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A Low Cost Transformer less Inverter for Grid-connected Hybrid Power Systems using Virtual DC Bus concept

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Abstract:

In order to achieve better reliability of power supply, hybrid power systems play a vital role. The wind energy along with a fuel cell is connected with PV system to make the system more reliable. These are connected in conjunction with a transformerless inverter and thereby eliminating the common mode (CM) leakage current. In this proposed paper, the virtual DC bus concept is used for the elimination of leakage current.

The stray capacitance in between the ground and the photovoltaic (PV) get bypassed by neutral line of grid which links directly to the negative pole of dc bus. Hence, leakage current will be eliminated permanently. Meanwhile, the negative voltage for the grid is provided by the concept of virtual dc bus. Using this, a new transformerless inverter topology is implemented using switched capacitor technology. This helps in reducing stress on the switches and also the cost of power electronic devices can be regulated.

This topology can be developed using double frequency sinusoidal pulse width modulation (SPWM) so that the ripples in the output current will be decreased. Consequently, a small filter inductor is used to decrease the size and the magnetic losses in the inverter. The implementation in SIMULINK represents the system with very less harmonic distortion and high power factor.

I.INTRODUCTION:

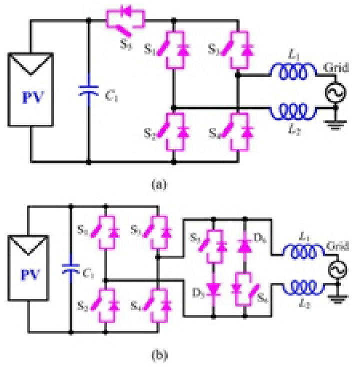
Now-a-days, the need for the hybrid power systems increasing due to increase in the power demand. No single power system is enough to satisfy the present day demand for the reliable power supply.Hence, hybrid power systems are gaining their demand in most of the commercial and residential sectors [1]-[3].

Generally, inverters play a major role in feeding hybrid power into the utility grid. The efficiency of the inverter is to be maintained at high due to combined utilization of different sources of energies.

Generally, PV systems are used as the main source of energy for the generation of power using transformer-less inverters to maintain high efficiency and reduced size and cost. However, if PV is used along with other sources of energy in generation of power such as wind energy and fuel cells.

By the combination such sources, the power quality problems can be minimized. In olden days, grid-tie inverters used either a line frequency or a high frequency transformer for galvanic isolation. This isolation transformer if removed helps in increasing the efficiency and also the size and cost of the entire system can also be decreased [4].

However, in the absence of transformer, the common mode ground leakage current creeps into the circuit and will have serious effects on the reduction of efficiency in power conversion, increased distortion in grid current, the electric magnetic compatibility is deteriorated, and more significantly, safety threats rises [5].



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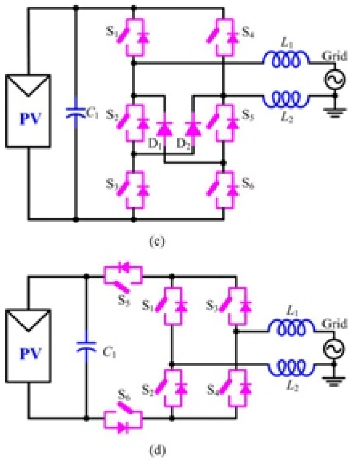

Fig. 1 Transformerless full bridge based inverter methods (a) H5 inverter circuit (b) HERIC inverter circuit (c) H6 inverter circuit with ac bypass (d) H6 inverter circuit with dc bypass.

For realization of this goal in a simple way is to use the bipolar sinusoidal pulse width modulation (SPWM) for full bridge inverter, in that CM voltage is equal to that of the voltage at half of the dc bus. The double frequency SPWM yields better results when compared with the bipolar SPWM considering switching losses and ripples of the output current. But it should not be used directly in the application of transformerless inverters because of the generation of switching frequency CM voltage.

Therefore, some advanced methodologies referring to full-bridge inverter considering HERIC inverter or H5 inverter [6] and so on are developed, to maintain CM voltage constant even the double frequency modulation is used. There are some topologies represented in Fig. 1 based on full bridge inverter. If additional switches are introduced both on ac or dc sides of the full-bridge inverter, the dc bus gets isolated from grid when zero voltage level of the inverter output voltage. Thus, the CM current path is remove.This paper contains a concept known as the virtual dc bus is presented for grid tied transformerless inverter. The dc bus negative pole is directly connected to grid neutral line, thus, voltage across the parasitic capacitor is held to zero. Consequently, the leakage current is totally suppressed. In the meantime, the virtual dc bus generates negative output voltage [7], [8]. The necessary dc bus voltage is constant and maintains the same as that in the full-bridge, and hence limitation will be zero on the modulation strategy due to natural elimination of the leakage current by the structure itself.

Thus, the merits of both full bridge and half bridge are held for better solution of the system. Considering above mentioned new method, a switched capacitor technology is employed using virtual dc bus for the suggested topology. Two modulation techniques are used for modulation of proposed inverter called unipolar SPWM and double frequency SPWM. It consists of a single filter inductor and only five power switches, thus the cost of the magnetic components and semiconductor devices decreases.

The systematic arrangement is discussed as follows. In Segment II, virtual dc bus concept is explained. Proposed method and respective modulation strategies along with the operational principles are discussed in section III. The simulation results are represented in segment IV and conclusion in the final segment.

II. VIRTUAL DC BUS CONCEPT:

When the neutral line of the grid and negative pole of the hybrid module is coupled together so that the voltage across the stray capacitance can be clamped zero. Thus, if any leakage currents creeps are bypassed directly to the grid where they are suppressed. The virtual dc bus concept is shown below in Fig.2.

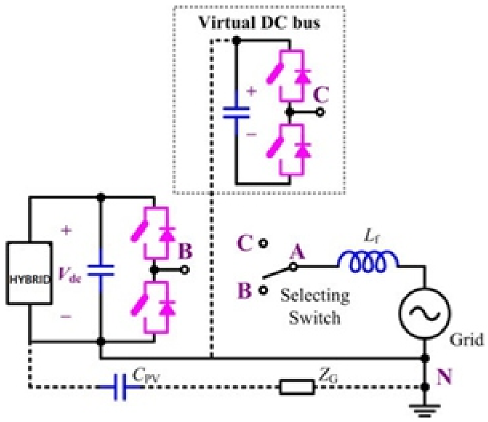

Fig. 2 Concept of virtual DC bus

Considering the position of the switch bridge, midpoint B has voltage zero or +Vdc referring to ground point N. The main intension of introduce the virtual dc bus is essential for the operation of the inverter since it produces the negative output voltage. If an appropriate designed method is employed for the energy flow between the virtual bus and the real bus, the voltage across the virtual bus can be maintained still as the real one.

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As depicted in Fig. 2, the positive pole of the virtual bus and ground point N is connected together, thus the voltage at the midpoint C is either zero or –Vdc. The dotted line in fig, 2 shows the connection can be understood indirectly by a wire or directly by a power switch. By joining the points B and C with smart selecting switch where the three different voltages such as + Vdc, - Vdc, and zero at point A.

Meanwhile, common mode current is naturally eliminated by the structure of the circuit and hence, no restriction on the modulation technique. There are some progressive modulation methods called unipolar SPWM or the double-frequency SPWM are developed fulfilling various hybrid power applications.

III. PROPOSED MODEL AND MODULATION TECHNIQUE :

Fig.3 Shows the advantages of the proposed methodology for a new inverter topology which is based on the concept of virtual dc bus. It contains five power switches S1–S5 and only one filter inductor Lf. The hybrid modules and capacitor C1 form the real dc bus whereas C2 is provided by the virtual dc bus [9].

Using switched capacitors, the real dc bus is charged by C2 throughout S1 and S3 for constant voltage. The modulation techniques called double frequency SPWM and uni-polar SPWM are being employed. For this method, double frequency SPWM technique is utilized for better reduction in the ripples of the output current of the grid and hence no lags in current. The complete analysis are given below.

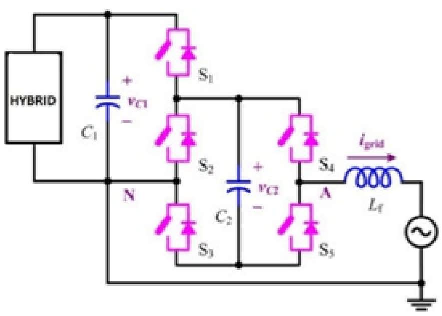

Fig. 3 Proposed topology

A. UNI-POLAR SPWM:

Fig. 4 shows proposed inverter waveforms for the uni-polar SPWM. The gate drive signals are generated based on the relative value of the carrier wave uc and modulation wave ug for the given power switches. For the duration of the positive half grid cycle ug >0, switches S1 and S3 are switched ON while S2 is switched OFF. Meanwhile, the switches S4 and S5 complementally commutate with the carrier frequency [10]. Both capacitors C1 and C2 are in parallel while the circuit revolves around the states 1 and 2 which are displayed in Fig. 6.Throughout the course of negative half cycle, when ug <0, S4 is switched OFF and S5 is switched ON. Carrier frequency synchronously commutate S1 and S3 and thus S2 complementally commutates to them. The circuit revolves around the states 3 and 2. During state 3, S1 and S3 are turned OFF and S2 is switched ON. The virtual dc bus C2 generates negative voltage required for the operation of the inverter [11]. While in state 2, S1, S3 are switched ON and S2 is switched OFF. The output voltage vAN of the inverter equals zero; in the meantime, C2 is being charged through S1 and S3 by the dc bus.

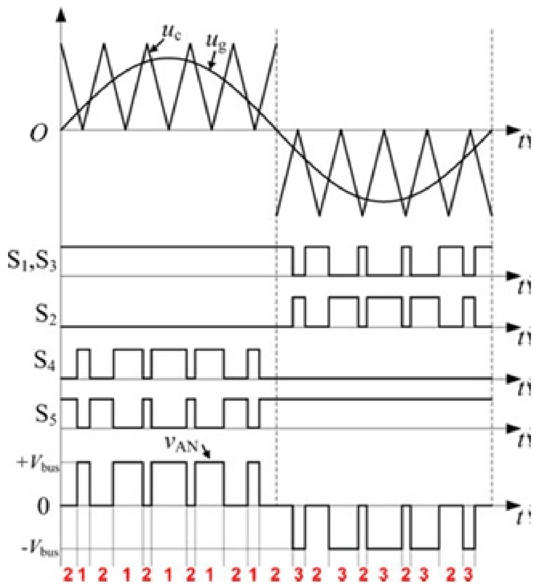

Fig. 4 Uni-polar SPWM

B. DOUBLE FREQUENCY SPWM:

The strategic methodology with double-frequency SPWM attains a high corresponding switching frequency, as depicted in Fig. 5.

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In this modulation strategy, the five power switches are divided into two parts while modulating using two reverse sinusoidal waves' ug1 and ug2 [12], Hence, switches S1, S2, and S3 are modulated with ug1, while S4 and S5 are modulated with ug2. The sequence of circuit rotation like "State 4 – state 1 – state 2 – state 1" is throughout the positive half grid cycle and the output voltage VAN vary with two times of the carrier frequency between +Vdc and zero. "State 4 – state 3 – state 2 – state 3," is the sequence of rotation throughout negative half grid cycle and the output voltage VAN vary between –Vdc and zero.

The two modulation approaches has their own merits which are mentioned above. The size as well as the weight of the filter inductor will decrease due to double-frequency SPWM which provides a high corresponding switching frequency [13]. Besides, the unipolar SPWM make sure that the virtual dc bus C2 is charged by the real bus for each switching cycle, hence current pressure on S1 and S3 generated by the process of the switched capacitor can be minimized. The double frequency SPWM is selected as an example for the simulation verification.

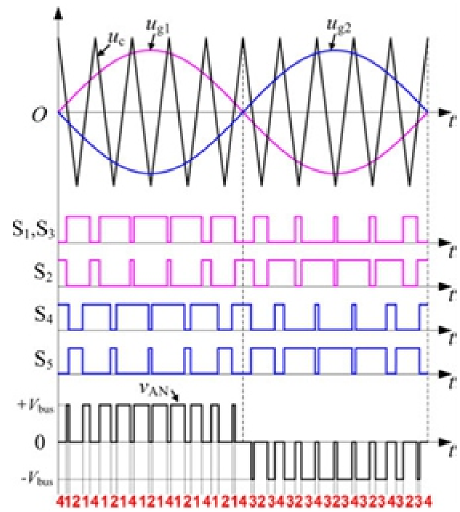

Fig. 5 Double frequency SPWM for the proposed topology.

The direction of the output current igrid having no limitations in all the four operation states, anti-parallel diodes of the power switches will have current flow in both direction [14]. Hence, the proposed method have the capacity to feed the reactive power into the grid to maintain the power system stability. This proposed method is also invulnerable to overvoltage due to transients in the grid.

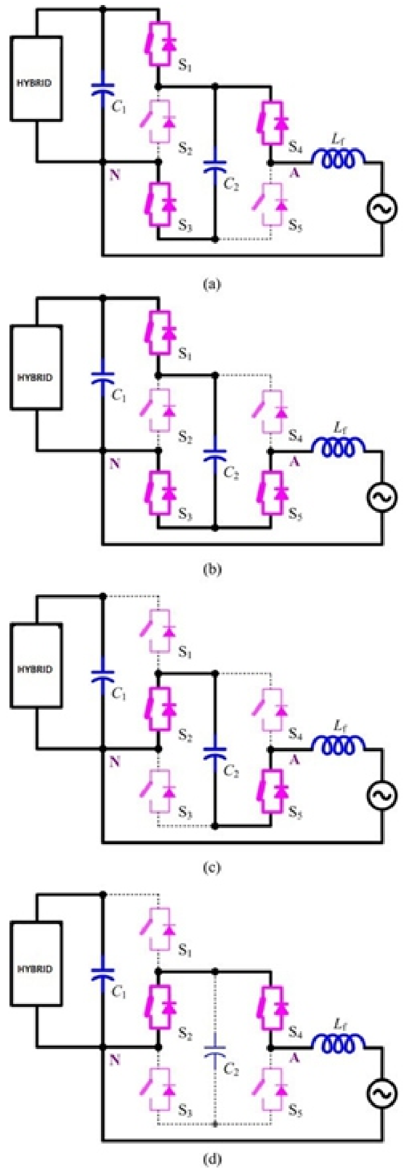

Fig. 6 Four states of operation for the proposed method

(a) State 1
(b) State 2
(c) State 3
(d) State 4

IV.SIMULATION RESULTS:

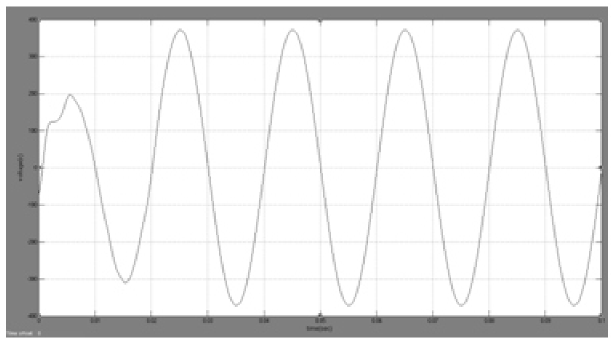

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Fig.7 Voltage waveform

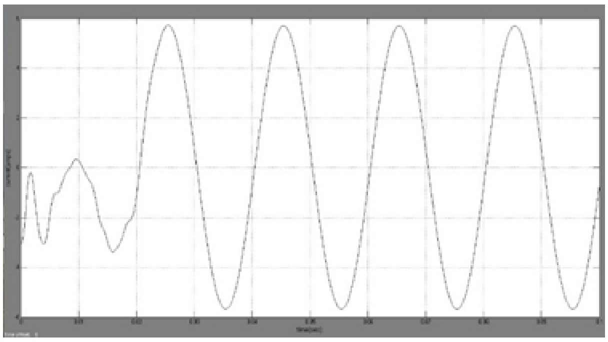

Fig.8 Current waveform

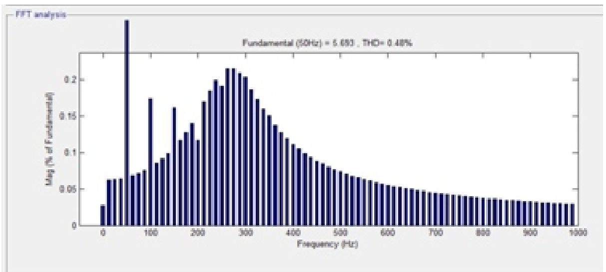

Fig.9 Current harmonic distribution

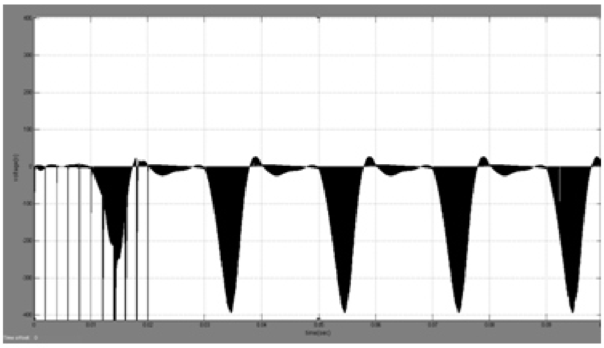

Fig.10 Current stress on S3

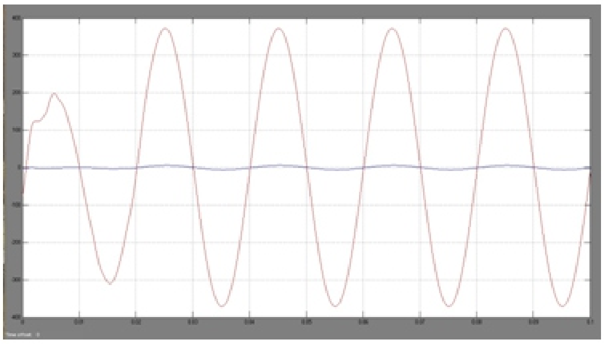

Fig.11 Output current and grid voltage

V.CONCLUSIONS:

The virtual dc bus concept is introduced to suppress the common mode current for the grid tied transformerless inverter. The dc bus negative pole is connected directly to grid neutral line and thus the common mode current is removed completely [15]. With the combination of hybrid power sources the reliability of power supply is maintained and power quality problems are reduced.

The proposed topology is best suitable where there are more problems with continuity of power. If one of the three power sources is inadequate to supply power, the remaining two will help in maintaining the reliability of supply. Limited number of switches are employed so that current stress on power switches is reduced. Since, the promising performance in the elimination of leakage current, this concept of virtual dc bus provides a hopeful solution for the grid connected transformerless inverters.

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