inverters are built with an internal transformer that synchronizes the DC voltage with the AC output.
- Transformer less inverters use a computerized multi-step process and electronic components to convert DC to high frequency AC, back to DC and ultimately to standard frequency AC.
- It is capable of handling Dual MPPT inputs and has higher efficiency ratings.
- It is much lighter than inverters with transformers and cheaper.

V. RESULTS AND DISCUSSIONS

Besides many advantages of the Transformer less inverters and qZSI, leakage current issue remains challenging in designing a reliable PV-CMI system simplified analytical models are derived and filters are employed along with the enhanced qZSI. The model is then simulated in MATLAB R2011a software. The presence of parasitic capacitance will make the leakage current to flow through the negative terminal of the PV side .The effect of leakage current through of both the existing and proposed system is shown in fig.6(a)&(b)

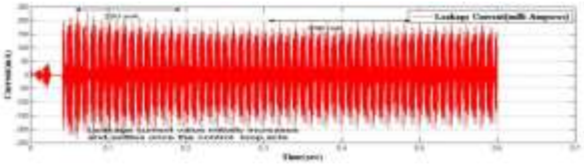


Fig 6(a) Leakage current in Existing system

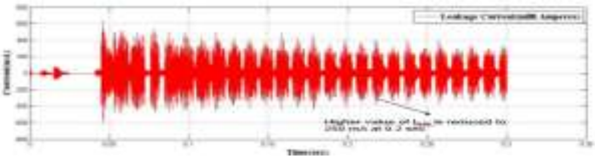


Fig 6(b) Leakage Current in Proposed System

Due to the impact of leakage current in the DC side of the network the PV side voltage and current would vary according to the magnitude of $i_{leak_Hx.}$The PV side input current and voltage of the existing and proposed system is shown in Fig 7 (a)&(b)

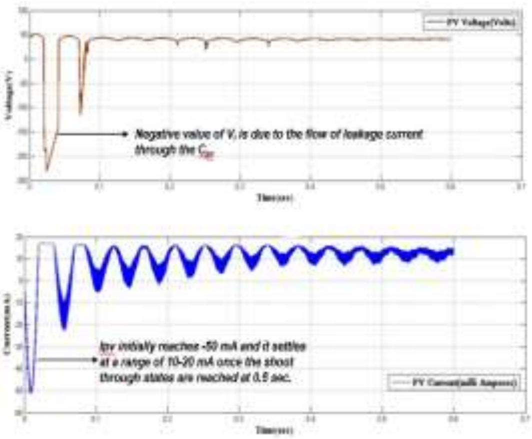


Fig 7(a)PV side inputs-Existing system

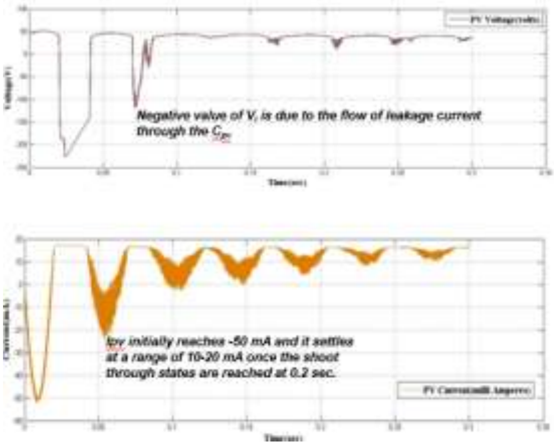


Fig 7(b) PV side inputs-Proposed system

Initially the negative current is higher for a system with power: 250W, input voltage range: 25-50V.The Output Voltage and Current of both the works are depicted in Fig8 (a) & (b).

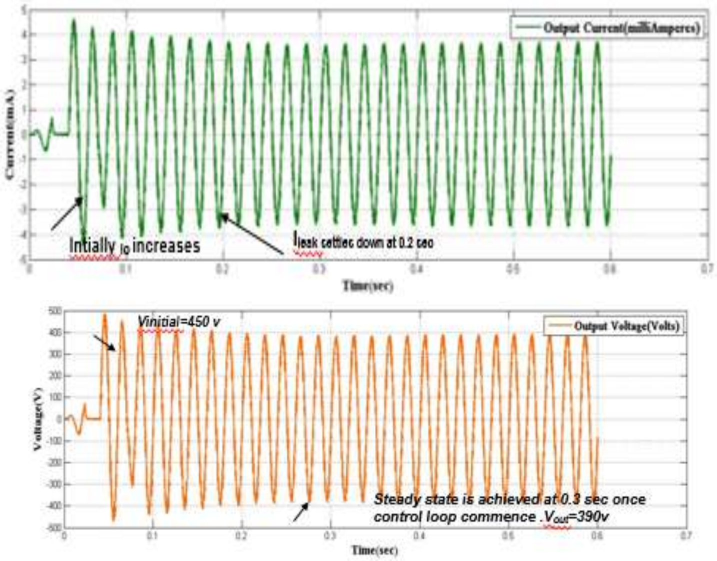


Fig.8(a)Output voltage and Current of Existing work

Once the modulation cycle triggered, the effective shoot-through states would reduce the leakage current from 0.61mA which in turn bring down the values of PV array input and finally the THD of system falls to 4.71%which is an acceptable IEEE standards for harmonics 519.The THD is found to be better in proposed work and the comparison is shown in fig.9

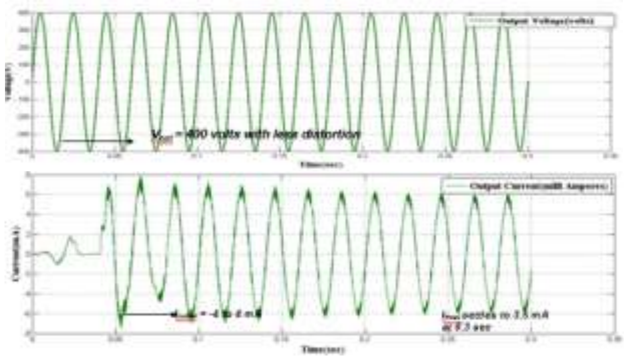


Fig.8(b)Output voltage and Current of Proposed work

VIII.VII.

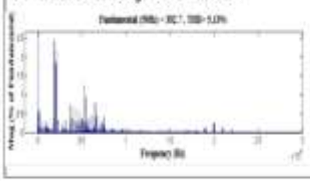
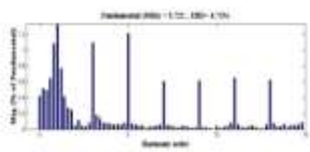
EXISTING SYSTEM	PROPOSED SYSTEM
1. Restricted to R load	Extended to grid applications
2. Filter solutions are focussed	Effective usage of Active states of qZSI
3. THD Analysis 5.13%	THD:4.71%
	

Fig 9.Comparison of Existing&Proposed Work

VI. CONCLUSION

This paper first analyzed the qZSI based PV-CMI system which is restricted to operate only with R loads since the focus in the existing work was fully theoretical analysis of the filters in order to mitigate the leakage current. In this work, the same qZSI PV-CMI system is integrated to a grid with the same filter available in the base work. The main strategy changed here was the Duty cycle variations in the Quasi Z source network thereby eliminating the dead time and effective utilization of shoot through states could be achieved.Thus, the leakage current suppression is achieved in the grid connected applications by the proper selection of filters and the modulation techniques.The realization of hardware and applying the SL-qZSI strategy for single and three phase inverters to reduce THD could be the future work.

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